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*See Appendix III for an overview of the versions of this report and the changes between the versions*

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# Management Samenvatting

Dit rapport vat de resultaten samen van een reeks onderzoeken naar monsters genomen van 17 snelwegvakken in het zuiden van Nederland in 2016. Het onderzoek werd gestart vanwege een aantal projecten waarbij vroegtijdige schade optrad in ZOAB deklagen ruim binnen de RWS-garantieperiode (7 jaar voor (D)ZOAB 16 en 5 jaar voor 2L-ZOAB8). Deze garantie perioden zijn aanzienlijk korter dan de gemiddelde levensduur van ZOAB deklagen (13,5 jaar voor ZOAB 16, 17 jaar voor DZOAB 16 17 jaar en 13 voor 2L-ZOAB 8).

In het onderzoek naar de 17 wegvakken zijn meer afwijkingen gevonden dan verwacht. Zo werd in 95%1 van de materialen een of meer afwijkingen tussen de gemiddelde samenstelling of eigenschappen van de kernen en de algemene vereisten voor de mengselgroep in de RAW Standard gevonden (Table 3.31 op pagina 157). Bij het toetsen van de gemiddelde resultaten van de kernen aan de specifieke mengselinformatie werden ook in 95% van de gevallen afwijkingen gevonden (Table 3.32 en Table 3.33). Daarbij bleek de bij RWS beschikbare mengsel informatie in veel gevallen niet alle vereiste informatie te bevatten, wat controles op kwaliteit (tijdens en na het project) onmogelijk maakt. In totaal wordt voor de gemiddelde samenstelling van de kernen uit de weg aan 29% van alle geldende eisen niet voldaan (Table 3.36), of de gegevens om dit te toetsen ontbreken. En niet voor geen enkel van de 17 onderzochte projecten lagen alle waarden aantoonbaar binnen de vereiste marges (Table 3.37 en Table 3.38).

De belangrijkste conclusie van alle informatie die voor deze studie is verzameld, is dat het systeem dat is opgezet om de administratieve kant van de materiële kwalificatie en kwaliteitscontrole aan te pakken, niet lijkt te werken. Uit het aantal, het type en het feit dat bepaalde fouten herhaaldelijk voorkomen is af te leiden dat het systeem geen ingebouwde correcties bevat. Uit ontbrekende formulieren, onvolledige formulieren, materiaalspecificaties die niet aan de eisen voldoen en materialen die niet aan hun eigen specificaties voldoen, blijkt dat het papiersysteem gescheiden is van de productie en constructie werkwijze. En er (b)lijken onvoldoende controles in het systeem ingebouwd te zijn om in de loop van de tijd voor verbetering te zorgen. Om deze reden moet een vorm van een "klachten- en waarnemingen" -procedure worden vastgesteld waar kwesties kunnen worden gemeld en verbeteringen van de formele procedures en richtlijnen voor de interpretatie van de voorschriften kunnen worden overeengekomen en zo een raamwerk voor verbetering te creëren. Het vaststellen van een kader voor kwaliteitscontroles met betrekking tot de volledigheid en juistheid van de verstrekte informatie met betrekking tot de gestelde eisen, inclusief een protocol voor het omgaan met onvolledige informatie en (gemelde) afwijkingen van de eisen, zou de ruggengraat kunnen vormen voor het doorvoeren van dergelijke verbeteringen. In het ideale geval maken de ervaringen met de compleetheid en juistheid van de aangeleverde informatie en de kwaliteit van de uitvoering, niet alleen op project-basis maar ook over de projecten heen, deel uit van een kwaliteitssysteem waarin opdrachtgevers en –nemers samen werken aan kwaliteit.

Al met al kan worden geconcludeerd dat het aantal afwijkingen aanzienlijk en groter is dan verwacht. Dit lijkt het gevolg te zijn van onvoldoende aandacht voor de details van het specificeren en karakteriseren van het materiaal, mogelijk versterkt door de complexe set eisen (verschillende EN-normen, RAW-standaard, contractuele specificaties). Eerst en vooral is het de verantwoordelijkheid

1 *Bij het bespreken van de resultaten met de betrokken aannemers werden vraagtekens geplaatst bij dit getal, omdat er vele eisen achterliggen en er in dit overzicht geen onderscheid wordt gemaakt tussen een materiaal met 1 of vele afwijkingen. Dit is inderdaad zo, maar de detail afwijkingen zijn later in het rapport ook in kaart gebracht en tonen een vergelijkbaar patroon. Ook werd in dit gesprek aangegeven dat de gegevens bij sommige aannemers anders lijken te zijn dan de bij RWS gearchiveerde gegevens. Dit zou de de aantallen afwijkingen inderdaad anders kunnen laten uitvallen, maar bevestigd tegelijkertijd het beeld dat het samenspel tussen aannemer en opdrachtgever in deze projecten niet goed gewerkt heeft.*

van de producent om ervoor te zorgen dat de documentatie en het materiaal aan de vereisten voldoen, maar dat is blijkbaar onvoldoende om deze afwijkingen te voorkomen. Het is belangrijk om dit aan te pakken en oplossingen te vinden om te om te komen tot een systeem waarin ingebouwde controles het opmerken van afwijkingen niet alleen mogelijk maken maar dit ook ondersteunen. Op die manier worden afwijken benut om continu te verbeteren. Voor RWS zelf lijkt het vooral belangrijk om enige controle op de volledigheid van de verstrekte documentatie op te nemen, omdat het huidige niveau van onvolledigheid betekent dat het niet altijd mogelijk is om achteraf te controleren of te leren van de ervaringen op het HWN. Er zijn aanbevelingen gegeven om de bepalingen uit te breiden, onder meer door het standaard bepalen van de penetratie na aanleg bij producttoetsen en het opbouwen van kennis over het verloop van deze eigenschap in de tijd. Hoewel dit geen vervanging is voor het initieel op orde hebben van de vereiste informatie, biedt het wel meer mogelijkheden om de oorzaak van goede of slechte prestaties te duiden.

De resultaten van deze studie duiden de noodzaak om dit soort informatie te verzamelen en een manier te vinden om de gevonden problemen en afwijkingen te delen en te bespreken om een verbetering te bewerkstelligen. Het lijkt erop dat het huidige systeem deze zelfcorrigerende functie niet heeft. Het kan de moeite waard zijn om te zien of deze mengsels recenter bij RWS zijn gebruikt en of de tekortkomingen inmiddels zijn verholpen. Als dit het geval is, verbetert het systeem, maar is het zaak het tempo waarin te verhogen. Als dit niet het geval is, zijn verbeteringen dringend nodig.

# Samenvatting

Dit rapport vat de resultaten samen van een reeks onderzoeken naar monsters genomen van 17 snelwegvakken in het zuiden van Nederland in 2016. Het onderzoek werd gestart vanwege een aantal projecten waarbij vroegtijdige schade optrad in ZOAB deklagen ruim binnen de RWS-garantieperiode (7 jaar voor (D)ZOAB 16 en 5 jaar voor 2L-ZOAB8). Deze garantie perioden zijn al aanzienlijk korter dan de gemiddelde levensduur van ZOAB deklagen (13,5 jaar voor ZOAB 16, 17 jaar voor DZOAB 16 17 jaar en 13 voor 2L-ZOAB 8).

In de onderzoeken die werden uitgevoerd om antwoorden te krijgen op garantieclaims betreffende nalatigheid in verband met de vroegtijdige schades werd in alle gevallen vastgesteld dat er verschillende aspecten van de mengsels waren die niet overeenkwamen met de specificaties en vereisten. Dit kon onopgemerkt blijven omdat het RWS-kwaliteitssysteem risico-gestuurd is en zich richt op de belangrijkste (top tien) risico's in een project. In veel projecten is asfaltbeton niet een van de top risico's. Voor andere risico's, die niet in de top tien worden genoemd, vertrouwt RWS op de contractuele eis dat de aannemer zijn kwaliteitscontrole uitvoert en eventuele afwijkingen rapporteert en oplossingen voorstelt om voldoende kwaliteit te waarborgen. In die projecten waar vroeg falen optrad, heeft dit niet gewerkt en zijn afwijkingen niet opgemerkt, vermeld en opgelost. Dit bracht RWS ertoe zich af te vragen of dergelijke afwijkingen vaker ongemerkt voorkwamen en zo ja, of er op meer locaties rekening moet worden gehouden met een verkorting van de levensduur.

Om deze vragen te beantwoorden, werd een onderzoek gestart waarin een selectie werd gemaakt van wegvakken met ZOAB-deklagen die nog in hun garantieperiode zaten en die door verschillende aannemers en onder verschillende soorten contracten werden gebouwd. Dit leidde tot 17 wegvakken in totaal, 13 met een DZOAB 16-deklaag en 4 met 2L-ZOAB (dat zoals de naam aangeeft, bestaat uit een top- en onderlaag), dus 21 verschillende mengsels. RWS liet verschillende onderzoekslaboratoria zowel standaard- als niet-standaardtests uitvoeren op boorkernen uit deze wegvakken om informatie te verkrijgen over het voldoen aan de vereisten en om een indicatie van de kwaliteit in algemene zin te krijgen. De resultaten van deze tests en het onderliggende systeem van eisen worden in dit rapport beschreven.

In de resultaten werden veel afwijkingen gevonden. Zo werd in 95% van de materialen een of meer afwijkingen tussen de gemiddelde samenstelling of eigenschappen van de kernen en de algemene vereisten voor de mengselgroep in de RAW Standard gevonden (Table 3.31 op pagina 157). Bij het controleren van de gemiddelde resultaten van de kernen ten opzichte van de specifieke mengselinformatie werden in 95% van de gevallen afwijkingen gevonden. Daarnaast bleek de bij RWS beschikbare informatie in veel gevallen niet alle vereiste informatie te bevatten. Deze bevindingen worden hierna in meer detail besproken.

De belangrijkste conclusie van alle informatie die voor deze studie is verzameld, is dat het systeem dat is opgezet om de administratieve kant van de materiële kwalificatie en kwaliteitscontrole aan te pakken, niet lijkt te werken. Van het aantal, het type en het feit dat bepaalde fouten herhaaldelijk voorkomen is af te leiden dat het systeem geen ingebouwde correcties bevat. Uit ontbrekende formulieren, onvolledige formulieren, materiaalspecificaties die niet aan de eisen voldoen en materialen die niet aan hun eigen specificaties voldoen, blijkt dat het papiersysteem gescheiden is van de productie en constructie werkwijze. En er (b)lijken onvoldoende controles in het systeem ingebouwd te zijn om in de loop van de tijd voor verbetering te zorgen. Om deze reden moet een vorm van een "klachten- en waarnemingen" -procedure worden vastgesteld waar kwesties kunnen worden gemeld en verbeteringen van de formele procedures en richtlijnen voor de interpretatie van de voorschriften kunnen worden overeengekomen en zo een raamwerk voor verbetering te creëren. Het vaststellen van een kader voor kwaliteitscontroles met betrekking tot de volledigheid en juistheid van

de verstrekte informatie in relatie tot de gestelde eisen, inclusief een protocol voor het omgaan met onvolledige informatie en (gemelde) afwijkingen van de eisen, zou de ruggengraat kunnen vormen voor het doorvoeren van dergelijke verbeteringen. In het ideale geval maken de ervaringen met de compleetheid en juistheid van de aangeleverde informatie en de kwaliteit van de uitvoering, niet alleen op project-basis maar ook over de projecten heen, deel uit van een kwaliteitssysteem waarin opdrachtgevers en –nemers samen werken aan kwaliteit.

Wat betreft de afwijkingen van de vereisten, zijn er verschillende niveaus van naleving, die ook elkaar beïnvloeden. Terwijl bijvoorbeeld in alle projectdossiers documenten werden gevonden, waren regelmatig niet alle vereiste documenten aanwezig. Dat gebrek aan documentatie maakt controles op de naleving van de eisen onmogelijk. In 10% van de projecten ontbrak zelfs de CE-markering (vereist volgens CEN-normen, die sinds januari 2008 publiekrechtelijk is). Als zodanig lijkt een soort controle op de volledigheid van de verstrekte informatie vereist, omdat het feit dat informatie moet worden verstrekt onvoldoende lijkt te zijn om te waarborgen dat dit het geval is. Dit is niet alleen belangrijk voor de eigenlijke projectfase, maar voor netwerkbeheer op de langer termijn, bijvoorbeeld als er een probleem met bepaald materiaal wordt gevonden en RWS wil controleren waar dit is gebruikt of in het opbouwen van inzicht op grond van ervaringsdata.
Vanwege dit gebrek aan volledigheid in de verstrekte informatie, werden twee niveaus van controle van de naleving van de eisen uitgevoerd, een waarbij het materiaal uit de secties werd vergeleken met de algemene eisen van de mengselgroep (paragraaf 3.11.1), die kon worden gedaan voor alle materialen, en een waarbij de materialen werden vergeleken met de verstrekte specifieke mengselinformatie, indien aanwezig (paragrafen 3.11.2 en 3.11.3).

Zoals hiervoor genoemd, werden in 95% van de materialen een of meer afwijkingen tussen de gemiddelde samenstelling of eigenschappen van de kernen en de algemene vereisten voor de mengselgroep in de RAW Standard gevonden (Table 3.31 op pagina 157), wat betekent dat dat materiaal feitelijk geen DZOAB 16 is, terwijl het wel zo wordt aangeboden. Aangezien de RAW de brede vereisten voor een mengselgroep geeft, zijn afwijkingen hiervan eigenlijk niet te verwachten. Hoewel er rekening mee moet worden gehouden dat de kernen enkele jaren na de bouw zijn genomen, worden in het geval van de gradering en het bindmiddelgehalte na de aanleg geen grote veranderingen meer verwacht, hetzelfde geldt voor de holle ruimte.

Bij het controleren van de gemiddelde resultaten van de kernen ten opzichte van de specifieke mengselinformatie werden in 95% van de gevallen afwijkingen gevonden. Alleen al het verschil tussen de gradering van kernen en de referentie samenstelling (inclusief bitumen gehalte en type) wijkt in meer dan 75% van de gevallen (16 van de 21, zie Table 3.32 and Table 3.33 en Table 3.38) te veel af, of er ontbreekt informatie. In meer dan 40% van de gevallen valt het gemeten bitumengehalte buiten de marges, of is er geen gespecificeerde waarde aanwezig. In twee gevallen is het type bitumen dat is gevonden in de kernen niet gelijk aan dat wat is opgegeven op de CE markering (penetratie bitumen 70/100 in plaats van polymeer gemodificeerde bitumen en vice versa).
Ook de PSV-waarde (cruciaal voor veiligheid) is in veel gevallen (te) afwijkend van de opgave. In bijna 50% (10 van de 21) van de materialen voldeed de gemeten PSV-waarde niet aan het algemene minimumvereiste (58 voor deklagen en 53 voor de onderlaag van 2L-ZOAB), terwijl volgens de documentatie bij de mengsels vrijwel overal (> 80% van de gevallen) een steenslag met voldoende hoge PSV gebruikt is. Dit lijkt een probleem te zijn met de algemene CE-markeringsprocedure, waarbij een enkel certificaat over de eigenschappen gedurende een aantal jaren kan worden gebruikt voor de hele productie, terwijl algemeen wordt aangenomen dat de eigenschappen van het materiaal in een steengroeve variëren van locatie naar locatie. Als zodanig voldoen de verstrekte certificaten aan de vereisten en mogen aannemers dit accepteren. Op basis van de resultaten van dit onderzoek lijkt het de moeite waard om te overwegen hoe extra ingangstests kunnen worden geïntroduceerd om de werkelijke PSV-waarde te beoordelen, vanwege de cruciale link met verkeersveiligheid. In zes van de 21 gevallen was geen PSV-informatie aanwezig, hoewel dit vereist is (PSV> = 58 voor de deklagen, PSV

≥> = 53 voor ZOAB in niet-deklagen). De vier materialen waarvoor geen PSV werd gegeven waren in drie gevallen DZOAB16, deklagen waarbij PSV een relatie heeft met veiligheid en een keer een onderlaag 2L-ZOAB. Voor alle materialen waarvoor een PSV beschikbaar was, was deze 58 of hoger, ook voor de onderlagen 2L-ZOAB. In maar twee van de zeventien materialen waarvoor een PSV-waarde beschikbaar was, was de gemeten waarde op de kernen niet lager dan opgegeven (2x gelijk), hoewel de opgegeven waarde een minimum waarde is. In totaal voldoet nog geen 12% (2 van de 17) kernen aan de PSV eis van 58 (de 4 onderlagen 2L-ZOAB zijn niet getest), vier kernen voldoen wel aan de minimum eis, maar zijn lager dan opgegeven in de documentatie. Een kern voldoet aan de minimum eis, maar er is geen verklaarde waarde om aan te toetsen. Deze vijf materialen en de vier onderlagen 2L-ZOAB zijn opgenomen in de categorie "M", omdat niet duidelijk is of ze aan de eisen voldoen.

De holle ruimte was over het algemeen aan de lage kant, waarbij 4 van de 21 mengsels buiten de marges van de RAW Standard met betrekking tot de aangegeven waarde vallen en nog eens 2 wel voldoen aan de RAW eis, maar niet aan de contractuele eis van RWS dat het gemiddelde holle ruimte gehalte van DZOAB 16 kernen ≥ 18% moet zijn (in verband met de geluidsregelgeving).Waar voor de kernen gediscussieerd zou kunnen worden over de vraag of deze afkomstig zijn uit een representatief deel van het project, is dit voor de gevonden tekortkomingen in de documentatie niet aan de orde. Een dergelijke afwijking, zoals een te groot verschil tussen doelsamenstelling en de eisen in de RAW-Standaard, of tussen doelsamenstelling en referentiesamenstelling werd gevonden in meer dan de helft van de gevallen (67% voor doelsamenstelling en RAW eisen, 86% voor referentiesamenstelling ten opzichte van samenstelling na extractie of doelsamenstelling.

In veel gevallen werd niet over alle vereiste zeven informatie gegeven en in twee gevallen was het bindmiddel niet het bindmiddel dat in de documentatie werd vermeld. Beiden zijn in strijd met de CE-markeringsprocedures, waarbij het niet verstrekken van de vereiste gegevens relatief eenvoudig is op te lossen, het gebruik van het verkeerde bindmiddel niet.

Al met al kan worden geconcludeerd dat het aantal afwijkingen aanzienlijk en groter is dan verwacht. Dit lijkt het gevolg te zijn van onvoldoende aandacht voor de details van het specificeren en karakteriseren van het materiaal, mogelijk versterkt door de complexe set eisen (verschillende EN-normen, RAW-standaard, contractuele specificaties). Eerst en vooral is het de verantwoordelijkheid van de producent om ervoor te zorgen dat de documentatie en het materiaal aan de vereisten voldoen, maar dat is blijkbaar onvoldoende om deze afwijkingen te voorkomen. Het is belangrijk om dit aan te pakken en oplossingen te vinden om te om te komen tot een systeem waarin ingebouwde controles het opmerken van afwijkingen niet alleen mogelijk maken maar dit ook ondersteunen. Op die manier worden afwijken benut om continu te verbeteren. Voor RWS zelf lijkt het vooral belangrijk om enige controle op de volledigheid van de verstrekte documentatie op te nemen, omdat het huidige niveau van onvolledigheid betekent dat het niet altijd mogelijk is om achteraf te controleren of te leren van de ervaringen op het HWN.

Een ander aspect dat het controleren van de naleving van de specificaties achteraf bemoeilijkt, is dat sommige vereisten gelden voor eigenschappen die in de loop van de tijd veranderen, dus ze moeten worden beoordeeld in het juiste tijdsinterval na de constructie of een tijdlijn van de verandering in de tijd als een functie van parameters moeten worden vastgesteld. Een voorbeeld daarvan is de penetratie van het bindmiddel, hieraan wordt een eis gesteld voor wat betreft de maximale afname tijdens productie en aanleg, maar dat wordt nu zelden of nooit gecontroleerd. Het wordt daarom aanbevolen om de penetratie na de aanleg toe te voegen aan de productcontrole, zowel om de eis te kunnen toetsen als om een trend voor het verloop vast te kunnen stellen. Daarnaast is het aan te raden om op het terug gewonnen bitumen infrarood metingen (FTIR) toe te passen om na te gaan of de samenstelling van het toegepaste bindmiddel overeen komt met het verklaarde, zeker voor mengsels met polymeer gemodificeerde bitumen (PMB). Indien de FTIR proef ook geschikt blijkt voor het bepalen van het gehalte aan calciumhydroxide in de vulstof, kunnen deze bepalingen beiden worden opgenomen. Dat is een aantrekkelijke oplossing omdat voor deze proeven weinig materiaal nodig is.

Voor het calciumhydroxidegehalte zijn er momenteel geen gevalideerde testmethoden voor na de aanleg, hoewel verschillende opties veelbelovend lijken. Het wordt aanbevolen om het nodige vervolgonderzoek uit te voeren om een degelijke test te ontwikkelen en om inzicht te krijgen in de ontwikkeling hiervan in de tijd in werkelijke veldomstandigheden, omdat het een belangrijke parameter lijkt te zijn. Het gebruik van CT-scanning voorafgaand aan enig (destructief) testen van kernen in kwaliteitscontrole-instellingen zal aanvullende informatie verschaffen over de samenstelling en verdeling van holle ruimten, hetgeen een nuttige toevoeging is. Met CT-scanning kan ook informatie worden verkregen over het drainagegedrag van de mortel2. In dit project toonde het aan dat, hoewel de DZOAB 16- en 2L-ZOAB 16-monsters gemiddeld een lage holle ruimte hadden, de holle ruimte relatief uniform verdeeld was over de hoogte waren en reproduceerbaar. Voor 2L-ZOAB 8 was de holle ruimte niet homogeen verdeeld over de hoogte.

Het wordt aanbevolen om het bepalen van de penetratie na aanleg op te nemen in de standaard controles en om inzicht op te bouwen over het verloop hiervan over de tijd. Dat geldt ook voor het $Ca(OH)_2$ gehalte, maar daarvoor dient eerst een betrouwbare, objectieve proefmethode te worden vastgesteld. Daarnaast is het zinvol gebruik te maken van ontwikkelingen in testmethoden, zoals bijvoorbeeld CT-scans en FTIR tests om gegeven over de verdeling van de holle ruimte, de aanwezigheid van breuk in stenen en van polymeren in het bitumen te bepalen en de ontwikkeling daarvan in de tijd te volgen.

Al met al duiden de resultaten van deze studie op de noodzaak om samenstellingsinformatie na aanleg standaard te verzamelen en een manier te vinden om de gevonden problemen en afwijkingen te delen en te bespreken om een verbetering te bewerkstelligen. Het lijkt erop dat het huidige systeem deze zelfcorrigerende functie niet heeft. Het kan de moeite waard zijn om te zien of deze mengsels recenter bij RWS zijn gebruikt en of de tekortkomingen inmiddels zijn verholpen. Als dit het geval is, verbetert het systeem, maar is het zaak het tempo waarin te verhogen. Als dit niet het geval is, zijn verbeteringen echt heel dringend nodig.

2 *Uitgaande van de definitie zoals ook gebruikt voor beton in het buitenland (mortar): bindmiddel en fijn toeslagmateriaal (tot en met 2mm, dus bitumen, vulstof* ***en zand****). Dit wijkt af van de in Nederland soms gebruikte definitie.*

# Summary

This report summarizes the results from a series of investigations in to samples taken from 17 highway sections in the south of the Netherlands in 2016. The investigation was started because of some projects in which premature damage occurred in PA wearing courses well within the RWS warranty period (7 years for (D)ZOAB16 and 5 years for 2L-ZOAB8). These warranty periods are already considerably less than the average life time of the corresponding PA wearing courses (13,5 years for ZOAB 16, 17 years for DZOAB 16 17 years and 13 years for 2L-ZOAB 8).

In the studies carried out to get answers regarding warranty claims in relation to those early failures in all cases it was found that there were several aspects of the mixtures that did not agree with the specifications and requirements. This could go unnoticed because the RWS quality system is risk based and focusses on the major (top ten) risks. In many projects, asphalt concrete is not one of the top risks. For other risks, not mentioned within the top ten, RWS relies on the contractual requirement that the contractor carries out his quality control and will report any deviations and propose solutions to ensure sufficient quality. In those early failure projects, this did not work out and deviations were not noticed, mentioned and resolved. This led RWS to wonder if such deviations occurred more often and if so, if as a result a reduction in life time is to be expected at more locations.

To address those questions, a study was started in which a selection was made of pavement sections with PA wearing courses that were still within their warranty period and that were constructed by different contractors and under different types of contracts. This lead to 17 sections in total, 13 with a DZOAB 16 wearing course and 4 with 2L-ZOAB (which, as the name indicates, consists of a top and bottom layer), resulting in 21 mixtures in total. RWS had a variety of research laboratories carry out both standard and non-standard tests on these cores in order to obtain information on their meeting the requirements and getting an overall indication of their quality. The results of these tests and the underlying system of requirements are described in this report.

The key conclusion from all the information gathered for this study is that the system that was established to deal with the administrative side of the material qualification and quality control does not appear to be working. From the amount, type and recurrence of errors, from missing forms, through incomplete forms, materials specifications that do not meet the requirements to materials that do not meet their own specifications, it is clear that the paper system is separate from the production and construction process. Also, it appears that there are insufficient checks and balances to ensure improvement over time. For this reason, some form of a “complaints and observations” procedure where issues can be reported and improvements of the formal procedures and guidelines on how to interpret the regulations can be agreed on, should be established to create a framework for improvement. Establishing a framework for quality assurance checks regarding the completeness and correctness of the provided information in relation to the requirements, including a procedure to follow in case incomplete information is provided or (reported) deviations from the requirements, would create a backbone for the adoption of such improvements. Ideally, the experiences with assessment of the completeness and quality of the provided information and the delivered work, not only per project, but extending over projects, should be part of an overall quality assurance system used by both contractors and clients.

Regarding the deviations from the requirements, there are various levels of compliance involved, which also affect each other. For example, while in all project dossiers documents were found, regularly not all required documents were present. That lack prohibits checks on compliance with the actual requirements. In 10% of the projects even CE marking (required under CEN standards, which is public law since January 2008) was missing. As such, some kind of check on the completeness of the provided information seems to be required, since the fact that information must be provided appears

insufficient to ensure that it is. This is not only important for the actual project phase, but also in network management, for example if a problem with a certain material is found and RWS wants to check where this has been used.

Because of this lack of completeness in the provided information, two levels of checks of compliance with the requirements were carried out, one in which the material taken from the sections was compared to the overall mixture group requirements (Section 3.11.1), which could be done for all materials, and one where the materials were compared to the specific mixture information provided, if present (Sections 3.11.2 and 3.11.3).

In 95% of the materials one or more deviations between the average composition or characteristics of the cores and the overall requirements for the mixture group in the RAW Standard were found (Table 3.31 on page 157), which means that that material does not qualify as for example a DZOAB 16, even though it is declared to be just that. Since the RAW gives the broad requirements for a mixture group, deviations from this are not expected. Although it must be taken into account that the cores were taken several years after construction, in the case of grading and binder content, only limited changes are expected after construction, the same holds for void content.

In checking the average results from the cores versus the specific mixture information if that was available in over 95% of the cases deviations were found. Just the difference between the grading of the cores and reference composition, including bitumen content and type, either deviates too much or is incomplete in over 75% of the mixtures (16 out of 21, see Table 3.32 and Table 3.33 and Table 3.38). In over 40% of the cases the measured bitumen content deviates too much from the specified value, or no specified value was present. In two cases, the type of bitumen indicated on the CE marking is not the type of bitumen found from the field cores (penetration bitumen 70/100 instead of PMB or vice versa).
Also the PSV value (crucial for safety) deviated in many cases. In nearly 50% (10 out of 21) of the materials the measured PSV value did not even meet the overall minimum requirement (58 for wearing courses and 53 for other PA mixtures), while according to the mix documentation in almost all cases (>80%) aggregates with a sufficiently high PSV was used. This appears to be an issue with the general CE marking procedure, where a single certificate on the properties can be used to cover the whole production for a number of years, while it is widely accepted that the properties of the material in a quarry vary from location to location. As such, the provided certificates meet the requirements and contractors are allowed to accept this. Based on the results from this study, it is worthwhile considering how additional entrance testing can be introduced to assess the actual PSV value, because of its crucial link to traffic safety. In six out of 21 cases no PSV information was provided, even though it is required (PSV>=58 for the wearing courses, PSV≥53 for other ZOAB materials). The four cases where no PSV value was provided, were three DZOAB16 mixtures, wearing courses for which PSV has a relation to traffic safety, and one bottom layer of 2L-ZOAB. For all materials for which information on the PSV was provided, this was declared to be 58 or higher, even for the bottom layers of 2L-ZOAB. In only two of the seventeen materials for which the PSV was determined on field cores, the value was equal to the declared value, despite the fact that this declared value is a minimum value. Overall, less than 12% (2 out of 17, the four bottom layers of 2L-ZOAB have not been tested) of the PSV values found from field cores, meet the minimum requirement of 58. Four cores meet the minimum requirement, but the results are lower than the declared value in the mix documentation. One core meets the minimum requirement, but no declared value is provided in the mix documentation. These five results and the four bottom layers of 2L-ZOAB are listed as “M” in the overview.

Void content was generally on the low side, with 4 out of 21 mixtures falling outside the margins of the RAW Standard with respect to the declared value and another 2 meeting this requirement but falling short of the RWS contractual requirement that the average void content of DZOAB 16 cores must be ≥18% (noise regulation).

Where for the cores there could be an argument about whether the cores were taken from a representative part of the project, for a number of deviations found in the documentation provided this is not an issue. Such deviation, like too large a difference between target composition and RAW Standard requirements, or between target and reference composition were found in over half of the cases (67% for target composition, 86% for reference versus composition after extraction or target composition). In several cases the provided information did include information on the grading on all required sieves and in two cases the binder used was not the binder specified in the documentation. This latter cases are in violation of the CE marking procedures, where incompleteness of the provided information can be remedied relatively easily, but using the wrong type of bitumen cannot.

Overall it can be concluded that the number of deviations is considerable and higher than expected. This appears to be an effect of insufficient attention to the details of specifying and characterising the material, possibly acerbated by the complex set of requirements (various EN standards, RAW Standard, contractual specifications). First and foremost it is the responsibility of the producer to ensure that the documentation and the material meet the requirements, but that is apparently insufficient to prevent these deviations. It is important to address this and find solutions to ensure a system in which build-in checks and balances allow deviations not only to be noticed, but used to continuously improve. For RWS itself, it appears especially important to include some check on the completeness of the provided documentation, because the current level of incompleteness means that it is not always possible to check afterwards.

Another aspect that complicates checking adherence to the specifications afterwards, is that some requirements are for properties that change over time, so they either need to be assessed in the proper time interval after construction or a timeline of its change over time as a function of various parameters needs to be established.
For example penetration of the binder, there is a requirement for the maximum reduction during production and construction, but this is rarely checked. It is recommended that this check is added to the standard set of product checks after construction, both to check for compliance and in order to establish a baseline. Additionally, using FTIR to obtain the binder composition after construction is advisable to check if the binder used is consistent with the declared type (PMB or not). If the FTIR method for determining $Ca(OH)_2$ in the filler proofs to be reliable, these could be combined. That would be an attractive solution, since the FTIR method requires little material.
For the calcium hydroxide content there are currently no validated test methods for after construction, although several options seem promising. It is recommended to carry out the necessary result to develop such a test and to develop insight in its development over time in actual field conditions, since it appears to be an important parameter.
The use of CT-scanning prior to any (destructive) testing of cores in quality control settings will provide additional information on the composition and distribution of voids, which is a useful addition. In this project, it showed that although the DZOAB 16 and 2L-ZOAB 16 samples had on average low void contents, they were relatively uniform over the height and reproducible. For 2L-ZOAB 8 the void content was not even over the height.

It is recommended to add determining the penetration after construction, for which requirements are set, to the standard checks and to develop insight in the development of the penetration over time. This also holds for the amount of $Ca(OH)_2$, but here a reliable and objective test method needs to be established first. Additionally, using new developments in test methods such as CT-scanning and FTIR testing is useful, among others to obtain information on the distribution of the voids, the presence of cracks in coarse aggregates and of polymers in the bitumen and to follow their development over time.

All in all, the results from this study indicate the need to regularly collect composition information after construction and establish a means of sharing and discussing the issues found, in order to establish an improvement. It seems the current system does not have this self-correcting feature. It could be worthwhile to see if these mixtures have been used at RWS more recently and if the deficiencies have been corrected in the meantime. If they have, the system does improve, but the speed of those improvement may have to be increased. If they haven't it means improvements are urgently needed.

# Content

# 1. Introduction and Approach

## *1.1 Introduction and Motivation*

This report gives an overarching summary of a series of reports produced by various institutions during a study, initiated by Rijkswaterstaat (RWS), into the variation in the composition of ZOAB (the Dutch acronym for Porous Asphalt concrete (PA)). This variation is studied in relation to the requirements as set down in various standards.

Because the tests used during the study vary from standard tests to new approaches, at least for the Netherlands, this overarching report aims to explain the various test methods and their results and to provide an overall conclusion regarding the results.

Rijkswaterstaat initiated this study because of a number of cases where (very) early damage occurred in PA pavements in the south of the Netherlands (Figure 1.1, region 7). Examples of these early failures are given in the text box page 17.


Figure 1.1: Geographic regions Rijkswaterstaat

**Examples of early failures that triggered the research:**

**1. A76 HRL van km 19.176-18.500**, contract 31035183 Kunderberg, a section that exhibited serious ravelling one month after opening, prior to the formal delivery of the project. It turned out that the wrong type of bitumen was used. After discussion, Open Emulsion Sand Asphalt was applied to get through the winter period. After winter, the section was replaced by the contractor.

**2. A76 contract LB6424 Nuth**, showed early onset raveling (sections were all less than 2 years of age) on a large scale. Molenaar et al., 2005 showed as causes the use of the wrong type (insufficient $Ca(OH)_2$) and amount of filler, insufficient quality of aggregates (presence of swelling clay and hematite) and insufficient amount of bitumen in the top layer. In a formal procedure through the panel of arbitrators (2007-2009), RWS's complaints were found valid and the asphalt was replaced (under contract LB-8436). However, the contractor was not required to bear all costs of replacement.

**3. A76 Kunderberg, HRR 20,5-23,0** a number of large pot holes occurred in the right-hand lane (ca 10 holes of about $1m^2$ each) in 2013, at an age of 6 years. This involved a PA wearing course on a continuously reinforced concrete pavement (CRCP) on a steep slope. After closing down the right hand lane, similar damage occurred in the other lanes within a day. The damage was claimed to be due to winter damage. Although, despite the young age of the section, repairs had been carried out in several sections of the project earlier.

Research showed that the amount of filler in the mixture was lower than in the mixture design, while the amount of bitumen was according to the design. The amount of calcium hydroxide in the fraction <63 μm was very low. Aggregates at the bottom of the PA layer showed damage (fracture through the aggregates) and adhesive failure between aggregates and mastic. Also the adhesion of the PA layer to the CRCP was very low Houben et al., 2014. The contractor replaced the wearing course, 25% of the costs thereof were charged to RWS.

The reference frame RWS uses for the expected life time of various wearing course mixtures is obtained from their maintenance planning system. Those life times are considerably longer than the standard seven year warranty (for (D)ZOAB) in RWS projects (Table 1.1), where theory is based on the expected/predicted life times and practice is based on actually replaced sections.

In the examples mentioned in the text block, the realized life time was considerably less than expected for PA and even less than the warranty period of seven years. Any reduction in the life time of a wearing course, leads to extra maintenance costs. For this reason, a pavement management organisation needs to know what causes deviations in order to counteract them if possible, or account for higher maintenance costs over time.

In each of these cases, it was found that the composition of the material deviated from the requirements. This could go unnoticed at the time of construction, because the RWS quality system is risk based and focusses on the major (top ten) risks. In many projects, asphalt concrete is not one of the top risks. For other risks, not mentioned in the top 10, RWS relies on the contractual requirement that the contractor carries out his quality control and will report any deviations and proposes solutions to ensure sufficient quality. Since this apparently did not work for these projects with early failures, this caused RWS to wonder how wide spread these deviations from the specifications were. Another concern was if, when large or multiple variations lead to an extreme reduction in life time, smaller and/or single deviations would also lead to (smaller) reductions in life time. They initiated this study to get insight into these questions.

Table 1.1: Average life times of PA wearing courses, based on RWS maintenance information after Schouten et al., 2018

| Wearing course | mode | Minimum life time [yrs] | Average life time [yrs] | Maximum life time [yrs] |
|---|---|---|---|---|
| PA (ZOAB 16) | Theory | 8 | **15** | 18 |
| | Practice | 9,3 | **13,5** | 22,6 |
| PA+ (DZOAB 16) | Theory | 10 | **17** | 20 |

| | | | | |
|---|---|---|---|---|
| 2LPA (2L-ZOAB 8) | Theory | 8 | **13** | 16 |

## 1.2 Research question(s), hypotheses and approach

### 1.2.1 Research question(s)

With this project RWS intended to address the relation between deviations from the specifications and reduced life times. Specifically, they wanted to find out if deviations from specifications always led to a reduction in life time, or if multiple or specific deviations were needed. They also wanted to know how often deviations from specifications occurred. This kind of information is crucial for any road authority: knowing the chance that deviations occur and the effect that they have, allows to determine the risk and from the risk, cost-effective mitigation measures can be decided upon.

This lead to the following research questions:

1. ***How often do deviations from the specifications occur?***
    a. *When and where do they occur, between design (target composition[1]) and the project specifications (reference composition) and/or between project specifications (reference composition) and actual composition after construction (field core composition)?*
    b. *How and when can deviations be determined?*
2. ***Do deviations always lead to a reduction in life time?***
    a. *Do all deviations have the same impact on performance/life time reduction, or do some have more effect than others?*
    b. *Are single deviations enough to reduce the life time, or does it require multiple deviations/specific combinations of deviations?*
    c. *Can we link specific deviations to a given reduction in life time?*

### 1.2.2 Hypotheses

These research questions were translated into the following hypotheses, and the research summarizes in this report is used to see if the hypotheses would be falsified or validated. The percentages used in the hypotheses are based on the percentage of deviations found between field cores and required composition RWS did in the past. Stories of RWS employees involved in these checks indicate that deviations were found in 10-25% of the cases.

In Rijkswaterstaat (2001a) and (2001b) the results for the checks carried out in 2000, relative to the RAW 1990 and 1995, are given. In Table 1.2 the total overviews are re-created, showing that deviations per type of requirements (layer thickness, bitumen content, grading etc.) in that year varied between 5-35%, and in about 10% of all the checks carried out, deviations were found.

Table 1.2: Results of checks of field core composition versus specification in 2000 (after: Rijkswaterstaat, 2001a and 2001b)

| | | DIAK 2000 vs RAW 1990 | DIAK 2000 vs RAW 1995 |
|---|---|---|---|
| layer thickness | # samples | 1536 | 3012 |
| | # deviations | 196 | 345 |
| | % deviations | **13** | **11** |
| bitumen content | # samples | 654 | 2564 |
| | # deviations | 27 | 131 |
| | % deviations | **4** | **5** |
| void content | # samples | 1534 | 2981 |
| | # deviations | 76 | 139 |
| | % deviations | **5** | **5** |
| degree of compaction | # samples | 1474 | 2904 |
| | # deviations | 246 | 338 |
| | % deviations | **17** | **12** |
| grading curve | # samples | 610 | 2564 |
| | # deviations | 219 | 592 |
| | % deviations | **36** | **23** |
| total | # samples | 5808 | 14025 |
| | # deviations | 764 | 1545 |
| | % deviations | **13** | **11** |

When looking at the comparison of the field core composition to the specifications, in the current situation, an additional step is added in the procedure. Before 2008 a composition was selected based on the mix design and the field composition was checked versus that composition, allow for specific margins. In the current procedure, after selecting the mix design (target composition), a core with that composition is made in the lab and extracted. That extracted composition is reported and used by the contractor to specify the so-called reference composition. There are limits for the difference between the extracted composition and the reference composition. Field cores are now compared to the reference composition, again taking into account certain margins. More details are given in Chapter 2.

Since there no recent indications of the number of deviations were found, a comparison is made to failure costs. Failure costs, defined as costs associated with avoidable errors in the construction process, remain high in the engineering sector. In 2008 an article in Land en Water listed the failure costs for contractors in geotechnical, pavement and hydraulic engineering (GWW) as 7,0% of their revenue in 2005 and 11,2% in 2008 (Economisch Instituut voor Bouwnijverheid (EBI) et al., 2008). A recent study from ABN-Amro (van Heel et al., 2019) showed that contractors are currently more positive in their estimates of the failure costs. More than half of them (54%) estimate the costs at less than 5%. The same study shows that manufacturers are less optimistic, they less than half of them (43%) expects to have failure costs under the 5%. Since manufacturers make their products in a controlled environment, it is unlikely that their failure costs are less than those of the contractors. This is noted, but not further pursued in the publication. Other publications cite other numbers, mostly around 10% (Bouwkennis (2013), Brokelman et al. (2005), Economisch Instituut voor Bouwnijverheid (EBI) et al. (2008), Lenferink (2018), Oomkes (2017), qumedia (2010)). All in all, it can be said that failure costs in this sector remain high.

Considering that the failure costs in the sector do not seem to change much over time and combining this with the fact that the current approach used by RWS for quality control depends largely on the contractors own quality control process, with little external controls, it is assumed that the deviations in composition will not have changed much, either. As such, the expected number of deviations in field cores composition when compared to the requirements is estimated at 20%. The deviations between the target composition/compositions after extraction and reference composition is expected to be less, it is therefore estimated at 5%. This leads to the following hypotheses:

**Hypotheses:**

1. Deviations exceeding the margins allowed between target3 and reference composition occur at most 5% of the time, deviations exceeding the margins between reference composition and field cores occur in up to 20% of the cases.
2. Deviations in composition cause a reduction of life time and/or functional characteristics.

It should be noted that, if hypothesis 1 is shown to be true, this does not mean that this level of deviations is unavoidable or acceptable, it just shows that the assumption that like the failure costs, the number of deviations from the requirements has been constant over the years. Even in that case, improvements are still possible and advisable. If this hypothesis is disproven, it will show that unlike the failure costs the number of deviations has increased.

### 1.2.3 Research approach

Since the research questions involve deviations from specifications, the first step is to define the specifications used to determine deviations. In this section, first the Dutch specifications for PA are given, then it is described how a research program was developed to determine if and to what extend deviations occurred. Finally, the link to performance is described.

#### 1.2.3.1 PA specifications

The composition information for asphalt concrete mixtures is specified in the "*Standaard RAW Bepalingen*", which is the Dutch Standard for Geotechnical, Pavement and Hydraulic Engineering. This set of specifications is drafted in cooperation between road authorities and contractors and published and maintained by CROW. From now on in this reports this standard will be referred to as the RAW Standard. The specifications for PA in the RAW Standard cover requirements for:

- Constituent materials
- Aggregate grading
- Bitumen content
- Mixture specific requirements

In this case, the mixture under consideration is Porous Asphalt (PA). Since 2008 PA is specified in the EN 13108-7. Because in that standard the grading, bitumen content and mixture specific requirements are less strict than in the RAW standard, the Dutch acronym for PA (ZOAB) is used in the RAW standard to identify specific PA mixtures that fulfil the stricter requirements with which there is considerable experience in the Netherlands. RWS automatically accepts ZOAB mixtures as having the same expected life time as was established for this material since its application in the late 1980's. PA mixtures that deviate from the stricter ZOAB specifications can be used after a validation shows that the expected performance is equal to that of ZOAB (Rijkswaterstaat, 2009).

In the current RAW Standard (2015) various types of specific PA mixtures are distinguished (Table 1.3, taken from the RAW standard 2015 table 81.2.11). The requirements listed in the table are (top to bottom): binder content, minimum and maximum void content, moisture sensitivity and binder drainage. For the maximum void content and binder drainage no requirements are specified.

3 Or composition after extraction of a core made according to the target composition, depending on the valid standard, see Chapter 2 and 3

Table 1.3: Requirements in the RAW Standard 2015 for various specific PA mixtures CROW, Standaard 2015 (2015), Table 81.2.11)

| eigenschap | ZOAB 11 | ZOAB 16 | DZOAB 16 | 2L-ZOAB 16 | 2L-ZOAB 5 | 2L-ZOAB 8 |
|---|---|---|---|---|---|---|
| bindmiddelgehalte | $B_{min\ 4,5}$ | $B_{min\ 4,5}$ | $B_{min\ 5,2}$ | $B_{min\ 4,2}$ | $B_{min\ 5,4}$ | $B_{min\ 5,4}$ |
| minimum holle ruimte | $V_{min20}$ | $V_{min20}$ | $V_{min20}$ | $V_{min25}$ | $V_{min20}$ | $V_{min20}$ |
| maximum holle ruimte | $V_{maxNR}$ | $V_{maxNR}$ | $V_{maxNR}$ | $V_{maxNR}$ | $V_{maxNR}$ | $V_{maxNR}$ |
| watergevoeligheid | $ITSR_{80}$ | $ITSR_{80}$ | $ITSR_{80}$ | $ITSR_{80}$ | $ITSR_{80}$ | $ITSR_{80}$ |
| afdruipen | $D_{NR}$ | $D_{NR}$ | $D_{NR}$ | $D_{NR}$ | $D_{NR}$ | $D_{NR}$ |

The additional specifications given for PA in article 81.26.04 of the RAW Standard 2015 are given in Figure 1.2 (In Dutch).

### 81.26.04 Zeer open asfaltbeton

**01** In aanvulling op het bepaalde in artikel 81.26.01 lid 01 moet asfalt voor zeer open asfaltbeton voldoen aan het bepaalde in NEN-EN 13108-7, met inachtneming van het bepaalde in de navolgende leden.

**02** Grof toeslagmateriaal voor zeer open asfaltbeton moet voldoen aan de eisen voor steenslag 2, echter grof toeslagmateriaal voor DZOAB 16, 2L-ZOAB 5 en 2L-ZOAB 8 moet voldoen aan de eisen voor steenslag 3.

**03** De korrelverdeling als bedoeld in onderdeel 5.2.2 van NEN 13108-7 wordt bepaald met behulp van de basis zeefset plus set 1 volgens onderdeel 4.1.2 van NEN-EN 13043.

**04** De waterdoorlatendheid van zeer open asfaltbeton wordt bepaald volgens onderdeel 5.4.2 van NEN 13108-7. Het bepaalde in onderdeel 5.4.3 van NEN-EN 13108-7 is niet van toepassing.

**05** De samenstelling van ZOAB 11, ZOAB 16, DZOAB 16, 2L-ZOAB 16, 2L-ZOAB 5 en 2L-ZOAB 8 moet voldoen aan de in tabel 81.2.10 vermelde eisen.

**06** In DZOAB 16 moeten zodanige maatregelen tegen afdruipen zijn toegepast dat het verschil tussen het bitumengehalte onderin en bovenin de laag niet meer bedraagt dan 0,7% *(m/m)*.

**07** Voor ZOAB 11 en ZOAB 16 bitumen 70/100 toepassen.
Voor DZOAB 16 bitumen 70/100 of polymeer gemodificeerde bitumen toepassen.
Voor 2L-ZOAB 16 bitumen 70/100 of polymeer gemodificeerde bitumen toepassen.
Voor 2L-ZOAB 5 en 2L-ZOAB 8 polymeer gemodificeerde bitumen toepassen.

**08** Voor ZOAB 11, ZOAB 16, DZOAB 16, 2L-ZOAB 16, 2L-ZOAB 5 en 2L-ZOAB 8 als fijn toeslagmateriaal brekerzand toepassen.

**09** Voor ZOAB 11, ZOAB 16, DZOAB 16, 2L-ZOAB 16, 2L-ZOAB 5 en 2L-ZOAB 8 middelsoort vulstof met hydroxide toepassen overeenkomstig het bepaalde in artikel 5 van NEN 6240.

**10** In ZOAB 11, ZOAB 16, DZOAB 16, 2L-ZOAB 16, 2L-ZOAB 5 en 2L-ZOAB 8 geen asfaltgranulaat toepassen.

**11** Voor de samenstelling van ZOAB 11, ZOAB 16 en DZOAB 16 geen grof toeslagmateriaal 2/5 of 2/6 toepassen.
Voor de samenstelling van 2L-ZOAB 16 geen grof toeslagmateriaal kleiner dan 8 mm toepassen.

**12** De in het verkort verslag vermelde eigenschappen van ZOAB 11, ZOAB 16, DZOAB 16, 2L-ZOAB 16, 2L-ZOAB 5 en 2L-ZOAB 8 moeten voldoen aan de in tabel 81.2.11 genoemde eisen.

Figure 1.2: Article 81.26.04 of the RAW Standard (CROW, Standaard 2015 (2015)) specifies the additional requirements for specific Dutch PA mixtures

In Figure 1.2**Fout! Verwijzingsbron niet gevonden.** the articles determine the following:

01. States that the specific ZOAB mixtures from Table 1.3 should fulfil the requirements of EN 13108-7, while taking into account the specifications in this list.

02. Specifies the requirements (particularly Polished Stone Value and amount of rounded particles) for course aggregate the various types of ZOAB

03. Specifies the use of sieve set plus 1 for the grading curve

04. Specifies that drainage is specified through the void content, not the direct drainage measurement from EN13108-7[4].

05. Refers to the mix type specific requirements shown in Table 1.3

06. Specifies an in-situ binder drainage requirement, limiting the difference between binder content in the top and bottom part of a DZOAB core to 0,7%

07. Specifies the type of binder for the various specific PA mixtures
  a. Pen grade 70/100 for ZOAB 11 and ZOAB 16,
  b. either pen grade 70/100 or polymer modified bitumen for DZOAB 16 and 2L-ZOAB 16
  c. polymer modified bitumen for 2L-ZOAB 5 and 2L-ZOAB 8

08. Specifies the use of crushed rock or gravel sand fraction (63μm-2mm)

09. Requires the use of fabricated middle type filler with hydroxide in all these specific types of PA

010. Prohibits the use of reclaimed asphalt (RA) in any of these specific types of PA

011. Prohibits the use of aggregates 2/5 or 2/6 in ZOAB11, ZOAB16 and DZOAB16 and coarse aggregates smaller than 8mm in 2L-ZOAB16

012. Requires that for each mixture the properties shown in Table 1.3 meet the requirements given in that table.

These RAW Standard specifications are updated every few years. The current specifications were published in 2015, the ones before were published in 2010 (CROW, Standaard 2010 (2010)). In 2010 only requirements for ZOAB11 and ZOAB 16 were given, in those specifications nothing changed. The requirements for DZOAB16 were based on those used by RWS and those for 2L-ZOAB were given in a publication of the Dutch Asphalt Contractors association (VBW, Bouwend Nederland (2012)). The current specifications in the RAW Standard (CROW, Standaard 2015 (2015)) are based on those requirements.

## 1.2.3.2 Research plan

In the research plan, the aim is to get a representative selection of PA constructed over the past, in order to determine if deviations occur regularly or not. Then, tests were specified to address the aspects covered in the specifications: grading, bitumen type and content, filler type and content and to determine if these meet the requirements. The tests selected to assess each of these aspects are given in this section and so is the list of sample locations.

### *1.2.3.2.1 Sample locations*

To address the first research question/hypothesis (Section 1.2.2, Hypothesis 1 on Page 20, repeated underneath), samples from pavement sections were tested. The hypothesis reads:

4 The RAW 2015 standard refers to the corresponding articles in the 13108-7:2006. In the 13108-7:2016 the corresponding sections are 5.3.2.2 and 5.3.2.3, respectively.

***Hypothesis 1***:

*How often do deviations from the specifications occur?*

Deviations exceeding the margins allowed between target5 and reference composition occur at least 5% of the time, deviations exceeding the margins between reference composition and field cores occur in 20% of the cases.

Based on communications with the RWS project team, the following summary of the selection procedure for the test sections and test program was obtained.

To get to a set of pavement sections to sample, sections paved with Porous Asphalt (PA) in the South of the Netherlands (RWS region South Netherlands, ZN) were inventoried. For this inventory both the regular maintenance and variable maintenance projects were taken into account. In the Netherlands road maintenance is separated in two types of strategies:

1. In Dutch; LevensduurVerlengend Onderhoud (LVO)

LVO means lifetime extending of the slow lane, to get the same lifetime as the fast lane. This contract-type is known in Rijkswaterstaat terminology Fixed Maintenance, in Dutch: Vast Onderhouds Contract (VOC)

2. In Dutch; Groot Onderhoud (GO)

GO means carriageway wide construction of PA and sometimes strengthen the structure with an extra binder layer. This contract-type is in Rijkswaterstaat terminology Large scale Variable Maintenance, in Dutch: Groot Variabel Onderhoud (GVO)

From the list of potential test sections, the ones that fulfilled the following criteria were selected:
a) still within their warranty period,
b) represented various types of contracts used by RWS and
c) were constructed by various contractors.

Within these road sections cores were taken in the right hand wheel track on the right hand lane, while the longitudinal starting point for taking the cores was selected randomly, taking into account practical issues (i.e. not drilling near or on an exit). The cores were taken 20 meters apart in longitudinal direction.
So, although this project was initiated because of doubts about the adherence to specifications and the quality of pavement construction, the sampling aimed to be representative of various types of contracts and contractors.

All in all, 17 locations from eleven different contractors were sampled. Two contractors have three sections in the set, two have two and the other seven contractors each have one. Because these contractors operate throughout the Netherlands, it can be said that they are representative for the Dutch situation. The same PA mixtures are often also applied in other parts of the Netherland, in which case they are produced by other asphalt mix plants, but with the same constituent materials. Per test section or location, five cores were taken, in some cases six, to ensure the required amount of material for the various tests. The overview of the sections and the samples is shown in Table 1.4**.** The contractors are denoted by a code letter, since the aim of the study is to get a representative impression of the deviations from specifications that occur in pavement construction. For that reason, a representative selection of contractors was chosen. Which contractor did what work, is not considered relevant. The contractor codes are used here to show the variation of contractors over the projects.

5 Or composition after extraction of a core made according to the target composition, depending on the valid standard, see Chapter 2 and 3

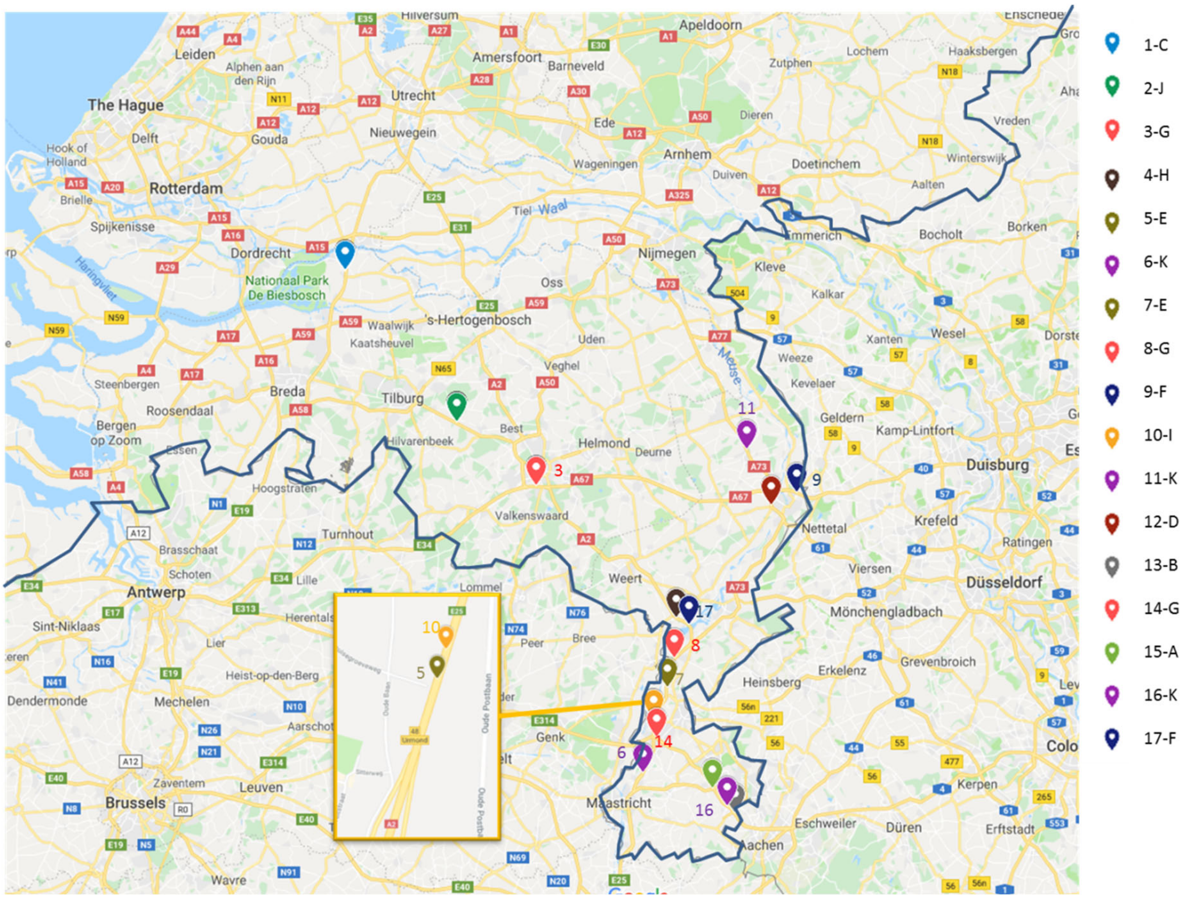


Figure 1.3: Overview of the 17 sample locations and the 11 contractors (colours), on the large map location 5 is overlapped by location 10 (see insert)

Table 1.4: Location and asphalt type information test sections

| code | Section | Mixture Type | km sample | sample code | Build in | Contractor code | GPS coordinates samples latitude | longitude |
|---|---|---|---|---|---|---|---|---|
| 1 | A27 HRR 2R-R Km. 29,500 - Km. 29,600 | DZOAB 16 | 29,500 | 1-1 | 2012 | C | N 51 46.915 | E 4 55.674 |
| | | | 29,520 | 1-2 | | | N 51 46.926 | E 4 55.679 |
| | | | 29,540 | 1-3 | | | N 51 46.937 | E 4 55.679 |
| | | | 29,560 | 1-4 | | | N 51 46.948 | E 4 55.681 |
| | | | 29,580 | 1-5 | | | N 51 46.959 | E 4 55.683 |
| 2 | A58 HRR 2R-R Km. 25.000 - Km. 25,100 | DZOAB 16 | 25,000 | 2-1 | 2013 | J | N 51 31.082 | E 5 14.539 |
| | | | 25,020 | 2-2 | | | N 51 31.089 | E 5 14.522 |
| | | | 25,040 | 2-3 | | | N 51 31.094 | E 5 14.508 |
| | | | 25,060 | 2-4 | | | N 51 31.098 | E 5 14.492 |
| | | | 25,080 | 2-5 | | | N 51 31.102 | E 5 14.475 |
| 3 | A2 HRL 3R-L Km. 167,300 - Km. 167,400 | 2LZOAB 8 & 2LZOAB 16 | 167,380 | 3-1 | 2009 | G | N 51 24.346 | E 5 27.895 |
| | | | 167,360 | 3-2 | | | N 51 24.347 | E 5 27.877 |
| | | | 167,350 | 3-3 | | | N 51 24.345 | E 5 27.866 |
| | | | 167,340 | 3-4 | | | N 51 24.346 | E 5 27.859 |
| | | | 167,320 | 3-5 | | | N 51 24.345 | E 5 27.839 |
| | | | 167,300 | 3-6 | | | N 51 24.346 | E 5 27.822 |
| 4 | A2 HRR 2R-R Km. 213.000 - Km. 216.000 | DZOAB 16 | 214,000 | 4-1 | 2010 | H | N 51 10.420 | E 5 51.276 |
| | | | 214,020 | 4-2 | | | N 51 10.428 | E 5 51.284 |
| | | | 214,040 | 4-3 | | | N 51 10.423 | E 5 51.296 |
| | | | 214,060 | 4-4 | | | N 51 10.419 | E 5 51.307 |
| | | | 214,080 | 4-5 | | | N 51 10.413 | E 5 51.322 |
| 5 | A2 HRR 2R-R Km. 237,000 - Km. 238,500 | 2LZOAB 8 & 2LZOAB 16 | 238,000 | 5-1 | 2008 | E | N 50 59.802 | E 5 47.258 |
| | | | 238,020 | 5-2 | | | N 50 59.792 | E 5 47.256 |
| | | | 238,040 | 5-3 | | | N 50 59.782 | E 5 47.250 |
| | | | 238,060 | 5-4 | | | N 50 59.772 | E 5 47.245 |
| | | | 238,080 | 5-5 | | | N 50 59.762 | E 5 47.242 |
| 6 | A2 HRL 2R-L Km. 250,000 - Km. 247,600 | DZOAB 16 | 249,000 | 6-1 | 2013 | K | N 50 54.201 | E 5 45.471 |
| | | | 248,980 | 6-2 | | | N 50 54.212 | E 5 45.477 |
| | | | 248,960 | 6-3 | | | N 50 54.221 | E 5 45.484 |
| | | | 248,940 | 6-4 | | | N 50 54.232 | E 5 45.485 |
| | | | 248,920 | 6-5 | | | N 50 54.242 | E 5 45.490 |
| 7 | A2 HRR 2R-R Km. 231,000 - Km. 234,700 | 2LZOAB 8 & 2LZOAB 16 | 231,000 | 7-1 | 2009 | E | N 51 3.170 | E 5 49.615 |
| | | | 231,020 | 7-2 | | | N 51 3.158 | E 5 49.618 |
| | | | 231,040 | 7-3 | | | N 51 3.147 | E 5 49.618 |
| | | | 231,060 | 7-4 | | | N 51 3.136 | E 5 49.620 |
| | | | 321,080 | 7-5 | | | N 51 3.127 | E 5 49.618 |
| 8 | A2 HRL 2R-L Km. 228,000 - Km. 222,000 | DZOAB 16 | 225,000 | 8-1 | 2011 | G | N 51 6.154 | E 5 50.875 |
| | | | 224,980 | 8-2 | | | N 51 6.162 | E 5 50.887 |
| | | | 224,960 | 8-3 | | | N 51 6.169 | E 5 50.897 |
| | | | 224,940 | 8-4 | | | N 51 6.178 | E 5 50.911 |
| | | | 224,920 | 8-5 | | | N 51 6.186 | E 5 50.925 |
| 9 | A2 HRR 2R-R Km. 216,500 - Km. 217,000 | DZOAB 16 | 216,800 | 9-1 | 2011 | F | N 51 9.690 | E 5 53.315 |
| | | | 216,820 | 9-2 | | | N 51 9.681 | E 5 53.325 |
| | | | 216,840 | 9-3 | | | N 51 9.672 | E 5 53.335 |
| | | | 216,860 | 9-4 | | | N 51 9.664 | E 5 53.348 |
| | | | 216,880 | 9-5 | | | N 51 9.656 | E 5 53.359 |
| 10 | A2 HRR 2R-R Km. 237,900 - Km. 238,000 | DZOAB 16 | 237,900 | 10-1 | 2013 | I | N 50 59.863 | E 5 47.286 |
| | | | 237,920 | 10-2 | | | N 50 59.852 | E 5 47.284 |
| | | | 237,940 | 10-3 | | | N 50 59.842 | E 5 47.280 |
| | | | 237,960 | 10-4 | | | N 50 59.834 | E 5 47.276 |
| | | | 237,980 | 10-5 | | | N 50 59.822 | E 5 47.270 |

Table 1.4-continued: Location and asphalt type information test sections

| code | Section | Mixture Type | Km sample | sample code | Build in | Contractor code | GPS coordinates samples | |
|---|---|---|---|---|---|---|---|---|
| 11 | A73 HRR 2R-R Km. 51,000 - Km. 66,600 | DZOAB 16 | 56,000 | 11-1 | 2013 | K | N 51 28.005 | E 6 3.362 |
| | | | 56,020 | 11-2 | | | N 51 28.016 | E 6 3.359 |
| | | | 56,040 | 11-3 | | | N 51 28.027 | E 6 3.357 |
| | | | 56,060 | 11-4 | | | N 51 28.035 | E 6 3.347 |
| | | | 56,080 | 11-5 | | | N 51 28.047 | E 6 3.346 |
| 12 | A73 HRR 2R-R Km. 43,300 - Km. 43,500 | 2LZOAB 8 & 2LZOAB 16 | 43,300 | 12-1 | 2015 | D | N 51 22.112 | E 6 7.394 |
| | | | 43,320 | 12-2 | | | N 51 22.122 | E 6 7.391 |
| | | | 43,340 | 12-3 | | | N 51 22.133 | E 6 7.387 |
| | | | 43,350 | 12-4 | | | N 51 22.138 | E 6 7.385 |
| | | | 43,360 | 12-5 | | | N 51 22.144 | E 6 7.385 |
| | | | 43,380 | 12-6 | | | N 51 22.156 | E 6 7.384 |
| 13 | A76 Parallelbaan | DZOAB 16 | 25,400b | 13-1 | 2013 | B | N 50 49.895 | E 6 0.679 |
| | | | 25,420b | 13-2 | | | N 50 49.887 | E 6 0.686 |
| | | | 25,440b | 13-3 | | | N 50 49.877 | E 6 0.695 |
| | | | 25,460b | 13-4 | | | N 50 49.868 | E 6 0.705 |
| | | | 25,480b | 13-5 | | | N 50 49.858 | E 6 0.716 |
| 14 | A76 HRL 2R-L Km. 4,800 - Km. 2,900 | DZOAB 16 | 3,500 vw-s | 14-1 | 2012 | G | N 50 57.849 | E 5 47.858 |
| | | | 3,480 vw-s | 14-2 | | | N 50 57.857 | E 5 47.846 |
| | | | 3,460 vw-s | 14-3 | | | N 50 57.868 | E 5 47.833 |
| | | | 3,440 vw-s | 14-4 | | | N 50 57.873 | E 5 47.817 |
| | | | 3,420 vw-s | 14-5 | | | N 50 57.879 | E 5 47.806 |
| 15 | A79 HRR 2R-R Km. 17,400 - Km. 16,600 | DZOAB 16 | 17,000 | 15-1 | 2014 | A | N 50 52.490 | E 5 57.057 |
| | | | 17,020 | 15-2 | | | N 50 52.495 | E 5 57.073 |
| | | | 17,040 | 15-3 | | | N 50 52.499 | E 5 57.089 |
| | | | 17,060 | 15-4 | | | N 50 52.502 | E 5 57.103 |
| | | | 17,060 | 15-5 | | | N 50 52.506 | E 5 57.118 |
| 16 | A76 HRL 2R-L Km. 23,775 - Km. 23,290 | DZOAB 16 | 23,430 | 16-1 | 2013 | K | N 50 50.643 | E 5 59.523 |
| | | | 23,420 | 16-2 | | | N 50 50.644 | E 5 59.514 |
| | | | 23,410 | 16-3 | | | N 50 50.649 | E 5 59.510 |
| | | | 23,400 | 16-4 | | | N 50 50.651 | E 5 59.503 |
| | | | 23,390 | 16-5 | | | N 50 50.654 | E 5 59.495 |
| 17 | A67 HRL 2R-L Km 74,040 - Km. 66,600 | DZOAB 16 | 74,040 | 17-1 | 2012 | F | N 51 23.309 | E 6 12.151 |
| | | | 73,800 | 17-2 | | | N 51 23.367 | E 6 11.960 |
| | | | 73,550 | 17-3 | | | N 51 23.426 | E 6 11.766 |
| | | | 73,340 | 17-4 | | | N 51 23.516 | E 6 11.460 |
| | | | 72,900 | 17-5 | | | N 51 23.575 | E 6 11.260 |

#### 1.2.3.2.2 *TYPES OF TESTS*

The types of tests were meant to assess two things;

- first of all if atthe locations mentioned in the previous paragraph, deviations from the requirements occurred
- and secondly, to determine the answer to the second research question/the validity of the second hypotheses (Section 1.2.2, hypothesis 2 on Page 20), repeated underneath:

***Hypothesis 2***:

*Deviations in composition cause a reduction of life time and/or functional characteristics.*

In order to address this, tests assessing those aspects for which there are requirements and tests able to determine if the sample material agreed with the mixture design were selected. In the next chapter the requirements on PA composition and the various tests carried out to assess if these criteria are met, are discussed. An overview of the components tested, the tests used and the underlying reports on which this chapter is based are given in Table 1.5.

Table 1.5: Overview of tests used, the location in this report and the underlying reports

| property | test method | tested by | discussed in | underlying report |
|---|---|---|---|---|
| **Asphalt cores** | | | | |
| Layer thickness | | Kiwa KOAC | *Not discussed in this report* | Kiwa KOAC, 2017 |
| Composition | CT-scans | TU Delft | 3.5.2<br>3.9.2.2 | van Tooren, M. et al., 2017 |
| Void content | | Kiwa KOAC | Section 3.4.2 | Kiwa KOAC, 2017 |
| Void Content | CT Scans | | 3.5.2 | |
| Grading | | Kiwa KOAC | 3.4 | Kiwa KOAC, 2017 |
| **Course aggregates** | | | | |
| Grading | | Kiwa KOAC | 3.9.1.1 | Kiwa KOAC, 2017 |
| PSV value | | | 3.9.1.2 | Schulze et al., 2018 |
| Petrographical characterisation course aggregates | Thin slices for visual analyses (polarisation microscope) | TU Delft | 3.9.2.1 | van Tooren, M. et al., 2017<br>Hellman, 2018b |
| CT-scans | | | 3.9.2.2 | van Tooren, M. et al., 2017 |
| **Filler** | | | | |
| Quantity | Sieve test | Kiwa KOAC | 3.7.1.1 | Hirsch, 2017b,Kiwa KOAC, 2017 |
| Size distribution | | BASt | 3.7.2.2 | Hirsch, 2017b |
| Filler to bitumen ratio | | - | 3.7.2.1 | |
| Amount of calcium hydroxide | Titrimetry | Kiwa KOAC<br>Bast | 3.7.2.3<br>3.7.2.4.2 | Kiwa KOAC, 2017<br>Hirsch, 2017b, 2017c |
| | Mass balance | Core Power | 3.7.2.4.3 | Hellman, 2018a, 2019 |
| | volumetry, gravimetry, thermogravimetry , FTIR and XRPD Rietveld | Bast<br>Kiwa KOAC<br>BASt<br><br><br>Core Power | 3.7.2.4.1<br>3.7.2.4.2<br><br>3.7.2.5.2 | Hellman, 2018a<br>Hellman, 2019<br>Kiwa KOAC, 2017<br>Hirsch, 2017c<br>Hirsch, 2019b |
| Reactivity | Acid number | BASt | 3.6.2.2.3 | Hirsch, 2019b |
| **Bitumen** | | | | |
| Binder content | | Kiwa KOAC | 3.6.1 | Kiwa KOAC, 2017 |
| Rheology | Penetration, EN- | Kiwa KOAC | 3.6.2.1 | Kiwa KOAC, 2017 |
| | MSCR, EN 16659 | BASt | 3.6.2.2.1 | Hirsch, 2017a |
| Chemistry | Oxidation state, presence of polymers: FTIR, | BASt<br>TNO | 3.6.2.2.2.1<br>3.6.2.2.2.2 | Hirsch, 2017a, van Vliet, 2018 |
| | Acid number, Titrimetry, test method of CEN-TC336-WG2 | BASt | 3.6.2.2.3 | Hirsch, 2017a |
| | Oil provenance, BASt in-house method | BASt | 3.6.2.2.5 | Hirsch, 2017a |
| | SARA-analysis | | 3.6.2.2.4 | Simnofske et al., 2018 |

For each set of samples the results will be compared to the declared properties of the mixture and its components and to the requirements, accounting for the changes that can be expected over time. Based on these results, it will be determined if the samples deviate from the required or declared properties and if this is the case for one or multiple properties.

## *1.3 Reading guide*

In this chapter the motivation for and approach to the project is described.
The requirements for ZOAB mixtures and their development over time are presented in Chapter 2. Chapter 3 describes the various tests and test results. Chapter 4 gives an overview of the expected effect of deviations in composition and properties on the performance and finally the conclusions and recommendations are given in Chapter 5 and the references are listed in Chapter 6.

# 2. Requirements and standard tests for ZOAB

In this section, the requirements for the properties of the various mixture components as specified in the RAW standard over time. The RAW Standard requirements for pavement engineering are part of a general standard for geotechnical, pavement and hydraulic engineering which is formally called "Standaard RAW Bepalingen", published by CROW. Every few years, the requirements are updated. As mentioned in Section 1.2.3.1, in this report this standard is referred to as RAW Standard, followed by the year of publication. This Chapter deals with various RAW Standards (CROW, Standaard 2005, 2005,CROW, Standaard 2008, 2008,CROW, Standaard 2010, 2010,CROW, Standaard 2015, 2015), the European standards (EN 13108-series) during the time the pavement sections were constructed and the tests used to determine the required properties.

The RAW standard is updated roughly once every five years. Since the introduction of the European standards for asphalt concrete in 2008 and the change at EU level from Construction Products Directive to the Construction Products Regulation (CPR) in 2013, both the requirements for the documentation and those for the materials have changed. Unfortunately, there are no standard formats available for the documentation and there remains discussion about what information should be provided and how. For this reason, in the next section an overview of the requirements is given. This leads to a framework that is used to assess the completeness and correctness of the provided documentation later in this report.

## *2.1 Required documentation for PA materials*

In the Netherlands, until 2008, the documentation required for any asphalt mixture in paving applications was specified through private law in the contract documents. Unlike the building industry with its building code (in Dutch: Bouwbesluit, since 1992) there was no overarching legal system covering pavement construction. The most commonly used set of requirements was given in the RAW Standard. The first RAW Standard, which was based on an earlier set of requirements (AV 1938), was published in 1979. Since 1987 the standards are managed by non-profit foundation CROW. The content of the standard is managed by working groups of representatives of road agencies and pavement contractors. The RAW Standard is updated roughly once every five years and in 2008 the current version was published, bringing the requirements in line with the European standards which became active on January 1$^{st}$ 2008 . The current version of the RAW Standard was published in 2015 (CROW, Standaard 2015, )

By 2008 the Dutch highway agency, Rijkswaterstaat, had moved to functional specifications in their contracts, but referred to the Standard for mixtures with a demonstrated history of successful application ("standard mixtures"). In the 2005 standard the requirements for all asphalt mixtures were recipe based, with the mixture design procedure based on Marshall testing to assess the optimum bitumen contact for a given grading and fitness for use of the constituents determined from a Proof of Origin (in Dutch: bewijs van oorsprong).

With the introduction of the European standards for Asphalt Concrete (EN 13108-series) in 2008, a public law component was introduced in a system that, until that time was fully based on private law. The resulting situation with both legal and contractual requirements, the former upheld by a national inspection agency (Inspectie Luchtvaart en Transport) and the latter by the client, is, to this day, causing confusion and discussion.

When European standards developed on request of the European Committee (EC), known as a "mandate", are published in the Official Journal of the European Union (OJEU) they become harmonized standards6. Using these standards enable the presumption of compliance. Using the standards is not obligatory, but meeting the legal requirements set by the EU is. These harmonized

6 https://ec.europa.eu/growth/single-market/european-standards/harmonised-standards_sv

standards are drawn up to reflect the state of the art in establishing the technical specifications which are sufficient to meet the technical requirements in the EU legislation. In the case of Asphalt Concrete, this is the Construction Products Directive (since 2013 Construction Products Regulation). Assessing a product and reporting its properties according to a harmonized standard, carries the presumption that the product meets the CPD/CPR requirements. Prior to publication in the OJEU the presumption is not formally in place. When a harmonised standard is cited in the OJEU, a date of applicability (i.e. starting date) and a data of the end of co-existence are given. Any conflicting standards need to be retracted by the end of the co-existence period.

When CEN publishes new standards, it includes a publication and co-existence period. For the EN 13108-7 the publication date by CEN was November 2006 and the end of the co-existence period was January 2008. In OJEU the dates were 1st of March 2007 and 1st of March 2008, respectively (Figure 2.1). That is when the required information started changing.

).3.2018 EN Official Journal of the European Union C 92/13

**Commission communication in the framework of the implementation of Regulation (EU) No 305/2011 of the European Parliament and of the Council laying down harmonised conditions for the marketing of construction products and repealing Council Directive 89/106/EEC**

*(Publication of titles and references of harmonised standards under Union harmonisation legislation)*

The provisions of Regulation (EU) No 305/2011 prevail over any conflicting provisions in the harmonised standards

**(Text with EEA relevance)**

(2018/C 092/06)

| ESO (1) | Reference and title of the standard (and reference document) | Reference of superseded standard | Date of applicability of the standard as a harmonised standard | Date of the end of the co existence period |
|---|---|---|---|---|
| CEN | EN 13108-6:2006<br>Bituminous mixtures — Material specifications — Part 6: Mastic Asphalt | | 1.3.2007 | 1.3.2008 |
| | EN 13108-6:2006/AC:2008 | | 1.1.2009 | 1.1.2009 |
| CEN | EN 13108-7:2006<br>Bituminous mixtures — Material specifications — Part 7: Porous Asphalt | | 1.3.2007 | 1.3.2008 |
| | EN 13108-7:2006/AC:2008 | | 1.1.2009 | 1.1.2009 |

Figure 2.1: Citation of EN 13108-7 in OJEU

### 2.1.1 March 2008-March 2009

#### 2.1.1.1 RAW standard 2005

The RAW Standard that was valid at the time the EN standards were introduced, was the version of 2005. Under this standard, the contractor was, among other things, responsible for carrying out a mixture design (Dutch: vooronderzoek), in case of PA this was limited to determining the void content of four Marshall specimens. The average void content had to meet the requirement (Figure 2.2). After this mixture design, the components of cores had to be reclaimed and used to set the reference mixture composition. For AC mixtures besides the void content also the Marshall stability, -flow, -

quotient and -degree of filling had to be determined. Both the mixture design report and the reference composition, as well as proof that the constituent materials used in production were the same as those used in the mixture design had to be submitted to the client.

The mixture design was valid for three years, but once a year the Marshall properties had to be determined to check if they did not deviate too much from the values found in the mixture design.

BEPALINGEN

HOOFDSTUK → 02 Proeven
PARAGRAAF → 02 Proeven
PROEF → 56.4 Zeer open asfaltbeton

Bereid 4 proefstukken overeenkomstig de Marshallproef *(proef 57.1)* of de gyratorverdichter *(proef 57.2)* met de in artikel 31.26.13 genoemde bouwstoffen en overeenkomstig de in tabel T 31.21 voor de desbetreffende soort zeer open asfaltbeton genoemde korrelverdeling en samenstelling zodanig, dat het gemiddelde van de holle ruimte *(proef 69)* gemeten aan deze vier proefstukken voldoet aan de daaraan in artikel 31.26.13 gestelde eis.
Bepaal, indien aan de eis voor de holle ruimte eis wordt voldaan, van de vier proefstukken de korrelverdeling na extractie, alsmede het gemiddelde daarvan.
De referentiesamenstelling wordt bepaald aan de hand van dit gemiddelde en door het voorgeschreven bitumengehalte.

Figure 2.2: Pre-investigation for PA

Also, a selection of the mixture designs had to be repeated by an independent, accredited, laboratory and the difference had to meet set criteria. These requirements can be seen in Figure 2.3, Figure 2.4 and Figure 2.5. Besides, the contactor also had clear responsibilities in assessing the quality of asphalt concrete production and construction (Figure 2.6).

BEPALINGEN

HOOFDSTUK → 31 Wegverhardingen II
DEELHOOFDSTUK → 2 Asfaltverhardingen

31.24 **Risicoverdeling en garanties**

31.24.01 **Vooronderzoek**

01 De aannemer is verantwoordelijk voor het vooronderzoek. De vooronderzoeken moeten geverifieerd zijn volgens proef 56.0 door een instelling die voor deze proef geaccrediteerd is door een nationale accreditatie-instelling (in Nederland de Raad voor Accreditatie).

02 De aannemer stelt het verslag van het vooronderzoek *(proef 56.0)* desgevraagd en met inachtneming van het bepaalde in lid 03 ter beschikking van de directie. Het vooronderzoek mag ten hoogste drie jaar voor het begin van de asfaltproductie voor dit bestek zijn uitgevoerd.
Gedurende deze periode moet met de op dat moment in gebruik zijnde bouwstoffen, die voldoen aan het oorspronkelijke bewijs van oorsprong, jaarlijks worden aangetoond dat de Marshalleigenschappen niet gewijzigd zijn ten opzichte van het eerder uitgevoerde volledige vooronderzoek *(proef 56.0)*.
Als toetsingscriteria worden hierbij de criteria gebruikt als genoemd in proef 56.0 onder 3.1.

03 De aannemer legt voor de aanvang van de productie van asfaltmengsels schriftelijk de referentiesamenstelling over aan de directie.

04 De aannemer toont aan dat de bij de productie te gebruiken bouwstoffen wat herkomst en eigenschappen betreft overeenkomen met de bij het vooronderzoek gebruikte bouwstoffen. Bij wijziging van de te gebruiken bouwstoffen in de loop van het werk wordt opnieuw een vooronderzoek verricht op basis van de te gebruiken bouwstoffen, met dien verstande dat geen nieuw vooronderzoek wordt uitgevoerd bij wijziging van het te gebruiken grind, indien aard en geologische herkomst van het grind overeenkomen met de bij het vooronderzoek gebruikte grind.
Bij wijziging van het te gebruiken natuurlijk zand wordt geen nieuw vooronderzoek uitgevoerd indien:
a. de aard van het natuurlijk zand overeenkomt met het bij het vooronderzoek gebruikte zand;
b. de dichtheid van de fractie 2 mm - 63 µm *(proef 60.1)* niet meer dan 15 kg/m$^3$ afwijkt van die van het bij het vooronderzoek gebruikte zand;
c. de holle ruimte *(proef 112)* van de fractie 2 mm - 63 µm van het (meng)zand niet meer afwijkt dan 2,0% van die van het bij het vooronderzoek gebruikte zand.

Figure 2.3: Requirements regarding the mixture design

:

BEPALINGEN

HOOFDSTUK → 02 Proeven
PARAGRAAF → 02 Proeven
PROEF → 56.0 Vooronderzoek van asfalt

Het verslag[3)] van het vooronderzoek van asfalt moet omvatten:

1. Een vermelding van de soort en het type asfalt.
2. De kopieën van de CE-markering betrekking hebbend op de toeslagmaterialen en vulstof voor het asfaltmengsel alsmede de bewijzen van oorsprong van de overige bouwstoffen.
3. Aanvullende gegevens van de bouwstoffen:
   - van de steenslag (per type/herkomst): de korrelvorm en de dichtheid;
   - van het zand: de soort, de korrelverdeling op de zeven 2 mm, 500 μm, 180 μm en 63 μm en de dichtheid;
   - van de fabrieksmatig vervaardigde vulstof: de soort, de korrelverdeling op de zeven 2 mm, 125 μm en 63 μm, de gemiddelde dichtheid en het bitumengetal;
   - van het eigen stof (indien toegevoegd): de korrelverdeling op de zeven 2 mm, 125 μm en 63 μm;
   - van het bitumen: de soort en de penetratie;
   - van het asfaltgranulaat: de gemiddelde samenstelling, de penetratie van het teruggewonnen bitumen; de dichtheid *(proef 60.1)* en de categorie ($C_{xxx}$) met betrekking tot het percentage gebroken oppervlak in grof toeslagmateriaal, volgens NEN-EN 13043 en NEN 6240, van het mineraal aggregaat en het aandeel nevenbestanddelen;
     (Opmerking: het percentage gebroken oppervlak in grof toeslagmateriaal alleen bij toepassing in asfalt waarvoor steenslag is voorgeschreven; alleen van die fracties van de steenslag, die voor meer dan 10% in het asfaltgranulaat voorkomen);
   - van de toeslagstoffen (bijvoorbeeld afdruipremmende stof): de soorten.

   Voorzover van toepassing moeten de waarden bij het vooronderzoek worden bepaald.
4. De onderzochte mengselsamenstellingen (korrelverdelingen en bitumengehalten); bij mengsels met asfaltgranulaat tevens de berekende penetratie van het mengbitumen (zie toelichting 1). Tevens de gewogen minerale dichtheid van het mengsel *(proef 127)* bij de voorgeschreven gewenste samenstelling en - indien de voorgeschreven bitumengehalten zijn aangepast in verband met deze gewogen dichtheid - deze gecorrigeerde bitumengehalten *(proef 127)*.
5. De resultaten van de (Marshall)onderzoeken met een vermelding van de datum waarop en de plaats waar dit onderzoek is uitgevoerd.
6. Bij dicht asfaltbeton, open asfaltbeton, grindasfaltbeton en steenslagasfaltbeton: het bitumentraject waarover aan de gestelde eisen voor de desbetreffende verkeersklasse(n) wordt voldaan.
7. Het resultaat van de zeving na extractie van één of meer proefstukken.

Figure 2.4: Required content of mixture design report

BEPALINGEN

HOOFDSTUK → 02 Proeven
PARAGRAAF → 02 Proeven
PROEF → 56.0 Vooronderzoek van asfalt

*.3 Bepaling referentiesamenstelling*

De referentiesamenstelling ten behoeve van de kwaliteitsbepaling wordt, met betrekking tot de korrelverdeling, bepaald op basis van het bij het vooronderzoek volgens de proeven 56.1 tot en met 56.6 vastgelegde extractieresultaat van de proefstukken. Het verschil tussen dit extractieresultaat en de referentiesamenstelling mag niet meer bedragen dan de helft van de in de tabel T 31.07 gegeven toleranties voor één monster, met dien verstande dat voor vulstof het verschil niet meer mag bedragen dan een kwart van de gegeven toleranties.

Het bitumengehalte wordt bepaald op de in de proeven 56.1 tot en met 56.6 omschreven wijze.

Figure 2.5: Determining the reference composition

BEPALINGEN

HOOFDSTUK → 31 Wegverhardingen II
DEELHOOFDSTUK → 2 Asfaltverhardingen

31.24.03 **Bedrijfscontrole**

01 De aannemer is verantwoordelijk voor de bedrijfscontrole tijdens de bereiding en de verwerking van het asfalt. Hij stelt de directie in de gelegenheid de bedrijfscontrole te volgen. Hij stelt de resultaten van de bedrijfscontrole desgevraagd ter beschikking van de directie.

02 Tijdens de bereiding van asfalt bedrijfscontrole verrichten aangaande de asfaltsamenstelling, het vochtgehalte, de dichtheid en de holle ruimte van het geproduceerde asfalt en de eigenschappen van het bitumen *(proef 110)* direct na menging (penetratie *(proef 32)* en penetratie-index *(proef 33)*).

03 Tijdens de productie van steenslagasfaltbeton met asfaltgranulaat bij dagproducties groter dan 100 ton ten minste één keer per 500 ton de holle ruimte *(proef 69)* bepalen als gemiddelde waarde van ten minste twee proefstukken vervaardigd van het in de asfaltmenginstallatie bereide mengsel. Tevens het voortschrijdend gemiddelde bepalen over 11 waarnemingen. Desgevraagd deze waarden aan de directie rapporteren.

04 Tijdens de verwerking van asfalt bedrijfscontrole verrichten aangaande de dikte van de lagen, de samenstelling, de holle ruimte, de verdichtingsgraad en de penetratie *(proef 32)* van het teruggewonnen bitumen *(proef 110)* van het asfalt.

05 Ten behoeve van de bepaling van de verdichtingsgraad tijdens de productie van steenmastiekasfalt 0/8 of 0/11 per dag ten minste vier proefstukken bereiden van het in de asfaltmenginstallatie bereide mengsel *(proef 66.2)*. Het bereiden van de proefstukken bij dagproducties groter dan 200 ton verdelen over de dag. Van deze proefstukken de dichtheid *(proef 67)* bepalen. Het rekenkundig gemiddelde van alle waarden verkregen over de periode waarover het asfalt is verwerkt, geldt als referentiewaarde voor de bepaling van de verdichtingsgraad *(proef 66.0)*. Deze waarde onmiddellijk na gereedkomen van het werk aan de directie rapporteren. Voor tussentijdse bepaling van de verdichtingsgraad geldt als referentiewaarde het rekenkundig gemiddelde van de tot dan toe verkregen waarden. Desgewenst worden tussentijdse waarden eveneens aan de directie gerapporteerd.
Indien de referentiesamenstelling wijzigt, per referentiesamenstelling het rekenkundig gemiddelde bepalen.

06 Bij de asfaltmenginstallatie dient een laboratorium aanwezig te zijn, waarin de voorgeschreven onderzoekingen worden verricht. Het vooronderzoek en het onderzoek ter bepaling van de Marshallwaarden van bij de asfaltmenginstallatie bereide proefstukken mogen elders worden verricht.

Figure 2.6: Requirements for the quality control during production and construction

The requirements in 2005 for PA were as follows:

BEPALINGEN

HOOFDSTUK → 31 Wegverhardingen II

DEELHOOFDSTUK → 2 Asfaltverhardingen

TABEL → Tabel T 31.21 Samenstelling van zeer open asfaltbeton (% m/m)

| | zeer open asfaltbeton 0/11 | | | zeer open asfaltbeton 0/16 | | |
|---|---|---|---|---|---|---|
| op zeef | gewenst | min. | max. | gewenst | min. | max. |
| C16 | - | - | - | - | 0,0 | 7,0 |
| C11,2 | - | 0,0 | 9,0 | - | 15,0 | 30,0 |
| C 8 | - | 60,0 | 85,0 | - | 50,0 | 65,0 |
| C 5,6 | - | 75,0 | 85,0 | - | 70,0 | 85,0 |
| 2 mm | 85,0 | - | - | 85,0 | - | - |
| 63 µm | 95,5 | - | - | 95,5 | - | - |
| bitumengehalte (op 100% mineraal aggregaat) | 4,5 | - | - | 4,5 | - | - |

Figure 2.7: Requirements PA in RAW 2005

Besides the requirements for grading, there were additional requirements, such as a design void content of at least 20%, no use of reclaimed asphalt or PMB and the prescribed use of fabricated filler with a minimum $Ca(OH)_2$ content.

### 2.1.1.2 EN 13108-7 Requirements

Starting March 2008 asphalt mixtures had to be CE marked, requiring it to conform to the Construction Products Directive (CPD). As explained above, the easiest way to show compliance with the CPD was using the harmonized standards. The ones that were most relevant for the Netherlands were 13108-7, 5 and 1, covering Porous Asphalt, Stone Mastic Asphalt and Asphalt Concrete mixtures respectively. As such, the RAW Standard was adapted to enable the use of these standards in order to show conformity to the CPD.

For PA (EN 13108-7) the properties related to the essential requirements from the CPD are shown in Figure 2.8, which shows a reproduction of the Table ZA.1 of the 13108-7:2006. The essential characteristics are given in the first column, the second column contains the properties from the standard that are considered to govern the essential characteristics. As can be seen, bitumen content is relevant for all mechanical essential requirements (but not for the fire class), grading for most etc. The third column indicates whether for any of the properties there are set requirements in levels or classes based on EU requirements. For PA (and other types of Asphalt Concrete) this is only the case for the reaction to fire and that is only relevant when applied in buildings.

For asphalt concrete, that means applications in tunnels. Most pavements are located outside tunnels and that is also the case for all sections discussed in this report. As such, no specific attention will be paid to the reaction to fire requirement, other than noting that, for any asphalt applied in a tunnel, the resistance to fire needs to be determined and declared. This property must be determined using EN 13501-1. Early tests by European Asphalt Producers Association (EAPA) showed that all mixtures tested had *Bfl* (indication for fire resistance, see EN 13501-1) or higher and could be used as flooring in tunnels without restriction. However, they include a warning that this is not the case for PA, which may allow the flow of flammable fluids EAPA, 2008. Generally, for projects that include tunnels, the proper documents regarding the resistance to fire for the mixtures used, need to be provided.

**Table ZA.1 — Relevant clauses related to essential characteristics**

**Product:** Porous Asphalt as covered in the Scope of this European Standard

**Intended use:** For surface courses of roads, and other trafficked areas, whether subject or not to reaction to fire regulations

| Essential Characteristics | Requirement clauses in this and other European Standard(s) | Levels and/or classes | Notes |
|---|---|---|---|
| Adhesion of binder to aggregate | 5.2.3 Binder content<br>5.5 Water sensitivity<br>5.6 Particle loss<br>5.12 Temperatures of the mixture | None<br>None<br>None<br>None | Categories<br>Categories<br>Categories<br>Threshold values |
| Stiffness | 5.2.2 Grading<br>5.2.3 Binder content<br>5.4.2 Void content<br>5.12 Temperatures of the mixture | None<br>None<br>None<br>None | Values %<br>Categories<br>Categories<br>Threshold values |
| Resistance to permanent deformation | 5.2.2 Grading<br>5.2.3 Binder content<br>5.4.2 Void content<br>5.12 Temperatures of the mixture | None<br>None<br>None<br>None | Values %<br>Categories<br>Categories<br>Threshold values |
| Resistance to fatigue | 5.2.3 Binder content<br>5.4.2 Void content<br>5.8 Binder drainage<br>5.12 Temperatures of the mixture | None<br>None<br>None<br>None | Categories<br>Categories<br>Categories<br>Threshold values |
| Skid resistance | 5.2.2 Grading<br>5.2.3 Binder content<br>5.4.2 Void content | None<br>None<br>None | Values%<br>Categories<br>Categories |
| Resistance to abrasion | 5.2.2 Grading<br>5.2.3 Binder content<br>5.6 Particle loss<br>5.8 Binder drainage | None<br>None<br>None<br>None | Values %<br>Categories<br>Categories<br>Categories |
| Hydraulic conductivity | 5.2.2 Grading<br>5.2.3 Binder content<br>5.4.2 Void content<br>5.4.3 Permeability | None<br>None<br>None<br>None | Values %<br>Categories<br>Categories<br>Categories |
| Reaction to fire[a] | 5.7 Reaction to fire | Euroclasses | |
| Noise absorption | 5.2.2 Grading<br>5.2.3 Binder content<br>5.4.2 Void content | None<br>None<br>None | Values %<br>Categories<br>Categories |
| Dangerous substances | See NOTE above | None | Substance 'x' less than 'y' ppm |
| Durability of the above characteristics against ageing, weathering, oxidation, wear, ravelling, chemicals, wear of studded tyres, stripping,..as relevant | All above mentioned requirement clauses are related to durability. | None | See above |

[a] Relevant only for Porous Asphalt intended for uses subject to reaction to fire regulations.

NOTE The manufacturer may wish to declare actual values as well or instead of categories or threshold parameters.

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Figure 2.8: Annex ZA of EN 13108-7:2006

Finally, column four indicates whether the properties from column two should be declared as categories, threshold values or values. As can be seen from the note at the bottom of the list, categories or threshold values can be replaced by, or added to, by declaring actually measured values, this is up to the discretion of the manufacturer.

The EN standard has a dual use, authorities can use it to set requirements for projects, while manufacturers use it to declare the performance of their products, both within the frame work of the CPD. As such, for setting requirements, there is a limit to which properties can be combined in a set in order to prevent over-specification or conflicting requirements (Figure 2.9). Obviously, when declaring the properties of a mixture, a manufacturer is allowed to ignore this, since in that case it is a matter of determining the properties of a specific mixture formulation. However, most manufacturers will limit themselves to the properties for which requirements are set.

| Requirements for | Combinations | | |
|---|---|---|---|
| | 1 | 2 | 3 |
| Binder content | x | x | x |
| Grading | x | x | x |
| Minimum void percentage | x | | |
| Maximum void percentage | x | x | x |
| Horizontal permeability | | x | |
| Vertical permeability | | | x |
| *ITSR* | x | x | x |
| Particle loss | x | x | x |

Figure 2.9: Combinations of requirements allowed under EN 13108-7:2016

When comparing the properties required for the EN standard with that of the RAW standard 2005, it can be seen that both require information on the grading and bitumen content, but the RAW Standard was based on Marshall testing, while the EN standard asks for ITSR (moisture sensitivity).

Another difference is that the RAW Standard deals with specifications for material properties and the check on both production and construction. The CEN standards cover the production of the asphalt mixture, in the plant, but not the process of transport, laying and compaction. Quality control in production is covered by the Factory Production Control standard (EN 13108-21). Specimen preparation and the test conditions to be used to determine the properties declared regarding the EN 13108-7 standard are given in the Type Test standard (EN 13108-20). In order to demonstrate conformity to the EN 13108-7, initial type testing and factory production control must be carried out according to these standards (Chapter 6 of EN 13108-7). As part of the conformity assessment procedure, the producer must create a Declaration of conformity (see Annex ZA 2.2 of the EN 13108-7). With this he takes responsibility for the compliance of the product 7. The declaration of conformity is kept by the producer, together with the Factory Production Control Certificate for 10 years after the product is first brought on the market.

The following information should be provided by the manufacturer upon delivery: the delivery ticket (Chapter 7 of EN 13108-7) and the CE Certificate. In the following sub-sections the required content for these documents is given, these sections are almost literally taken from EN 13108-7.

#### *2.1.1.2.1 Declaration of Conformity*

The declaration of conformity must upon request be shown to the inspection authority (in the Netherlands ILT), it is not quite clear if it can also be requested by a client. That depends on what the phrase" how to obtain the full details demonstrating conformity with this European Standard" that should be contained on the delivery ticket should be interpreted. It could refer to the full CE marking

7 Declaration of conformity (see Annex ZA 2.2 of the EN 13108-7)

information in case of abbreviated delivery tickets, but it could also relate to the declaration of conformity or the underlying TT report (Section 2.1.1.3).

The declaration of conformity for products under System2+ (all products not intended for use in tunnels, because resistance to fire is System 1) is drawn up by the manufacturer and should include (EN 13108-7):

- name and address of the manufacturer, or his authorised representative established in the EEA, and the place of production;
- description of the product (type, identification, use,…), and a copy of the information accompanying the CE marking;
- provisions to which the product conforms (e.g. Annex ZA of EN 13108-7);
- particular conditions applicable to the use of the product (e.g. provisions for use under certain conditions etc.);
- number of the accompanying factory production control certificate (see under factory production control certificate);
- name of, and position held by, the person empowered to sign the declaration on behalf of the manufacturer or his authorised representative.

##### *2.1.1.2.2 Factory Production Control Certificate*

As stated in EN 13108-7, the declaration of conformity will be kept together with a factory production control certificate, drawn up by the notified inspection body, which shall contain the same information as shown on the declaration of conformity and additionally:

- name and address of the notified body;
- number of the factory production control certificate;
- conditions and period of validity of the certificate, where applicable;
- name of, and position held by the person empowered to sign the certificate

##### *2.1.1.2.3 Delivery ticket*

In order to uniquely identify a given mixture, the delivery ticket should contain at least (EN 13108-7):

- manufacturer and mixing plant;
- mixture identification code;
- designation of the mixture, giving the kind of mixture, upper sieve size and kind of binderhow to obtain the full details demonstrating conformity with this European Standard;
- in case of use on airfields, details of compliance with sections 5.9, 5.10 and 5.11 of EN 13108-7
- details of any additives (according to section 4.5 of EN 13108-7).

An example is given in Figure 2.10.

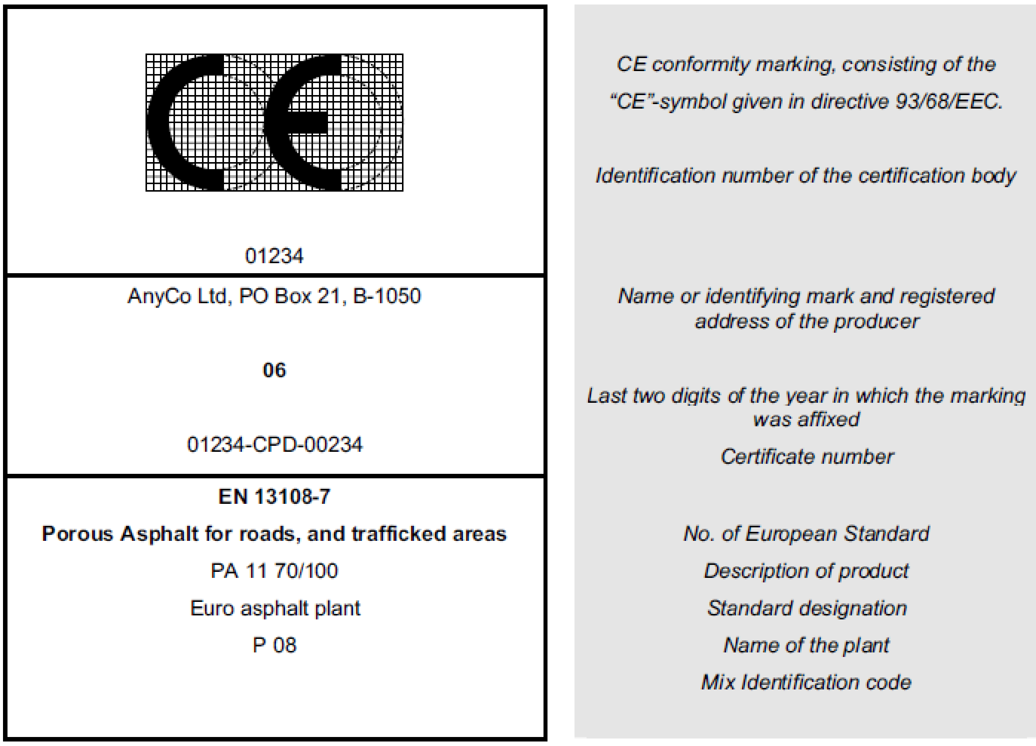



Figure 2.10: Example of the delivery ticket (Fig. ZA.1b of EN 13108-7:2006)

#### *2.1.1.2.4 CE MARKING*

The CE marking, consists of the specified CE logo on a document containing the following information (EN 13108-7):

- identification number of the certification body;
- name or identifying mark and registered address of the producer;
- last two digits of the year in which the marking is affixed;
- number of the EC Certificate of conformity or Factory Production Control certificate (if relevant);
- reference to this European Standard;
- description of the product: generic name, material, dimensions, … and intended use
- information on the relevant essential characteristics listed in Table ZA.1 of EN 13108-7 presented as:
  - declared values and, where relevant, level or class to declare for each essential characteristic as indicated in the column headed "Notes" in Table ZA.1 of EN 13108-7;
  - as an alternative, standard designation(s) alone or in combination with declared values as above,
  - or "No performance determined" for characteristics where this is relevant

Where the last point (information on the relevant essential characteristics) contains the bulk of the information. An example is given in Figure 2.11.

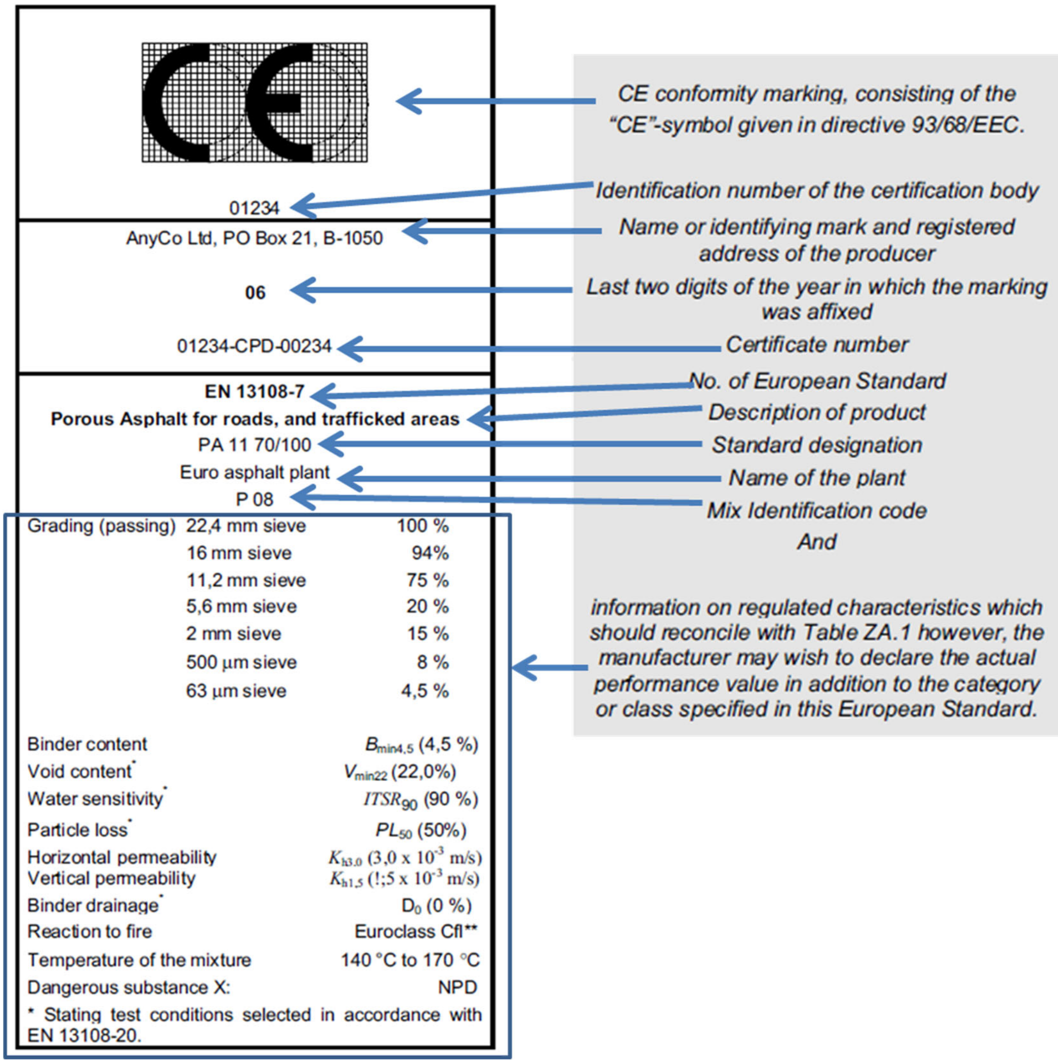



Figure 2.11: Example of CE marking given in Annex ZA EN 13108-7:2006 as Figure ZA.1a

The name of the plant and the mixture identification code are shown on the example, but not listed above it in the Annex ZA. This kind of discrepancies caused a lot of confusion. It is clear that the mixture identification code is crucial, since this is what identifies the specific mixture formulation. Identifying the plant is also crucial, because of its effect on the mixture production. However, if the name and address of the plant are given as name and address of the producer, the name does not need to be repeated separately.

According to Annex ZA.3, the CE marking should be shown on the accompanying commercial documents, such as a delivery note. This seems to be the same as the delivery ticket, even though for the delivery ticket use of the CE symbol is not specified (it is included in the example in the Standard, see Figure 2.10). As such, in many cases the two are seen as one, even though that would require adding details on additives and information on how to obtain the full details demonstrating conformity to the CE certificate.

## 2.1.1.3 Requirements EN 13108-20

The Initial Type Test (TT) described in EN 13108-20 is part of the declaration of conformity (Chapter 7.1 of the EN 13108-7). As such, it is not part of the information provided upon delivery, since the declaration of conformity is kept by the producer.

The TT addresses the performance of a single mixture formulation, defined as the combination of the constituent materials, the grading curve and the percentage of bitumen added (Chapter 3 of EN 13108-7). The information required includes information on the constituent materials. For those delivered under CE marking, this information can be used provided that the corresponding certificates are added to the TT report. For Reclaimed Asphalt, actual testing on the material used in production is prescribed.

The TT report requirements are:

a. name and address of manufacturer making declaration;
b. date of issue;
c. identification of mixing plant;
d. designation of mixture type and categories with which conformity is being declared;
e. statement of (specimen preparation & test) methods used in mixture validation under 6.5.2 or 6.5.3 with reference to Annex C.

About the constituent materials the TT report should show:

f. each aggregate size: source and type;
g. binder: type and grade;
h. filler: source and type;
i. additives: source and type;
j. reclaimed asphalt: statement of permissible range of properties and control methods;
k. all constituents: tests results in accordance with Annex A of EN 13108-20 (Figure 2.12) as appropriate

| Column | 1 | 2 | 3 | 4 |
|---|---|---|---|---|
| Line | **Constituent** | **Property** | **Test method** | **Number of results** |
| 1 | Aggregate (EN 13043) | Grading | EN 933-1 | 1 by size |
| 2 | | Density | EN 1097-6 | 1 by size |
| 3 | Binder, hard paving grade bitumen and modified binder | Penetration or softening point | EN 1426 or 1427 | 1 |
| 4 | (EN 12591, prEN 13924 and EN 14023) | Viscosity [a] | EN 12595 or 12596 | 1 |
| 5 | Filler (EN 13043) | Grading | EN 933-10 | 1 |
| 6 | | Density | EN 1097-7 | 1 |
| 7 | Additives | Type | | |
| 8 | Granulated reclaimed asphalt [b] EN 13108-8) | Grading | EN 12697-2 | 1 |
| 9 | | Binder content | EN 12697-1 | 1 |
| 10 | | Recovered penetration | EN 12697-3 or EN 12697-4; plus EN 1426 | 1 |
| 11 | | or recovered softening point | EN 12697-3 or EN 12697-4; plus EN 1427 | 1 |
| 12 | | Density | EN 12697-5 | 1 |

[a] For soft asphalt.
[b] The properties validated shall be appropriate to the percentage addition. At low addition percentages minimal requirements apply.

Figure 2.12: Required information on constituent materials in the TT report (EN13018-20)

Furthermore the TT report should contain:

a) Mixture formulation expressed as:
   a. input target composition (=constituent materials, grading curve and percentage of bitumen) and/or
   b. output target composition.
b) Maximum and minimum temperatures for the mixtures with modified or hard grade binders or additives where these are different from the default values in the product standards.
c) Test results for the mixture in accordance with B.1 to B.7 as appropriate to the mixture type. Which for PA comes down to Appendix B7 of the EN 13108-20 (Figure 2.13)

**Table B.7 — Type and number of tests for Porous Asphalt**

| Column | 1 | 2 | 3 |
|---|---|---|---|
| Line | **Property** | **Test method** | **Number of Tests** |
| 1 | Binder content (prescriptive) | EN 12697-1 and -39 | 1 for production validation<br>0 for laboratory validation |
| 2 | Grading (prescriptive) | EN 12697-2 | 1 for production validation<br>0 for laboratory validation |
| 3 | Void content (prescriptive) | EN 12697-8<br>Using bulk density to EN 12697-6, procedure D, by dimensions.<br>Using maximum density to EN 12697-5 using procedure A in water. | 1 |
| 4 | Void content of gyratory compacted specimens (prescriptive) | EN 12697-31 | 1 |
| 5 | Permeability (performance related) | EN 12697-19 | 1 |
| 6 | Water sensitivity (performance related) | EN 12697-12 | 1 |
| 7 | Bitumen-aggregate affinity (performance related — airfields) | EN 12697-11, part C, static method | 1 |
| 8 | Binder drainage (performance related) | EN 12697-18 | 1 |
| 9 | Particle loss (performance related) | EN 12697-17 | 1 |
| 10 | Resistance to fuel (performance related — airfields) | EN 12697-43 | 1 |
| 11 | Resistance to de-icing fluid (performance related — airfields) | EN 12697-41 | 1 |

Figure 2.13: Properties to be declared for PA according to EN 13108-20, for setting requirements Figure 2.9 needs to be considered to prevent over-specification

For each property, the selected options in preparing the specimens and carrying out the tests must be specified.

### 2.1.1.4 Requirements EN 13108-21

The En 13108-21 describes the requirements for the Factory Production Control (FPC) process intended to ensure consistency in quality. This FPC process is a required aspect of establishing conformity. The standard required the producer to establish and maintain a policy and procedures for Factory Production Control in a quality plan. This quality plan must enable the identification and detail the specific processes, which directly affect product quality and conformity. It must include (EN13108-20, section 4.2):

a) producer's organisational structure relating to conformity and quality;
b) document control;
c) control procedures for constituent materials and purchaser supplied product;
d) process control;
e) requirements for the handling and storage of the product;
f) plant calibration and maintenance;
g) requirements for inspection and testing of processes and products;

h) procedures for handling non-conformity

The quality plan shall also include frequencies of inspection and testing. The frequencies given under Clause 6 and Annex A (EN 13108-21) are the minimum frequencies to be used initially. These may be changed where an acceptable alternative statistical system is developed.

The FPC standard specifies details and minimum frequencies and requirements for the various components of the quality plan. It also specifies that the quality plan should contain the measures to be taken in case con-conformity is found, either in the constituent materials, in processing of the product or in handling, storage and delivery of the product. These measures are aimed at preventing the non-conforming product to leave the plant and in identifying the cause of the non-conformity and resolving it, preventing it from occurring again. The quality plan should also address these issues in case non-conformity is found after construction. In this case, the quality plan should also specify the circumstances under which the customer is notified of the non-conforming results. This latter is a rather vague formulation, considering that if a non-conformity is found during in-process control it can only be despatched to the customer after his agreement to accept the non-conforming product. As such, it would appear that any non-conformity in the finished asphalt mixture should also be reported, since in this case it involves an actual composition deviation, while earlier on it may be a process deviation. This apparent discrepancy may be due to the somewhat artificial split between production (covered by the EN 13108-series) and construction (on-site). The finished product under EN 13108-21 is the still uncompacted mixture, which can only be tested for composition.

Besides the quality plan, the FPC involves the establishment of records on the results of the various checks carried out, building a track record on the plants conformity. None of the requirements from the FPC require information to be shared with the client.

## 2.1.1.5 RAW Standard 2005 changes may 2008

When the co-existence period for the EN 13108-series ended in March 2008, the requirements in the RAW Standard were adapted to allow for this. The mixture design using Marshall testing was removed and a Type Test using EN 13108-20 was included. Then the Netherlands chose to use the option of functional requirements for the AC mixtures (mixtures conforming to EN 13108-1). Also, a split between production and construction was introduced, because the EN-series deals with the production of the mixture, not its application on the road and the compaction into a pavement layer. Besides, also some smaller changes such as grading defined as “passing” rather than “remaining on” sieve and bitumen content as the % “in” 100% mixture mass rather than “on” 100% aggregate mass were addressed to align the RAW Standard with the EN 13108-series.

For AC mixtures, requirements were set for stiffness (EN 12697- 26, using beam specimens in the four point bending test), fatigue (EN 12679-24 , same type of specimens and test set-up as for stiffness), resistance to permanent deformation (EN 12697-25, cyclic triaxial test on cylindrical specimens) and the moisture sensitivity (EN 12697-12 (moisture sensitivity) EN 12697-23 (indirect tensile strength).

Then For mixes within the EN 13108-5 and EN 13108-7. For standard Dutch Stone Mastic Asphalt (SMA-NL) and PA (ZOAB) mixtures, the Netherlands chose to use the option of composition requirements and the existing composition requirements were only extended with requirements on the moisture sensitivity.

For the standard mixtures from the RAW Standard, a transition period was introduced (Figure 2.14) in order to obtain information on the new requirements for these materials. From March 2008 until September 2008, all mixtures could be delivered with an valid (less than three years old) mixture design report according to the RAW Standard 2005. The report should be from a mixture design carried out before January 2008. In parallel to this information, empirical type testing as to grading, binder content and moisture sensitivity was required. This information was provided on the CE-marking, meeting the EN 13108 requirements.

From September 2008 until March 2009, in parallel to the mixture design information also the functional TT (stiffness, fatigue, permanent deformation) had to be carried out for AC mixtures. The information collected was used to set the formal requirements in the new RAW Standard.

BEPALINGEN

HOOFDSTUK → 31 Wegverhardingen II
DEELHOOFDSTUK → 2 Asfaltverhardingen

31.26.02 **Levering asfalt(specie) gedurende de periode tot 1 maart 2009**

01 Tot 1 maart 2009 mogen in plaats van de asfaltbetonmengsels voor deklagen, tussenlagen en onderlagen als bedoeld in artikel 31.26.03, de asfaltmengsels dicht asfaltbeton, open asfaltbeton, steenslagasfaltbeton dan wel grindasfaltbeton zoals beschreven in artikel 31.26.12, artikel 31.26.11, artikel 31.26.10 respectievelijk artikel 31.26.09 van de Standaard RAW Bepalingen 2005(uitgave 2005) worden toegepast. Indien in genoemde asfaltbetonmengsels asfaltgranulaat wordt toegepast moet dit asfaltgranulaat voldoen aan het bepaalde in artikel 31.26.07 van de Standaard RAW Bepalingen 2005 (uitgave 2005).

02 Tot 1 maart 2009 mogen in plaats van steenmastiekasfalt als bedoeld in artikel 31.26.04 en zeer open asfaltbeton als bedoeld in artikel 31.26.05, de asfaltmengsels steenmastiekasfalt en zeer open asfaltbeton zoals beschreven in artikel 31.26.13 respectievelijk 31.26.14 van de Standaard RAW Bepalingen 2005 versie oktober 2005 worden toegepast.

03 Voor de in lid 01 en 02 bedoelde asfaltmengsels moet een geldig vooronderzoek beschikbaar zijn overeenkomstig het bepaalde in proef 56.0 van de Standaard RAW Bepalingen 2005 (uitgave 2005), dat is uitgevoerd voor 1 januari 2008.
Het bepaalde in artikel 31.24.01 van de Standaard RAW Bepalingen 2005 (uitgave 2005) is onverminderd van toepassing, met dien verstande dat in afwijking van het bepaalde in lid 02 van genoemd artikel, de aannemer het verslag van het volledige vooronderzoek in alle gevallen ter beschikking van de directie stelt.

04 Op de in lid 01 bedoelde asfaltmengsels moet tevens een typeonderzoek als bedoeld in artikel 31.26.01 lid 02 worden uitgevoerd, waarbij in afwijking van het bepaalde in genoemd lid het typeonderzoek gericht mag zijn op de samenstelling en eigenschappen volgens 5.1.2 'Empirische eisen' van NEN-EN 13108-1 'Bitumineuze mengsels - Materiaalspecificaties - Deel 1: Asfaltbeton' waarbij:
- de korrelverdeling als bedoeld in 5.2.1.2 van NEN 13108-1 wordt bepaald met behulp van de basis zeefset plus set 1 volgens 4.1.2 van NEN-EN 13043 'Toeslagmaterialen voor asfalt en oppervlakbehandeling voor wegen, vliegvelden en andere verkeersgebieden'.
- voor de weerstand tegen afslijting door spijkerbanden volgens 5.2.5 van NEN-EN 13108-1 geldt categorie AbrANR (geen eis).
- het bepaalde in 5.2.6 'Weerstand tegen permanente vervorming' van NEN-EN 13108-1 (wielspoorproef) niet van toepassing is.

05 Op de in lid 02 bedoelde asfaltmengsels moet tevens een typeonderzoek als bedoeld in artikel 31.26.01 lid 02 worden uitgevoerd.

06 Gedurende de periode 1 september 2008 tot 1 maart 2009 moet voor de in lid 01 bedoelde mengsels tevens het typeonderzoek volgens het bepaalde in NEN-EN 13108-20 'Bitumineuze mengsels - Materiaalspecificaties - Deel 20 Typeonderzoek' worden uitgevoerd met in achtneming van het bepaalde in proef 250.

07 De aannemer of de producent van de asfaltbetonspecie namens hem, moet voordat het betreffende asfalt wordt verwerkt de gegevens van het vooronderzoek en het typeonderzoek als bedoeld in de voorgaande leden 04, 05 en 06 inbrengen in de Database Asfaltmengsels bij de Stichting CROW (zie www.crow.nl/asfalt). De Stichting CROW draagt er zorg voor dat deze gegevens vertrouwelijk worden behandeld. De gegevens worden geanonimiseerd en beoordeeld door de Deskundigen Commissie Asfaltverhardingen van CROW ten behoeve van de kalibratie van de in Tabel T 31.09 vermelde waarden voor de functionele eigenschappen en de vaststelling van bepalingsmethoden van andere eigenschappen volgens de NEN-EN 13108-1 'Bitumineuze mengsels - Materiaalspecificaties - Deel 1: Asfaltbeton' De conclusies met betrekking tot deze functionele eigenschappen zullen openbaar zijn.

Figure 2.14: Transition period in the RAW Standard 2008

In the Type Test section of this adaption on the RAW Standard, the short report was introduced (Figure 2.15). The short report reproduces those aspects of the TT that are relevant for quality control in the road or for assessing the pavement design. Since the total TT is part of the Declaration of Conformity, which is kept at the manufacturer and not part of the information provided to the client, it was decided to require the relevant aspects separately. The information is linked to the CE marking of the mixture by the requirement of the reference to the CE marking of the mixture.

BEPALINGEN

HOOFDSTUK → 02 Proeven
PARAGRAAF → 02 Proeven
PROEF → 250 Typeonderzoek van asfalt

*5 Bepaling referentiesamenstelling*
De referentiesamenstelling ten behoeve van de kwaliteitsbepaling wordt, met betrekking tot de korrelverdeling bepaald op basis van de in te wegen doelsamenstelling. Het verschil tussen de referentiesamenstelling en de in te wegen doelsamenstelling mag niet meer bedragen dan de in tabel T 31.07 gegeven toleranties voor één monster.

*6 Rapportage*
Van het type-onderzoek, naast de rapportage conform NEN-EN 13108-20, een verkort verslag maken ten behoeve van de afnemer en directie. Dit verslag moet ten minste omvatten:
a. een vermelding van het soort en type asfalt;
b. de referentiesamenstelling (korrelverdeling en bindmiddelgehalte) van het asfaltmengsel ten behoeve van de kwaliteitscontrole;
c. een verwijzing naar de CE-markering;
d. de streefdichtheid (dichtheid proefstuk);
e. de resultaten van de frequency-sweep.

Figure 2.15: First version of the short report

The requirements for the standard PA mixtures (PA 11 and PA 16) used in the Netherlands at that time are more strict than the EN 13108-7 requirements, i.e. excluding the use of reclaimed asphalt. These additional requirements were maintained for the specific PA mixtures used in the past in the Netherlands. These mixtures were labelled as ZOAB rather than PA.

BEPALINGEN

HOOFDSTUK 31 Wegverhardingen II
DEELHOOFDSTUK 2 Asfaltverhardingen
TABEL Tabel T 31.12 Samenstelling van zeer open asfaltbeton (% m/m)

| Door zeef (mm) | ZOAB 11 | ZOAB 16 |
|---|---|---|
| 22,4 | | 100 |
| 16 | 100 | 93 - 100 |
| 11,2 | 91 - 100 | 70 - 85 |
| 8 | 15 - 40 | |
| 2 | 15 - 25 | 15 - 25 |
| 0,5 | DV | DV |
| 0,063 | 2,0 - 10,0 | 2,0 - 10,0 |

DV: Declared Value door de producent op te geven waarde

Opm.: De voorgeschreven karakteristieke grove zeef is niet D/2.

BEPALINGEN

HOOFDSTUK 31 Wegverhardingen II
DEELHOOFDSTUK 2 Asfaltverhardingen
TABEL Tabel T 31.13 Eigenschappen van zeer open asfaltbeton

| Eigenschap | ZOAB 11 | ZOAB 16 |
|---|---|---|
| Bitumengehalte | $B_{min\ 4,5}$ | $B_{min\ 4,5}$ |
| Minimum holle ruimte | $V_{min20}$ | $V_{min20}$ |
| Maximum holle ruimte | $V_{maxNR}$ | $V_{maxNR}$ |
| Watergevoeligheid | $ITSR_{90}$ | $ITSR_{90}$ |
| Afdruipen | $D_{NR}$ | $D_{NR}$ |

Figure 2.16: Grading and property requirements for the standard ZOAB 11 and ZOAB 16 mixtures

### 2.1.2 March 2009 to 2010

In March 2009 the transition period ended and existing Marshall mixture design data was no longer valid. From then on, the information provided had to follow the requirements of the RAW Standard 2005 - changes May 2008 (Section 2.1.1.5) and the EN 13108-7 (Section 2.1.1.2).

### 2.1.3 2010- 1st of July 2013

In 2010 a new RAW Standard was published, in which the results from the data collection during the transition period were used to set requirements for the properties addressed in the EN 13108-series. These experiences led to a change in the requirement for the moisture sensitivity (ITSR80 instead of ITSR90). The other requirements stayed the same (Figure 2.17).

*31.2.13 Tabel T 31.13 Eigenschappen van zeer open asfaltbeton*

ERRATA

| eigenschap | ZOAB 11 | ZOAB 16 |
|---|---|---|
| bitumengehalte | $B_{min\ 4,5}$ | $B_{min\ 4,5}$ |
| minimum holle ruimte | $V_{min20}$ | $V_{min20}$ |
| maximum holle ruimte | $V_{maxNR}$ | $V_{maxNR}$ |
| watergevoeligheid | $ITSR_{80}$ | $ITSR_{80}$ |
| afdruipen | $D_{NR}$ | $D_{NR}$ |

*31.2.12 Tabel T 31.12 Samenstelling van zeer open asfaltbeton (% m/m)*

ERRATA

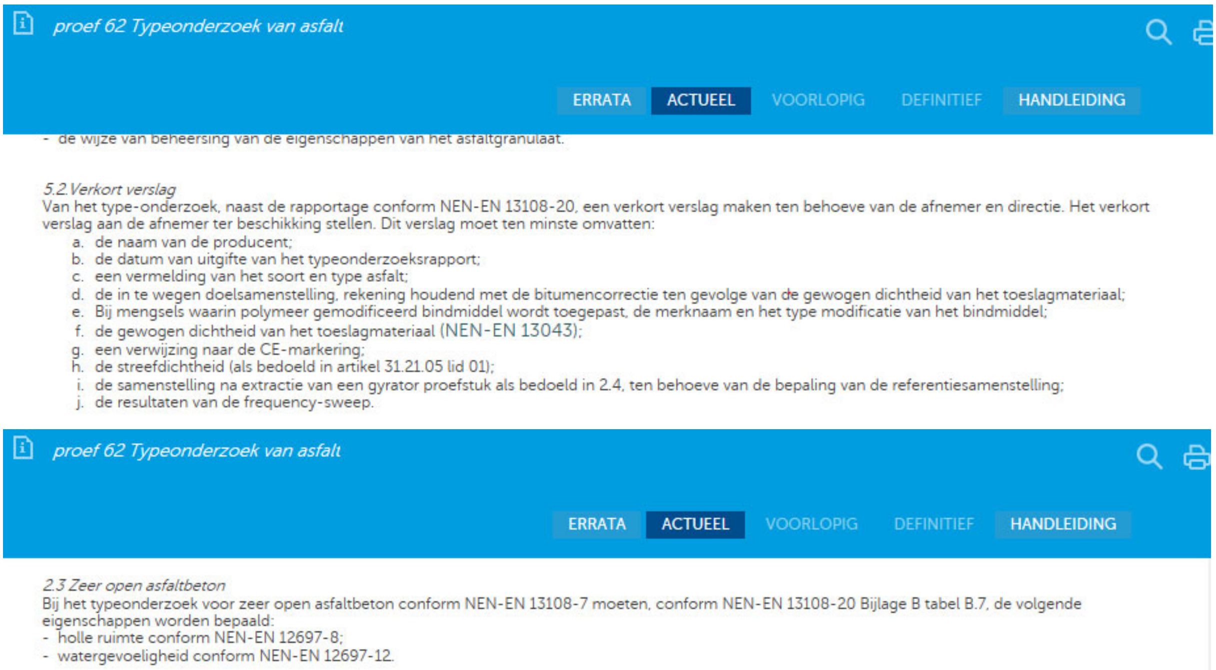
| door zeef | ZOAB 11 | ZOAB 16 |
|---|---|---|
| C22,4 | | 100 |
| C16 | 100 | 93 - 100 |
| C11,2 | 91 - 100 | 70 - 85 |
| C8 | 15 - 40 | |
| 2 mm | 15 - 25 | 15 - 25 |
| 0,5 mm | DV | DV |
| 0,063 mm | 2,0 - 10,0 | 2,0 - 10,0 |

DV: Declared Value; door de producent op te geven waarde.

Opmerking: Als karakteristieke grove zeef is in afwijking van het bepaalde in NEN-EN 13108-7 niet zeef D/2 voorgeschreven.

Figure 2.17: New requirements for PA in the RAW Standard 2010 (CROW, Standaard 2010 (2010))

Besides this limited change in the required properties, the required information in the short report was extended (Figure 2.18). This extension involved: the name of the producer and the target composition of the mixture (including bitumen content correction for the weighted average density of the aggregates), both required on the CE marking information, as well as the weighted average density of the aggregates, brand and the type of modification in the case PMB was used and the date of publication of the Type Test report. As such, the extensions were partially meant to repair a lack of consistency and completeness in the CE marking information provided and partially because it was realized that the relevant aspects of the Type Test involved more than just the essential characteristics of the mixture.


*proef 62 Typeonderzoek van asfalt*

ERRATA ACTUEEL VOORLOPIG DEFINITIEF HANDLEIDING

- de wijze van beheersing van de eigenschappen van het asfaltgranulaat.

*5.2 Verkort verslag*

Van het type-onderzoek, naast de rapportage conform NEN-EN 13108-20, een verkort verslag maken ten behoeve van de afnemer en directie. Het verkort verslag aan de afnemer ter beschikking stellen. Dit verslag moet ten minste omvatten:

a. de naam van de producent;
b. de datum van uitgifte van het typeonderzoeksrapport;
c. een vermelding van het soort en type asfalt;
d. de in te wegen doelsamenstelling, rekening houdend met de bitumencorrectie ten gevolge van de gewogen dichtheid van het toeslagmateriaal;
e. Bij mengsels waarin polymeer gemodificeerd bindmiddel wordt toegepast, de merknaam en het type modificatie van het bindmiddel;
f. de gewogen dichtheid van het toeslagmateriaal (NEN-EN 13043);
g. een verwijzing naar de CE-markering;
h. de streefdichtheid (als bedoeld in artikel 31.21.05 lid 01);
i. de samenstelling na extractie van een gyrator proefstuk als bedoeld in 2.4, ten behoeve van de bepaling van de referentiesamenstelling;
j. de resultaten van de frequency-sweep.

*proef 62 Typeonderzoek van asfalt*

ERRATA ACTUEEL VOORLOPIG DEFINITIEF HANDLEIDING

*2.3 Zeer open asfaltbeton*

Bij het typeonderzoek voor zeer open asfaltbeton conform NEN-EN 13108-7 moeten, conform NEN-EN 13108-20 Bijlage B tabel B.7, de volgende eigenschappen worden bepaald:
- holle ruimte conform NEN-EN 12697-8;
- watergevoeligheid conform NEN-EN 12697-12.

Figure 2.18: Short report and PA TT requirements in RAW Standard 2010 CROW, Standaard 2010, 2010

### 2.1.4 July 1st 2013 to 2015

On July 1st 2013 the Construction Products Directive (CPD) was superseded by the Construction Products Regulation (CPR). The CPR became automatically valid in all EU member states with no need for supplemental implementation into each countries-specific national law. With the introduction of the CPR all construction products on the market must comply with the regulation, demonstrated by a written declaration of performance and modified CE marking. Under the CPR the declaration of conformity is replaced by the declaration of performance. The manufacturer still has to prepare the technical documentation and on its basis draw up a Declaration of Performance and affix CE marking to the product as well as ensure that the product maintains its conformity with the Declaration of Performance (Regulation (EU) No 305/2011, Construction Products Directive[8]).

In Figure 2.19 and Figure 2.20 an overview of the information to be included on the DoP and CE marking, respectively, are shown European Commission, 2015. Though roughly the same as mentioned based on the EN 13108-7 before, this is updated and based on information from the European Commission, not based on a specific application.

The CE marking is a summary of the DoP information, the DoP should list all essential requirements in the relevant Annex ZA (Figure 2.20), but can state No Performance Determined (NPD) for those properties that are not relevant or for which no requirements are set. The DoP is also dated and signed by or on behalf of the manufacturer (Annex III of the CPR[4]). The CE information needs only to mention the characteristics which have values and is not signed.

In principle the CE marking is affixed to the product itself (Figure 2.21). For AC mixtures this is clearly impossible. In these cases the CE marking can be applied to the wrappings (also impossible) or accompany the sales documentation, together with the DoP.

8 Background on and full text of the CPR can be found on https://ec.europa.eu/growth/sectors/construction/product-regulation_en

| DECLARATION OF PERFORMANCE | | |
|---|---|---|
| | Number of the declaration of performance | This number allows you to classify the declaration of performance (2.1.7). It can be the same as the unique identification code of the product type. |
| 1. | Unique identification code of the product type: | This code is linked to the declared performance of the product. It has to identify without any ambiguity the link between the product and its performance.<br>You can use any code you find useful, including numbers, letters, dates, etc. but you have to be very careful to not repeat the same code for two different products. |
| 2. | Intended use/es: | In this point you have to include all the intended uses you have foreseen for your product (1.2.1 and 1.2.2). Copy the relevant text included in the annex ZA of the harmonised standard or in the European Assessment Document. |
| 3. | Manufacturer | You have to include not only the name of your company, the registered trade name or registered trade mark but also your contact address as the manufacturer. The address can be anywhere in the world. |
| 4. | Authorised representative | The authorised representative has to be included in the document only if you, as the manufacturer, have designated an authorised representative (or your agent). Otherwise you can delete this point. |
| 5. | System/s of AVCP | System or systems of assessment and verification of constancy of performance (AVCP system) as indicated in Annex ZA of the harmonised standard or in the chapter for AVCP of the European Assessment Document (2.1.2). If there are multiple systems, each of them must be declared and can be included in point 7 (for example in a table). |
| 6a. | Harmonised standard (either 6a or 6b) | In this point you have to include the reference number of the harmonised standard including the date it was issued according to the Official Journal of the European Union (1.2.1). |
| | Notified Body/ies | If Notified Bodies have carried out AVCP tasks you must include their identification numbers here (2.1.2). |
| 6b. | European Assessment Document | In this point you have to include the reference number of the European Assessment Document including the date it was issued (1.2.2) |
| | European Technical Assessment | Number of the European Technical Assessment issued by the Technical Assessment Body. |
| | Technical Assessment Body | Name of the Technical Assessment Body who issued the European Technical Assessment; |
| | Notified Body/ies | If Notified Bodies have carried out AVCP tasks you must include their identification numbers here (2.1.2). |
| 7. | Declared performance | This is the core of the document and consists of the declared performance of the product. You have to include the full list of essential characteristics as it is in the annex ZA of the harmonised standard or the European Assessment Document for the intended uses already declared in point 2. Declaring "NPD" is possible following the conditions listed in 2.1.3.<br>The best way to fill in this point when drawing up a DoP on paper is to use a table with a row for each essential characteristic and the declared performance in columns. If different AVCP systems are applied, add additional columns for them. |
| 8. | Appropriate Technical Documentation and/or Specific Technical Documentation | When the assessment of your product has been carried out following any simplified procedure you will have to include the reference or references to the specific and/or appropriate technical documentation you have developed in this point (2.1.5). The documents have to be stored by the manufacturer, only the references to them have to be included in this point. |
| | Link to the online copy of the declaration of performance | If you are going to upload a copy of the declaration of performance onto a website you can include the link here to access it. |

Figure 2.19: Information to be declared on the DoP (European Commission, 2015)

| | |
|---|---|
| CE | The symbol CE can be found on the website for CE marking of the European Commission[XV] in different formats. |
| 14 | You are obliged to include the last two digits of the year in which this specific CE marking was affixed for the first time. In case you change any information in the declaration of performance linked to this CE marking you will have to also update the digits. |
| Name and address | You have to include the name and the registered address of the manufacturer, or an identifying mark which easily allows the identification of the name and address of the manufacturer. |
| Unique identification code of the product type | The unique identification code of the product type without any ambiguity which will link the CE marking to the declaration of performance and the declared performance (2.1.7 and 2.3.1). |
| Reference number of the declaration of performance | In case the unique identification code of the product type is not the same as the reference number of the declaration of performance you will also have to include this number. Both have similar purposes (2.1.7). |
| Declared performance | CE marking has to include the declared performance of the product which means that the declared value of the essential characteristics which are not NPD must be found here. Due to the lack of space on the label you may have to simplify the declaration but be careful to keep the meaning (2.1.3). |
| Reference to the harmonised technical specification | The reference to the harmonised standard or to the European Assessment Document applied to assess the product. You do not need to include the date they were issued because this information is already in the declaration of performance. (1.2.1 and 1.2.2). |
| Identification number of the Notified Body | It is also important that you include the identification number of the Notified Body, if your essential characteristics are subject to AVCP systems 1, 1+, 2+ or 3. (2.1.2). |
| Intended use/es | The relevant information about the intended use or uses (to be found in annex ZA of the relevant harmonised standard) has to be included; it must be the same as the corresponding point in the declaration of performance (1.2.1 and 1.2.2). |
| Website where the declaration of performance can be found | If your declaration of performance is available on a website you can also include here the website hosting the document (2.3.1). |

Figure 2.20: Information to put on the CE mark, based on the DoP


Figure 2.21: Examples of CE mark affixed to products or packaging

### 2.1.5 2015 to now (2019)

### 2.1.6 Current situation

In 2015 a new version of the RAW Standard was published, the changes relevant to PA were that besides the traditional ZOAB 11 and ZOAB 16 mixtures also DZOAB 16 (with extra bitumen) and 2L-ZOAB9 were introduced in the standard. These materials had been used in the Netherlands since 2003-2008 and were now considered to have become standard.

Other than this, no changes were made in the requirements for the mix properties (Figure 2.23 and Figure 2.26), but the information required was adapted to reflect the change from CPD to CPR and the kind and amount of information required in the short report was again extended (details on page 39 and further).

Since this is the current RAW Standard and it covers the type of mixtures used in this project, these are the requirements used in the section 2.2.

### 2.1.7 Status of EN 13108-7:2016

In 2016 CEN published a new version of the EN13108-series, which supersede the existing ones. As CEN standards, the 2016 version is now the current one. To become the harmonized standards for the EU, however, they must be published in OJEU.

However, the European Commission has been reticent in recent years in approving new standards. This is at least in part because of the ruling of the Court of Justice of the European Union (CJEU) in the case of James Elliott Construction Limited v Irish Asphalt Limited10. This ruling showed that standards are considered part of EU law. This has led to many activities trying to sort out the procedures related to the development and acceptance of standards, which is delaying the publication of various standards, among which the EN13108:2016 series.

Since the new series of EN13108 standards has not been published in OJEU11 until the writing of this report12, they are not currently harmonized standards, meaning the previous standards from 2006 remain the ones to be used for CE marking. This despite the fact that CEN has formally published the new standards and retracted the previous ones. NEN lists them as such on their site, following CEN policy. Yet, for harmonization purposes and CE-marking of products, the retracted standards are the ones to use.
The exceptions are the EN 13018-8, -20 and -21, which are non-harmonized standards. These parts have never been published in the OJEU and for them CE marking is not relevant. For the EN-13108-20 and -21 this is easy to understand: although crucial for the CE-marking of the various types of Asphalt

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9 consisting of top-layers 2L-ZOAB 5 (PA 5) or 2L-ZOAB 8 (PA 8) and a bottom-layer 2L-ZOAB 16 (PA 16)

10 See: http://blog.renforce.eu/index.php/nl/2017/01/03/how-failing-aggregates-brought-about-a-landmark-decision-of-the-cjeu/

11 https://ec.europa.eu/growth/single-market/european-standards/harmonised-standards/construction-products_en , accessed on August 16th, 2019

12 https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=uriserv:OJ.C_.2018.092.01.0139.01.ENG, https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=uriserv:OJ.L_.2019.077.01.0080.01.ENG&toc=OJ:L:2019:077:TOC and https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=uriserv:OJ.L_.2019.318.01.0185.01.ENG&toc=OJ:L:2019:318:TOC. First site lists the EN13108 series 2006 as published, the other two show updates and do not mention En 13108:2016. Last checked on December 29th 2019

Mixtures, a Type Test or the Factory Production Control (FPC) themselves are not Construction Products and, therefore, they are not CE marked. For the Reclaimed Asphalt (RA) standard (EN13018-8), this makes less sense, since RA is a constituent material and there are also standards for other constituents. However, RA was not addressed in the original mandate to develop the standards for Asphalt Mixtures. As a result, like the EN13108-20 and -21 this standard is crucial for the CE marking of the various Asphalt Mixtures, if they include RA, but the RA itself is not CE-marked.

## 2.2 Current requirements for PA mixtures and test methods

The general requirements regarding the information to be provided according to the current RAW Standard are shown in Figure 2.22. Since many of the sections were constructed before this Standard was published, in comparing the performance of the mixtures to the standard, any relevant changes in the standard over the years (as discussed in the previous section) will be taken into account as far as possible.


*81.23.02 Gegevens asfalt*

ERRATA ACTUEEL VOORLOPIG DEFINITIEF

**01** De aannemer verstrekt de directie uiterlijk tien werkdagen voor de aanvang van de verwerking van asfalt:
- a. het verkort verslag als bedoeld in proef 62 punt 5.2;
- b. de referentiesamenstelling als bedoeld in artikel 81.21.04 lid 01;
- c. eventueel specifieke voorwaarden van toepassing op het gebruik van het product;
- d. van grof toeslagmateriaal voor deklagen, een verklaring dat dit voldoet aan de in het bestek gestelde eisen met betrekking tot korrelvorm en polijstgetal.

Figure 2.22: General requirements on information on the materials that needs to be provided prior to the start of paving CROW, Standaard 2015, 2015

The reference in point a) of Figure 2.22 is to the short report, which is basically a summary of the type test information of a specific asphalt mixture. This short report should be provided for all the mixtures that will be used in the project.

The short report is required to contain at least:

- a. Name of the producer
- b. Date of publication of the Type Test report and the corresponding TT report number
- c. The nature and properties of all additives have to be listed and agree with the specification in –art 4.1 of the corresponding EN 13108-X series of standards
- d. A reference to the Declaration of Performance (DoP) and the datum it was published
- e. A reference to the DoP’s of the constituent materials used in the Type Test of the asphalt mixture that are CE marked
- f. Proof of Applicability for those constituents that are not CE marked and do not have to have a DoP
- g. Indication of the kind of Asphalt Mixture (i.e. PA or AC), type of mixture (AC 8 surf or AC 16 base) and the unique mixture identification code for this mixture
- h. Properties of the bitumen that is used in the mixture
- i. For Stone Mastic Asphalt (SMA) the design void content
- j. Weighted aggregate density
- k. The target composition according to EN13043, taking into account the bitumen correction based on the weighted aggregate density
- l. The composition to base the reference composition on
- m. The target density according to Article 81.21.05 section 01

n. For mixtures in which polymer modifications are used, the type and brand of polymer and the solvent advised by the producer
o. For mixtures in which Reclaimed Asphalt Concrete (RA) is used:
    i. The percentage of RA in the mixture
    ii. The grading of the RA (NEN-EN 12697-2), the soluble bitumen content (Test 65.0) and the penetration (NEN-EN 1426) of the reclaimed bitumen (NEN-EN 12967-3) and the standard deviation in it
    iii. The weighted density according to NEN-EN 1097-6 and the category $C_{xx/x}$ regarding coarse crushed aggregates according to NEN-EN 13043 and NEN 6240 of those fractions that are present in the mixture at levels of 10%m/m or higher
    iv. The content of foreign matter in the RA
    v. Whether or not the RA is solely comprised of PA
p. The average value and standard deviation of the results of the properties relevant for this mixture type, as specified in part 2 of Test 62
q. Frequency sweep stiffness test results
r. The OIA (Dutch multi-layer design program) parameters for the mixture to be used in pavement design calculations

Since the RAW Standard (CROW, Standaard 2015, 2015) specifies that this is the information that should *at least* be provided, this should be available for the various locations. Now, the Standard has been updated twice CROW, Standaard 2010, 2010,CROW, Standaard 2015, 2015 since the initial adaption to the European standards in 2008 CROW, Standaard 2008, 2008 and that means that during this time the requirements may have changed somewhat, but roughly the information listed under *a-c, e-h, j, k* and *m* should be provided in all these projects.

The specific requirements for PA are based on its composition, the properties of the constituent materials and its moisture sensitivity (Figure 2.23). The requirements for DZOAB16 and 2L-ZOAB have been added to the RAW Standard in 2015. Prior to that, for DZOAB 16 , for which at that time ZOAB+ was used as an acronym, RWS specified the composition as "*the same as ZOAB 16, but with one percent more bitumen on 100% mass of aggregate and measures to limit bitumen drainage*" (Rijkswaterstaat, 2009). Since standard ZOAB 16 (CROW, Standaard 2008 (2008)) had a bitumen content of 4,5% on the total aggregate mass (4,3% in 100% mixture), this amounted to 5,5% "on" 100% mixture (=5,2% "in" 100% mixture). The current description in the RAW Standard is taken from here, except that for the sand fraction the lower limit is a little lower to accommodate the extra bitumen in the mixture volumetrics. For 2L-ZOAB the Dutch Association of Asphalt Contractors (VBW) had their own specifications (VBW Asfalt et al., 2002), which were updated in 2012 (Bouwend Nederland, 2012) and the requirements in the RAW Standard, version RAW Standard 2015 are based on these specifications. The current specifications by VBW (published in 2016) are in line with the RAW requirements.

**KENNISMODULES**

*81.26.04 Zeer open asfaltbeton*

ERRATA ACTUEEL VOORLOPIG DEFINITIEF

**01** In aanvulling op het bepaalde in artikel 81.26.01 lid 01 moet asfalt voor zeer open asfaltbeton voldoen aan het bepaalde in NEN-EN 13108-7, met inachtneming van het bepaalde in de navolgende leden.

**02** Grof toeslagmateriaal voor zeer open asfaltbeton moet voldoen aan de eisen voor steenslag 2, echter grof toeslagmateriaal voor DZOAB 16, 2L-ZOAB 5 en 2L-ZOAB 8 moet voldoen aan de eisen voor steenslag 3.

**03** De korrelverdeling als bedoeld in onderdeel 5.2.2 van NEN 13108-7 wordt bepaald met behulp van de basis zeefset plus set 1 volgens onderdeel 4.1.2 van NEN-EN 13043.

**04** De waterdoorlatendheid van zeer open asfaltbeton wordt bepaald volgens onderdeel 5.4.2 van NEN 13108-7. Het bepaalde in onderdeel 5.4.3 van NEN-EN 13108-7 is niet van toepassing.

**05** De samenstelling van ZOAB 11, ZOAB 16, DZOAB 16, 2L-ZOAB 16, 2L-ZOAB 5 en 2L-ZOAB 8 moet voldoen aan de in tabel 81.2.10 vermelde eisen.

**06** In DZOAB 16 moeten zodanige maatregelen tegen afdruipen zijn toegepast dat het verschil tussen het bitumengehalte onderin en bovenin de laag niet meer bedraagt dan 0,7% *(m/m)*.

**07** Voor ZOAB 11 en ZOAB 16 bitumen 70/100 toepassen.
Voor DZOAB 16 bitumen 70/100 of polymeer gemodificeerde bitumen toepassen.
Voor 2L-ZOAB 16 bitumen 70/100 of polymeer gemodificeerde bitumen toepassen.
Voor 2L-ZOAB 5 en 2L-ZOAB 8 polymeer gemodificeerde bitumen toepassen.

**08** Voor ZOAB 11, ZOAB 16, DZOAB 16, 2L-ZOAB 16, 2L-ZOAB 5 en 2L-ZOAB 8 als fijn toeslagmateriaal brekerzand toepassen.

**09** Voor ZOAB 11, ZOAB 16, DZOAB 16, 2L-ZOAB 16, 2L-ZOAB 5 en 2L-ZOAB 8 middelsoort vulstof met hydroxide toepassen overeenkomstig het bepaalde in artikel 5 van NEN 6240.

**10** In ZOAB 11, ZOAB 16, DZOAB 16, 2L-ZOAB 16, 2L-ZOAB 5 en 2L-ZOAB 8 geen asfaltgranulaat toepassen.

**11** Voor de samenstelling van ZOAB 11, ZOAB 16 en DZOAB 16 geen grof toeslagmateriaal 2/5 of 2/6 toepassen.
Voor de samenstelling van 2L-ZOAB 16 geen grof toeslagmateriaal kleiner dan 8 mm toepassen.

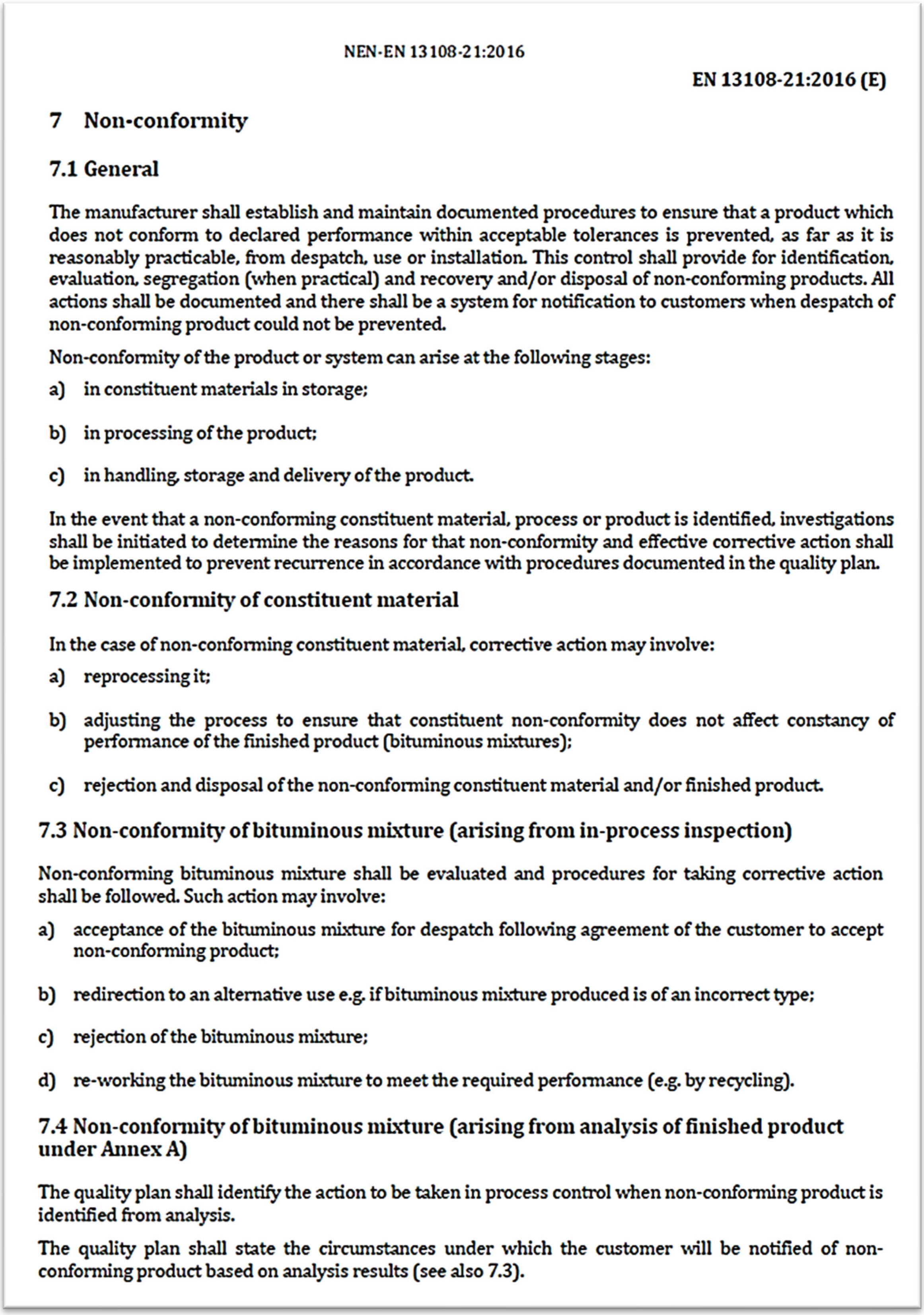
**12** De in het verkort verslag vermelde eigenschappen van ZOAB 11, ZOAB 16, DZOAB 16, 2L-ZOAB 16, 2L-ZOAB 5 en 2L-ZOAB 8 moeten voldoen aan de in tabel 81.2.11 genoemde eisen.

Figure 2.23: Composition, constituent materials and property requirements for various PA mixtures in the RAW Standard (CROW, Standaard 2015 (2015))

These properties cover:

- Grading
- Void content
- Amount and properties of bitumen
- Amount and properties of filler
- Amount and properties of sand
- Moisture sensitivity
- Properties of the course aggregate

During production and construction errors can occur that affect these aspects. If this happens during production, it should be noticed in the Factory Production Control (FPC) procedures and remedied. Although the aim of the FPC is to identify and remedy any non-conformity prior to the finished product leaving the plant, part of it is also concerned with dealing with deviations found from the finished product. If this occurs, it should be brought to the attention of the client. The decision on whether to accept a non-conforming product is up to the client.



NEN-EN 13108-21:2016

EN 13108-21:2016 (E)

# 7 Non-conformity

## 7.1 General

The manufacturer shall establish and maintain documented procedures to ensure that a product which does not conform to declared performance within acceptable tolerances is prevented, as far as it is reasonably practicable, from despatch, use or installation. This control shall provide for identification, evaluation, segregation (when practical) and recovery and/or disposal of non-conforming products. All actions shall be documented and there shall be a system for notification to customers when despatch of non-conforming product could not be prevented.

Non-conformity of the product or system can arise at the following stages:

a) in constituent materials in storage;

b) in processing of the product;

c) in handling, storage and delivery of the product.

In the event that a non-conforming constituent material, process or product is identified, investigations shall be initiated to determine the reasons for that non-conformity and effective corrective action shall be implemented to prevent recurrence in accordance with procedures documented in the quality plan.

## 7.2 Non-conformity of constituent material

In the case of non-conforming constituent material, corrective action may involve:

a) reprocessing it;

b) adjusting the process to ensure that constituent non-conformity does not affect constancy of performance of the finished product (bituminous mixtures);

c) rejection and disposal of the non-conforming constituent material and/or finished product.

## 7.3 Non-conformity of bituminous mixture (arising from in-process inspection)

Non-conforming bituminous mixture shall be evaluated and procedures for taking corrective action shall be followed. Such action may involve:

a) acceptance of the bituminous mixture for despatch following agreement of the customer to accept non-conforming product;

b) redirection to an alternative use e.g. if bituminous mixture produced is of an incorrect type;

c) rejection of the bituminous mixture;

d) re-working the bituminous mixture to meet the required performance (e.g. by recycling).

## 7.4 Non-conformity of bituminous mixture (arising from analysis of finished product under Annex A)

The quality plan shall identify the action to be taken in process control when non-conforming product is identified from analysis.

The quality plan shall state the circumstances under which the customer will be notified of non-conforming product based on analysis results (see also 7.3).

Figure 2.24: FPC non-conformity requirements (EN 13108-21 version 2016)

Under the FPC the producer should register the results of FPC procedures as well as any solutions or changes implemented to remedy and prevent established non-conformities. The exact procedure followed depends on the facilities quality plan.

Construction is not part of the FPC procedures, but both within the RAW quality control CROW, Standaard 2015, 2015 article 81.24.01) and the RWS System Oriented Contract control (in Dutch: Systeemgerichte Contract Beheersing, SCB), the same holds for noticing errors during construction and bringing this to the attention of the client.

*81.24.01 Kwaliteitsborging*

ERRATA ACTUEEL VOORLOPIG DEFINITIEF

**01** De aannemer stelt voor de uitvoering van het werk een kwaliteitsplan op.
Hij verstrekt het kwaliteitsplan aan de directie.
Hij stelt op basis van een in dit kwaliteitsplan vastgelegde procesbeheersingsmethodiek vast of is voldaan aan hetgeen in het bestek is voorgeschreven.
Hij legt zijn bevindingen schriftelijk vast.
Hij vermeldt in het kwaliteitsplan onder meer op welke wijze hij de bedrijfscontrole verricht aangaande de dikte van de lagen (proef 63), de korrelverdeling (NEN-EN 12697-2), het oplosbaar bindmiddelgehalte (proef 65.0), de holle ruimte (proef 69.0), de verdichtingsgraad (proef 66) en de penetratie (NEN-EN 1426) van het teruggewonnen bitumen (NEN-EN 12697-3) van het asfalt.

**02** De aannemer stelt de directie in de gelegenheid de bedrijfscontrole als bedoeld in lid 01 te volgen. Hij stelt de resultaten van de bedrijfscontrole desgevraagd ter beschikking van de directie.

**03** Als de aannemer tijdens de uitvoering van het werk vaststelt dat niet is voldaan aan hetgeen in het bestek is voorgeschreven, neemt hij onmiddellijk maatregelen om het voortduren van de tekortkomingen te voorkomen. Tevens stelt hij vast over welk gedeelte van het werk de tekortkomingen optreden, meldt hij deze tekortkomingen aan de directie en stelt hij de directie correctieve maatregelen voor.
Bij de vastgestelde correctieve maatregelen wordt tevens de methode van beoordeling van de kwaliteit overeengekomen.

**04** De directie kan tijdens de uitvoering van het werk besluiten een eigen onderzoek in te stellen.

**05** Als bij het in het vorige lid bedoelde onderzoek tekortkomingen worden vastgesteld ten opzichte van de in het bestek gestelde eisen, die zouden leiden tot kortingen of tot het niet goedkeuren van het werk en die niet door de aannemer zijn vastgesteld dan wel waarvoor geen correctieve maatregelen zijn voorgesteld, moet de aannemer alsnog correctieve maatregelen voorstellen.
De directie kan besluiten het onderzoek uit te breiden.

**06** Als de in het vorige lid bedoelde tekortkomingen worden vastgesteld, moet ervan worden uitgegaan dat de kwaliteitsborging van de aannemer niet adequaat functioneert. Deze moet de oorzaak daarvan terstond opsporen en herstellen.
Getroffen maatregelen moeten schriftelijk worden vastgelegd en aan de directie te worden gerapporteerd.

**07** De kosten van het eigen onderzoek als bedoeld in lid 04 en de eventuele uitbreiding daarvan overeenkomstig lid 05, komen voor rekening van de opdrachtgever. De aannemer verleent om niet de benodigde medewerking om de uitvoering van deze onderzoeken mogelijk te maken.
Als het eigen onderzoek of de eventuele uitbreiding daarvan uitgevoerd wordt door een instelling die voor het desbetreffende onderzoek geaccrediteerd is door een nationale accreditatie-instelling (in Nederland: Raad voor Accreditatie) en de in lid 05 bedoelde tekortkomingen worden vastgesteld, komen voor de desbetreffende eigenschap, de kosten van het laboratoriumonderzoek dan wel de kosten voor de uitbreiding van het laboratoriumonderzoek, voor rekening van de aannemer.

**08** Binnen zes weken na het gereedkomen van de bovenste laag verstrekt de aannemer de directie een samenvattend rapport aangaande de kwaliteit van het door hem uitgevoerde asfaltwerk.
Het rapport omvat:
- de bevindingen van de aannemer omtrent de kwaliteit van het werk;
- een overzicht van de geconstateerde afwijkingen;
- een overzicht van de voorgestelde en uitgevoerde corrigerende maatregelen.

Figure 2.25: Quality control procedures according to the RAW Standard 2015

Some deviations from the mixture specifications can occur in production and construction, but the limits to which this is acceptable (sometimes with a fine) are specified in the RAW Standard. In their performance based contracts, RWS uses those same limits. In the next sections the requirements and the limits of variation for each of the components mentioned above are discussed in more detail.

### 2.2.1 Requirements for the grading

The grading requirements for various types of standard PA mixtures used in the Netherlands are given in Figure 2.26. The number after the name is the nominal maximum aggregate size (like in the EN 13108-7), the percentages show the percentage of the total mass of aggregates passing the sieve size shown in the first column.

KENNISMODULES

*81.2.10 Samenstelling van zeer open asfaltbeton (% m/m)*

ERRATA ACTUEEL VOORLOPIG DEFINITIEF

| door zeef | ZOAB 11 | ZOAB 16 | DZOAB 16 | 2L-ZOAB 16 | 2L-ZOAB 5 | 2L-ZOAB 8 |
|---|---|---|---|---|---|---|
| 22,4 mm | | 100 | 100 | 100 | | |
| 16 mm | 100 | 93 - 100 | 93 - 100 | 90 - 100 | | |
| 11,2 mm | 91 - 100 | 70 - 85 | 70 - 85 | DV | | 100 |
| 8 mm | 15 - 40 | | | | 100 | 90 - 100 |
| 5,6 mm | | | | | 90 - 100 | NR |
| 4 mm | | | | | NR | |
| 2 mm | 15 - 25 | 15 - 25 | 13 - 25 | 5 - 25 | 5 - 25 | 5 - 25 |
| 0,5 mm | NR | NR | NR | NR | NR | NR |
| 0,063 mm | 2,0 - 10,0 | 2,0 - 10,0 | 2,0 - 10,0 | 2,0 - 10,0 | 2,0 - 10,0 | 2,0 - 10,0 |

DV: Declared Value; door de producent op te geven waarde.

Opmerking: Als karakteristieke grove zeef is in afwijking van het bepaalde in NEN-EN 13108-7 niet zeef D/2 voorgeschreven.

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Figure 2.26: Composition requirements for PA mixtures in RAW standard (CROW, Standaard 2015, 2015)

As can be seen, the requirements on the 1,4D, D, 2mm and 0,063mm sieves are a bit more strict than specified in the EN 13108-7 (Figure 2.27). The reason for this is that the RAW Standard describes specific PA mixtures used in the Netherlands. When using the description ZOAB, the producers declares that the material meets this narrower grading curve as well as the other specific requirements set for the PA mixtures in the RAW Standard 2015. In short, all ZOAB mixtures in the RAW Standard are PA mixtures, but not all PA mixtures are standard PA/ZOAB mixtures in conformity with the RAW Standard.

| **Sieve** mm | **Percentage passing by mass** |
|---|---|
| 1,4 *D*[a] | 100 |
| *D* | 90 to 100 |
| 2 | 5 to 25 |
| 0,063 | 2,0 to 10,0 |

[a] Where the sieve calculated as 1,4 *D* is not an exact number in the basic set plus set 1 series then the next nearest sieve in the set shall be adopted.

Figure 2.27: Grading requirements PA according to EN 13108-7

The difference between ZOAB 16 and DZOAB 16 is the requirements for the bitumen content (which also leads to a difference in the requirement sand fraction). DZOAB contains 1% more bitumen, based on research that showed that this leads to a longer service life (Voskuilen et al., 2004), to produce a mix with this higher bitumen content, a bit more flexibility in the sand fraction (through 2mm sieve) is required. To avoid too much drainage of bitumen, a drainage inhibitor (mostly cellulose fibre) is applied in DZOAB 16. The 2L-ZOAB 8 mixture is the fine graded top layer of a two layer PA.

Deviations in grading can occur during production, if the wrong recipe is prepared or if, due to malfunctions in part of the plant the ratio of the masses of the various aggregate size groups deviates from the intention. As stated before, large deviations should be noticed in the Factory Production Control procedures and remedied. In Figure 2.28 the deviation up to which a mixture will be accepted, based on the number of tests done, is given. The mixture gradation is determined using EN 12697-2 and the deviations shown here are relative to the target mixture grading provided, not the boundary values shown in Figure 2.26. These latter are overall boundaries, if a specific mixture falls outside these boundaries it no longer qualifies as, i.e. a ZOAB 16.

To assess the deviations between the material from the road sections and its intended grading, not only samples tested are needed, also the gradation from the original mixture design needs to be known for comparison. This kind of information is required to be delivered, both according to the EN standards and the RAW Standard, allowing this comparison to be carried out.

One aspect of construction that can affect the grading, particularly a reduction of the coarser fraction, is crushing of the aggregates. If the aggregate properties meet the requirements, this should under normal conditions not happen to the extent that it exceeds the margins used in assessing the composition based on field cores. In case of over-compaction or the use of dynamic compaction, particularly on a relatively cold mixture, excessive crushing may occur. This is difficult to ascertain from the grading only, because this only shows the final situation, but CT scans (not a standard test) could indicate fractures in the coarse aggregates prior to reclaiming the aggregates for a sieve analysis.
Any deviation from the grading or fractures in course aggregates are likely to initiate in production or construction, they are not affected by chemical reactions over time and the traffic loads will not affect the gradation. The only exception could be cracks in coarse aggregates if these are weathered and/or contain clay-like components like smectite. This is something that should be assessed when looking into the coarse aggregate properties (Section 2.2.6).

KENNISMODULES

*81.2.6 Afwijking van de korrelverdeling (% m/m)*

ERRATA ACTUEEL VOORLOPIG DEFINITIEF HANDLEIDI

| door zeef | één monster | gemiddelde van n monsters per uitvoeringseenheid | | | | | |
|---|---|---|---|---|---|---|---|
| | | n = 2 | n = 3 | n = 4 of 5 | n = 6 t/m 8 | n = 9 t/m 19 | n = ≥ 20 |
| | onthouding van goedkeuring als de afwijking groter is dan | | | | | | |
| asfaltbeton (AC) voor onderlagen met D ≥ 16 mm | | | | | | | |
| D | 4 | - | - | - | - | - | - |
| D/2 of CCS | 9 | - | - | - | - | - | - |
| 2 mm | 7 | 5,5 | 5,0 | 4,5 | 4,0 | 3,8 | 3,5 |
| 0,063 mm | 2,3 | 1,40 | 1,30 | 1,20 | 1,10 | 0,90 | 0,75 |
| asfaltbeton (AC) voor onderlagen met D < 16 mm, tussenlagen en deklagen | | | | | | | |
| D | 3 | - | - | - | - | - | - |
| D/2 of CCS | 8 | - | - | - | - | - | - |
| 2 mm | 6 | 4,5 | 4,0 | 3,8 | 3,5 | 3,3 | 3,0 |
| 0,063 mm | 2,3 | 1,40 | 1,30 | 1,20 | 1,10 | 0,90 | 0,75 |
| zeer open asfaltbeton (PA) | | | | | | | |
| D | 6 | - | - | - | - | - | - |
| D/2 of CCS | 7 | - | - | - | - | - | - |
| 2 mm | 5 | 3,8 | 3,5 | 3,3 | 3,0 | 2,8 | 2,5 |
| 0,063 mm | 2,3 | 1,40 | 1,30 | 1,20 | 1,10 | 0,90 | 0,75 |
| zeer open asfaltbeton (PA) | | | | | | | |
| D | 6 | - | - | - | - | - | - |
| D/2 of CCS | 7 | - | - | - | - | - | - |
| 2 mm | 5 | 3,8 | 3,5 | 3,3 | 3,0 | 2,8 | 2,5 |
| 0,063 mm | 2,3 | 1,40 | 1,30 | 1,20 | 1,10 | 0,90 | 0,75 |
| steenmastiekasfalt (SMA) | | | | | | | |
| D | 4 | - | - | - | - | - | - |
| D/2 of CCS | - | - | - | - | - | - | - |
| 2 mm | 5 | 3,8 | 3,5 | 3,3 | 3,0 | 2,8 | 2,5 |
| 0,063 mm | 2,3 | 1,40 | 1,30 | 1,20 | 1,10 | 0,90 | 0,75 |
| gietasfalt (GA) | | | | | | | |
| 8 mm | 2 | - | - | - | - | - | - |
| 4 mm | 8 | - | - | - | - | - | - |
| 2 mm | 6 | 4,5 | 4,0 | 3,8 | 3,5 | 3,3 | 3,0 |
| 0,063 mm | 2,8 | 1,75 | 1,60 | 1,45 | 1,30 | 1,15 | 1,00 |
| CCS: karakteristieke grove zeef. | | | | | | | |

Figure 2.28: Deviations per mixture type and sieve size up to which the grading will not be refused RAW Standard (CROW, Standaard 2015, 2015)

Tests to run for this aspect:

- Grading based on EN 12697-2
- CT scans of the cores, looking for crushing in coarse aggregates

## 2.2.2 Requirements for the void content

The test used to determine the void content in PA is specified in Test 69.0 of the RAW Standard, which in turn is based on test method EN 12697-8. The maximum density is determined using EN 12697-5, procedure A: the volumetric procedure, in water.

For PA the RAW Standard (CROW, Standaard 2015, 2015) prescribes (in Test 67) the use of EN 12697-6 Procedure D, by dimensions, to determine the bulk (or specimen) density. The relevant articles from the RAW Standard are shown in Figure 2.29.

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*proef 69 Bepalen van het gehalte aan poriën (holle ruimte) van asfalt*

ERRATA ACTUEEL VOORLOPIG DEFINITIEF HANDLEIDING

Verwezen wordt naar NEN-EN 12697-8, met dien verstande dat voor mengsels van asfaltbeton (AC), mengsels van steenmastiekasfalt (SMA) respectievelijk mengsels van zeer open asfaltbeton (PA), gebruik wordt gemaakt van de dichtheid proefstuk bepaald volgens proef 67.
Voor dichtheid mengsel wordt gebruikgemaakt van de dichtheid mengsel in overeenstemming met EN 12697-5; procedure A, in water.

(a)

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*proef 67 Bepalen dichtheid proefstuk van asfalt (dichtheid van het materiaal met ingesloten lucht, bijvoorbeeld boorkern, gyratortablet of tegel)*

ERRATA ACTUEEL VOORLOPIG DEFINITIEF HANDLEIDING

Verwezen wordt naar NEN-EN 12697-6, met dien verstande dat voor:

a. mengsels van asfaltbeton (AC):
   - met een ontwerp holle ruimte ≤ 7% de dichtheid proefstuk ($\rho_{proefstuk}$) wordt bepaald in overeenstemming met EN 12697-6; procedure B, in een verzadigde toestand met droog oppervlak;
   - met een ontwerp holle ruimte > 7% en ≤ 10 % de dichtheid proefstuk ($\rho_{proefstuk}$) wordt bepaald in overeenstemming met EN 12697-6; procedure C, afgedicht met wax;
   - met een ontwerp holle ruimte > 10% de dichtheid proefstuk ($\rho_{proefstuk}$) wordt bepaald in overeenstemming met EN 12697-6; procedure D, door opmeting;
b. mengsels van steenmastiekasfalt (SMA) de dichtheid proefstuk ($\rho_{proefstuk}$) wordt bepaald in overeenstemming met EN 12697-6; procedure B, in een verzadigde toestand met droog oppervlak;
c. mengsels van zeer open asfaltbeton (PA) de dichtheid proefstuk ($\rho_{proefstuk}$) wordt bepaald in overeenstemming met EN 12697-6; procedure D, door opmeting.

(b)

Figure 2.29: Prescribed methods to determine the void content, maximum density (top, a) and bulk density (bottom, b), from the RAW Standard 2015 (CROW, Standaard 2015 (2015))

The void content requirements per PA mixture type are given in article 81.2.11 of the RAW Standard (Figure 2.30).

KENNISMODULES

*81.2.11 Eigenschappen van zeer open asfaltbeton*

ERRATA ACTUEEL VOORLOPIG DEFINITIEF

| eigenschap | ZOAB 11 | ZOAB 16 | DZOAB 16 | 2L-ZOAB 16 | 2L-ZOAB 5 | 2L-ZOAB 8 |
|---|---|---|---|---|---|---|
| bindmiddelgehalte | $B_{min\ 4,5}$ | $B_{min\ 4,5}$ | $B_{min\ 5,2}$ | $B_{min\ 4,2}$ | $B_{min\ 5,4}$ | $B_{min\ 5,4}$ |
| minimum holle ruimte | $V_{min20}$ | $V_{min20}$ | $V_{min20}$ | $V_{min25}$ | $V_{min20}$ | $V_{min20}$ |
| maximum holle ruimte | $V_{maxNR}$ | $V_{maxNR}$ | $V_{maxNR}$ | $V_{maxNR}$ | $V_{maxNR}$ | $V_{maxNR}$ |
| watergevoeligheid | $ITSR_{80}$ | $ITSR_{80}$ | $ITSR_{80}$ | $ITSR_{80}$ | $ITSR_{80}$ | $ITSR_{80}$ |
| afdruipen | $D_{NR}$ | $D_{NR}$ | $D_{NR}$ | $D_{NR}$ | $D_{NR}$ | $D_{NR}$ |

Figure 2.30: Requirement for among others the void content per mixture type RAW Standard 2015 (CROW, Standaard 2015 (2015))

Deviations in void content can occur in the production as an effect of errors in the grading, or in production due to aggregate segregation or variation in compaction effort, temperature variations or combinations thereof.

For the quality control at delivery some variations in void content are allowed in the RAW Standard (Figure 2.31). RWS sets additional requirements, in order to ensure the required noise reduction. These requirements are that the average void content of the field cores has to be ≥18% and the lowest void content found must be ≥15%.

**KENNISMODULES**

*81.2.4 Afwijking van de holle ruimte (%)*

ERRATA ACTUEEL VOORLOPIG DEFINITIEF

| mengselgroep asfaltmengsels | één monster | | gemiddelde van n monsters per uitvoeringseenheid | | | | |
|---|---|---|---|---|---|---|---|
| | | | n = 2 | n = 3 of 4 | n = 5 t/m 8 | n = 9 t/m 19 | n ≥ 20 |
| | tolerantie | onthouding van goedkeuring als de afwijking groter is dan | | | | | |
| asfaltbeton | 3,0 | 4,4 | 3,00 | 2,75 | 2,00 | 2,00 | 2,00 |
| steenmastiekasfalt | 4,0 | 5,4 | 4,00 | 3,75 | 3,00 | 3,00 | 3,00 |
| zeer open asfaltbeton | 5,0 | 7,4 | 5,00 | 4,00 | 3,00 | 2,50 | 2,00 |
| gietasfalt | 0,2 | 1,4 | - | - | - | - | - |

Figure 2.31: Deviation from the specified void content above which the new pavement layer is not accepted, given per kind of mixture for a given number of coresRAW Standard 2015 (CROW, Standaard 2015, 2015)

Void content from the field cores should be determined using the same procedures as used to set the requirements and the results should be compared to the requirements and the information provided on the mixture prior to the construction project. It could be interesting to also use the CT scan information of the cores to obtain a void content and compare it to the other data, but it should be kept in mind that there is as yet no study that shows these methods provide the same result. However, the CT scans have the advantage that they not only allow the determination of the overall void content, but also the distribution of voids over the height and diameter, which is additional information.

Tests to run for this aspect:

- Void content based on EN 12697-8 (and EN 12697-5 and 6)
- CT scans of the cores, looking for the distribution of voids over the cores and the average values per core

### 2.2.3 Requirements for the bitumen content or properties

The minimum required binder content is specified per PA type (Figure 2.30), typically these are also the values used with sometimes small deviations to correct for higher or lower aggregate densities. The provided mixture information should be compared to the requirements. The values found from field cores can be compared to both. Some material loss is to be expected due to wear and tear, but this does usually not affect the bitumen to a larger extend than the aggregates, so all in all this will not affect the results.

The test method to determine the soluble binder content is Test 65.0, covering two methods (65.1 and 65.2), all of which refer directly to the EN standard, EN 12697-1 Method B2.1 Continuous flow centrifuge (Test 69.2) and Method B1.3 Soxhlet extractor method (Test 69.1), respectively (Figure

2.32). For disputes upon delivery, Soxhlet extraction is specified. In case Polymer Modified Bitumen (PMB) is used, appendix D of the EN standard applies.

*81.22.15 Eisen aan het resultaat: bindmiddelgehalte en penetratie van het bitumen*

ERRATA ACTUEEL VOORLOPIG DEFINITIEF

**01** Het oplosbaar bindmiddelgehalte (proef 65.0) van het asfalt moet gelijk zijn aan dat van de referentiesamenstelling.
De afwijking van het oplosbaar bindmiddelgehalte (proef 65.0) mag niet meer bedragen dan de in tabel 81.2.5 aangegeven waarden.
De afwijking van het gemiddelde oplosbaar bindmiddelgehalte (proef 65.0) mag niet meer bedragen dan de in tabel 81.2.5 aangegeven waarden.

**02** Als polymeer gemodificeerd bitumen is toegepast, dan wordt het bindmiddelgehalte bepaald volgens NEN-EN 12697-1 bijlage D.

**03** De penetratie (NEN-EN 1426) van teruggewonnen bitumen (NEN-EN 12697-3) uit aangebracht asfaltbeton en steenmastiekasfalt moet, bepaald binnen 14 dagen na aanbrengen, ten minste 60% van de ondergrens van de toegepaste bitumengrade dan wel de (reken)waarde bij het typeonderzoek zijn.

**04** De penetratie (NEN-EN 1426) van teruggewonnen bitumen (NEN-EN 12697-3) uit zeer open asfaltbeton moet, bepaald binnen 14 dagen na aanbrengen, ten minste 40% van de ondergrens van de bitumengrade dan wel de (reken)waarde bij het typeonderzoek zijn.

Figure 2.32: Standards and test methods used to determine the bitumen content and properties RAW Standard 2015(CROW, Standaard 2015, 2015)

Deviations in bitumen content can occur during production (wrong amount added), or locally in construction (segregation). Deviations in properties may occur due to production errors (wrong type added, adding reclaimed asphalt and getting a mix-penetration that does not meet the criteria, overheating/burning of the bitumen), but the properties do not change much during the construction phase.

**KENNISMODULES**

*81.2.5 Afwijking van het oplosbaar bindmiddelgehalte (% m/m)*

ERRATA ACTUEEL VOORLOPIG DEFINITIEF

| mengselgroep asfaltmengsels | één monster | | gemiddelde van n monsters per uitvoeringseenheid | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | | n = 2 | n = 3 | n = 4 of 5 | n = 6 t/m 8 | n = 9 t/m 19 | n ≥ 20 |
| | tolerantie | onthouding van goedkeuring als de afwijking groter is dan | | | | | | |
| asfaltbeton voor een deklaag | 0,5 | 0,7 | +0,50 −0,60 | +0,40 −0,50 | +0,35 −0,45 | +0,30 −0,40 | +0,25 −0,35 | +0,20 −0,30 |
| asfaltbeton voor een onder- of tussenlaag, zeer open asfaltbeton, gietasfalt | 0,6 | 0,8 | | | | | | |
| steenmastiekasfalt: D = 5 | 0,7 | 0,9 | | | | | | |
| steenmastiekasfalt: D = 8 en D = 11 | 0,6 | 0,8 | | | | | | |

Figure 2.33: Deviations in bitumen content above which the new pavement is not accepted, for various applications and numbers of specimens RAW Standard 2015(CROW, Standaard 2015, 2015)

Looking beyond the binder content to the properties of the bitumen, the penetration is the onely property for which specific requirements are set, both in mixture design and specification and in acceptance of a pavement. In the mixture design phase, the penetration range also set a number of other properties, since these are all linked to penetration classes.

For reclaiming the binder from samples from the field for further testing (not just determining the binder content, but its properties), the rotary evaporator (EN 12697-3) is specified (81.22.15 – 03 and 04, Figure 2.32).

Regarding the properties after production, the RAW standard requires that fourteen days after construction the penetration value of bitumen used in PA is at least 40% of the lower boundary of the specified pen grade. The rather steep drop in penetration value is due to the large aging effect of production on an asphalt mixture. During the service life this aging continues at a lower rate, gradually reducing the penetration value.

As such, it would be useful to be able to compare the penetration values of the field cores to quality control values obtained after construction, if these are available. Since this will not be the case for all sections, comparing them to each other while taking into account their ages, will provide a relative comparison. This will show if they all show a similar (change in) penetration or if there are differences.

Tests to run for this aspect:

- Soluble binder content (EN 12697-1, Procedure 1.3 Soxhlet extraction)
- Penetration (EN 1426)
- Collect the quality control data on penetration of bitumen after construction for the test sections

### 2.2.4 Requirements for the filler content or properties

In the RAW Standard, for PA mixtures active fillers are required. These are fabricated fillers which meet the requirements of EN13043. As specified in RAW Standard 2015 paragraph 81.26.04-09 (Figure 2.23), middle type fabricated filler with hydroxide is required.

The filler content can deviate due to errors in production, i.e. adding the wrong amount or type or due to the production process, i.e. dust from courser aggregates increasing the overall fines content.

The filler composition can be affected if the wrong type is added, but also due to chemical reactions changing the composition over time. The composition of reclaimed filler can also be affected by fines from clogging in the cores.

The amount of filler size particles can be determined from the grading, for the properties the amount of calcium hydroxide needs to be determined, since a requirement is set for that for DZOAB and 2LZOAB (NEN-EN 459-2 art 5.8 ).

Tests to run for this aspect:

- Grading in order to determine the amount of filler size particles
- Amount of calcium hydroxide (NEN-EN 459-2 art 5.8 ).
- Collect the type and amount of filler added from the CE information provided

### 2.2.5 Requirements for the sand content and properties

Sand is defined as the aggregate fraction between 2mm and 63μm in size. Other than that, for ZOAB it is required that the sand used is crushed natural rock or crushed gravel (Figure 2.35 and Figure 2.34). These are the two things that can be tested.

*81.2.13 Eigenschappen van fijn toeslagmateriaal*

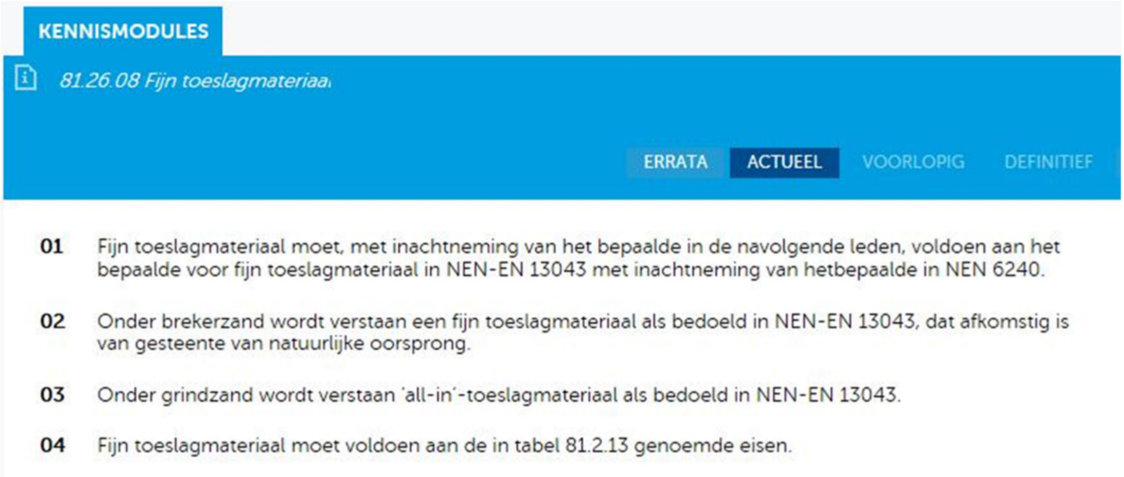
ERRATA ACTUEEL

| artikel in NEN-EN 13043 | eigenschap | natuurlijk zand | brekerzand | grindzand |
|---|---|---|---|---|
| 4.1.2 | korrelgroep | 0/2 | | DV |
| 4.1.3.2 | korrelverdeling | NEN 6240 artikel 4.1.3.2 | | |
| | - categorie | $G_F85$ | $G_F85$ | $G_A85$ |
| | - tolerantie korrelverdeling | $G_{TC}10$ | | |
| | gehalte zeer fijn materiaal ≤ 0,063 mm | $f_3$ | | $f_{10}$ |
| 4.1.5 | kwaliteit zeer fijn materiaal | DV | | |
| 4.1.8 | hoekigheid van fijn toeslagmateriaal | $E_{cs}NR$ | $E_{cs}35$ | $E_{cs}NR$ |
| 4.2.7.1 | dichtheid | DV | | |
| 4.2.7.2 | waterabsorptie | DV | | |
| 4.2.9.1 | waterabsorptie (vorst/dooi controleproef) | $WA_{24}1$ | | |
| 4.2.9.2 | bestandheid tegen vorst/dooi | $F_2$ | | |
| 4.2.10 | bestandheid tegen thermische schok (hitte) | DV | | |
| 4.3.2 | petrografische samenstelling | DV | | |

DV: Declared Value; door de producent op te geven waarde.
NR: No Requirement; in Nederland wordt hiervoor geen eis gesteld

| | |
|---|---|
| Opmerking 1: | Bij 'all-in'-toeslagmateriaal geldt de tolerantie korrelverdeling alleen voor toeslagmateriaal met D ≤ 8 mm. |
| Opmerking 2: | De eis aan de hoekigheid van fijn toeslagmateriaal geldt niet voor asfaltbeton. |
| Opmerking 3: | De eis aan de waterabsorptie geldt niet voor natuurlijk zand. |
| Opmerking 4: | De eis aan de bestandheid vorst/dooi geldt niet voor natuurlijk zand. |
| Opmerking 5: | Als de waterabsorptie voldoet aan categorie $WA_{24}1$ geldt voor de bestandheid vorst/dooi geen eis (NR). |

Figure 2.34: Requirements sand, included crushed rock RAW Standard 2015(CROW, Standaard 2015, 2015)



KENNISMODULES

*81.26.08 Fijn toeslagmateriaa*

ERRATA ACTUEEL VOORLOPIG DEFINITIEF

**01** Fijn toeslagmateriaal moet, met inachtneming van het bepaalde in de navolgende leden, voldoen aan het bepaalde voor fijn toeslagmateriaal in NEN-EN 13043 met inachtneming van hetbepaalde in NEN 6240.

**02** Onder brekerzand wordt verstaan een fijn toeslagmateriaal als bedoeld in NEN-EN 13043, dat afkomstig is van gesteente van natuurlijke oorsprong.

**03** Onder grindzand wordt verstaan 'all-in'-toeslagmateriaal als bedoeld in NEN-EN 13043.

**04** Fijn toeslagmateriaal moet voldoen aan de in tabel 81.2.13 genoemde eisen.

Figure 2.35: Requirements for fine aggregate or sand RAW Standard 2015 (CROW, Standaard 2015, 2015)

Tests to run for this aspect:

- Grading in order to determine the amount of sand particles
- Potentially: mineralogy to determine the source of fine aggregate/sand particles (to ensure it is crushed rock or crushed gravel)

### 2.2.6 Requirements for the course aggregate properties or content

Since the materials discussed here are wearing course materials, the course aggregates have to meet extra stringent requirements (Eisen Steenslag 3) to ensure sufficient long-term skid resistance. Specifically, the Polished Stone Value (PSV), indicating the polishing resistance has to be 58 or higher and the percentage broken surface of the coarse material has to be $C_{100/0}$ (Figure 2.36).

*81.2.12 Eigenschappen van grof toeslagmateriaal*

ERRATA | ACTUEEL | VOORLOPIG | DEFINITIEF | HANDLEIDING

| artikel in NEN-EN 13043 | eigenschap | | steenslag 1 | steenslag 2 | steenslag 3 | grind |
|---|---|---|---|---|---|---|
| 4.1.2 | korrelgroep | | NEN 6240 artikel 4.1.2 | | | |
| 4.1.3 | korrelverdeling | | NEN 6240 artikel 4.1.3 | | | |
| 4.1.3.1 | korrelverdeling, grenzen en toleranties | | NEN 6240 artikel 4.1.3.1 | | | |
| 4.1.4 | gehalte zeer fijn materiaal (aanhangend stof) | | NEN 6240 artikel 4.1.4 | | | |
| 4.1.6 | korrelvorm vlakheidsindex FI | D ≤ 8 mm | $FI_{30}$ | $FI_{25}$ | | $FI_{30}$ |
| | | D > 8 mm | $FI_{20}$ | $FI_{20}$ | | $FI_{20}$ |
| 4.1.7 | percentage gebroken oppervlak | | $C_{95/1}$ | | $C_{100/0}$ | $C_{NR}$ |
| 4.2.2 | weerstand tegen verbrijzeling Los Angeles-coëfficiënt LA | | $LA_{25}$ | $LA_{20}$ | $LA_{15}$ | $LA_{30}$ |
| 4.2.3 | grof toeslagmateriaal voor deklagen en tijdelijke deklagen weerstand tegen polijsting PSV | wegen waarop een maximumsnelheid geldt van 30 km/u en wegen gesloten voor motorvoertuigen | $PSV_{verklaard}$ ≥ 48 | $PSV_{verklaard}$ ≥ 53 | $PSV_{verklaard}$ ≥ 58 | $PSV_{NR}$ |
| | | overige wegen | - | | | |
| 4.2.7.1 | dichtheid (opmerking 2) | | DV | | | |
| 4.2.7.2 | waterabsorptie | | DV | | | |
| 4.2.9.1 | waterabsorptie (vorst/dooi controleproef) | | $WA_{24}1$ | | | |
| 4.2.9.2 | bestandheid vorst/dooi | | $F_2$ | | | |
| 4.2.10 | bestandheid tegen hitte | | DV | | | |
| 4.2.11 | affiniteit van grof toeslagmateriaal voor bitumineuze bindmiddelen | | DV | | | |
| 4.3.2 | petrografische samenstelling | | DV | | | |
| 4.3.3 | grove lichtgewicht verontreinigingen | | $m_{LPC}0,1$ | | | |

DV: Declared Value; door de producent op te geven waarde.
NR: No Requirement; in Nederland wordt hiervoor geen eis gesteld.

Opmerking 1: Steenslag 3 is alleen bedoeld voor toepassing in asfaltdeklagen onder zeer hoge verkeersintensiteiten.

Opmerking 2: Het verschil in dichtheid met de op de prestatieverlaring vermelde dichtheid $\rho_a$ (apparent density), bepaald volgens artikel 8 van NEN-EN 1097-6, mag ten hoogste 30 kg/m$^3$ zijn.

Opmerking 3: Als wordt voldaan aan categorie $WA_{24}1$, geldt voor 4.2.9.2 bestandheid vorst/dooi geen eis (NR).

Figure 2.36: Requirements for the coarse aggregates RAW  Standard 2015(CROW, Standaard 2015, 2015)

Tests to run for this aspect:

- Grading
- Polishing resistance
- Angularity

### 2.2.7 Requirements for the moisture sensitivity

For all PA mixtures, the requirement for the moisture sensitivity (ITSR) is (at least) 80% (Figure 2.30). This can be tested on the cores obtained from the test sections, but it is to be expected that the sensitivity will have changed over time and there is little or no information on how that change develops. This is further complicated, because the boundary conditions of field cores differ from laboratory produced gyratory cores. Also, this test will break the specimens, which could make other tests more complicated or requires additional specimens.

So, although relevant, this test would at best give a relative indication of performance, based on the values from the sections of different ages. If actual test results (rather than just $ITSR_{80}$) are reported on the mixture information, this would provide an extra base for comparison. But all in all, other tests seem more relevant and important.

Tests to run for this aspect:

- Potentially, determine the moisture sensitivity (EN 12697-12 and 12697-23)
- Potentially: obtain the measured ITSR for this mixture for comparison

# 3. Analysis and discussion of test results

## 3.1 Completeness of provided information

In this chapter, an analysis is made of the data available on each section within RWS. RWS collected the available data from the project teams and districts that manage the particular sections and archived them in set of directories. They inventoried the available information and provided an overview of the information, including the type of documents and the information on them, such as various types of grading, reference density. The analysis of the declared information in these documents was also done by RWS and provided to the project team. This information is combined with the results from the various studies that were carried out on samples taken from the roads, results that were collected by the TUD research team in a number of overviews. The analyses presented in this chapter, is based on the combination of those datasets.

Generally, it is striking that not all required information is available for each project. One would expect the project information on paving projects to contain:

- An overview of the construction(s) made, identifying the layers and constructions sections
- Per section and layer the code of the mixture used and
    - DoP/CE information on the mixture
    - Reference composition and target density
    - CE information or other material information regarding the component materials
    - Short report according to the relevant RAW Standard
    - Information on the contractor quality control for that mixture during the construction of that part of the work
    - Every now and then: results from additional quality control by/on behalf of the client

In reality, the available material is considerably more limited and the material that is there varies in what it includes. It may help both contractors and clients to specify what is required and develop a standard format, since this will facilitate gathering, disclosing and assessing the information.

The information on these projects was collected by RWS and an inventory of the available information was provided by them. In Table 3.1 the presence of the CE marking information (required since January 2008), the short report according to the (RAW) Standard (required since May 2008and the Declaration of Performance, DoP, (required since July 1st 2013) obtained from this inventory are shown.

As can be seen, the CE marking is present in about 80% of the information sets and the short report in a similar amount of cases13. //the short report is present in about 40%.

The DoP is required since July 1st 2013, which means that the projects in which these sections were constructed were mostly (over 60%) build before 2013 and, hence, before the Construction Products Directive (CPD) became the Construction Products Regulation (CPR) and the DoP was introduced. For the five sections build after 2013, only 2 (less than 50%) included a DoP in their documentation. For the six sections build in 2013 it is unclear if a DoP was required, it depends on whether construction took place before or after July 1st. For this reason, projects constructed in 2013 where the documentation did not include a DoP were coded orange (unclear). Two of the projects in 2013 did include a DoP, bringing the total number of DoP's in the data set up to four. In the table the presence

13 For Locations 4 and 8 there is no document clearly labeled short report or (additional) product information, but there are documents that contain the sort of information required as the short report. These are counted as such. For CE marking and DoP only documents clearly labeled as such (with the CE symbol or the Declaration of Performance title) are counted, since these labels are part of the requirements for these documents (see: Figure 2.11, Figure 2.19 and Figure 2.20).

of of DoP's is shown both including 2013 (overall results with ** after them) and excluding 2013. In the latter case only projects constructed later than 2013 are taken into account (results followed by ***). In the table, green denotes that the information was present, red that it was not, orange means it is unclear (because of the DoP date, see above) and black means it is not required (DoP's for projects constructed before 2013).

Overall, for less than 50% of the cases all required documentation is provided.

Table 3.1: Information available in the project dossiers for the 17 locations

| **location** | **Type of mix** | ***CE marking*** | ***Short Report RAW*** | ***DoP*** | **build in** | ***all req docs*** |
|---|---|---|---|---|---|---|
| 1 | DZOAB 16 | | | | 2012 | |
| 2 | DZOAB 16 | | | | 2013 | |
| 3* | 2LZOAB 8 | | | | 2009 | |
| 3* | 2LZOAB 8 | | | | 2009 | |
| 3* | 2LZOAB 8 | | | | 2009 | |
| 3* | 2LZOAB 16 | | | | 2009 | |
| 3* | 2LZOAB 16 | | | | 2009 | |
| 3* | 2LZOAB 16 | | | | 2009 | |
| 4 | DZOAB 16 | | | | 2010 | |
| 5 | 2LZOAB 8 | | | | 2008 | |
| 5 | 2LZOAB 16 | | | | 2008 | |
| 6 | DZOAB 16 | | | | 2013 | |
| 7 | 2LZOAB 8 | | | | 2009 | |
| 7 | 2LZOAB 16 | | | | 2009 | |
| 8* | DZOAB 16 | | | | 2011 | |
| 8* | DZOAB 16 | | | | 2011 | |
| 9* | DZOAB 16 | | | | 2012 | |
| 9* | DZOAB 16 | | | | 2012 | |
| 10 | DZOAB 16 | | | | 2013 | |
| 11 | DZOAB 16 | | | | 2013 | |
| 12 | 2LZOAB 8 | | | | 2015 | |
| 12 | 2LZOAB 16 | | | | 2015 | |
| 13 | DZOAB 16 | | | | 2014 | |
| 14* | DZOAB 16 | | | | 2013 | |
| 14* | DZOAB 16 | | | | 2013 | |
| 15 | DZOAB 16 | | | | 2014 | |
| 16 | DZOAB 16 | | | | 2014 | |
| 17* | DZOAB 16 | | | | 2012 | |
| 17* | DZOAB 16 | | | | 2012 | |
| | present | 23 (79%) | 19 (66%) | 4 (14%) | 4 (36%)**<br>***2 (40%)**** | 14 (48%) |
| | missing | 6 (21%) | 10 (34%) | 3 (10%) | 3 (27%)**<br>***3 (60%)**** | 13 (45%) |
| | not required /unclear | 0 (0%) | 0 (0%) | 22 (76%) | 4 (27%)**<br>***0 (0%)**** | 2 (7%) |
| | total | 29 | 29 | 29 | 11** (5 ***) | 29 |

***: 2 or more mixes of the same type, unclear which one was used in the location that was sampled**
****: considering only works from 2013 and later, when a DoP was required (July 1st 2013)**
*****: considering only works after 2013, ingnoring the two 2013 mixes with a DoP**

It should be noted that this does not yet include a check on the completeness or correctness of the information provided in these documents. It only addresses whether the information was available.

Obviously, completeness of documentation is an issue. Since this is the start of knowing what is delivered and staying in control, both from a contractor and client point of view, it is important to improve this.

Besides completeness in the information delivered, also clarity of the provided information can be improved. In the table 29 materials are listed, while only 17 materials were sampled. This is because in several dossiers multiple mixtures of the same type were included and no information was provided on which was actually used. As can be seen, this was the case for 5 of the sections (six of the mixtures, since location 3 involves a 2L-ZOAB wearing course). It is understandable that, when preparing the bid, options regarding the specific mixture (recipe, plant) still exist. Yet, by the time this detailed information is required (at least ten days prior to the start of construction, RAW Standard 2015 article 81.23.02 CROW, Standaard 2015, 2015), it should be possible to provide details on which material will be used where. And after construction, this information should be available to confirm or correct the initial plan, providing the client with the necessary information on what material is used where.

Considering that the sections where multiple mixtures were included in the project information coincide to a large extend with those where CE marking information is missing, this strengthens the impression of preliminary information. However, this was apparently not updated during the project with the result that, in case the contractor did not provide the information, the contractual and legislative requirements (under the CPD and CPR) were not met. If the information was provided, but not properly stored, it still results in a situation where RWS cannot trace the information necessary to show that the legal and contractual requirements were met and, as such, payment was legitimate. Also, it prevents any checks later on to find the use of materials or techniques which are found to have issues later on or the use of the available network to get reliable information on materials used and life times achieved.

Correcting the data above for the multiple mixtures submitted, is made easy because in 4 out of the five occasions the (in)completeness is the same for the various mixtures. Only for section 3 there is variation, with two of the three mixtures for both top and bottom layer having complete documentation. For this reason, and because it is unknown which mixtures are actually used in construction, for both mixtures in section 3 the label “unclear” is used for the completeness of the mix documentation.

This provides the numbers regarding the presence of the required mixture documentation for the 21 materials (17 sections, 4 of them with 2L-ZOAB). As can be seen from Table 3.3, about 80% of the mixture documentation did include CE marking, about two thirds did include the short report (66%) and a about 40% of the mixtures that required a DoP (construction date later than 2013) included one. In most cases where a DoP is required and delivered, also CE marking is provided.
Since both DoP and CE are related to the CPD/CPR, these documents are part of the public law framework and required to be allowed to sell asphalt concrete for pavements within the EU.

Table 3.2: Overview of whether or not the CE marking, RAW short report and DoP were presented in the documentation for each section (red: not present, green: present, orange: unclear, black: not required)

| location | Type of mix | *CE marking* | *Short Report RAW* | *DoP* | build in | *all req docs* |
|---|---|---|---|---|---|---|
| 1 | DZOAB 16 | | | | 2012 | |
| 2 | DZOAB 16 | | | | 2013 | |
| 3* | 2LZOAB 0/8 | | | | 2009 | |
| 3* | 0/16 | | | | 2009 | |
| 4 | DZOAB 16 | | | | 2010 | |
| 5 | 2LZOAB 0/8 | | | | 2008 | |
| 5 | 0/16 | | | | 2008 | |
| 6 | DZOAB 16 | | | | 2013 | |
| 7 | 2LZOAB 0/8 | | | | 2009 | |
| 7 | 0/16 | | | | 2009 | |
| 8* | DZOAB 16 | | | | 2011 | |
| 9* | DZOAB 16 | | | | 2012 | |
| 10 | DZOAB 16 | | | | 2013 | |
| 11 | DZOAB 16 | | | | 2013 | |
| 12 | 2LZOAB 0/8 | | | | 2015 | |
| 12 | 0/16 | | | | 2015 | |
| 13 | DZOAB 16 | | | | 2014 | |
| 14* | DZOAB 16 | | | | 2013 | |
| 15 | DZOAB 16 | | | | 2014 | |
| 16 | DZOAB 16 | | | | 2014 | |
| 17* | DZOAB 16 | | | | 2012 | |
| | present | 19 (90%) | 17 (81%) | 4 (19%) | 4 (40%)**<br>***2 (40%)**** | 12 (57%) |
| | missing | 2 (10%) | 4 (19%) | 3 (14%) | 3 (30%)**<br>***3 (60%)**** | 5 (24%) |
| | not required /unclear | 0 (0%) | 0 (0%) | 14 (67%) | ***3 (30%)*****<br>**0 (0%)***** | **4 (19%)** |
| | total | 21 | 21 | 21 | 10**/ 5*** | 21 |

***: 2 or more mixes of the same type, unclear which one was used in the location that was sampled**
****: considering only works from 2013 and later when a DoP was required (July 1st 2013)**
*****: considering only works after 2013, ingnoring the two 2013 mixes with a DoP**

All in all, all required documents are present in under 60% of the cases, in nearly 25% they are not (final column Table 3.3). This is a shocking result. Particularly since this is required documentation and this check addresses only ***if*** such documents were provided. It does not include an assessment of the completeness or correctness of the information provided in these documents.

Table 3.3: Overview of available mixture documentation considering one recipe per material and section

| Type of mix | CE marking | Short Report RAW | DoP | after 2013 DoP present | all req docs |
|---|---|---|---|---|---|
| present | 19 (90%) | 17 (81%) | 4 (19%)<br>***0*** | 4 (40%)**<br>***2 (40%)**** | 12 (57%) |
| missing | 2 (10%) | 4 (19%) | 3 (14%)<br>***0*** | 3 (30%)**<br>***3 (60%)**** | 5 (24%) |
| not required /unclear | 0 (0%) | 0 (0%) | 14 (67%)<br>***0*** | 3 (30%)**<br>***0 (0%)**** | 4 (19%) |
| total | 21 | 21 | 21 | 10**/ 5*** | 21 |

****: considering only works from 2013 and later when a DoP was required (CPD became CPR on July 1st 2013)**
*****: considering only works after 2013, ingnoring the two 2013 mixes with a DoP**

It is clear that the current system, including the contractor organised quality control that is central in the RWS system, is not living up to the intended system that ensures quality checks and continuous improvements. To see if this has improved, it would be interesting to see if any of the materials used in these projects have been used in RWS projects more recently and if the documentation has become more complete. If it has, the system is improving, if not, it is still not working as intended. Resolving this is crucial, not just to ensure proper project delivery but also to ensure a reliable stock of data for life cycle analysis and decision support as well as dealing with future challenges, with increasing variation in applied materials and the corresponding health and environmental challenges regarding recycling.

## 3.2 Disclaimer

In the remainder of this Chapter the properties of the cores that were taken from the 17 Locations are analysed and discussed and, where applicable, compared to the RAW Standard requirements. For this, the current standard (CROW, Standaard 2015, 2015) is used. It must be noted that this is the first standard that includes these mixtures and that at the time these sections (with the exception of Location 12, which was constructed in 2015) were constructed, neither of the three materials used in the 17 Locations studied, were part of the RAW Standard. As such, not all current requirements were in place at the time of the construction of the locations studied in this research. This is also the case for the tolerances between the various compositions, this is something to keep in mind in assessing the results. Especially for the 2L-ZOAB mixtures, because the specifications from VBW did *not* include grading requirements.

However, the current specifications in the RAW Standard are based on the existing experience with those VBW requirements, so they are expected to be close to what was the state of practice. Moreover, for DZOAB 16 the original RWS requirement used the ZOAB 16 specification, except for bitumen content and the requirement to limit drainage. The current RAW requirements are exactly the same, except for the grading interval on the 2 mm sieve, which is wider in the current RAW Standard (15-25% for ZOAB 16 versus 13-25% for DZOAB 16). All in all, using the current requirements to assess these works seems a reasonable approach. An overview of the quantities for which requirements are specified for the various compositions and types of mixes is given in Table 3.4.

Table 3.4: Quantities for which requirements are set for the various compositions in the RAW 2015

| RAW 2015 | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | *REQUIREMENTS FOR D=16* | | | | | | | | |
| composition | **1,4D** | **D** | **CCS (=11,2mm)** | **2** | **0,063** | **Bmin** | **voids** | **density** | **compaction** |
| target | Y | Y | Y(* | Y | Y | Y | Y | N | N |
| ref | N | Y | Y | Y | Y | Y(** | N | Y | N |
| field core | N | Y | Y | Y | Y | Y | Y | N | Y |
| average of field cores | N | N | N | Y | Y | Y | Y | M(*** | N |
| | *REQUIREMENTS FOR D=8* | | | | | | | | |
| composition | **1,4D** | **D** | **CCS** | **2** | **0,063** | **Mb** | **HR** | **dichtheid** | **VG** |
| target | Y | Y | N | Y | Y | Y | Y | N | N |
| ref | N | Y | N | Y | Y | Y(** | N | Y | N |
| field core | N | Y | N | Y | Y | Y | Y | N | Y |
| average of field cores | N | N | N | Y | Y | Y | Y | M(*** | N |

**) for 2LZOAB16 this is DV, so no requirements for the value, but a value must be given for sieve 11,2mm*

***) no margins specified between reference composition and composition after extraction (c.a.e.), but a composition is defined as grading + bitumen content, so the minimum specified bitumen content for the mixture group is used*

****) for the average of multiple field cores, no margins are given for degree of compaction. However, in the type test it is specified that all specimens should have the target density +/- 30kg/m3. This can be used as an alternative requirement*

To assess the effect of using the current or past requirements, in Section 3.11 and especially Subsection 3.11.3 the number of deviations according to both the current standard and the requirements referred to at the time are shown.

### 3.2.1 DZOAB 16

This mixture was not included in the RAW Standard before 2015, but in the RWS specifications (Rijkswaterstaat, 2009) in the sections 4.2.2.3 and 6.7.2 DZOAB 16 is described as a material that conforms to the RAW Standard 2005 requirements (for ZOAB 16) with the additional requirements:

- Bitumen content increased to >= 5,2%
- Measures taken to ensure that the difference in bitumen content at the top and lower half of a core would be ≤0,7% (in practice: drainage inhibitors like cellulose fibres or PMB are used)
- Steenslag 3 (PSV≥58)

These requirements did not change over time, until the implementation in the RAW Standard 2015, where the requirement passing 2mm sieve was changed from 15-25 % to 13-25%. As such, the difference between the current and previous requirements is a tighter requirement for the 2mm sieve in the past. The quantities for which requirements are set in the RAW 2010 and 2008 for the various compositions are the same (Table 3.5), even though the specific requirements and margins can sometimes vary.

Table 3.5: Quantities for which requirements are set for DZOAB16 in RAW 2010 and 2008

| RAW 2010/2008 | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | *REQUIREMENTS FOR DZOAB16* | | | | | | | | |
| composition | 1,4D | D | CCS (=11,2mm) | 2 | 0,063 | Bmin | voids | density | compaction |
| target | Y | Y | Y | Y | Y | Y | Y | N | N |
| ref | N | Y | Y | Y | Y | Y(* | N | Y | N |
| field core | N | Y | Y | Y | Y | Y | Y | N | Y |
| average of field cores | N | N | N | Y | Y | Y | Y | M | N |

**) no margins specified between reference composition and composition after extraction (c.a.e.), but a composition is defined as grading + bitumen content, so the minimum specified bitumen content for the mixture group is used*

### 3.2.2 2L-ZOAB 8

In the guidelines for 2L-ZOAB (VBW Asfalt et al., 2002) for the top-layer 2L-ZOAB 8 a minimum binder content of 6,0%[14], modified bitumen, a minimum layer thickness of 25mm, average void content of 20% and at least steenslag 2, which translates to PSV≥53. Since 2005 this has been superseded by the RWS requirement of steenslag 3 and PSV≥58 for all wearing courses for highways. The void content in the design phase must be at least 20%. No requirements for the grading were given in the guideline, so for this the current requirements are used but it must be kept in mind that these were not in place during the construction of the investigated sections. On the other hand, the current specifications were based on past experience, so it is to be expected that these reflect the common approach towards the mix composition.

14 at the time bitumen content was defined "on" 100% mass of mineral aggregate, which translates to 5,66% "in" 100% mass of mixture, this was apparently fixed as 5,4 percent in the new requirements (Bouwend Nederland, 2012)

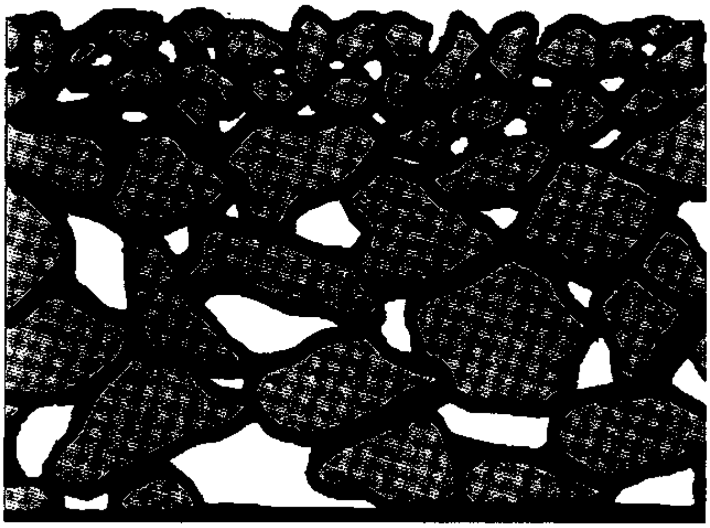



Figure 3.1: Structure and rough mix requirements for the top and bottom layer of 2LZOAB (VBW Asfalt et al., 2002)

The quantities for which requirements are set in the RAW 2010 and 2008 for the various compositions are the same (Table 3.6), even though the specific requirements and margins can sometimes vary.

Table 3.6: Quantities for which requirements are set for 2L-ZOAB8 in RAW 2010 and 2008

| RAW 2010/2008 | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | *REQUIREMENTS FOR 2L-ZOAB8* | | | | | | | | |
| composition | 1,4D | D | CCS | 2 | 0,063 | Mb | HR | dichtheid | VG |
| target | N | N | N | N | N | Y | Y | N | N |
| ref | N | N | N | N | N | Y(* | N | Y | N |
| field core | N | N | N | N | N | Y | Y | N | Y |
| average of field cores | N | N | N | N | N | Y | Y | M | N |

**) no margins specified between reference composition and composition after extraction (c.a.e.), but a composition is defined as grading + bitumen content, so the minimum specified bitumen content for the mixture group is used*

### 3.2.3 2L-ZOAB 16

In the guidelines for 2L-ZOAB (VBW Asfalt et al., 2002) for the bottom-layer a minimum binder content of 4,5%15, modified bitumen, a minimum layer thickness of 50mm and at least steenslag 2, which translates to PSV≥53. The void content must be ≥25%. No requirements for the grading were given in the guideline, so also for this mixture for this the current requirements are used and it must be kept in mind that these were not in place during the construction of these sections. Yet also for this mixture the current specifications are based on past experience, so it can be argued that these reflect the common approach towards the mix composition.

15 at the time bitumen content was defined “on” 100% mass of mineral aggregate, which translates to 4,31% “in” 100% mass of mixture, this was apparently fixed as 4,2 percent in the new requirements (Bouwend Nederland, 2012)

Also for 2L-ZOAB16 the quantities for which requirements are set in the RAW 2010 and are the same (Table 3.7), even though the specific requirements and margins can sometimes vary.

Table 3.7: Quantities for which requirements are set for 2L-ZOAB16 in RAW 2010 and 2008

| RAW 2010/2008 | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | REQUIREMENTS FOR 2L-ZOAB16 | | | | | | | | |
| composition | 1,4D | D | CCS (=11,2mm) | 2 | 0,063 | Bmin | voids | density | compaction |
| target | N | N | N | N | N | Y | Y | N | N |
| ref | N | N | N | N | N | Y(* | N | Y | N |
| field core | N | N | N | N | N | Y | Y | N | Y |
| average of field cores | N | N | N | N | N | Y | Y | M | N |

**) no margins specified between reference composition and composition after extraction (c.a.e.), but a composition is defined as grading + bitumen content, so the minimum specified bitumen content for the mixture group is used*

## 3.3 General properties per mixture

In this Chapter the requirements, if applicable the properties obtained from the declared information about each mixture in the project documentation and the results from the various tests on field cores are given and compared. Two examples are given here in Figure 3.2 and Figure 3.3, for Location 1 and 6, respectively. In the first part of this Chapter, the core results are compared to the RAW 2015 requirements. An analyses of all individual results from the sections in relation to their mixture specific documentation is given in Sections 3.11.2 and 3.11.3 and an overview for all locations can be found in Appendix II.

| Location 1 | Cores for TUD scans | | | Composition of cores | | | | Dimensies | | Reqs | CE target composition | comp after extraction | reference comp | margin CE/extr-refs | min | max | margin (n=3) | MIN | MAX |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Core nr, | 12 | 14 | | 11 | 13 | 15 | Av, (n=3) | | | | | | | | | | | | |
| Layer thickness | 51 | 54 | | 55 | 55 | 51 | | (mm) | | | | | | | | | | | |
| %voids* | 14,6 | 14,6 | | 14,1 | 12,6 | 16,5 | 14,4 | % (v/v) | (14,48, N=5) | 20 | 20 | | | | | | 4 | 16 | 24 |
| bulk density | 2124 | 2124 | | 2130 | 2172 | 2082 | 2128 | kg/m3 | (2126, n=5) | | 1990 | | | | | | 30 | 1960 | 2020 |
| %bitumen | | | | 5,5 | 5,3 | 5 | 5,3 | %(m/m) | of the total mass | 5,2 | 5,2 | | 5,1 | | | | +0,4 / -0,5 | 4,6 | 5,5 |
| ashes | | | | 0,8 | 0,7 | 0,9 | 0,8 | %(m/m) | | | | | | | | | | | |
| Through 63µ sieve | | | | 6,6 | 5,7 | 5,5 | 5,9 | %(m/m) | of total mass of aggregates | | 5 | | | | | | | | |
| Penetration | | | | 22 | 22 | 15 | 20 | (0,1 mm) | | 28 | | | | | | | | | |
| Ca(OH)2 | | | | 0,35 | 0,35 | 0,29 | 0,33 | %(m/m) | in fraction <63µ | | | | | | | | | | |
| ITSR | | | | | | | | | | 90 | 95 | | | | | | | | |
| GRADING | | | | | | | | | | | | | | | | | | | |
| Through | | | | | | | Av, (n=3) | | | | | | | | | | | | |
| 22,4 | | | | | | | 100 | | | 100 | 100 | | 100 | | | | | | |
| 16 | | | | | | | 99 | | | 93-100 | 98 | | 99 | 3 | 95 | 101 | | | |
| 11,2 | | | | | | | 77 | | | 70-85 | 72,5 | | 73 | 3,5 | 69 | 76 | | | |
| 8 | | | | | | | 53 | | | | 35 | | 36 | | | | | | |
| 5,6 | | | | | | | 28 | | | | 24 | | 25 | | | | | | |
| 2 | | | | | | | 17 | | | 13-25 | 15 | | 15 | 2,5 | 12,5 | 17,5 | 3,5 | 11,5 | 18,5 |
| 0,063 | | | | | | | 5,9 | | | 2,0-10 | 5 | | 6 | 0,575 | 4,425 | 5,575 | 1,3 | 4,7 | 7,3 |

Figure 3.2: Results from composition tests on field cores (left) versus requirements and declared values for location 1

| Location 6 | TUD scans | | | Composition of cores | | | gem(n=3) | | | Requirements | CE targetcomposition | | reference mix | | | | margin (n=3) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Core nr, | 62 | 64 | | 61 | 63 | 65 | 3 | | | | | | | | | | |
| Layer thickness | 58 | 55 | | 57 | 59 | 59 | | | | | | | | | | | |
| %voids | 16,6 | 14,6 | | 16,9 | 14,3 | 15,1 | 15,4 | | | 20 | 20 | | | | | | 4 |
| bulk density | 2062 | 2112 | | 2057 | 2115 | 2102 | 2091 | kg/m3 | (2090, n=5) | | 1978 | | | | | | 30 |
| %bitumen | | | | 5,1 | 5,4 | 5,2 | 5,2 | | | 5,2 | 5,2 | | | | | | +0,4 / -0,5 |
| ashes | | | | 0,6 | 0,6 | 0,9 | 0,7 | | | | | | | | | | |
| Through 63µ sieve | | | | 6 | 5,3 | 6,1 | 5,8 | | | 5,5 | 5,5 | | | | | | |
| Penetration | | | | 19 | 30 | 19 | 23 | | | | | | | | | | |
| Ca(OH)2 | | | | 1,34 | 1,13 | 0,84 | 1,1 | | | 25 | | | | | | | |
| ITSR | | | | | | | | | | 80 | 90 | | | | | | |
| GRADING | | | | | | | | | | | | | | | | | |
| | | | | | | | Av, (n=3) | | | | | | geen ref sam gegeven | | | | |
| Through 22,4 | | | | | | | 100 | | | 100 | 100 | | | | | | |
| 16 | | | | | | | 99 | | | 93-100 | 100 | | | | | | |
| 11,2 | | | | | | | 80 | | | | | | | | | | |
| 8 | | | | | | | 44 | | | | 40 | | | | | | |
| 5,6 | | | | | | | 22 | | | | | | | | | | |
| 2 | | | | | | | 15 | | | 13-25 | 14 | | | | | | 3,5 |
| 63 | | | | | | | 5,8 | | | 2,0-10 | 5,5 | | | | | | 1,3 |

Figure 3.3: Results from composition tests on field cores (left) versus requirements and declared values for location 6 (see footnote for meaning of **16)

The mixtures used in these two locations are DZOAB 16 mixtures, in Location 1 constructed in 2012 and in Location 6 in 2013. In both cases the void content (and, correspondingly, the bulk density) does not meet the requirements or fall within acceptable margins of the declared values. This is striking, since for Location 1 information on samples after construction is given and those do meet the requirements.

This seems to indicate that the material becomes denser after construction. Theoretically, this could be due to clogging, although the driving lanes are generally thought to be kept sufficiently clean by traffic. Also, if the changes are due to clogging, the clogged material appears to have a similar density as the PA itself. But it cannot be material that was eroded from the PA itself, since that would not lead to an increase in mass. These results need to be compared to the CT scans to arrive at any definite conclusions. Alternatively, the decrease in void content (and increase in density) could be due to under-compaction, causing traffic to further compact the mixture. If during construction the target density was aimed for, this could conceivably the case, since this is much lower than the actually achieved density. However, it seems unlikely that a PA mixture could be compacted under traffic to this extend, without causing ravelling or damage to the aggregates. It would also indicate a flaw in the procedure to determine target density, since a properly constructed and compacted PA mixture would not be expected compacted further under traffic to this extend.

More detailed analyses of the individual properties are given in the remainder of this Chapter.

## *3.4 Tests related to grading*

### 3.4.1 Overall requirements

The requirements for the grading of the three types of mixtures used in the test sections are given in Section 2.2.1. In Figure 3.4 and Table 3.8 the average grading curves of the test sections (based on three cores) are given Kiwa KOAC, 2017, along with the requirements per mixture group.

16 Declared bitumen content is after correction for aggregate density, before is 5,1%

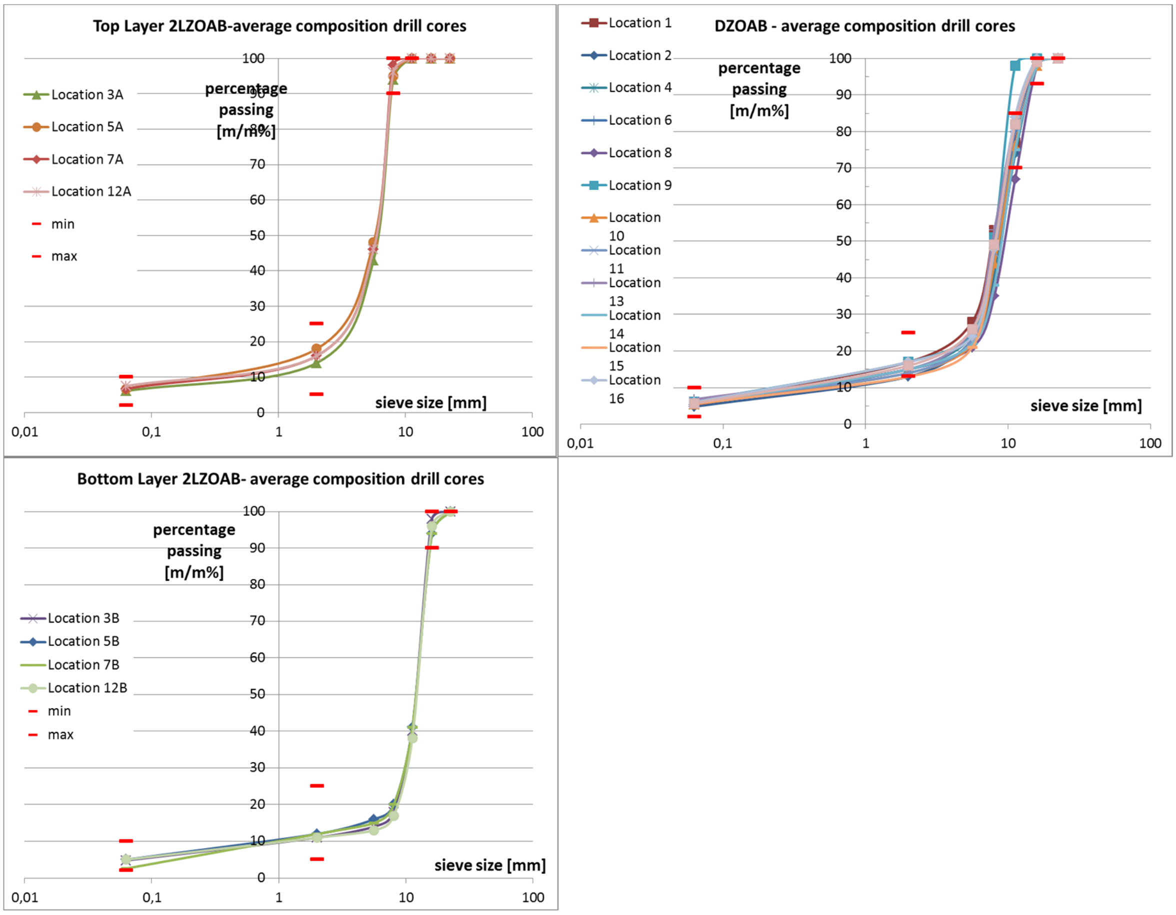



Figure 3.4: Average grading curves (n=3) for each of the test locations, split over the three kinds of mixes

It can be seen that the 2L-ZOAB mixtures follow the overall requirements, but that several of the DZOAB 16 mixtures do not meet the standard grading requirement, used to identify a mixture as a certain mixture kind.

The RAW Standard distinguishes mixture groups (in Dutch: mengselgroep, i.e. AC, SMA, ZOAB) and within each mixture group, mixture kinds (in Dutch asfaltsoort) which are identified by their maximum aggregate size (PA 11, PA 16). Within a mixture kind, there are types of mixtures (in Dutch type asfalt), which are the unique recipes or mixture formulations, based on grading and bitumen content. In this project, there are three mixture kinds (DZOAB 16 and the top and bottom layer of 2L-ZOAB, respectively) and each section represents one or two (in the case of 2L-ZOAB) mixture types.

In the graphs in Figure 3.3 the individual mixtures are grouped per mixture kind and the red bars indicate the grading limits associated with that mixture kind. The 2L-ZOAB mixtures fall within those boundaries, but the DZOAB 16 mixtures not always.

The mixture in Location 9 seems to be a ZOAB 11 rather than DZOAB 16 (with 98% too much material passes the 11,2mm sieve for a (D)ZOAB16, although the CE mixture information provided is for a DZOAB 16. Location 8 has too little material passing this sieve (11,2mm) and locations 2, 10, 11 and 15 fall below the minimum requirement for the 2mm sieve. So from the 13 (D)ZOAB mixtures 5 do not meet the basic grading criteria on one sieve. That seems a lot and as such, it would be worthwhile to check the average grading found per location to the reference grading provided for that specific mixture.

Table 3.8: Average grading (n=3) per location compared to the overall mixture kind requirements

| (n=3) | Location 1 | Location 2 | Location 3A | Location 3B | Location 4 | Loc 5A | Loc 5B | Loc 6 | Loc 7A | Loc 7B | | Requirements | | | | margin (n=3) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Through | (D)ZOAB | (D)ZOAB | 2L-ZOAB8 | 2L-ZOAB16 | (D)ZOAB | 2L-ZOAB8 | 2L-ZOAB16 | (D)ZOAB | 2L-ZOAB8 | 2L-ZOAB16 | | ZOAB16 | DZOAB16 | 2L-ZOAB16 | 2L-ZOAB8 | ZOAB |
| 22,4 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | | 100 | 100 | 100 | | |
| 16 | 99 | 99 | 100 | 98 | 99 | 100 | 94 | 99 | 100 | 94 | | 93-100 | 93-100 | 90-100 | | |
| 11,2 | 77 | 74 | 100 | 40 | 74 | 100 | 41 | 80 | 100 | 41 | | 70-85 | 70-85 | | 100 | |
| 8 | 53 | 40 | 94 | 18 | 42 | 95 | 20 | 44 | 98 | 20 | | | | | 90-100 | |
| 5,6 | 28 | 23 | 43 | 14 | 24 | 48 | 16 | 22 | 46 | 15 | | | | | | |
| 2 | 17 | 13 | 14 | 11 | 15 | 18 | 12 | 15 | 16 | 12 | | 15-25 | 13-25 | 5-25 | 5-25 | 3,5 |
| 0,063 | 5,9 | 4,8 | 6,1 | 4,8 | 5,3 | 6,6 | 5 | 5,8 | 6,7 | 2,6 | | 2,0-10 | 2,0-10 | 2,0-10,0 | 2,0-10,0 | 1,3 |
| | | | | | | | | | | | | | | | | |
| (n=3) | Location 8 | Location 9 | Location 10 | Location 11 | Loc 12A | Loc 12B | Loc 13 | Loc 14 | Loc 15 | Loc 16 | Loc 17 | Requirements | | | | margin (n=3) |
| Through | (D)ZOAB | (D)ZOAB | (D)ZOAB | (D)ZOAB | 2L-ZOAB8 | 2L-ZOAB1( | (D)ZOAB | (D)ZOAB | (D)ZOAB | (D)ZOAB | (D)ZOAB | ZOAB16 | DZOAB16 | 2L-ZOAB16 | 2L-ZOAB8 | ZOAB |
| 22,4 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | | |
| 16 | 98 | 100 | 98 | 99 | 100 | 96 | 99 | 98 | 99 | 100 | 99 | 93-100 | 93-100 | 90-100 | | |
| 11,2 | 67 | 98 | 76 | 81 | 100 | 38 | 83 | 75 | 83 | 84 | 82 | 70-85 | 70-85 | | 100 | |
| 8 | 35 | 51 | 44 | 47 | 96 | 17 | 53 | 38 | 48 | 48 | 49 | | | | 90-100 | |
| 5,6 | 21 | 25 | 22 | 23 | 46 | 13 | 26 | 22 | 21 | 24 | 26 | | | | | |
| 2 | 15 | 17 | 14 | 14 | 16 | 11 | 15 | 15 | 13 | 17 | 16 | 15-25 | 13-25 | 5-25 | 5-25 | 3,5 |
| 63 | 5,3 | 6,2 | 5,4 | 6,2 | 7,5 | 5 | 6,8 | 5,7 | 5,6 | 6 | 5,7 | 2,0-10 | 2,0-10 | 2,0-10,0 | 2,0-10,0 | 1,3 |

Green: meets the requirement for this sieve for this mixture type

Black: no requirement for this sieve for this mixture type

Orange: top boundary which overlaps with the previous sieve size/is equal to upper boundary of requirement, there is discussion if the requirement is including or excluding the values themselves17

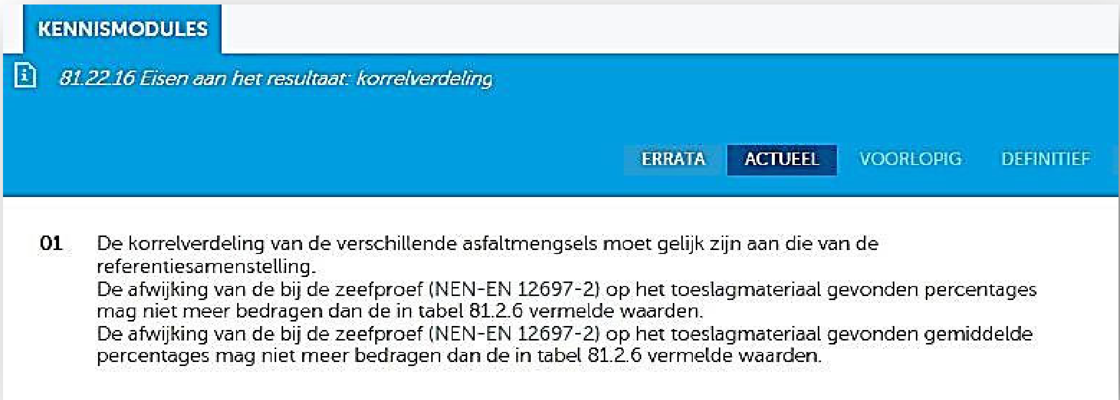
Red: does not meet the requirement for this sieve for this mixture type (so below the minimum or above the maximum specified)

17 The requirements can be read 90-100 meaning in- or excluding 90 and 100 themselves. There is no clear definition for the determination of D, only the 13108-8 (reclaimed asphalt, gives one: **D**: upper sieve size of the aggregate in millimetres D is the larger of: sieve M/1,4, where M is the smallest sieve with 100 % passing; and the smallest sieve with 85 % passing for both L9 and L16 M=16mm and M/1,4≈11,2, the smallest sieve with 85% passing is 11,2 for L9 and 16 (just) for L16. L9 would be a PA11, L16 PA16.

In summary, in two out of 17 (>10%) of the cases one of the general overall sieve requirements for the mixture type is not met. Considering that this is not a comparison to the mixture specific grading compared, but to the overall boundaries of the mixture types, this can be considered a considerable deviation.

### 3.4.2 Mixture specific requirements

A direct check on the criteria for acceptance after construction requires a comparison of the grading found from the sections to the reference gradation provided for each specific mixture type (Figure 3.5 and Figure 3.6). This check, which should be a regular quality control check by the producer, contractor and, every now and then, client, has so far been done for two or three mixtures, as an illustration.


KENNISMODULES

*81.22.16 Eisen aan het resultaat: korrelverdeling*

ERRATA ACTUEEL VOORLOPIG DEFINITIEF

01 De korrelverdeling van de verschillende asfaltmengsels moet gelijk zijn aan die van de referentiesamenstelling.
De afwijking van de bij de zeefproef (NEN-EN 12697-2) op het toeslagmateriaal gevonden percentages mag niet meer bedragen dan de in tabel 81.2.6 vermelde waarden.
De afwijking van de bij de zeefproef (NEN-EN 12697-2) op het toeslagmateriaal gevonden gemiddelde percentages mag niet meer bedragen dan de in tabel 81.2.6 vermelde waarden.

Figure 3.5: Article from the RAW Standard, defining the maximum difference between samples taken from the road and the reference composition

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*81.2.6 Afwijking van de korrelverdeling (% m/m)*

ERRATA ACTUEEL VOORLOPIG DEFINITIEF HANDLEIDI

| door zeef | een monster | gemiddelde van n monsters per uitvoeringseenheid | | | | | |
|---|---|---|---|---|---|---|---|
| | | n = 2 | n = 3 | n = 4 of 5 | n = 6 t/m 8 | n = 9 t/m 19 | n = ≥ 20 |
| | | onthouding van goedkeuring als de afwijking groter is dan | | | | | |
| asfaltbeton (AC) voor onderlagen met D ≥ 16 mm | | | | | | | |
| D | 4 | - | - | - | - | - | - |
| D/2 of CCS | 9 | - | - | - | - | - | - |
| 2 mm | 7 | 5,5 | 5,0 | 4,5 | 4,0 | 3,8 | 3,5 |
| 0,063 mm | 2,3 | 1,40 | 1,30 | 1,20 | 1,10 | 0,90 | 0,75 |
| asfaltbeton (AC) voor onderlagen met D < 16 mm, tussenlagen en deklagen | | | | | | | |
| D | 3 | - | - | - | - | - | - |
| D/2 of CCS | 8 | - | - | - | - | - | - |
| 2 mm | 6 | 4,5 | 4,0 | 3,8 | 3,5 | 3,3 | 3,0 |
| 0,063 mm | 2,3 | 1,40 | 1,30 | 1,20 | 1,10 | 0,90 | 0,75 |
| zeer open asfaltbeton (PA) | | | | | | | |
| D | 6 | - | - | - | - | - | - |
| D/2 of CCS | 7 | - | - | - | - | - | - |
| 2 mm | 5 | 3,8 | 3,5 | 3,3 | 3,0 | 2,8 | 2,5 |
| 0,063 mm | 2,3 | 1,40 | 1,30 | 1,20 | 1,10 | 0,90 | 0,75 |
| steenmastiekasfalt (SMA) | | | | | | | |
| D | 4 | - | - | - | - | - | - |
| D/2 of CCS | - | - | - | - | - | - | - |
| 2 mm | 5 | 3,8 | 3,5 | 3,3 | 3,0 | 2,8 | 2,5 |
| 0,063 mm | 2,3 | 1,40 | 1,30 | 1,20 | 1,10 | 0,90 | 0,75 |
| gietasfalt (GA) | | | | | | | |
| 8 mm | 2 | - | - | - | - | - | - |
| 4 mm | 8 | - | - | - | - | - | - |
| 2 mm | 6 | 4,5 | 4,0 | 3,8 | 3,5 | 3,3 | 3,0 |
| 0,063 mm | 2,8 | 1,75 | 1,60 | 1,45 | 1,30 | 1,15 | 1,00 |

CCS: karakteristieke grove zeef.

Figure 3.6: The maximum variation for the grading for each single (n=1) and the average for multiple (in this case n=3) cores compared to the reference composition for the various mixture groups in the RAW Standard

As can be seen, for the coarser sieves, there are requirements for a single sample, but not if more samples are considered. This seems odd, in one core having one more coarse aggregate can actually affect the percentages of grading, but this affect diminishes with multiple specimens. If you have more cores, the differences should average out and you should get closer to the intended overall grading. The effect of crushing in production and construction will be found through a higher content on the fine sieves, but other problems such as dosing the wrong amounts, wrong materials or segregation during transport are not covered this way. It is not quite clear why there are no requirements set for the coarse sieves, but this was already the case before the introduction of the EN standards (CROW, Standaard 2005 (2005)).

The intention was to use the same Locations as used in Section 3.2 (location 1 and 6), but for location 6 no reference composition was provided, only the reclaimed composition from the TT. The reference composition can differ somewhat from the target composition due to production and construction effects. For that reason, it is the reference composition that is used in quality control.
This missing reference composition can be a case of lacking information, it may also have to do with the changes in requirements over time. Initially, a reference composition was declared on the basis of the target composition from the CE information CROW, Standaard 2008, 2008, but this could lead to

difficulties, since the target composition is provided by the plant, cannot not account for construction effects. For this reason, later on the extraction of a core made with the target composition was required by the plant. A contractor specifies the reference composition based on this reclaimed composition and his experience with his laying and compaction strategy CROW, Standaard 2010, 2010,CROW, Standaard 2015, 2015. So, since 2008 a target composition and reference composition are required. Materials type tested after the publication of the 2010 standard, should also come with a composition after extraction. There are requirements for the deviation between the reference composition and either the target (up to 2010) or the reclaimed composition (since 2010). A Type Test is valid for five years, however the reference composition is linked to pavement construction and defined in the RAW Standard. As such, it is the RAW Standard valid for the project that determines which method has to be used. In any case, a reference composition is needed and since this was missing for Location 6 it was for the detailed check replaced by location 9. This location was not selected randomly, it is the one which seems, based on the composition of the cores, to fall into another kind of mixture (ZOAB 11 instead of ZOAB 16).

The resulting detailed comparison of the target grading (design), reference grading (quality control) and average grading of the field cores is shown in Figure 3.7

| | | | | | ref comp vs after extr/CE | | | av field cores vs reference | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| sieves | RAW reqs | CE target composition | after extraction (c.a.e) extraction | reference comp | margin | min | max | field cores | margin (n=3) | MIN | MAX |
| location 1 | | | | | | | | | | | |
| 22,4 | 100 | 100 | | 100 | | | | 100 | | | |
| 16 | 93-100 | 98 | | 99 | 3 | 95 | 101 | 99 | | | |
| 11,2 | 70-85 | 72,5 | | 73 | 3,5 | 69 | 76 | 77 | | | |
| 8 | | 35 | | 36 | | | | 53 | | | |
| 5,6 | | 24 | | 25 | | | | 28 | | | |
| 2 | 13-25 | 15 | | 15 | 2,5 | 12,5 | 17,5 | 17 | 3,5 | 11,5 | 18,5 |
| 0,063 | 2,0-10 | 5,0 | | 6,0 | 0,58 | 4,43 | 5,58 | 5,8 | 1,3 | 4,7 | 7,3 |
| location 6 | | | | | | | | | | | |
| 22,4 | 100 | 100 | 100 | | | | | 100 | | | |
| 16 | 93-100 | 100 | 99,7 | | 3 | 97 | 103 | 99 | | | |
| 11,2 | 70-85 | | | | 3,5 | -3,5 | 3,5 | 80 | | | |
| 8 | | 40 | 41,8 | | | | | 44 | | | |
| 5,6 | | - | - | | | | | 22 | | | |
| 2 | 13-25 | 14 | 15,3 | | 2,5 | 11,5 | 16,5 | 15 | 3,5 | 11,8 | 18,8 |
| 0,063 | 2,0-10 | 5,5 | 6,1 | | 0,58 | 4,93 | 6,08 | 5,8 | 1,3 | 4,8 | 7,4 |
| 1 st DZOAB16 mixture Location 9 | | | | | | | | | | | |
| 22,4 | 100 | 100 | | 100,0 | | | | 100 | | | |
| 16 | 93-100 | 97 | | **97,0** | 3 | 94 | 100 | 100 | | | |
| 11,2 | 70-85 | | | | 3,5 | -3,5 | 3,5 | 98 | | | |
| 8 | | 42,5 | | 44,1 | | | | 51 | | | |
| 5,6 | | | | | | | | 25 | | | |
| 2 | 13-25 | 14 | | **14,7** | 2,5 | 11,5 | 16,5 | 17 | 3,5 | 11,2 | 18,2 |
| 0,063 | 2,0-10 | 5,5 | | **6,6** | 0,58 | 4,93 | 6,08 | 6,2 | 1,3 | 5,3 | 7,9 |
| 2nd DZOAB16 mixture Location 9 | | | | | | | | | | | |
| 22,4 | 100 | 100 | | 100,0 | | | | 100 | | | |
| 16 | 93-100 | 95 | | **95,5** | 3 | 92 | 98 | 100 | | | |
| 11,2 | 70-85 | | | | 3,5 | -3,5 | 3,5 | 98 | | | |
| 8 | | 45,2 | | 49,3 | | | | 51 | | | |
| 5,6 | | | | | | | | 25 | | | |
| 2 | 13-25 | 14,9 | | **15,9** | 2,5 | 12,4 | 17,4 | 17 | 3,5 | 12,4 | 19,4 |
| 0,063 | 2,0-10 | 5,5 | | **6,1** | 0,58 | 4,93 | 6,08 | 6,2 | 1,3 | 4,8 | 7,4 |

. The comparison between the target and reference grading is formally not a direct one, the grading of the mixture used in the Type Test (based on the target grading) is used to specify the reference composition. The requirements are set for the difference between that composition after extraction (c.a.e.) and the reference grading (Figure 3.7). However, since neither of these mixtures came with both a c.a.e. and a reference composition, the available composition is used.

| | | | | | ref comp vs after extr/CE | | | av field cores vs reference | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| sieves | RAW reqs | CE target composition | after extraction (c.a.e) extraction | reference comp | margin | min | max | field cores | margin (n=3) | MIN | MAX |
| **location 1** | | | | | | | | | | | |
| 22,4 | 100 | 100 | | 100 | | | | 100 | | | |
| 16 | 93-100 | 98 | | 99 | 3 | 95 | 101 | 99 | | | |
| 11,2 | 70-85 | 72,5 | | 73 | 3,5 | 69 | 76 | 77 | | | |
| 8 | | 35 | | 36 | | | | 53 | | | |
| 5,6 | | 24 | | 25 | | | | 28 | | | |
| 2 | 13-25 | 15 | | 15 | 2,5 | 12,5 | 17,5 | 17 | 3,5 | 11,5 | 18,5 |
| 0,063 | 2,0-10 | 5,0 | | 6,0 | 0,58 | 4,43 | 5,58 | 5,8 | 1,3 | 4,7 | 7,3 |
| **location 6** | | | | | | | | | | | |
| 22,4 | 100 | 100 | 100 | | | | | 100 | | | |
| 16 | 93-100 | 100 | 99,7 | | 3 | 97 | 103 | 99 | | | |
| 11,2 | 70-85 | | | | 3,5 | -3,5 | 3,5 | 80 | | | |
| 8 | | 40 | 41,8 | | | | | 44 | | | |
| 5,6 | | - | - | | | | | 22 | | | |
| 2 | 13-25 | 14 | 15,3 | | 2,5 | 11,5 | 16,5 | 15 | 3,5 | 11,8 | 18,8 |
| 0,063 | 2,0-10 | 5,5 | 6,1 | | 0,58 | 4,93 | 6,08 | 5,8 | 1,3 | 4,8 | 7,4 |
| **1 st DZOAB16 mixture Location 9** | | | | | | | | | | | |
| 22,4 | 100 | 100 | | 100,0 | | | | 100 | | | |
| 16 | 93-100 | 97 | | **97,0** | 3 | 94 | 100 | 100 | | | |
| 11,2 | 70-85 | | | | 3,5 | -3,5 | 3,5 | 98 | | | |
| 8 | | 42,5 | | 44,1 | | | | 51 | | | |
| 5,6 | | | | | | | | 25 | | | |
| 2 | 13-25 | 14 | | **14,7** | 2,5 | 11,5 | 16,5 | 17 | 3,5 | 11,2 | 18,2 |
| 0,063 | 2,0-10 | 5,5 | | **6,6** | 0,58 | 4,93 | 6,08 | 6,2 | 1,3 | 5,3 | 7,9 |
| **2nd DZOAB16 mixture Location 9** | | | | | | | | | | | |
| 22,4 | 100 | 100 | | 100,0 | | | | 100 | | | |
| 16 | 93-100 | 95 | | **95,5** | 3 | 92 | 98 | 100 | | | |
| 11,2 | 70-85 | | | | 3,5 | -3,5 | 3,5 | 98 | | | |
| 8 | | 45,2 | | 49,3 | | | | 51 | | | |
| 5,6 | | | | | | | | 25 | | | |
| 2 | 13-25 | 14,9 | | **15,9** | 2,5 | 12,4 | 17,4 | 17 | 3,5 | 12,4 | 19,4 |
| 0,063 | 2,0-10 | 5,5 | | **6,1** | 0,58 | 4,93 | 6,08 | 6,2 | 1,3 | 4,8 | 7,4 |

Figure 3.7: Detailed grading comparison for location 1,6 and 9 (documentation for Location 9 contains 2 DZOAB 16 mixtures)

The coloured numbers in the table indicate fractions on which requirements are set. There are five checks between the target composition and the overall mixture group requirements (1,4D, D, CCS (=11,2mm), 2mm and 0,063mm), four checks for the variation between reference composition and the composition after extraction (which is missing, so the target composition is used instead), namely D, CCS, 2mm and 0,063mm. And finally two checks (only for the fine sieves) for the variation between the average of the field cores and the reference composition (if that is missing, the c.a.e. is used). In total that gives eleven checks per mixture, a total of 44 in this table. Of these checks, ten are either not met or the required information is not provided. So 10/44, or 23%, of the checks turn out not to meet the requirements or have not been provided. This is despite the fact that a missing c.a.e. or reference composition is not counted as a deviation.

For location 1, where the initial overall check did not reveal any deviations from the overall grading requirements for a DZOAB 16, now a potential issue is seen between the reference and target grading for the filler. For location 9 based on the field cores, the amount of material passing the 11,2mm sieve seems too much. Interestingly, there are no maximum margins provided on the average value on the coarse sieves, only on the results from the individual cores. However, the 11,2mm sieve is not included in the information provided for the target and reference composition mixtures in location 9, instead information on the 8mm (D/2) sieve is given. This is incorrect, since the requirements for a (D)ZOAB 16 include a requirement on 11,2mm sieve (Figure 2.26). Since this is required, this missing information is considered a deviation.

A possible source for this error can be found in the specifications for the maximum deviation from the reference composition Figure 2.28, which refers to the D/2 or CCS (characteristic coarse sieve), leaving the choice which to check open. The EN 13108-7 prescribes the overall grading requirements for a PA using four sieves (1,4*D*, *D*, 2 and 0,063 mm, Figure 2.27), but allows additional sieves for the grading requirements (two between *D* and 2mm and one between 2 and 0,063mm, section 5.2.2. of EN 13108-7:2006). In the specifications of ZOAB 16 one extra coarse sieve was defined, the 11,2mm sieve. It would have been possible to define also D/2 (8mm) or the 5,6mm sieve as an additional coarse sieve, bringing the description closer to that used before the introduction of the CEN standards. In the RAW Standard 2005 ZOAB 16 had requirements for the grading on the 16; 11,2; 8; 5,6; 2 and 0,063mm sieves. However, only one additional coarse sieve was specified, the 11,2mm sieve for the specific PA 16 mixture designated ZOAB 16. So in order to use that label, as was the case on the documents for Location 9, the material also has to fulfil these requirements. Which means first of all, providing information on the 11,2mm sieve and second of all, ensuring that the mixture design fulfils the requirements on this (and the other) sieves. Neither was fulfilled.

Another striking bit of information is that the target (and reference) composition for the Location 9 mixtures are limited to those sieves on which requirements are set (where sieve 8mm ought to have been sieve 11,2mm), the 31,5mm sieve does not add any information for a D=16mm mixture, so the only sieve added is 0,5mm. This is seen more often, when contractors think they should only specify the sieves for which there are requirements. However, mixture design involves all relevant fractions and if more fractions are used to make the mixture, that information is part of the target (and reference) composition. The requirements may be set on a limited number of sieves, production and quality control are related to the full mixture design and should include all sieves actually used.

| Mengsel | Doelsamenstelling | referentie |
|---|---|---|
| Zeefmaat | Zeefdoorval (%) | |
| C31,5 | 100,0 | 100,0 |
| C22,4 | 100,0 | 100,0 |
| C16 | 97,0 | 97,0 |
| C11,2 | | |
| C8 | 42,5 | 44,1 |
| C5,6 | | |
| C4 | | |
| 2 mm. | 14,0 | 14,7 |
| 0,5 mm. | 8,8 | 10,8 |
| 0,180 mm. | | |
| 0,063 mm. | 5,5 | 6,6 |
| | | |
| Bindmiddelgehalte | 5,1 | 5,1 |

| Mengsel | Doelsamenstelling | referentie |
|---|---|---|
| Zeefmaat | Zeefdoorval (%) | |
| C31,5 | 100,0 | 100,0 |
| C22,4 | 100,0 | 100,0 |
| C16 | 95,0 | 95,5 |
| C11,2 | | |
| C8 | 45,2 | 49,3 |
| C5,6 | | |
| C4 | | |
| 2 mm. | 14,9 | 15,9 |
| 0,5 mm. | 10,2 | 11,1 |
| 0,180 mm. | | |
| 0,063 mm. | 5,5 | 6,1 |
| | | |
| Bindmiddelgehalte | 5,1 | 5,1 |

Figure 3.8: Target and reference composition for the two Location 9 mixtures

From the two locations selected for an indepth check, both show deviations from the requirements. It must be kept in mind that location 9 was selected because it showed a deviant grading based on the analyses in the previous paragraph. However, the results seem ample indication that checking the provided information, not just on being present but on the actual content and agreement with the requirements, is necessary.

Also, considering the fact that a ZOAB 16 is delivered without providing the required grading information, a mixture more over that does not appear to meet the requirements, suggests that somekind of interaction between clients, contractors and regulatory bodies sharing the errors made and generally improving the knowledge about and quality of the delivered information would be worthwhile.

Finally, for Location 9 two DZOAB 16 (intended) mixtures where available. It would make sense to request and store information on which mixture is used where in the actual project, both in the planning phase, but definitely after construction.

## 3.5 Tests related to void content

In Figure 3.9 the void content as determined according to EN 12697-8 is given for all 17 locations on 3 samples. The colours are related to the types of mixtures (blue=(D)ZOAB 16, green=2L-ZOAB 8 and red=2L-ZOAB 16). The minimum design void content for (D)ZOAB 16 and 2L-ZOAB 8 is the same (20%), indicated by the continuous green line in the top graph. For 2L-ZOAB 16 the minimum design void content is 25%, indicated by the solid green line in bottom graph. Additionally, the margins for the average void content over three cores (+/-4,00% relative to the design void content) and for individual cores +/-5,0%, are also shown in the graphs. For individual cores, apart from the tolerance of +/-5%, there is also a limit for acceptance: +/- 7,4%, this is not plotted in the graphs.

Besides the basic requirements from the RAW Standard, RWS sets requirements on the void content of DZOAB 16 to ensure the required noise reduction. These are a lower limit of 18% for the average of the cores and a lower limit of 15% for individual values. These are shown as light blue lines in the top graph. These additional requirements apply to the DZOAB mixtures only, for 2L-ZOAB the requirement after construction is set on the drainage capacity (specified as less than 20 s per test, less than 17 s on average, Table A.5-1 row number 2 from van Dommelen, 2017, measure according to Section 3.5 of Blanken, 2017).
As can be seen, there are a few 2L-ZOAB 8 and even less (D)ZOAB 16 cores that exceed the 20% required and none of the 2L-ZOAB 16 cores exceed the 25%. This is to be expected, since the risk of early failure in raveling increases with increasing void content. However, the values do seem to be quite low, which can lead to less drainage and noise reduction, but a longer life

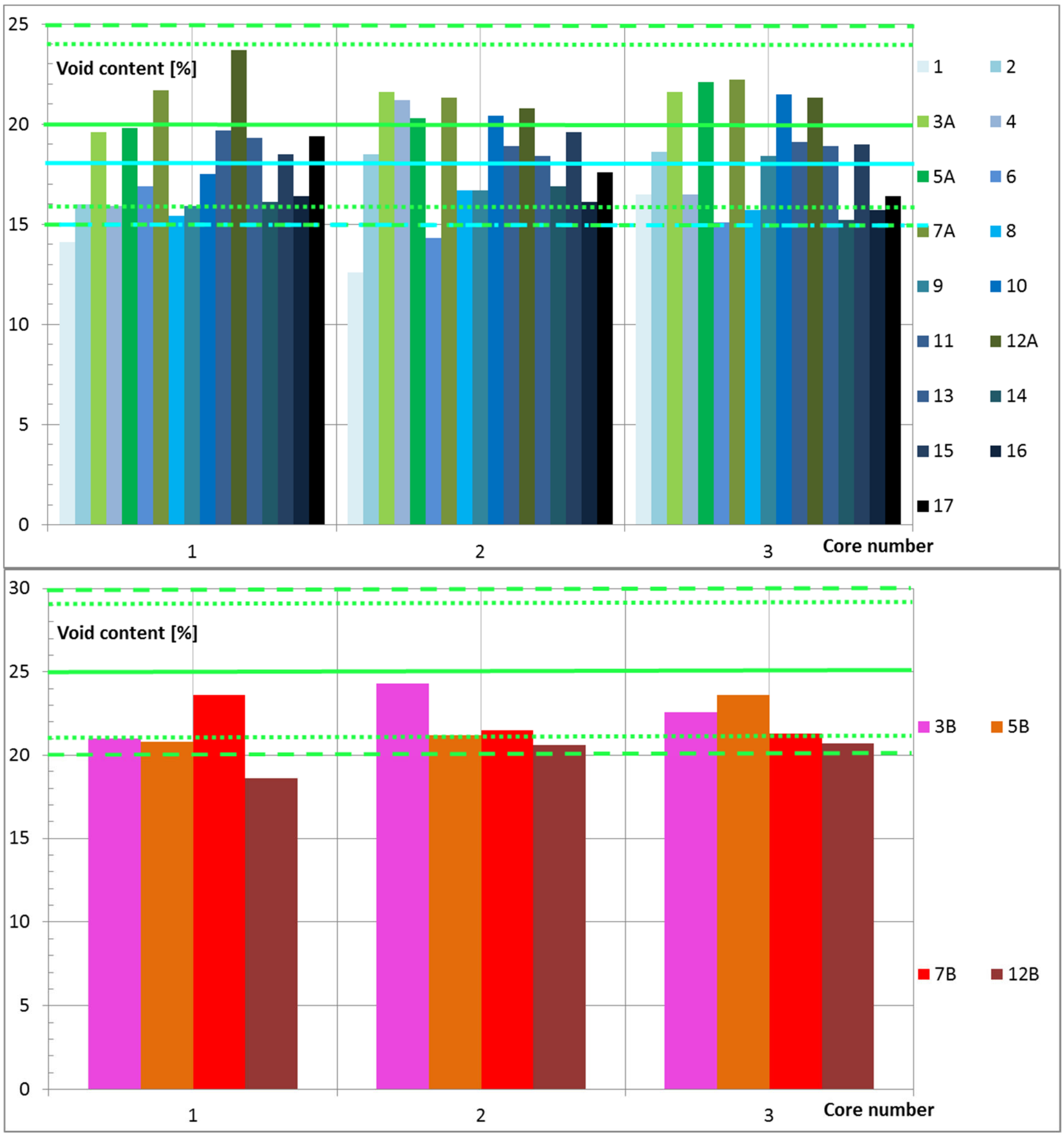



Figure 3.9: Void content from field cores for all 17 locations (D)ZOAB 16 (=blueish) and 2L-ZOAB 8 (greenish) in the top graph and 2L-ZOAB 16 in the bottom graph, *continuous green lines give required minimum void content (20% for top graph, 25% for bottom graph), dotted green lines show the maximum deviation in the average of three cores (+/-4%), striped green lines the maximum deviation for a single core (+/-5%). The blue lines give the minimum requirement RWS sets for the average (continuous) and individual (dotted) void content of cores.*

As can be seen the Locations 1 and 6 that were used in Section 3.2, are within the lower scoring Locations18, the majority of the Locations seems to fall within the maximum variation, but at the lower end. For the added location (9), this is less extreme, but also at this location all cores have a void content lower than the general requirement for this mixture group (20%).

This can also be seen from Figure 3.10, which shows the average void content found from the three cores per section, plotted versus the age of the section. In the left hand graph the results for DZOAB 16 and the top layer (2L-ZOAB 8) of 2L-ZOAB are given, both have a minimum design void content of 20%. The right hand graph shows the bottom layer (2L-ZOAB 16) of 2L-ZOAB, with a minimum design void content of 25%. For three to four cores, the deviation in void content for all types of ZOAB mixtures must be less than 4%. That lower limit for approval is also shown in the graphs.

18 Accidentally, the two locations were selected before the overall analysis of void content was done

From this, and the underlying data (Table 3.9) it can be seen that indeed locations 1 and 6 do not meet the minimum requirement based on the average of three cores. Additionally, sections 8 and 12B also do not meet the requirement, while Locations 16 and 14 only just make it. Location 9 meets the overall requirement, its average value is higher than the minimum boundary of 16%, but lower than the design value of 20%. Of all DZOAB 16 mixtures, none have an average result that is higher than this minimum design void content of 20%. The locations in the left hand side of Figure 3.10 that are above 20% are all 2L-ZOAB 8 mixtures.

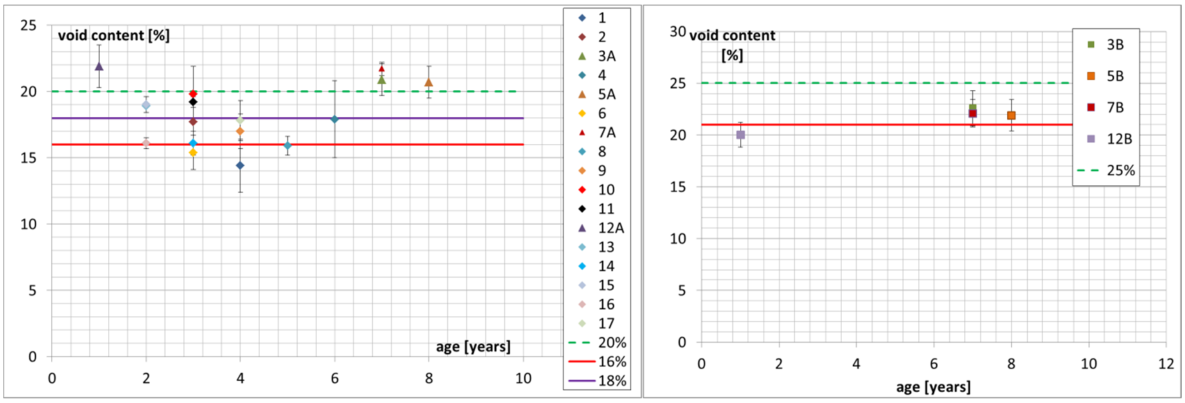


Figure 3.10: Average void content versus the age of the sections (at the time of sampling in 2016), left DZOAB 16 and 2L-ZOAB 8, right 2L-ZOAB 16

From Figure 3.10 it seems that the low void contents do not have a relation with the age of the specimens. However, it must be noted that the oldest three samples as well as the youngest are all top layers of 2LZOAB. But samples in between also do not seem to show an age related trend. This is in line with the expectations, since there are no known indications that PA mixtures are further compacted by traffic. Studies into rutting of pavements with a top layer of PA usually find that the cause of the deformation is in the underlying layers or the subgrade (Voskuilen et al., 2001,Voskuilen et al., 2002). Still, since there are no known studies determining the void content of DZOAB 16 and 2L-ZOAB mixtures, or standard ZOAB 16 for that matter, several years after construction, it cannot be fully excluded that some reduction of the void content could take place.

This could for example be caused by:

- abrasion during production and construction, leading to the creation of additional fine material,
- clogging by material worn from the pavement surface or tyres,
- or some form of densification due to traffic. In DZOAB this could be an unknown side effect of the higher bitumen content.

Another way of looking at these results is showing their distribution, this is done in Figure 3.11. Based on the average value and standard deviation in void content per mixture group (DZOAB 16, 2L-ZOAB 8 or 2L-ZOAB 16), the void distribution is plotted (dark red lines). Void content is plotted on the horizontal axis, from 10 to 30%. The underlying void contents are given by the columns (vertical blue lines), indicating how often each void content occurs (right hand axis).

Additionally, the group requirement and minimum and maximum boundary are shown by green (dotted) vertical lines. Assuming that 95% of the void contents in the field will fall within the boundary conditions, the standard deviation is half of the allowed margin per individual sample. Using that assumption, also the expected distribution of the void content is shown, as a dotted smooth green line.

These normal distribution (red and green curves) have their maximum at the average value, for the red curve the average found from the cores, for the green the required void content. The width of the curves is determined by the variation. In all three cases the width of the green curve is larger than that of the red. This indicates that the variation found in the cores used for this project (13 or 4 separate projects for DZOAB 16 and 2L-ZOAB) is less than that allowed for a single core in one project (based on the individual values). This seems to indicate that the current margins are rather wide.

As can be seen from figure 3.10, both DZOAB 16 mixtures have an actual distribution (red line) that is shifted to the left compared to the expected (dotted green line curve). The 2L-ZOAB 8 actual distribution is shifted somewhat to the right, but falls almost completely within the expected distribution curve. This indicates that the void content for the D=16 mixtures is on the low side, while for the 2L-ZOAB8 it is more or less as expected.

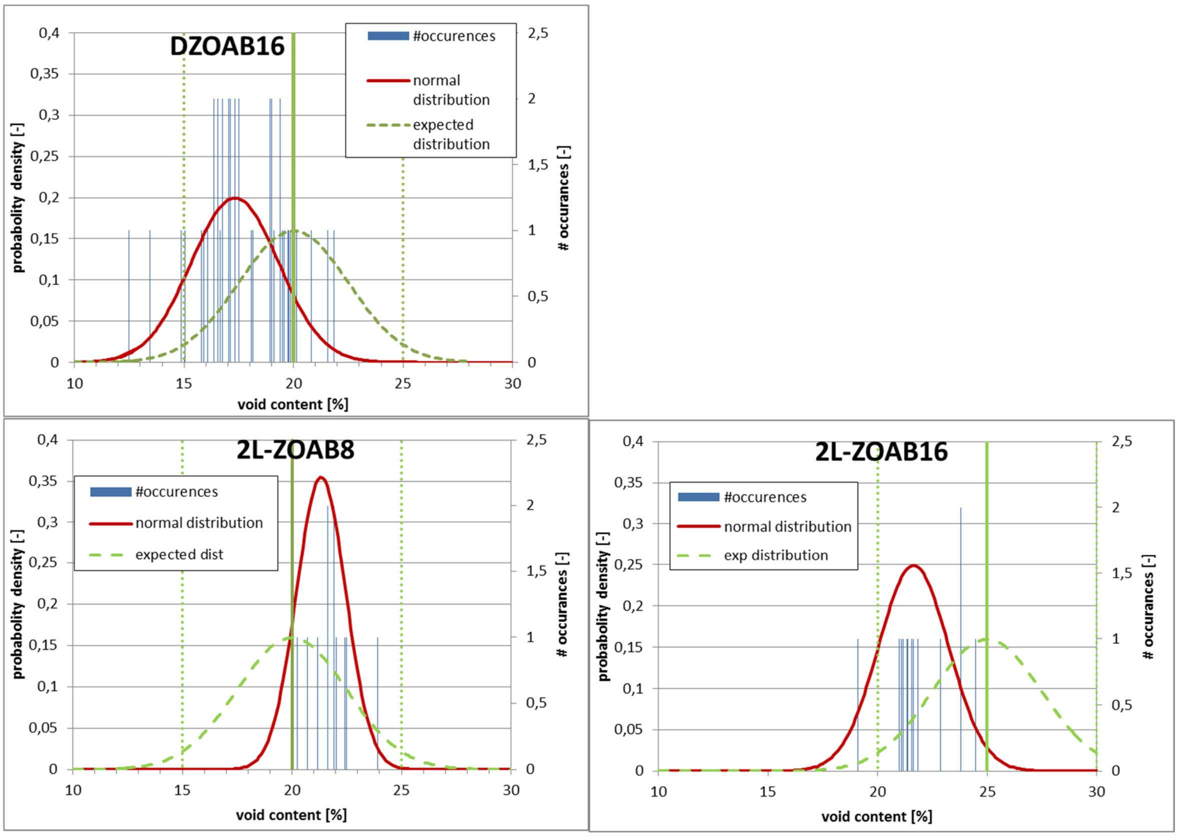



Figure 3.11: Distribution (lines, left axis) and occurrence (columns, right axis) of void content for the three types of mixtures

The underlying data from these figures are given in Table 3.9, where again the void contents per core (given as sample 1 to 3) and the average of these three values are compared to the overall mixture group requirement (20 or 25%, respectively). Individual cores that deviate more than the maximum of 5% are plotted in red, averages that deviate by more than +/-4% are highlighted in red.

From the overall results it seems that generally, the void contents for the 2L-ZOAB 8 mixtures are quite close to the required void content. For the DZOAB 16 mixtures, they are on the low side. For raveling resistance a lower void content is probably beneficial. The effect on the noise reduction remains to be seen.

Also, the variation in the data set is small compared to the allowable margins.

Table 3.9: Void content for three cores per location, individual values and the average of three compared to the requirement & variation allowed for the mix group (DZOAB 16, 2L-ZOAB8 and 2L-ZOAB 16)

| location ID | mixture type | sample 1 | sample 2 | sample 3 | average | stdev | requirement | year | age |
|---|---|---|---|---|---|---|---|---|---|
| 1 | (D)ZOAB | 14,1 | 12,6 | 16,5 | **14,4** | 2 | 20% | 2012 | 4 |
| 2 | (D)ZOAB | 16 | 18,5 | 18,6 | **17,7** | 1,5 | 20% | 2013 | 3 |
| 3A | 2L_ZOAB8 | 19,6 | 21,6 | 21,6 | **20,9** | 1,2 | 20% | 2009 | 7 |
| 3B | 2L-ZOAB16 | 21 | 24,3 | 22,6 | **22,6** | 1,7 | 25% | | 7 |
| 4 | (D)ZOAB | 15,9 | 21,2 | 16,5 | **17,9** | 2,9 | 20% | 2010 | 6 |
| 5A | 2L_ZOAB8 | 19,8 | 20,3 | 22,1 | **20,7** | 1,2 | 20% | 2008 | 8 |
| 5B | 2L-ZOAB16 | 20,8 | 21,2 | 23,6 | **21,9** | 1,5 | 25% | | 8 |
| 6 | (D)ZOAB | 16,9 | 14,3 | 15,1 | **15,4** | 1,3 | 20% | 2013 | 3 |
| 7A | 2L_ZOAB8 | 21,7 | 21,3 | 22,2 | **21,7** | 0,5 | 20% | 2009 | 7 |
| 7B | 2L-ZOAB16 | 23,6 | 21,5 | 21,3 | **22,1** | 1,3 | 25% | | 7 |
| 8 | (D)ZOAB | 15,4 | 16,7 | 15,7 | **15,9** | 0,7 | 20% | 2011 | 5 |
| 9 | (D)ZOAB | 15,9 | 16,7 | 18,4 | **17** | 1,3 | 20% | 2012 | 4 |
| 10 | (D)ZOAB | 17,5 | 20,4 | 21,5 | **19,8** | 2,1 | 20% | 2013 | 3 |
| 11 | (D)ZOAB | 19,7 | 18,9 | 19,1 | **19,2** | 0,4 | 20% | 2013 | 3 |
| 12A | 2L_ZOAB8 | 23,7 | 20,8 | 21,3 | **21,9** | 1,6 | 20% | 2015 | 1 |
| 12B | 2L-ZOAB16 | 18,6 | 20,6 | 20,7 | **20** | 1,2 | 25% | | 1 |
| 13 | (D)ZOAB | 19,3 | 18,4 | 18,9 | **18,9** | 0,5 | 20% | 2014 | 2 |
| 14 | (D)ZOAB | 16,1 | 16,9 | 15,2 | **16,1** | 0,9 | 20% | 2013 | 3 |
| 15 | (D)ZOAB | 18,5 | 19,6 | 19 | **19** | 0,6 | 20% | 2014 | 2 |
| 16 | (D)ZOAB | 16,4 | 16,1 | 15,7 | **16,1** | 0,4 | 20% | 2014 | 2 |
| 17 | (D)ZOAB | 19,4 | 17,6 | 16,4 | **17,8** | 1,5 | 20% | 2012 | 4 |

### 3.5.1 Detailed analysis selected sections

For the three locations studied in more detail (L1, L6 and L9), for only one a value for the void content that differs from the general requirement (20%) is given. The location for which a different value is declared on the CE information (L6, 21,7% (or 23,7% for the second mixture[19]) fulfils the requirements when looking only at the general requirement (20%). However, the deviations allowed are linked to the value found in the TT (art 81.22.14 part 05, CROW, Standaard 2015, 2015). If this is applied, two out of the three cores and the average of the three do no longer fulfil the requirements (Table 3.10). This shows that it is important to have and use the detailed information for a given mixture, not just the overall group information.

19

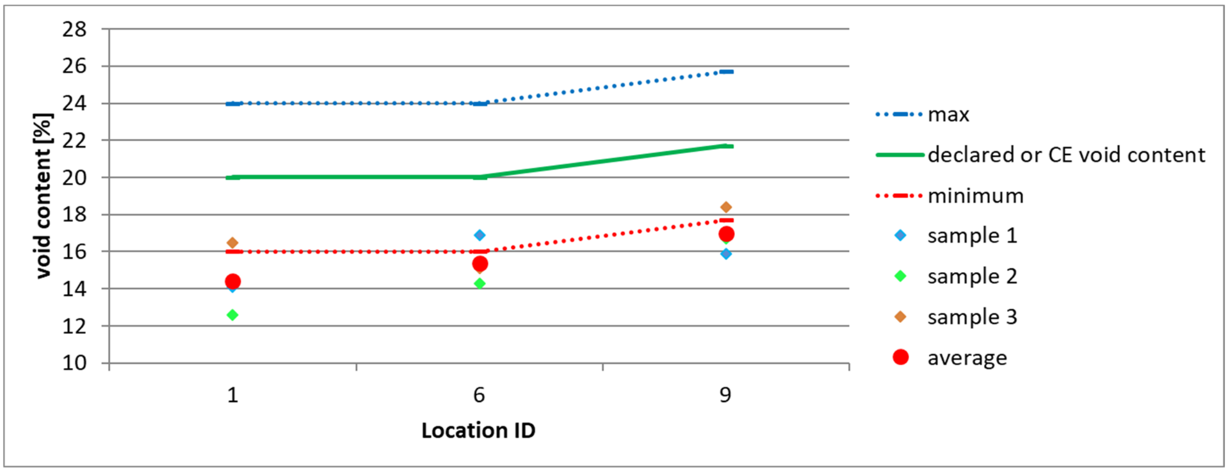



Figure 3.12: Individual results and requirements for three locations (L1, L6 and L9)

Table 3.10: Individual and average void contents compared to the declared values (CE information) for three locations

| location ID | mixture group | sample 1 | sample 2 | sample 3 | average | stdev | Vmin CE | Vmin DV | year | age |
|---|---|---|---|---|---|---|---|---|---|---|
| 1 | (D)ZOAB | 14,1 | 12,6 | 16,5 | **14,4** | 2 | - | 20 | 2012 | 4 |
| 2 | (D)ZOAB | 16 | 18,5 | 18,6 | **17,7** | 1,5 | | | 2013 | 3 |
| 3A | 2L_ZOAB8 | 19,6 | 21,6 | 21,6 | **20,9** | 1,2 | | | 2009 | 7 |
| 3B | 2L-ZOAB16 | 21 | 24,3 | 22,6 | **22,6** | 1,7 | | | | 7 |
| 4 | (D)ZOAB | 15,9 | 21,2 | 16,4 | **17,8** | 2,9 | | | 2010 | 6 |
| 5A | 2L_ZOAB8 | 19,8 | 20,3 | 22,1 | **20,7** | 1,2 | | | 2008 | 8 |
| 5B | 2L-ZOAB16 | 20,8 | 21,2 | 23,6 | **21,9** | 1,5 | | | | 8 |
| 6 | (D)ZOAB | 16,9 | 14,3 | 15,1 | **15,4** | 1,3 | 20 | - | 2013 | 3 |
| 7A | 2L_ZOAB8 | 21,7 | 21,3 | 22,2 | **21,7** | 0,5 | | | 2009 | 7 |
| 7B | 2L-ZOAB16 | 23,6 | 21,5 | 21,3 | **22,1** | 1,3 | | | | 7 |
| 8 | (D)ZOAB | 15,4 | 16,7 | 15,7 | **15,9** | 0,7 | | | 2011 | 5 |
| 9 | (D)ZOAB | 15,9 | 16,7 | 18,4 | **17** | 1,3 | 20 | 21,7 | 2012 | 4 |
| 10 | (D)ZOAB | 17,5 | 20,4 | 21,3 | **19,7** | 2 | | | 2013 | 3 |
| 11 | (D)ZOAB | 19,7 | 18,9 | 19,1 | **19,2** | 0,4 | | | 2013 | 3 |
| 12A | 2L_ZOAB8 | 23,7 | 20,8 | 21,3 | **21,9** | 1,6 | | | 2015 | 1 |
| 12B | 2L-ZOAB16 | 18,6 | 20,6 | 20,7 | **20** | 1,2 | | | | 1 |
| 13 | (D)ZOAB | 19,3 | 18,4 | 18,9 | **18,9** | 0,5 | | | 2014 | 2 |
| 14 | (D)ZOAB | 16,1 | 16,9 | 15,2 | **16,1** | 0,9 | | | 2013 | 3 |
| 15 | (D)ZOAB | 18,5 | 19,6 | 19 | **19** | 0,6 | | | 2014 | 2 |
| 16 | (D)ZOAB | 16,4 | 16,1 | 15,7 | **16,1** | 0,4 | | | 2014 | 2 |
| 17 | (D)ZOAB | 19,4 | 17,6 | 16,4 | **17,8** | 1,5 | | | 2012 | 4 |

If this approach of looking at detailed information is applied to the three potential explanations for the low void contents mentioned on page 83, it seems unlikely that they explain the values found.

Looking at the first explanation, changes in grading due to production and construction, the differences between the actual amount of material smaller than 0,063mm from the field cores (average of 3) versus the target and, if specified, reference composition, does show a tendency towards a larger amount of fines in the field cores. This shown inFigure 3.13 . In this graph positive values mean more fines in the field cores than in the target and/or reference composition. However, only in two cases the difference with the reference composition exceeds 1%, while the tolerance allowed for this sieve and n=3 is 1,3%.

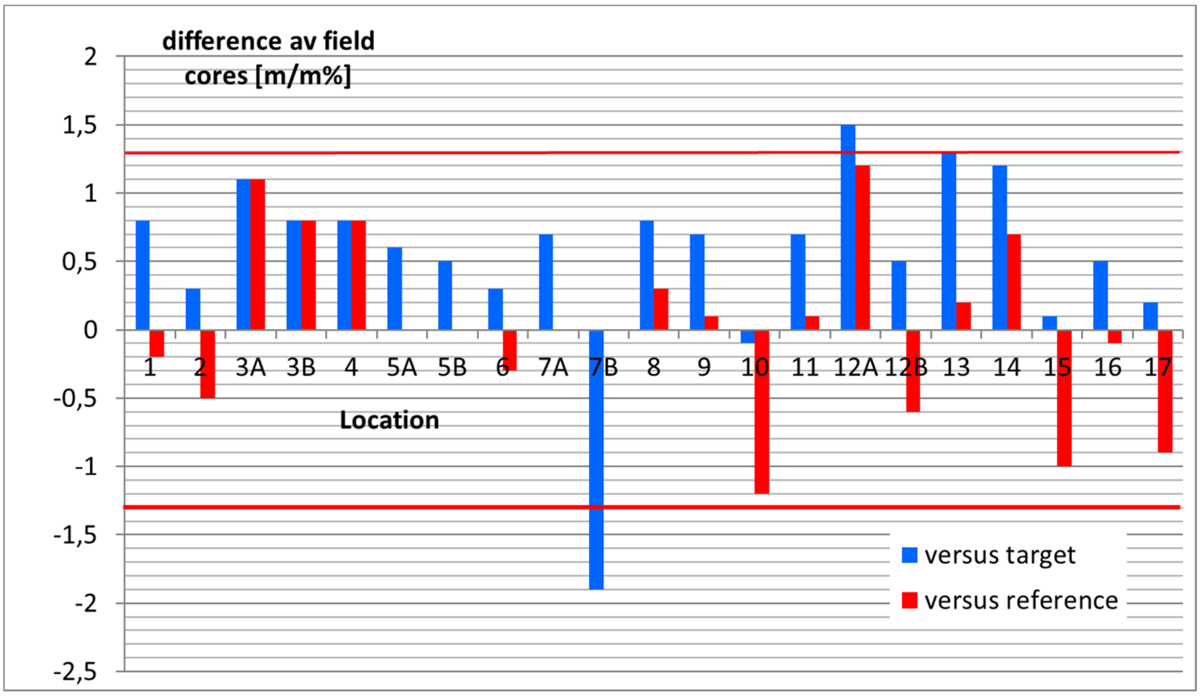


Figure 3.13: Difference in m/m% material ≤ 0,063mm in the field cores vs target and reference composition

From the CT-scans, which are discussed in the next section, it was determined that the cores did not exhibit signs of clogging, which argues against the second explanation.

The CT-scans also showed that, for the DZOAB 16 mixtures, the void content is evenly distributed over the height. The latter would appear to be a contra-indication for compaction by traffic over time, since that effect would not be expected to be homogeneous over the layer thickness. Furthermore, if the void content from the field cores is plotted versus their bitumen content (Figure 3.14, top), there does not appear to be a direct relation between the two. The highest bitumen contents fall within the average void contents and the lowest void contents are mixes that have average bitumen contents. Naturally, any sensitivity to permanent deformation in the mortar would not just depend on the amount of bitumen, but also on the hardness. For that reason, in the bottom of the figure the void content is plotted versus the penetration of the reclaimed bitumen, but here also there is no apparent relation. As such, it can be said that none of the potential explanations for densification over time seem likely. Of course, this does not mean that together they could not lead to such an effect or that there might not be another cause. To be completely sure about this, would require following the void content in and outside the wheel paths for a number of sections over the years, taking sufficient samples to account for the variations expected and, for the same reason, using a leapfrog system of sampling over the years (Figure 3.15). By taking the samples far enough apart, every year the sampling grid can be shifted and the spatial variation in the cores is the same year after year (Erkens, 2014).

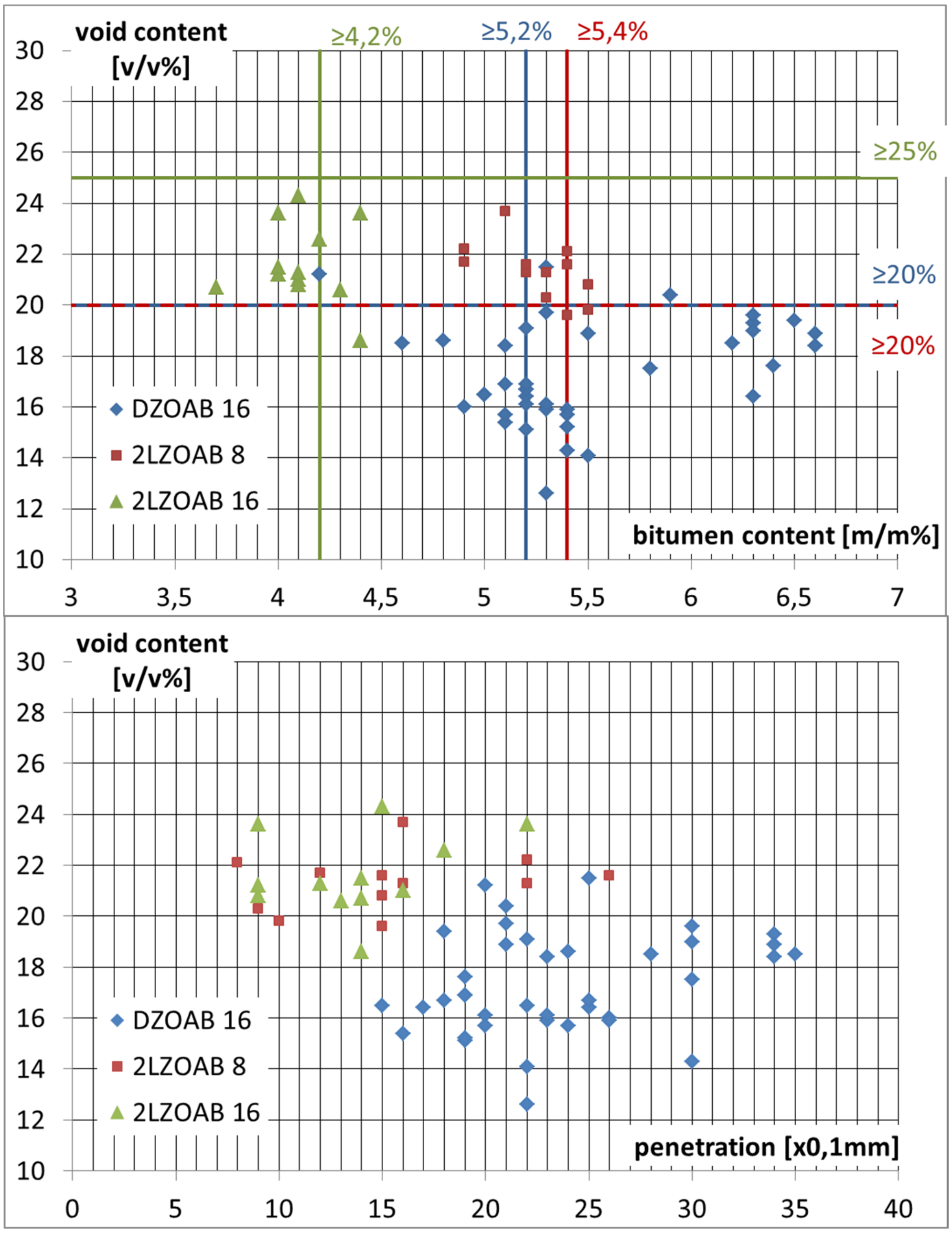



Figure 3.14: Plot of the void content versus bitumen content(top) and versus penetration of the bitumen (bottom), distinguishing the three groups of mixtures

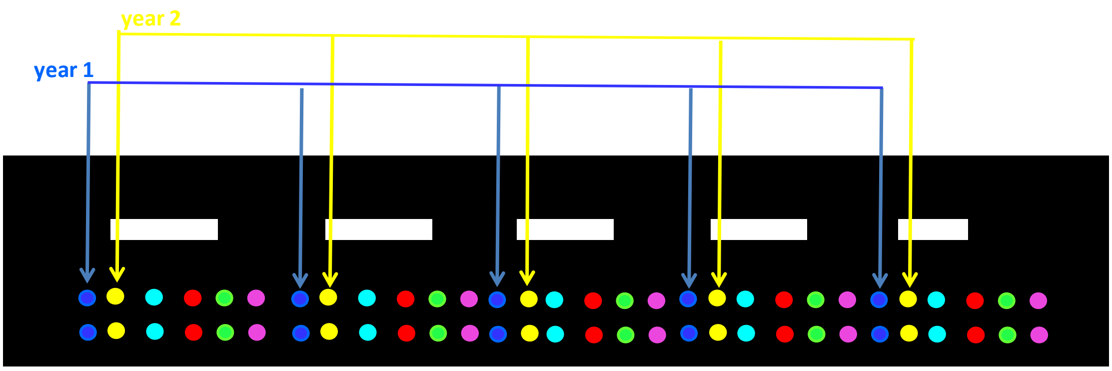



Figure 3.15: Leapfrog method of sampling, so that consecutive years of sampling cover the same distance of road, limiting the effect of location bound variation

### 3.5.2 Additional tests: CT scans

The CT-scans are discussed in Section 3.9.2.2 regarding the relation to the state and quality of the coarse aggregate. Additionally, the scans provide information on the volume ratios of mortar (and clogging), voids and coarse aggregates over the height. Regarding the voids it is often seen that we have less voids just below the road surface (first 5 to 7 mm). The reason can be compaction during construction or by traffic. An example of this phenomenon is shown in Figure 3.16, where the voids content reduces very fast from 100% to below 10% in the first 4 mm. After this the voids content increases to a stable higher value around 15%. This "dip" in void content is not due to clogging[20]. Although the distinction between mortar and clogging cannot (yet) be made automatically, experienced research can make the distinction visually. A possible explanation could be that the top layer of stones, tends to be flattened out during laying and compaction. If this is the case, the effect should occur only in materials with somewhat elongated particles. A visual analyses of the current scans does not confirm this suspicion. Scanning with a higher resolution in combination with image recognition techniques could help to study this in more detail in order to find an explanation.

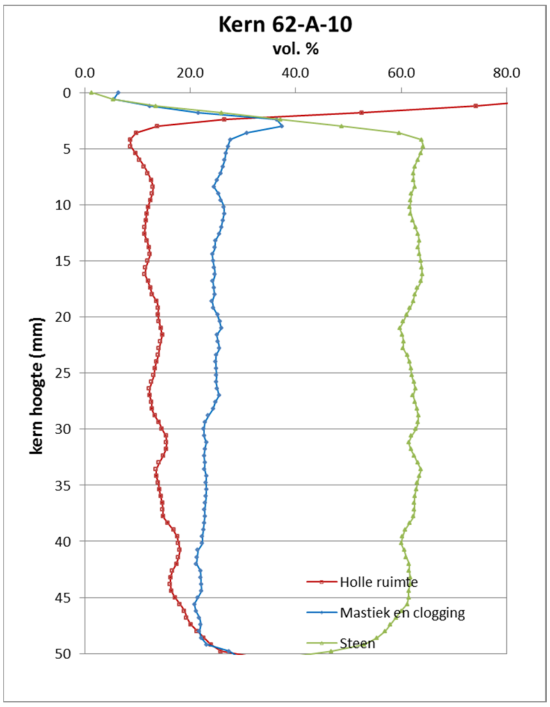



**Figure 3.16: Low percentage of voids at the top increasing with depth. Increasing percentage of mortar with depth**

Based on the scans, an overall void content can be determined. The actual value found, depends on the height that is taken into account. Usually, in measuring the void content, the core height is determined using sliding calipers. On a rough surface this will cause the tops of the stones to determine the height, including a bit of surface roughness in the void content calculation. It needs to be determined how much of the height should be taken into account in the calculation based on the scans in order to incorporate this effect. In Figure 3.17 the void contents determined by Kiwa KOAC for the DZOAB 16 cores are shown together with the values determined from the CT data over the height. The Kiwa KOAC data consist of the average over three cores that was determined based on the maximum density determined after extraction of each core and reported in Section 3.5. additionally, for the two cores used for CT-scanning the calculated void content (based on the specimen weight and the average maximum density for the three cores from the same section that were extracted) is given. These void

20 Experienced users can distinguish clogging from mortar, unfortunately, this cannot yet be automated with the resolution of the scanner used

contents were determined by Kiwa KOAC and reported in Kiwa KOAC, 2017. The latter void contents have not been used in this report before because they are obviously less accurate, but they are used here because they concern the cores that were actually scanned. The void contents determined from the CT-scans consist of a calculation that takes the full height into account (0-end, where 0 or top is defined as the height at which 80% voids were measured) and one that only uses the part between 5-25mm.

The same is done for the 2L-ZOAB 8 and 2L-ZOAB 16 cores and the results are given in Figure 3.18. It is important to note that in order to determine the void content in the classical way, the layers have to be separated. As such, the cores always have a flat, cut, surface at the bottom. For 2L-ZOAB 16, which is located underneath 2L-ZOAB 8, both the top and bottom are cut surfaces. As such, these cores should be easiest to compare. As can be seen from the graphs, the 2L-ZOAB 16 results are indeed most comparable. Another aspect of core geometry that affects the void content is any deviation from a 90° (perpendicular) angle between the core surface and its axis. In several cases of the cores used here, this angle was not 90°, which affects the percentage voids found. Finally, missing coarse aggregates at the cutting surfaces will affect the void content found in the traditional assessment, while for CT-scanning that part of the core can be excluded, to get a more representative void content.
Alternatively, CT-scanning could be done on uncut cores. There are limits for cross-sectional area, but the height of the cores is not really limited. As such, cores could be scanned and analysed for their composition and void content, without separating the layers and losing material. This would provide additional information about the interface between two pavement layers.

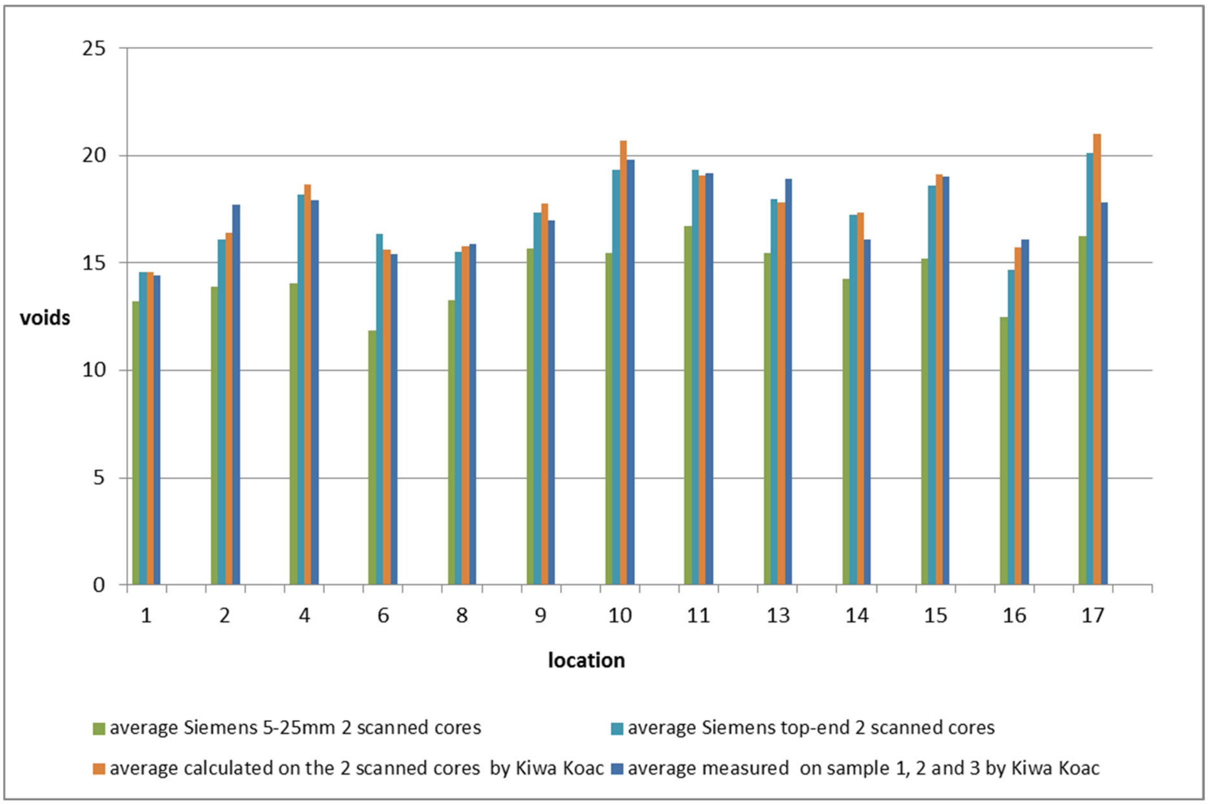


Figure 3.17: Calculated overall void content and void content over part of the height from the scans of DZOAB 16 samples compared to the calculated and measurement values by Kiwa KOAC

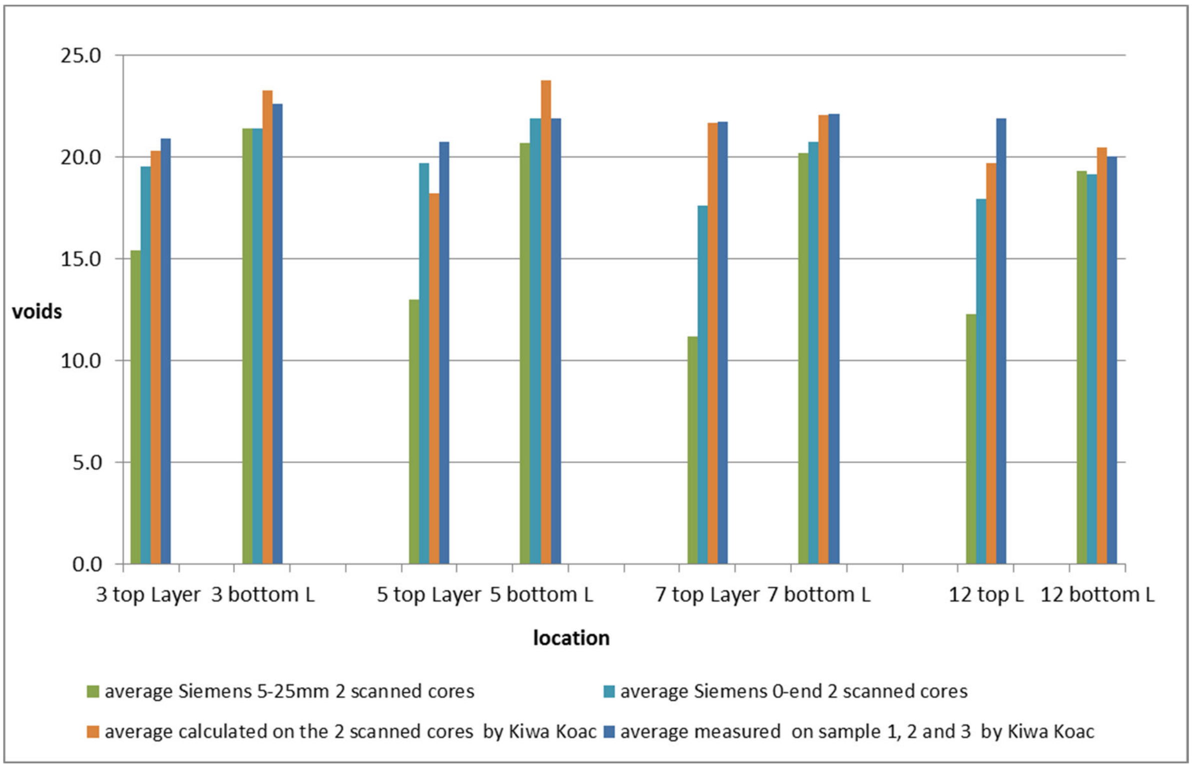



Figure 3.18: Calculated overall void content and void content over part of the height from the scans of 2L-ZOAB 8 and 16 samples compared to the calculated and measurement values by Kiwa KOAC

In

Table 3.11 an overview of the void content over the height for all the locations is given (a description is also given in Table 3.30, Section 3.9.2.2 ), including the requirement for that mixture. As can be seen, in almost all cases the void content is (considerably) lower than the requirement over almost the full height. Only one core from Location 17 appears on average to have the required void content.

Most DZOAB 16 cores have a more or less uniform distribution of void content over the height, indicating proper timing in the laying and compaction. However, that also seems to indicate that the required compaction effort is often overestimated, since overall too low a void content is realized.

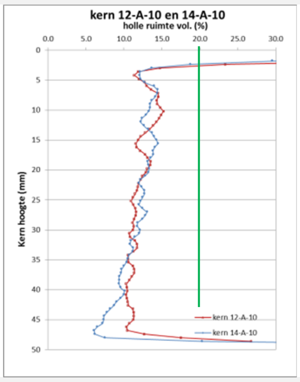
In most cases, the distribution of void content over the height is similar for the two or three cores tested, indicating continuity in the compaction process. Location 2 is the exception in this sense.

For the top-layer of 2L-ZOAB the distribution over the height is not uniform, it is higher at the top and the bottom and lower in the middle of the layer. This is the case for all top-layers of 2L-ZOAB, so it seems that compactability of these thin top-layers is an issue.

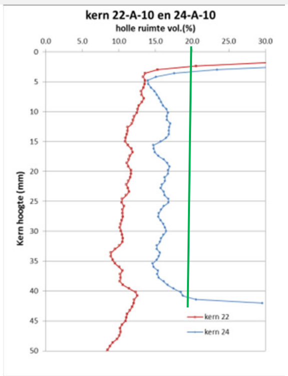
Finally, in a number of cases the cores from one section have a different height. The two cores for 3B, 7B, 12B, 14 and 15 have a difference of ca 5mm, for those from 2, 4, 5B and 9 it is more than 5mm.

Table 3.11-part 1: Overview of void content over the height for all sections

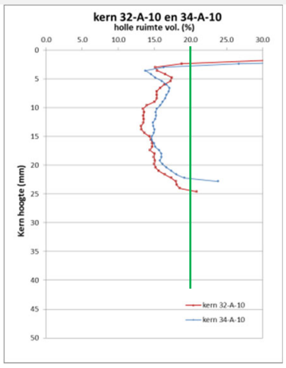
Location 1



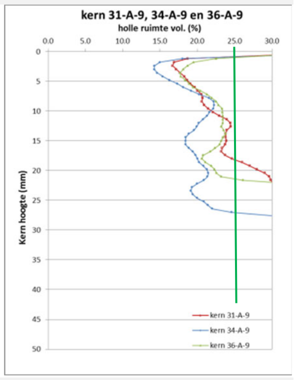

Location 2



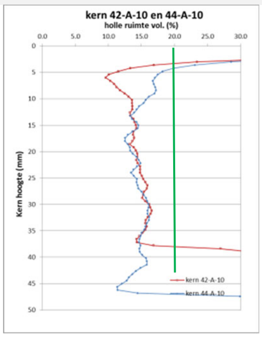

Location 3A



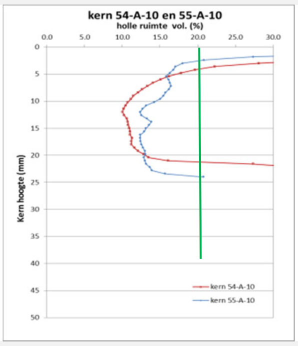

Location 3B



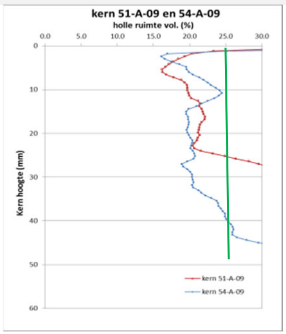

Location 4



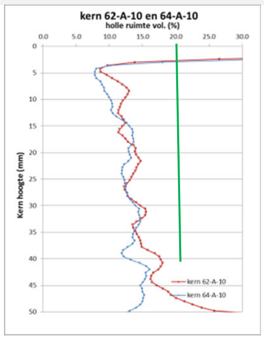

Location 5A



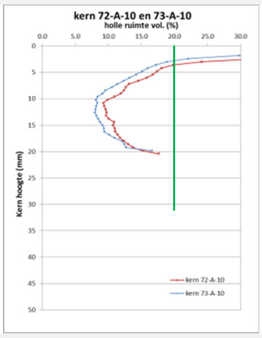

Location 5B



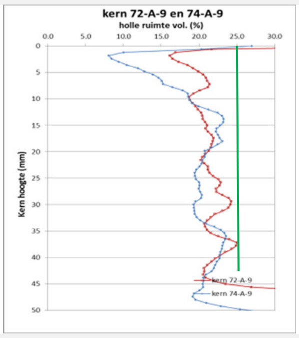

Location 6



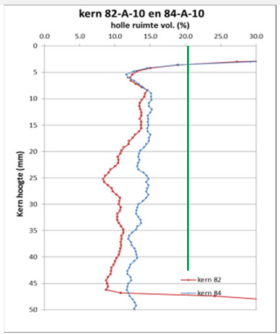

Location 7A



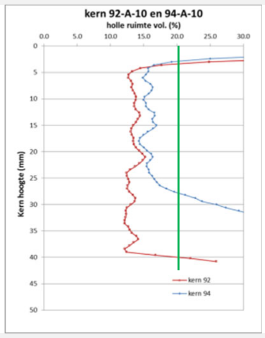

Location 7B



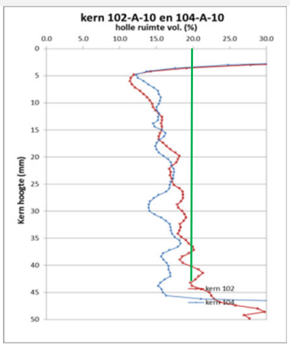

Location 8



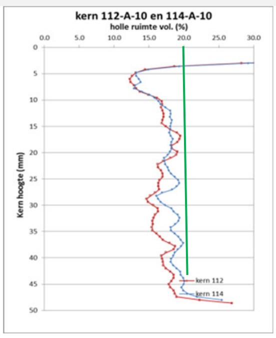

Location 9



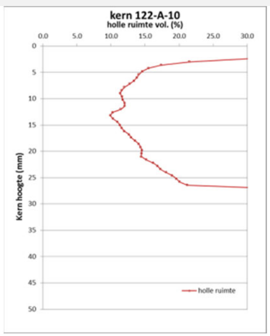

Location 10




Location 11




Location 12A




Location 12B

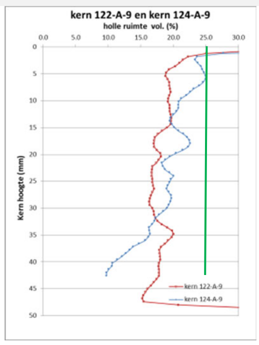
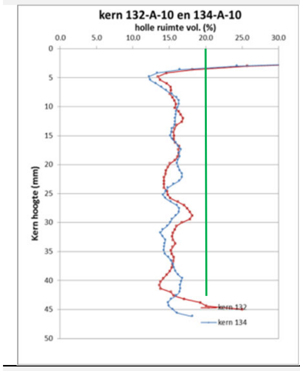
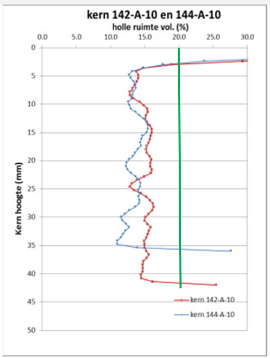
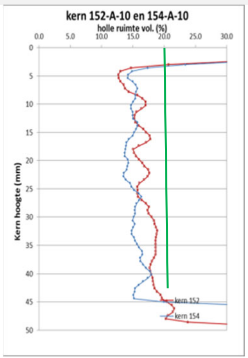
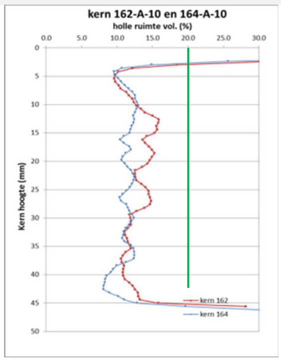
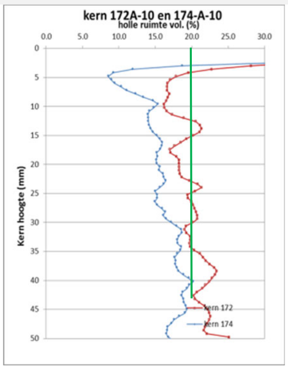


Table 3.11-part 1: Overview of void content over the height for all sections

| Location 13 | Location 14 | Location 15 | Location 16 |
|---|---|---|---|
|   |   |   |   |
| **Location 17** | | | |
|   | | | |

Regular control on the void content, including its distribution over the height, is to be recommended. None of the sections meet the design criterion for these mixtures, although in many cases the results do fall within the acceptable margins. However, if only deviations to the lower margin are found, this indicates a bias rather than the expected variation in construction. Somehow, during construction, the material becomes less porous (and more dense) than intended in the mixture design.

Particularly, a study comparing the initial to eventual void content, proofing or disproving the reduction of voids after construction, either through compaction or by clogging, is advised. If the ability to distinguish clogging from mastic could be automated, using higher resolution scans and image recognition, that would provide a great advantage.

Using scans to determine the void content has the additional advantage of not requiring separation of the layers, allowing also the analyses of the interface between two layers. As shown, from the scans the void content can be calculated. A study into a basis for the comparison to the current method would be beneficial.

## *3.6 Tests related to bitumen content or properties*

As discussed in Section 2.2.3, there are requirements for the bitumen content and for how much the bitumen is allowed to harden during production and construction. In this section, first of all these properties are discussed. The values are determined based on the cores taken from the sections (Kiwa KOAC, 2017), in this section these results are shown and discussed.

### 3.6.1 Bitumen content

The bitumen content is determined according to EN 12697-1 B.2.1 (Kiwa KOAC, 2017). As shown in Section 2.2.3, the required bitumen content differs for the different ZOAB mixture types. For that reason, in  the results are ordered per type of mixture and the requirements for that mixture type are included. The deviation per individual sample (+/- 0,6%) and the average of three cores is the same for all types of mixture: +0,4% and -0,5%. However, this deviation is linked to the declared bitumen content, the requirement for the mixture group is a minimum value only.

The results are summarized in Table 3.12 and Figure 3.19. As can be seen, in most cases the bitumen content is reasonably close to the target content per mixture group. No location has too little bitumen, based on the average value and there is only one sample that has to low a bitumen content.

Surprisingly, there are four locations where the average bitumen content of the DZOAB 16 mixtures exceeds the upper limit for the minimum binder content of this mixture group. This is surprising, since bitumen is the most expensive component in the material, so using too much is not cost effective. However, these mixtures may have been designed with an above average bitumen content. It is unlikely, since it would make the mixture relatively expensive within its category. But it could theoretically be the case, that would have to be determined from the individual information.

Table 3.12: Bitumen content for the test locations

| | | | bitumen content | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| **ID** | **type of mixture** | **required** | **sample 1** | **sample 2** | **sample 3** | **average** | **stdev** | **build** | **age** |
| **Location 1** | DZOAB 16 | 5,2 | 5,5 | 5,3 | 5 | **5,3** | *0,3* | 2012 | 4 |
| **Location 2** | DZOAB 16 | 5,2 | 4,9 | 4,6 | 4,8 | **4,8** | *0,2* | 2013 | 3 |
| **Location 4** | DZOAB 16 | 5,2 | 5,3 | 4,2 | 5 | **4,8** | *0,6* | 2010 | 6 |
| **Location 6** | DZOAB 16 | 5,2 | 5,1 | 5,4 | 5,2 | **5,2** | *0,2* | 2013 | 3 |
| **Location 8** | DZOAB 16 | 5,2 | 5,1 | 5,2 | 5,1 | **5,1** | *0,1* | 2011 | 5 |
| **Location 9** | DZOAB 16 | 5,2 | 5,4 | 5,2 | 5,1 | **5,2** | *0,2* | 2012 | 4 |
| **Location 10** | DZOAB 16 | 5,2 | 5,8 | 5,9 | 5,3 | **5,7** | *0,3* | 2013 | 3 |
| **Location 11** | DZOAB 16 | 5,2 | 5,3 | 5,5 | 5,2 | **5,3** | *0,2* | 2013 | 3 |
| **Location 13** | DZOAB 16 | 5,2 | 6,3 | 6,6 | 6,6 | **6,5** | *0,2* | 2014 | 2 |
| **Location 14** | DZOAB 16 | 5,2 | 5,2 | 5,2 | 5,4 | **5,3** | *0,1* | 2013 | 3 |
| **Location 15** | DZOAB 16 | 5,2 | 6,2 | 6,3 | 6,3 | **6,3** | *0,1* | 2014 | 2 |
| **Location 16** | DZOAB 16 | 5,2 | 5,2 | 5,3 | 5,4 | **5,3** | *0,1* | 2014 | 2 |
| **Location 17** | DZOAB 16 | 5,2 | 6,5 | 6,4 | 6,3 | **6,4** | *0,1* | 2012 | 4 |
| **Location 3A** | 2LZOAB 8 | 5,4 | 5,4 | 5,4 | 5,2 | **5,3** | *0,1* | 2009 | 7 |
| **Location 5A** | 2LZOAB 8 | 5,4 | 5,5 | 5,3 | 5,4 | **5,4** | *0,1* | 2008 | 8 |
| **Location 7A** | 2LZOAB 8 | 5,4 | 4,9 | 5,2 | 4,9 | **5** | *0,2* | 2009 | 7 |
| **Location 12A** | 2LZOAB 8 | 5,4 | 5,1 | 5,5 | 5,3 | **5,3** | *0,2* | 2015 | 1 |
| **Location 3B** | 2LZOAB 16 | 4,2 | 4,1 | 4,1 | 4,2 | **4,1** | *0,1* | 2009 | 7 |
| **Location 5B** | 2LZOAB 16 | 4,2 | 4,1 | 4 | 4,4 | **4,2** | *0,2* | 2008 | 8 |
| **Location 7B** | 2LZOAB 16 | 4,2 | 4 | 4 | 4,1 | **4** | *0,1* | 2009 | 7 |
| **Location 12B** | 2LZOAB 16 | 4,2 | 4,4 | 4,3 | 3,7 | **4,1** | *0,4* | 2015 | 1 |

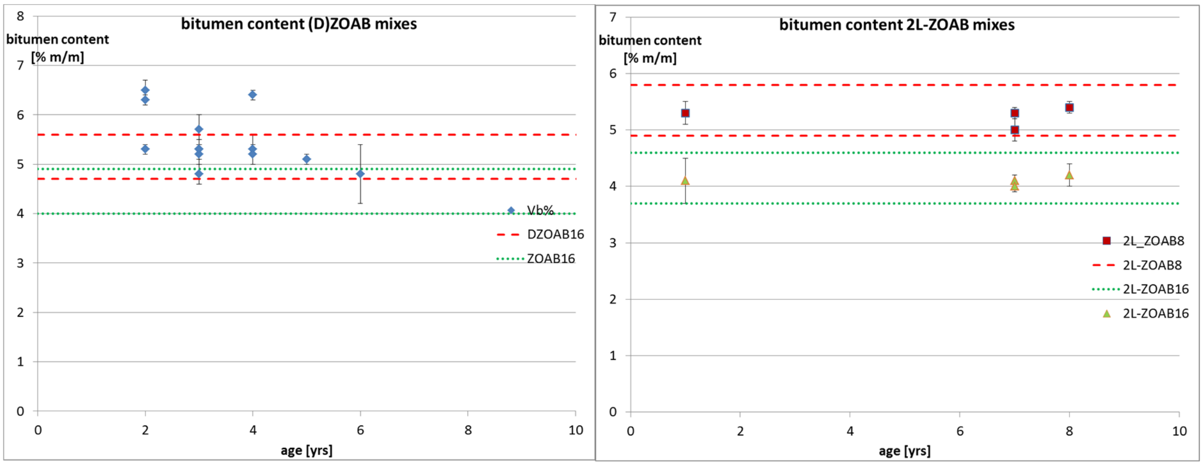



Figure 3.19: Bitumen content (n=3) for (D)ZOAB 16 (left) and 2L-ZOAB 8 and 2L-ZOAB 16 (right), with the corresponding margins

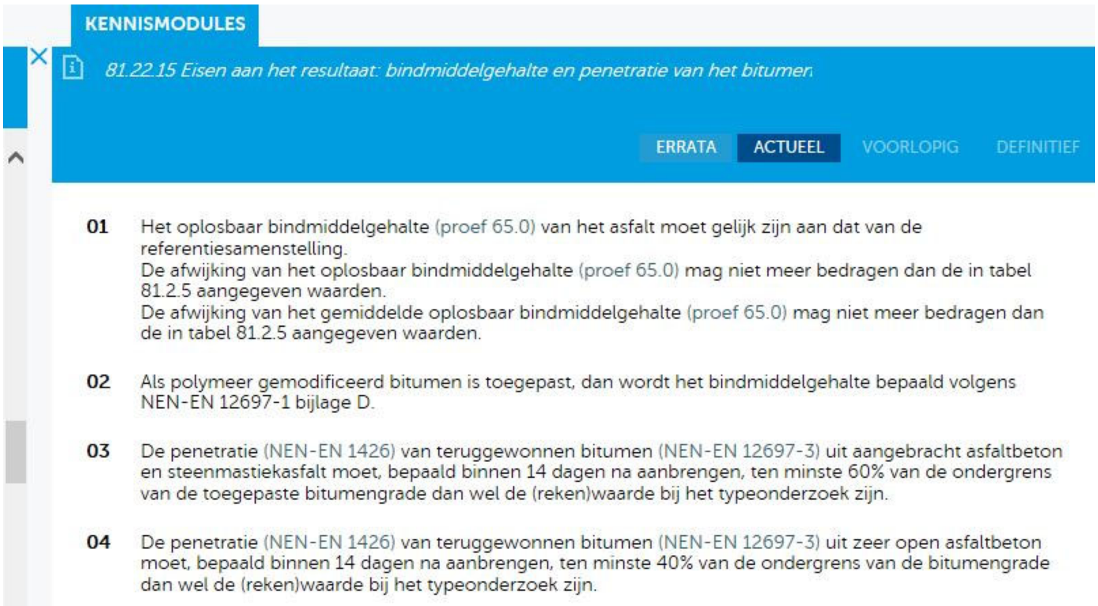
## 3.6.2 Bitumen properties

### 3.6.2.1 Penetration

It is known that during production and construction of asphalt pavements, the bitumen ages and, as a result, becomes harder and more brittle. Production errors, such as overheating the asphalt can lead to extreme aging during production, which leads to an increased risk of early failure.

For this reason, there is maximum reduction of the bitumen penetration defined (Figure 3.20). For PA this is 60% of the lower limit of the required pen grade or the penetration found or used in the Type Test (so the minimum requirement is that the penetration must be 40% of the lower limit of the required pen grade). This requirement must be met up to fourteen days after construction.
There are two challenges when looking into the penetration values form the sections in this study, the first is that the actual penetration value of the bitumen is often not provided, so all that is known in the lower boundary of the bitumen type that is used. For the penetration bitumen this can be set to 70x0,1mm, for the PMB this is unknown.

However, more detailed information is not available. Since this is one of the potential checks during quality control at or around the time of delivery, RWS may want to consider including it in product checks in order to develop a reference frame and put the information to use. Without checking it, the requirement loses its relevance.


KENNISMODULES

*81.22.15 Eisen aan het resultaat: bindmiddelgehalte en penetratie van het bitumen*

ERRATA ACTUEEL VOORLOPIG DEFINITIEF

**01** Het oplosbaar bindmiddelgehalte (proef 65.0) van het asfalt moet gelijk zijn aan dat van de referentiesamenstelling.
De afwijking van het oplosbaar bindmiddelgehalte (proef 65.0) mag niet meer bedragen dan de in tabel 81.2.5 aangegeven waarden.
De afwijking van het gemiddelde oplosbaar bindmiddelgehalte (proef 65.0) mag niet meer bedragen dan de in tabel 81.2.5 aangegeven waarden.

**02** Als polymeer gemodificeerd bitumen is toegepast, dan wordt het bindmiddelgehalte bepaald volgens NEN-EN 12697-1 bijlage D.

**03** De penetratie (NEN-EN 1426) van teruggewonnen bitumen (NEN-EN 12697-3) uit aangebracht asfaltbeton en steenmastiekasfalt moet, bepaald binnen 14 dagen na aanbrengen, ten minste 60% van de ondergrens van de toegepaste bitumengrade dan wel de (reken)waarde bij het typeonderzoek zijn.

**04** De penetratie (NEN-EN 1426) van teruggewonnen bitumen (NEN-EN 12697-3) uit zeer open asfaltbeton moet, bepaald binnen 14 dagen na aanbrengen, ten minste 40% van de ondergrens van de bitumengrade dan wel de (reken)waarde bij het typeonderzoek zijn.

Figure 3.20: In part 04 of Article 81.22.15 (CROW, Standaard 2015 (2015)) the lower boundary for the penetration within fourteen days from construction is specified

The second complication is that aging continues during the service life, so the penetration will have reduced further over time (Figure 3.21). From the results shown here, it can be seen that after nine years all these types of binder had a penetration value of 20x0,1mm or lower.

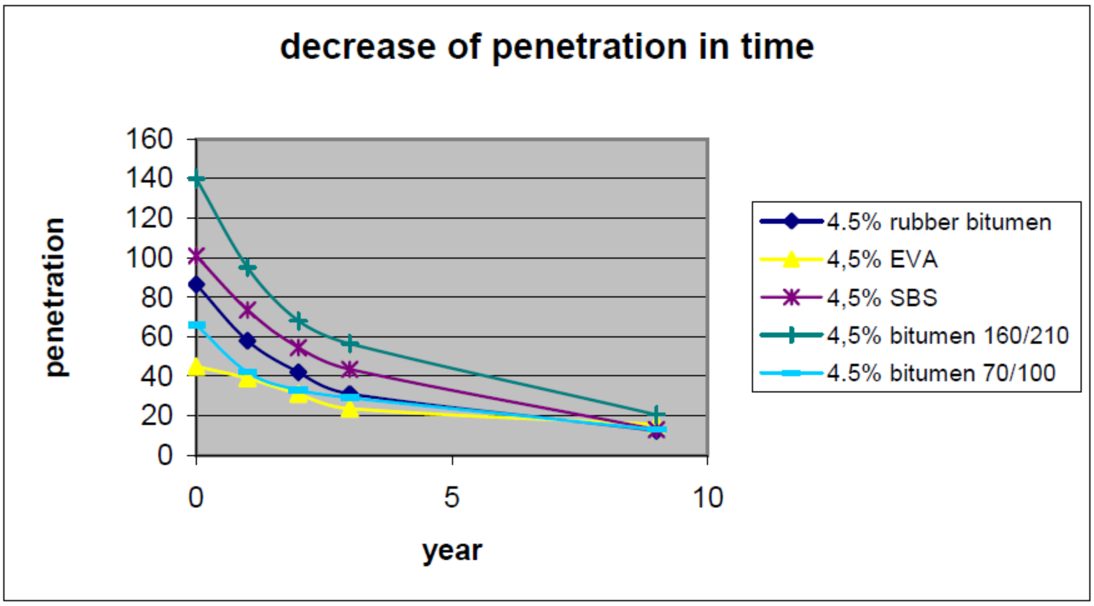



Figure 3.21: reduction of penetration of ZOAB 16 mixtures over time (after: Voskuilen et al., 2004)21

So, basically, values lower than the requirement of 40% of 70x0,1mm (=28x0,1mm) do not mean that the material did not meet the specifications after construction. The variation of penetration over time will give some indication, as can be seen, after about five years the changes are gradual more or less

21 The bitumen content shown here is expressed as %m/m "on" 100% mixture, 4,5% and 5,5% relate to 4,3% and 5,2% bitumen m/m "in" 100% mixture, the current way of expressing bitumen content. Because of the specifications in the EN 13108-7 4,3% is expressed as $B_{min}$=4,2%, while 5,2 remains $B_{min}$=5,2%

linear with time. However, differences here can also be the case of initial differences in penetration, especially for pavements younger than 5 years.

In Figure 3.22 the penetration as a function of the age of the section (and the type of mixture) is given for the sections studied in this project. As can be seen, the penetration decreases roughly with time, but there is a lot of variation. It does seem clear that something odd happened in section 12, the 2L-PA that is only one year old. Both layers show a very low penetration, while the three older 2L-PA materials (there are two sets of 7 years old) do not show behaviour that deviates much from the overall data set. Based on this observation, the information provided on the mixtures was checked and it was found that a Styrelf PmB 40/100-65 AAP was used in both top- and bottom-layer. Additionally, according to the additional information (“verkort verslag”) in the bottom-layer fibres were used (Arbocell ZZ 8/1). The specifications for 2L-ZOAB (VBW Asfalt et al. (2002), Bouwend Nederland (2012) and CROW, Standaard 2015 (2015)) indicate polymer (SBS or EVA) modified bitumen for the top-layer and a choice between pen grade 70/100 or PMB for the bottom-layer. If an PMB is used the rather low bitumen content prescribed for the bottom-layer does not usually require an additional drainage inhibitor.

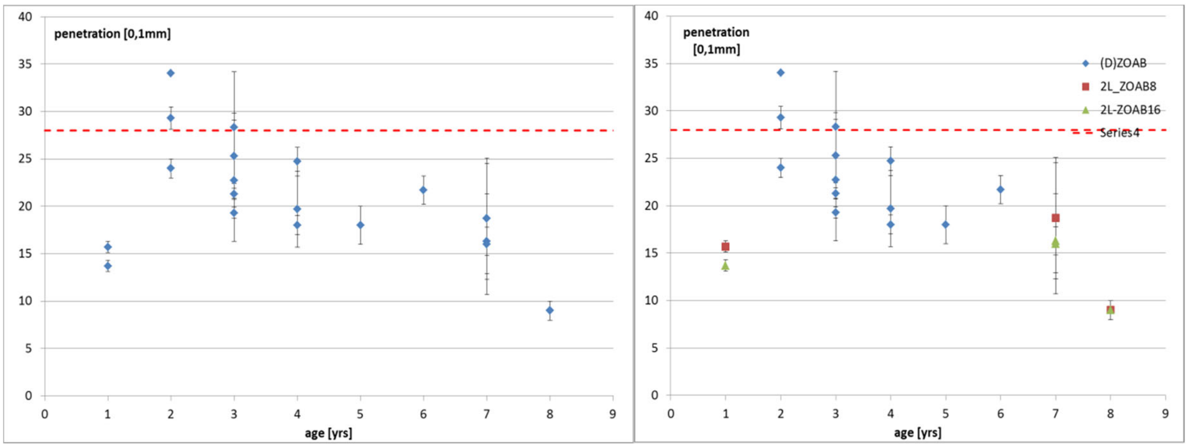



Figure 3.22: Penetration as a function of age for all sections (left) and with the different types of PA indicated (right)

In Figure 3.23 the results from the test sections reported on in Voskuilen et al., 2004 are digitized and combined with the results found in this project. As can be seen, the pen grade 70/100 bitumen results for (D)ZOAB 16 seem to be in line with what was observed in the project that followed the penetration over time. The results from the 2L-ZOAB mixtures, aged 1 and 8 years (Location 12 and 5, respectively) however, deviate considerably.

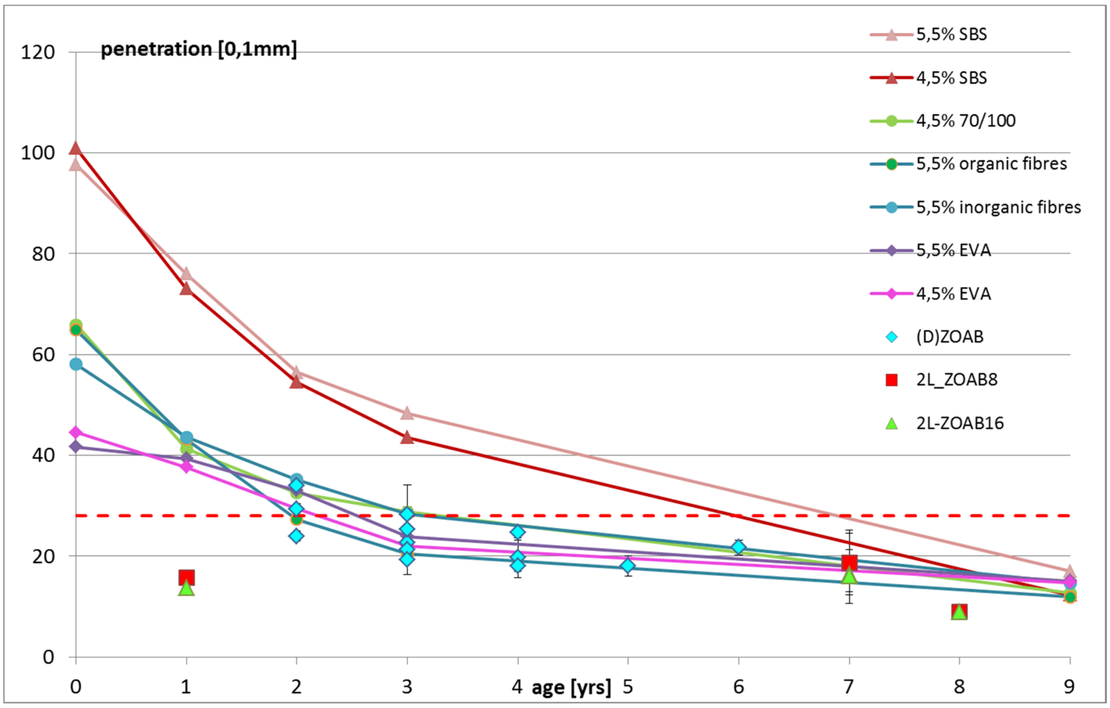



Figure 3.23: A selection of the penetration over time results from Voskuilen et al. (2004) combined with the values found for the cores from the road sections in this project

Based on these results, most samples would appear to perform as expected regarding the penetration development. The exceptions are the 2L-ZOAB mixtures that are one year old (Location 12) and possibly the 8 year old (Location 5).

### 3.6.2.2 Additional properties

Additional tests were carried out on the bitumen to distinguish between PMB and penetration bitumen, try to link the recovered bitumen to specific sources, assess the presence of aging products and determine the effect of filler (discussed in Section 3.7 on page 109 and further). These analyses were done at BASt and are described in Hirsch (2017a). An overview of the tests carried out is shown in Table 3.13.

Table 3.13: Additional bitumen properties determined at BASt

| **Properties/Parameter** | **Methods** | **Reference** |
|---|---|---|
| Rheological Properties | MSCRT | Following EN 16659 [1,2] |
| Oxidation state/Polymers | FTIR-Spectrometry | In-house method [3,4] |
| Acid number | Titrimetry | Proposed test method of CEN-TC336-WG2 [5] |
| Oil provenance | Element analysis (ICP) | In-house method |

#### *3.6.2.2.1 MSCR Test*

In the report it is described how the MSCR test is used to distinguish PMB's from pen grade bitumen, based on the difference in elastic response, SBS-PMB shows a clear elastic recovery, while non or lightly modified bitumen show less elasticity. This is expressed in the shear strain ($\varepsilon_1$) that occurs based on the applied shear stress, which is an indication of the specimen stiffness and is plotted on the horizontal axis. So, the stiffer the material, the closer to the vertical axis it is plotted.

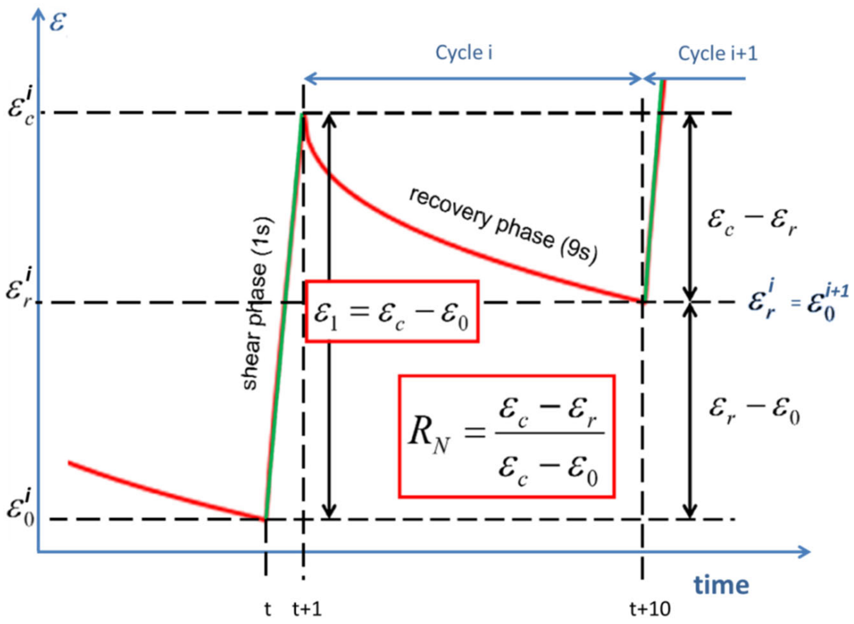



Figure 3.24: Data analyses principle used in the MSCR test Hirsch, 2017a, with some additions

Vertically, the ratio of recovery is plotted, which is the ratio of the recovered over the unrecovered strain in during the 9 seconds before the next shear stress pulse is applied. If a material is more elastic, more deformation will be recovered in the rest period, so those materials will be higher on the Y-axis. The initial strain and strain recovery ratio are shown in Figure 3.24,Figure 3.24: Data analyses principle used in the MSCR test Hirsch, 2017a, where green lines indicate the (shear stress) loading phase, red lines are the strain.

The (additional) shear strain caused by the shear stress in one second, is the strain $\varepsilon_1$. This is the difference between the strain at the end of the shear loading pulse, $\varepsilon_c$, and that at the beginning of that pulse, $\varepsilon_0$. After building the shear load over one second, it is immediately removed. The sample will start recovering and after nine seconds, again one second of shear loading occurs. Since repeated load cycles are applied, the strain at the beginning of a cycle *i*, is $\varepsilon^i_0$ . The strain at the end of one cycle, is that at the beginning of the next: $\varepsilon^i_r = \varepsilon^{i+1}_0$.

The ratio of the amount of this strain that is recovered over the non-recovered part of the strain within a cycle is $R_N$. In a fully elastic material, $R_N$ is 1 (or 100% when using percentage), because the strain would be fully recovered. In a fully plastic or highly viscous material, $R_N$ =0, because no strain would be recovered in 9 seconds.

The data analyses and representation deviates somewhat from the original approach (Figure 3.25). The figure shows the test, where ten low level (0,1 kPa) shear cycles of 1 second with 9 second rest intervals are followed by ten high level shear (3,2 kPa) cycles, while continuously measuring the strain (top left). The graph on the top right hand side of the Figure shows how for each cycle the unrecovered strain over applied stress is used to determine $J_{NR}$, an indication of stiffness/compliance. The graph in bottom left corner shows the determination of the recovery (BASt calls this $R_N$). Using the graph on the bottom right, the distinction between PMB and non-modified is made based on recovery versus $J_{NR}$ and the centre equation expresses stress sensitivity. Instead of $J_{NR}$ BASt uses $\varepsilon_1$, which removes the link to stress level. It is not explained why they follow a different procedure, nor do they explain their protocol.

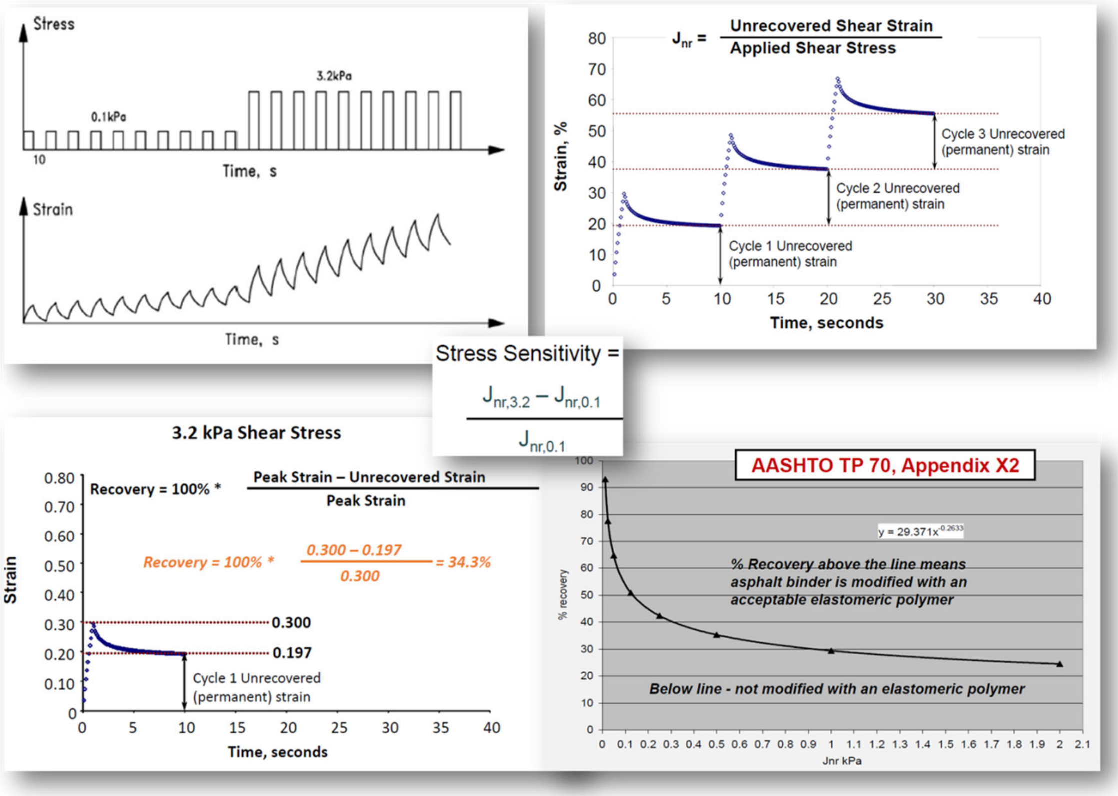



Figure 3.25: MSCR test principle (AASHTO TP70)

Because of this, it is not quite clear how it is possible that negative R and $\varepsilon_1$ values are measured (Figure 3.26). The definition shown in Figure 3.24 (and Figure 3.25) would appear to lead to an R value between zero (no recovery) and 1 (full recovery). A negative value would require $\varepsilon_c$ to be smaller than $\varepsilon_0$, which would make the bottom term in the expression negative. This means the material recovers more strain in the nine seconds of unloading than occurred in the one second of loading. While theoretically possible, it seems unlikely that that strain would not have been recovered in the previous cycle. Alternatively, $\varepsilon_c$ could be smaller than $\varepsilon_r$, making the top part of the expression negative. That would mean the material keeps on developing strain after removing the load, which is physically incorrect. Similarly, $\varepsilon_1$ is the additional strain due to the applied load, a negative value would indicate that under additional stress, the strain decreased.

The results from the test, reproduced in Figure 3.26, indicate values for $R_N$ that far exceed 100 (assuming R is reported as a percentage, its value should be between 0 and 100), values that seem to indicate that the recovered strain exceeds the strain from the loading cycle.
Small negative values or values slightly larger than 1 or 100%, could be due to measurement errors. But values going to –30% and 120% are very odd and should, considering the test principle, at least be explained in the report.

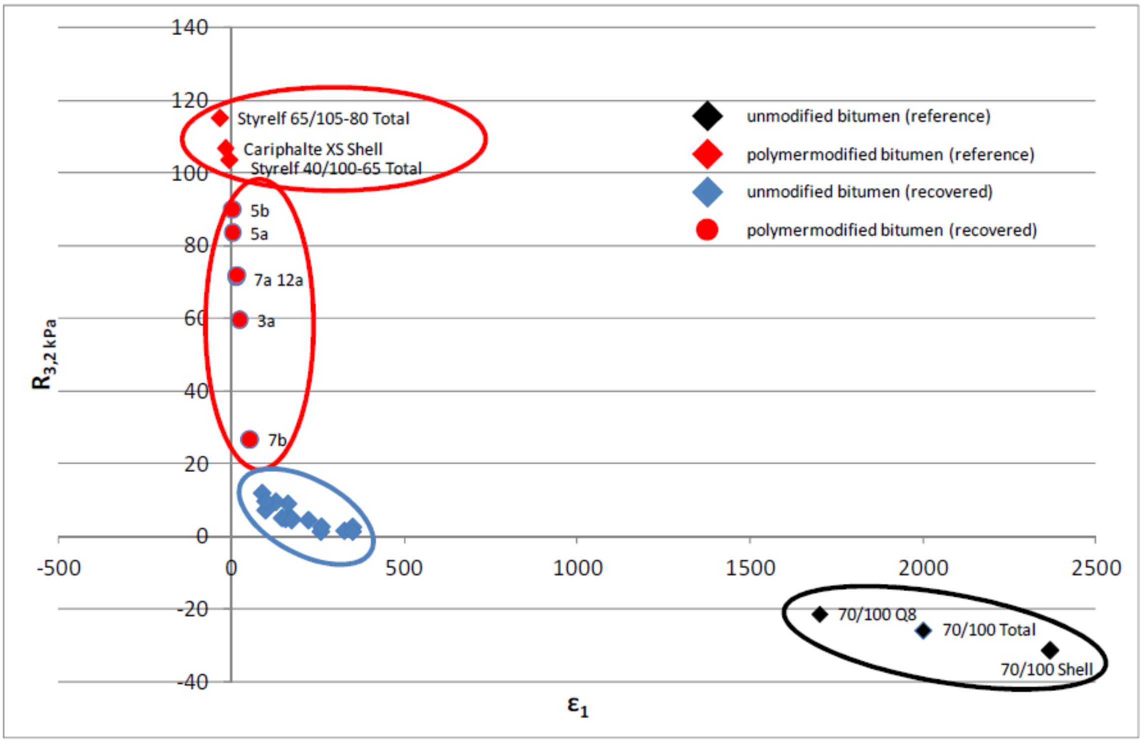



Figure 3.26: Graphical representation of the results from the MSCR test (Hirsch, 2017a)

The results are plotted as $R_N$ versus $\varepsilon_1$, in Figure 3.26. The (fresh) reference PMB's and pen grade bitumens can be easily distinguished. Furthermore, it can be seen that the aged pen grade bitumens become much stiffer (move closer to the vertical axis) and less viscous/more elastic and generally behave more like PMB's. This is similar to the AASHTO approach, except that there $J_{NR}$ is used instead of $\varepsilon_1$. It is unclear if the curve from AASHTO is used to distinguish PMB from non-PMB.

The aged PMB's show the opposite behaviour, they become less stiff and less elastic. This is probably related to the effect that due to aging, polymers degrade, which sometimes counteracts the effect of the aging bitumen. An effect that is known to be stronger in SBS than in EVA, which is more agng resistant. Whether (and how) it is possible to distinguish i.e. bitumen 7b from the aged pen grade bitumens, purely on the basis of the MSCR test, remains unclear. In the report the author indicates that they find 7b to be a PMB, based on its rheological properties (in this case, the MSCR test). In the reported FTIR data, the results are already split into PMB and pen grade bitumen and the different results are not identifiable, so it is not quite clear how definitive the FTIR data are on the PMB identification of bitumen 7B.

A point of attention is that the bitumen from the lower layer of Location 12 (12B), is classified as a penetration bitumen (Figure 3.27), but as discussed in Section , because of its low penetration after only 1 year, the mixture information was checked and that indicated a PMB (Styrelf). That this is in fact not a PMB is supported by the IR spectrogram (Table 3.14), where there is no styrene peak visible in the bitumen of 12B. However, it is found that this is one of the bitumens with a rather high acid number, which could be indicative of SBS degradation. But according to the BASt report (Hirsch, 2017a), the statistical cluster analyses carried out seem to indicate that it is highly unlikely that the 12B bitumen is a PMB and similarly, that it is highly likely that 7B is.

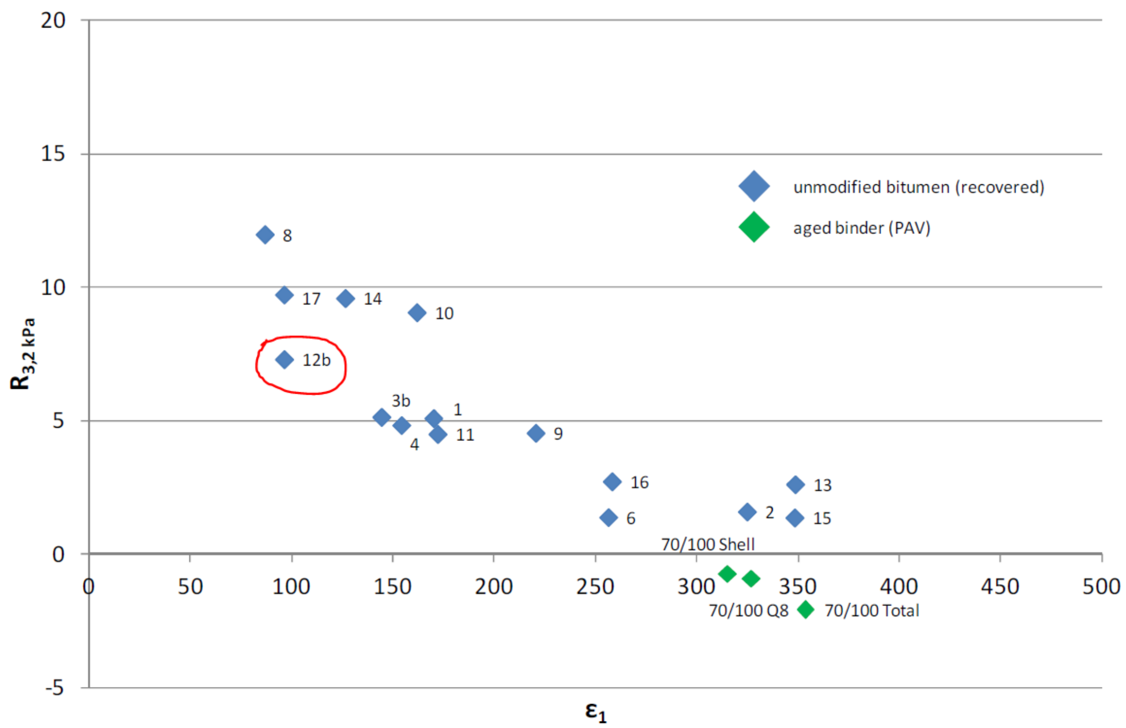



Figure 3.27: Close up of the penetration binders from the MSCR test, indicating 12B as a penetration binder

The aged reference bitumens did increase in stiffness to something resembling the softer field aged bitumen, but the effect on the elasticity remains considerably lower than that observed in the field aged samples (Figure 3.27).

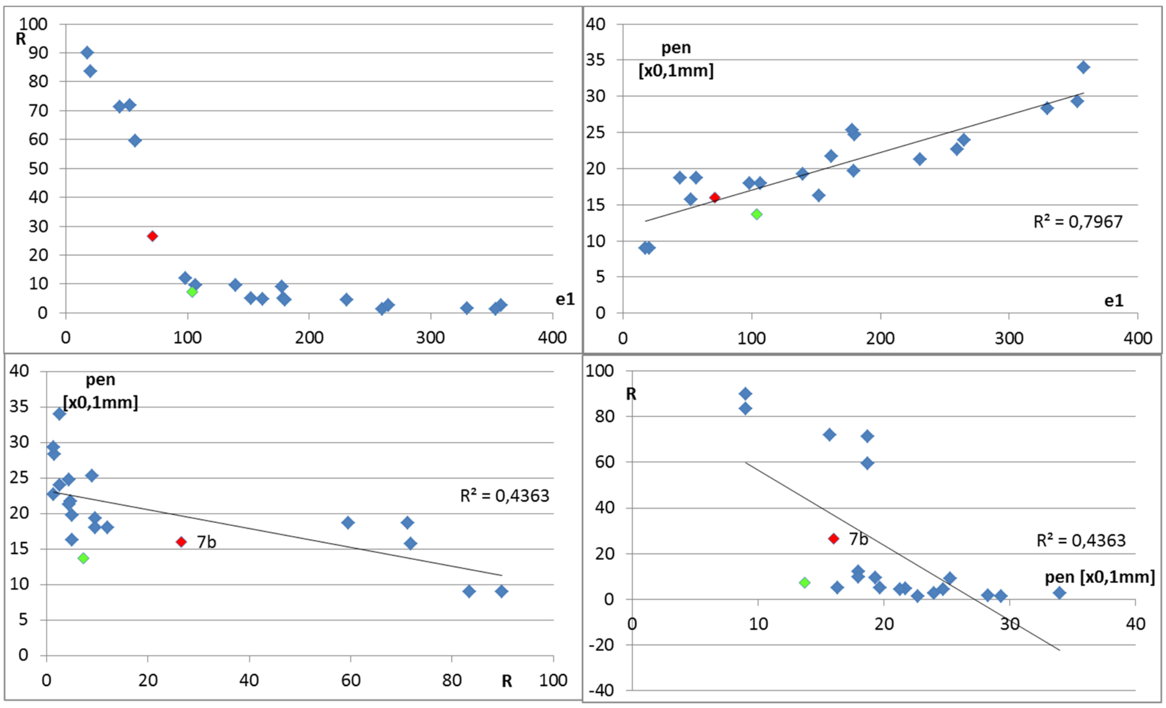



Figure 3.28: Plotting $e_1$, R and penetration versus each other in various combinations, green marker=12B, red=7B

Since the $\varepsilon_1$ seems to be closely related to the penetration, the data for the 17 samples in this study were plotted separately, and then R was plotted versus the penetration and $\varepsilon_1$ and the penetration were plotted versus each other (Figure 3.21). As can be seen, there is indeed a strong relation between $\varepsilon_1$ and the penetration. From these plots, it seems that Location 7B is a material that falls between the PMB's and the pen grade bitumens. Location 12B appears to belong to the pen grade bitumen group, except for a relatively low (particularly considering its young age) penetration. It needs to be seen if any of the other tests provide an explanation for this.

Although the method of reporting deviates somewhat from the usual approach and raises some question regarding the actual values, the trend in data is similar and recognizable and allows PMBs to be separated from non-PMB's.

#### *3.6.2.2.2 FTIR: Fourier Transform Infrared Spectroscopy*

FTIR testing is based on the fact that, above absolute zero (T=0 [°K]) all bonded molecules vibrate. If a specific amount of energy, corresponding to the vibration frequency is added to the molecule it can absorb the energy and be exited to a higher level of vibration. FTIR uses this principle by applying various levels of energy to the compound being tested through sending infrared light of varying frequencies through the sample and registering how much of it is being absorbed. The energy levels associated with the various molecular bonds are known and because the absorption occurs at resonant frequencies (=wave lengths) that matches the vibration frequency, from the IR spectrum that is absorbed, the type and amount of molecular bonds present in the sample can be determined.

##### **3.6.2.2.2.1 BASt FTIR analyses**

In the BASt study (Hirsch, 2017a) FTIR was used to look at two types of bonds, two that occur in SBS-polymers (styrene and butadiene) and two that increase due to bitumen aging, carbonyl (C=O) and sulfoxide (S=O) bonds. The results are reported separately in graphs for the PMBs and penetration bitumen (Figure 3.29).

In the graphs on the left it can be seen that the styrene and butadiene peaks are larger in the reference (unaged) PMBs, after aging the peaks are smaller, of a similar size as in the reclaimed binders. The bottom picture also shows a very small carbonyl peak in the reference binder where that is not there the unaged signal. Similarly, on the right it can be seen that the aged reference binders show a closer resemblance to the reclaimed samples than the unaged. However, it is difficult to compare the PMB and pen grade bitumens from these separate graphs.

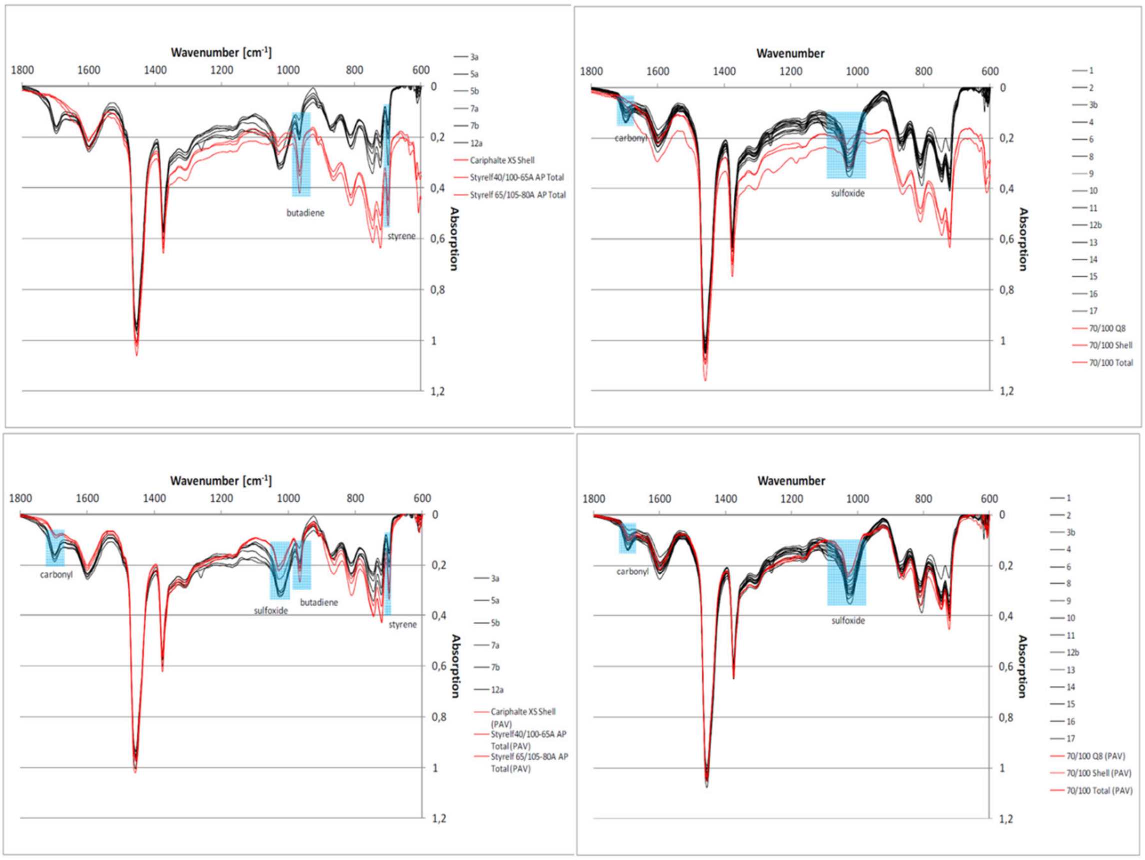



Figure 3.29: FTIR spectra, left is the PMB and right are pen graden bitumens, top are the unaged reference binders and bottom are the results from the reclaimed bitumen from the field cores (Hirsch, 2017a)

For that reason, in Figure 3.30 these graphs have been combined in a simple way. By removing the background from the regular bitumen graph, matching their axes and setting the PMB curves to green colour. This allows the PMB peaks to show up clearly and as can be seen from the enlargements, there is no black line showing up in these peaks. From this, it can be concluded that Location 12B does indeed not contain SBS, so its deviant behaviour in penetration has another cause. This also indicates that the material used and the material information that was provided, do not match up.

There is one green line giving only a very limited peak in the butadiene peak, for the styrene this does not seem the case. This could be Location 7B, but the separate signals cannot be identified from the results. This could be checked with BASt.

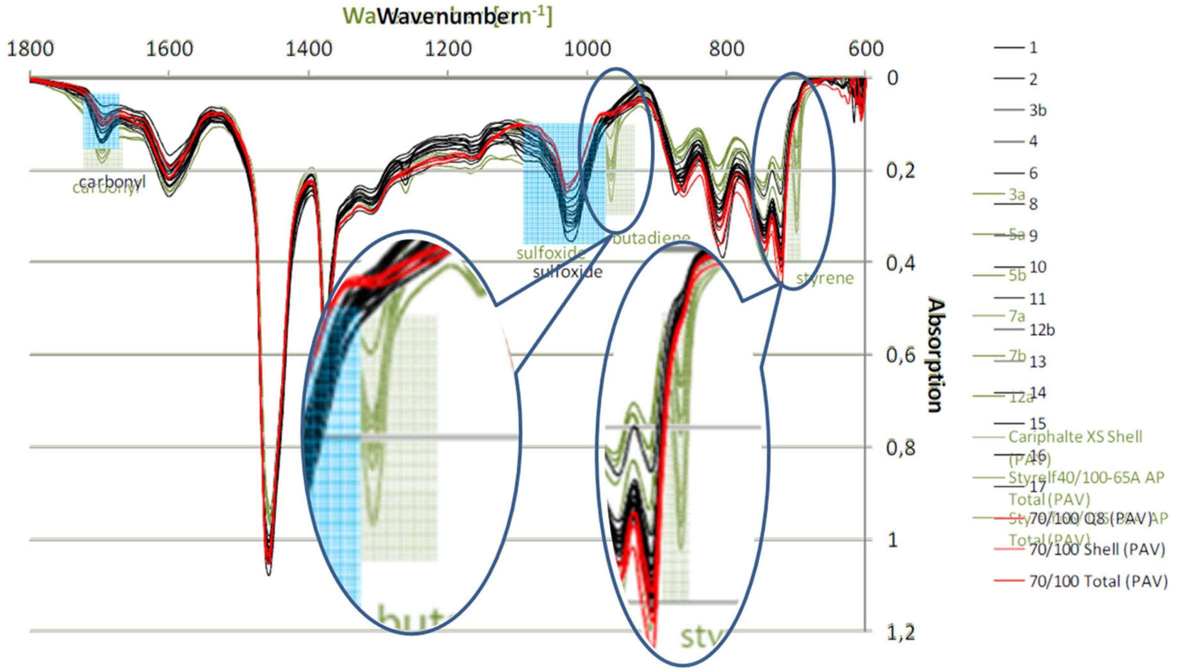



Figure 3.30: Combined signals for aged PMBs and pen grade bitumen from Hirsch, 2017a

#### 3.6.2.2.2.2 FTIR tests by TNO

Additional FTIR work was done on dissolved bitumen samples by TNO van Vliet, 2018. The samples provided consisted of bitumen reclaimed with soxhlet extraction using methylene chloride. After homogenising the samples, these were tested in FTIR. In these analyses various indicators (peaks in the results) for different types of polymers, aging indications and presence or reaction products of fillers were studied. The results are summarized in Table 3.14, where the TNO codes from their original report have been replaced by the original ones used throughout this report.

Table 3.14: Overview of results FTIR analyses TNO, van Vliet, 2018

| characteristic peaks | | sample number | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| MATERIAL | WAVENR (CM-1 | L1 | L2 | L3A | L3B | L4 | L5A | L5B | L6 | L7A | L7B | L8 | L9 | L10 | L11 | L12A | L12B | L13 | L14 | L15 | L16 | L17 |
| APP | 973 | | | | | | | | | | | | | | | | | | | | | |
| APP | 998 | | | | | | | | | | | | | | | | | | | | | |
| APP | 1164 | | | | | | | | | | | | | | | | | | | | | |
| C=O | 1692 | Y | Y | Y | Y | Y | Y | Y | Y | Y | Y | Y | Y | Y | Y | Y | Y | Y | Y | Y | Y | Y |
| C=O/EVA? | 1735 | Y | Y | Y | | | | | | Y | Y | | | | | Y | Y | Y | Y | Y | Y | Y |
| CaO | 712 | | | | | | | | | | | | | | | | | | | | | |
| CaO | 874 | Y | | Y | | Y | Y | Y | | Y | | Y | Y | Y | Y | Y | Y | | Y | | Y | Y |
| C-O | 1259-1263 | Y | Y | Y | Y | Y | Y | Y | Y | Y | Y | Y | Y | Y | Y | Y | | Y | Y | | | |
| C-O rek? | 1228-1216-1208 | Y | Y | Y | | | | | | Y | Y | | | | | Y | Y | Y | Y | Y | Y | Y |
| EVA | 1242 | | | | | | | | | | | | | | | | | | | | | |
| S=O | 1040 | | | | | | | | | | | | | | | | | | | | | |
| S=O | 1015-1030 | Y | Y | Y | Y | Y | Y | Y | Y | Y | Y | Y | Y | Y | Y | Y | Y | Y | Y | Y | Y | Y |
| SBS | 699 | | | Y | | | Y | Y | | Y | Y | | | | | Y | | | | | | |
| SBS | 966 | | | Y | | | Y | Y | | Y | Y | | | | | Y | | | | | | |
| SBS | 908-910 | | | Y | | | Y | Y | | | | | | | | Y | | | | | | |
| vulstof? | 1647 | | | | | Y | | | | | | | | | | | | | | | | |
| vulstof? | 1087-1093 | | | | | Y | | | Y | | | | | | | | | | | | | |

Y=peak detected, orange background: aging related, blue: SBS polymer, white: potentially filler related

As can be seen, only SBS modifications are found, in six of the samples. All samples show evidence of aging-related chemical bonds and most of CaO that could be filler related.

#### *3.6.2.2.3 ACID NUMBER*

The additional test carried out on the bitumen by BASt Hirsch, 2017a include the acid number test. This test determines the content of carboxylic acid functions in the bitumen. Since calcium hydroxide reacts with the functional groups in the bitumen that contain oxygen, and mostly with the acidic components Lesueur et al., 2012, this tests provides information on the amount of groups available to interact with the calcium hydroxide. For this reason, this test and its result will also be discussed in the section about additional tests for the filler.

The total acid number (TAN) is a standard test for the characterisation of crude oil, where high acid levels can lead to corrosion problems. Different crude oils will have different acid levels and these can further increase during oxidation.
In this test, the bitumen sample is dissolved in a mixture of chlorobenzene and ethanol. Then an alkaline solution, specifically a 0.1 solution (KOH), is added to the bitumen solution at a carefully controlled rate. The free ions from the acid bitumen solutions react with the basic ions from the alkaline solution. This reduces the amount of ions, changing the electric potential. This change is measured and from the amount of alkaline solution needed to neutralize the acids in the bitumen solution, the amount of acidic groups in the bitumen can be computed. The test is carried out according to the test method proposed by WG2 of CEN TC 336, for details see Hirsch, 2017a.

The results are shown in Figure 3.31. Roughly, the PMB binders show a higher acidity on average, (exceptions are Location 3a and the fresh bitumens) both for the reference materials (with the exception of Q8 70/100) and for the test section. The test sections typically show a higher acidity than the reference materials, which is consistent with aging (oxidation) and possibly polymer degradation. However, the results are not so consistent that it provides a time line or frame of reference.

What is unclear in this analysis is how relevant this test is for non-fresh bitumen. Once mixed with the filler, reaction with the $Ca(OH)_2$ would take place. It is unclear if this would lead to a reduction in the acid groups detected in the test after reclaiming the bitumen. If so, low acid numbers in the reclaimed bitumen samples can indicate a high content of reactive filler or a low natural acid content. If it matches with a low carbon hydroxide of the reclaimed filler, it could point a less acidic bitumen interacting with an active filler, or an acidic bitumen combined with a low amount of active filler.

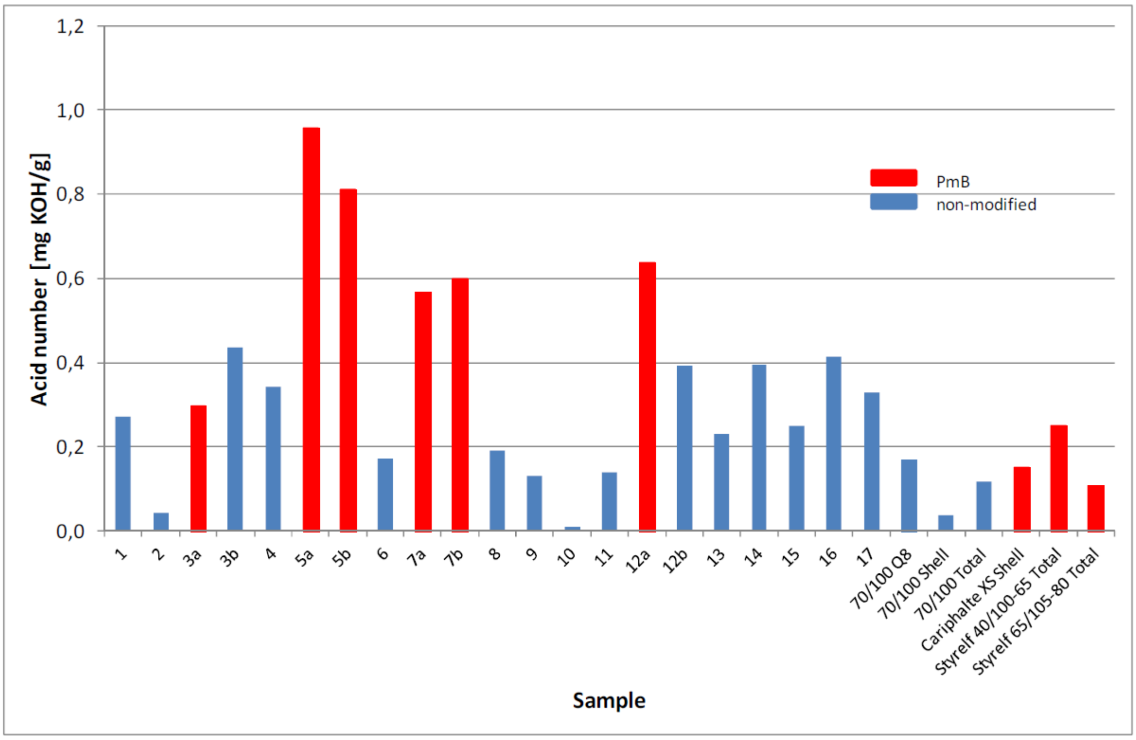



Figure 3.31: Acid number results per Location Hirsch, 2017a

### *3.6.2.2.4 SARA-ANALYSES*

It is not quite clear how the samples relate to locations of the field cores, there are 17 locations, 4 are 2L-ZOAB (leaving 13 top layers), two sets of 10 samples are discussed in the report from the university of Kessel Simnofske et al., 2018. Because of this, the results are not further discussed here.

### *3.6.2.2.5 ELEMENT ANALYSIS*

The element analyses gives the content of a number of elements in the bitumen. These were not sufficient to link the binders to specific sources. What did show up clearly, is the higher Ca content in the reclaimed bitumen compared to the reference materials (Figure 3.32). This is attributed to the interaction with the filler and will be discussed in that Section3.7.

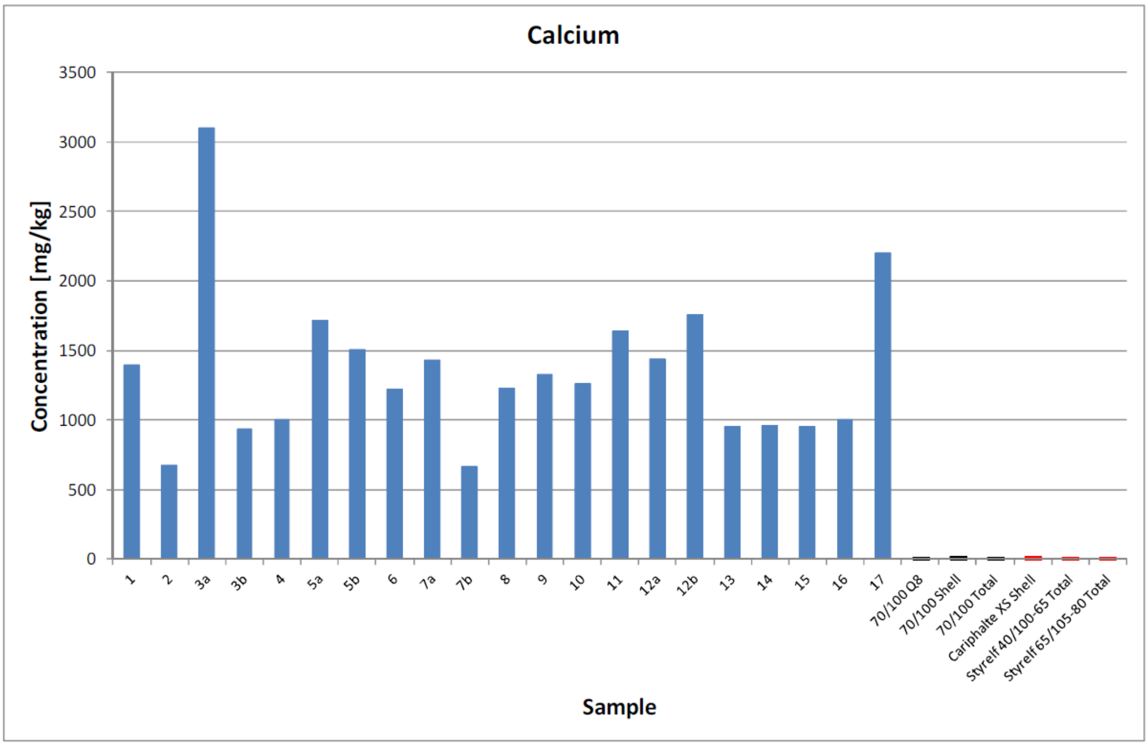



Figure 3.32: Calcium content in the reclaimed and reference bitumen

## 3.6.2.3 Summary of the non-standard tests regarding PMB detection

In the non-standard test, several addressed the presence of polymers. The most detailed were the TNO FTIR analyses (Section3.6.2.2.2.2), but also the BASt MSCR test (Section 3.6.2.2.1), FTIR (Section 3.6.2.2.2.1)and the BAST acid number test (Section 3.6.2.2.3) addressed this.

Table 3.15: Overview of polymer modification indications of the various additional test methods

| WAVE NR (CM-1) | what | L1 | L2 | L3A | L3B | L4 | L5A | L5B | L6 | L7A | L7B | L8 | L9 | L10 | L11 | L12A | L12B | L13 | L14 | L15 | L16 | L17 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| FTIR-TNO | APP | | | | | | | | | | | | | | | | | | | | | |
| FTIR-TNO | C=O/ EVA? | Y | Y | Y | | | | | | Y | Y | | | | | Y | Y | Y | Y | Y | Y | Y |
| FTIR-TNO | EVA | | | | | | | | | | | | | | | | | | | | | |
| FTIR-TNO | SBS | | | Y | | | Y | Y | | Y | Y | | | | | Y | | | | | | |
| MSCR BASt | PMB | | | Y | | | Y | Y | | Y | Y | | | | | Y | | | | | | |
| acidnr BASt | PMB | | | Y | | | Y | | | Y | Y | | | | | Y | | | | | | |
| Project docs | PMB | | | Y[22] | [23] | | Y[24] | [25] | | Y[13] | -[14] | | | | | Y[26] | Y[15] | | | | | |

A summary is presented in Table 3.15 . As can be seen, all methods indicate that 3A, 5A, 7A and B and 12A were polymers. The TNO FTIR analyses also included a peak that could be either EVA modification or C=O, which is present in many cases and most probably shows C=O, because the other potential EVA peak is not present in any of these materials. From the TNO analyses, it can be seen that these are mostly SBS modifications, no EVA and APP modifications were found.

As can be seen in the comparison with the project documentation, in one case (7B) the tests all indicate the presence of polymers while the project documentation says it does not contain modification. In another case (12B) the project documentation states that PMB is used, while none of the tests indicate the presence of the polymer. It is unlikely that this is due to an error in the tests, since they do pick up the PMB modification in the top layer (12A), which is the same type of PMB according to the project documentation.

## *3.7 Tests related to filler content or properties*

The standard tests in this case deal with the amount of filler sized material (<063μm) and the amount of calcium hydroxide still present in that material. The former is determined by Kiwa KOAC (2017), the latter both by them, by BASt (Hirsch, 2017b) and by CorePower (Hellman, 2018b). Additionally, BASt and CorePower did other tests, such as the bitumen acid number (which is related to the potential for interaction with active filler groups) and a detailed analyses of the reclaimed filler particles. All these tests are presented and discussed in this section.

### 3.7.1 Standard tests

#### 3.7.1.1 Quantity of filler-sized material

The percentage of reclaimed minerals passing the 63μm sieve is given as part of the total grading in Section 3.4. These all fall between the required 2-10%, but it must be noted that the filler content found in Location 7B is very low (2,6%), while the mixture was designed to have a filler content of 4,5%.

22 Three mixture sheets provided, all contained Cariphalte XS
23 Three mixture sheets provided, all with pen grade 70/100
24 One PA 8, with PMB, type not specified
25 One PA 16 bottom-layer 2L-ZOAB 18, pen grade 70/100
26 Styrelf PMB

An overview is shown in Table 3.16 and Figure 3.33.

Table 3.16: Average (n=3) mass percentage material <0,063mm per location

| | **<0,063mm [m/m%]** | | **<0,063mm [m/m%]** |
|---|---|---|---|
| Location 1 | 5,9 | Location 8 | 5,3 |
| Location 2 | 4,8 | Location 9 | 6,2 |
| Location 3A | 6,1 | Location 10 | 5,4 |
| Location 3B | 4,8 | Location 11 | 6,2 |
| Location 4 | 5,3 | Loc 12A | 7,5 |
| Loc 5A | 6,6 | Loc 12B | 5 |
| Loc 5B | 5 | Loc 13 | 6,8 |
| Loc 6 | 5,8 | Loc 14 | 5,7 |
| Loc 7A | 6,7 | Loc 15 | 5,6 |
| Loc 7B | 2,6 | Loc 16 | 6 |
| | | Loc 17 | 5,7 |

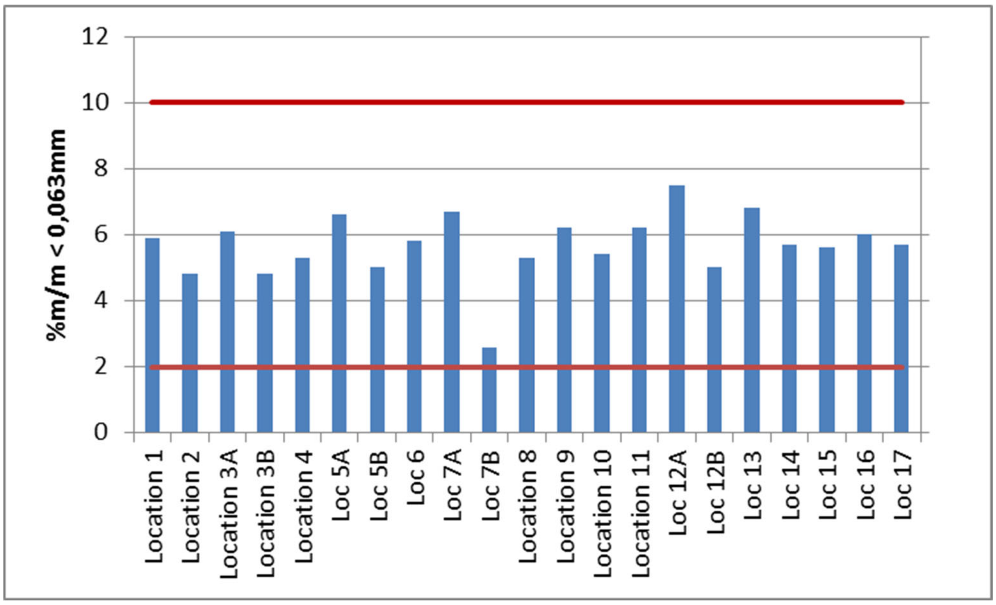


Figure 3.33: Average amount (m/m%) of material < 0,063mm per location (n=3)

As indicated in Section 2.2.4, the type of filler to be used in all these PA mixtures is a middle type filler with hydroxide. The amount of calcium hydroxide in this filler has to be at least 25% m/m according to NEN-EN 459-2. Testing for the calcium hydroxide content is, despite the fact that it is a requirement, not standard. For this reason, this topic is addressed in the next section, about non-standard tests.

### 3.7.2 Additional tests

Despite the requirement to use fabricated fillers, there are currently no standard tests to assess what kind of filler is used. The use of fabricated fillers is focussed on the presence of $Ca(OH)_2$, which is considered to have a positive effect on the life time of the asphalt mixture (see underneath). In order to be able to assess the type of filler and the presence and amount of $Ca(OH)_2$, additional tests were carried out. An overview of the various additional tests that were carried out is given in Table 3.17.

Table 3.17: Overview of filler tests carried out

| Properties/Parameter | Methods | Protocol used | Described in |
|---|---|---|---|
| Particle size distribution | Laser scattered light method | DIN EN 725-5 | Hirsch, 2017b |
| Microscopic analysis | Digital microscopy | In-house method | Hirsch, 2017b |
| Calcium hydroxide | Titrimetry | EN 459-2 und TPGestein-StB Teil 3.9 | Hirsch, 2017b, 2019b |
| Calciumcarbonate | Volumetry | DIN EN ISO 10693 | Hirsch, 2017b |
| Calcium hydroxide/Calciumcarbonate | Thermogravimetry | In-house method | Hirsch, 2017b |
| Calcium hydroxide/Calciumcarbonate | Attenuated total reflection– Fourier Transformation Infrared Spectroscopy (ATR-FTIR) | Arnold, T.S.; Rozario, J.; Youtcheff, J., New Lime Test for Hot Mix Asphalt Unveiled, FHWA-HRT-07-003 Vol. 70 No. 5, 03/04, 2007 | Hirsch, 2017b |
| Elemental composition of the acid soluble fractions | Inductively coupled plasma – Optical Emission-Spectroscopy (ICP-OES) | Following DIN EN ISO 11885 | Hirsch, 2017b |
| Elemental composition of the acid-insoluble components after aquaregia digestion | Inductively coupled plasma – Optical Emission-Spectroscopy (ICP-OES) | Following DIN EN ISO 11885 | Hirsch, 2017b |
| Filler mineralogy and $Ca(OH)_2$ content | X-ray powder diffraction (XRPD) using the Rietveld method | Own method, limited description in report | Hellman, 2018b, Hellman, 2019 |
| Filler mineralogy | Geochemistry | In-house method, limited description in report | Hellman, 2018b |
| Calcium hydroxide presence | Fourier Transformation Infrared Spectroscopy (FTIR) | TNO method | van Vliet, 2018 |
| Calcium hydroxide amount | Titrimetry | EN 459-2 | Kiwa KOAC, 2017 |

### 3.7.2.1 Filler to bitumen ratio

The filler/bitumen (f/b) ratio can have a significant impact on the performance of asphalt mixtures (Diab et al., 2018). It can be expressed in mass (m/m%) or volume (V/V%) percentages, both are used in literature.

There is no consensus about an optimized f/b ratio. Studies are reporting f\b mass ratios that range between 1.05 and 1.45 for modified bitumen using additives (Qiu et al., 2013) or between 0.33–0.35 (volume ratio's) in the case that the self-healing capacity is taken into account (Zhang et al., 2019). Nevertheless, other factors such as the filler size and size distribution, shape, texture, the surface area

of the filler particles and the void content of filler appear to be more critical in relation to the filler's influence on bitumen than the f/b ratio (Faheem et al., 2010).
Although the literature does not give an answer as to an optimum f/b ratio in many cases it is given as (just) over 1 (m/m%), which is close to the average values found based on the requirements in the RAW Standard (Table 3.18).

Figure 3.34 shows the filler/bitumen ratio (m/m%) for all specimen locations. Location 7B has the lowest f/b ratio, which can be explained by the low filler content as shown in Table 3.12, increasing the likelihood that this mixture is more susceptible to fatigue, rutting, moisture and ageing. According to the product specifications for Location 7b, the f/b ratio should be 0,96, which is already on the low side. In reality in the cores it was found to be only just over 0,6.

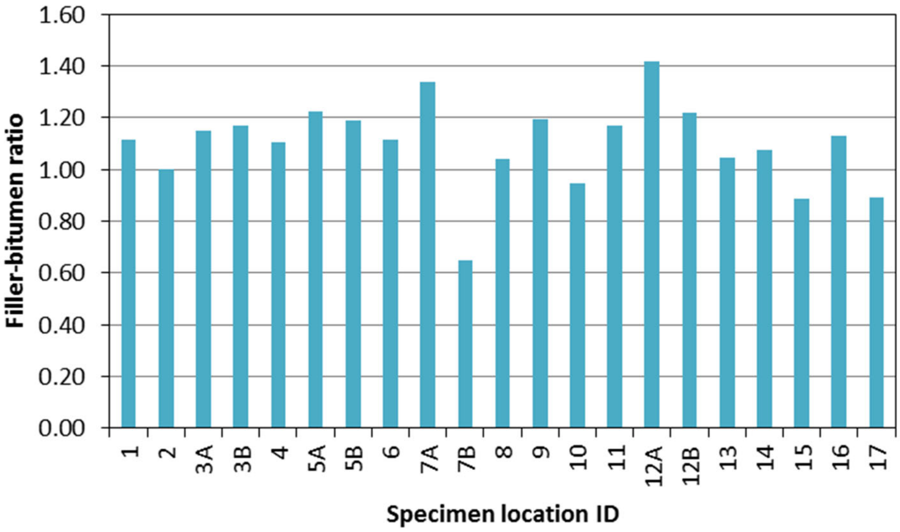



Figure 3.34: Results on the filler-bitumen ratio based on the average filler and bitumen content values in Table 3.16 and Table 3.12

Based on the requirements for the various ZOAB mixtures in the RAW Standard CROW, Standaard 2015, 2015, the average f/b ratio (m/m%) varies between 1,11 and 1,43 (Table 3.18). Assuming that all aggregates have a density of 2650 kg/m$^3$ and the bitumen is 1030 kg/m$^3$, the DZOAB 16 f/b volume ratio falls between 0,15 and 0,75 with an average of 0,45.

Table 3.18: Ratio's for f/b based on the requirements for various ZOAB mixtures CROW, Standaard 2015 (2015)

| **Mixture** | **ZOAB 16** | **DZOAB 16** | **2L-ZOAB 16** | **2L-ZOAB 8** |
|---|---|---|---|---|
| **Filler** | 2-10 | 2-10 | 2-10 | 2-10 |
| **bit** | 4,5 | 5,2 | 4,2 | 5,4 |
| **f/b min** | 0,44 | 0,38 | 0,48 | 0,37 |
| **f/b max** | 2,22 | 1,92 | 2,38 | 1,85 |
| **f/b average** | **1,33** | **1,15** | **1,43** | **1,11** |

### 3.7.2.2 Size distribution and microscopic analysis

In these tests the size distribution of the fillers and their particle shapes is studied. For these tests both fresh fillers, which are allowed to have an amount of material larger than 0,063 mm, and reclaimed filler, which is the fraction < 0,063 mm from the reclaimed mineral aggregate from asphalt cores were used.

The tests showed a difference in size distribution between Wigro and Wigro 60K on the one hand and Rhecom 60 on the other hand. Rhecom 60 showed a considerable amount of very fine glass pearls in its shapes, which were not so common in the other fillers Hirsch, 2017b. These results gave some possible groupings of the fillers and reference fillers, but it was not definite. Wigro and Wigro 60k fell into one group, together with the filler from location 12A, Rhecom 60 feel into a group together with the fillers from location 14 and the other reclaimed fillers were divided into an additional three groups. For this reason, this test does not seem to be promising as a tool to assess the type of filler used from cores taken after construction. The microscopic analyses also allowed for the division of the reclaimed fillers into groups (six), but these did not include the reference fillers.

## 3.7.2.3 Calcium hydroxide content of the filler fraction

The reason that the presence and amount of calcium hydroxide is specified, lies in the specific advantages of this material when applied in asphalt mixtures. Initially used as a means to reduce the sensitivity to moisture damage by improving the adhesion between bitumen and aggregates, there are experiences that indicate that it also reduces the resistance to chemical aging and improves mechanical properties (stiffness, strength, rutting resistance and thermal cracking resistance). Field experience from North America suggests that calcium hydroxide at the usual rate of 1-1.5% in the mixture (based on dry aggregate mass) increases the durability of asphalt mixtures by 2 to 10 years Lesueur et al., 2012. In the next section the background of the expected benefits of calcium hydroxide is discussed based on existing literature.

### *3.7.2.3.1 Existing work on the effect of $Ca(OH)_2$*

#### 3.7.2.3.1.1 Resistance to aging

Regarding aging, it is suggested by Lesueur et al., 2012 that the interaction between bitumen acid groups and $Ca(OH)_2$ effectively neutralize the polar molecules, because they stay strongly adsorpted to the calcium hydroxide. Since these polar groups age easily, the neutralisation by the $Ca(OH)_2$ effectively retards the aging.

In literature, there are a lot of studies that investigated the effect of mineral fillers on ageing of bitumen. Han, 2011 reported that the presence of mineral filler in mastics may mitigate the oxidation of bitumen in two possible ways: *(i)* the mineral filler is less permeable to air and therefore it forces the oxygen molecules to follow a spiral trajectory through bitumen, thus lengthening the diffusion path and reducing the rate of age-hardening of bitumen and, *(ii)* the addition of mineral filler increases the binder viscosity, thus leading to further hindrance of the oxygen diffusion process. Moreover, the potential chemical interactions between the filler and bitumen can also affect ageing of bitumen. On one hand, the existence of certain mineral components on their surface may catalyse the oxidation of bitumen Petersen et al., 1974.

On the other hand, an adsorption mechanism may occur according to which the polar functional groups, (either coming from the chemical structure of bitumen or from the oxidation products) are adsorbed and immobilized at the mineral fillers' surface, thus decelerating the ageing process Wu, 2009.

Past studies have highlighted the mitigating effect of fillers on bitumen ageing. Those studies have used a great variety of filler and bitumen types as well as evaluation methods such as DSR, FTIR, gel permeation chromatography (GPC), differential scanning calorimetry (DSC). The studies concluded that the addition of mineral filler decelerated the ageing of mastics compared to the reference bitumen. Curtis et al., 1993, reported that the presence of mineral filler decreases the rate of the binder's viscosity build-up when compared to pen grade bitumen under the same ageing conditions.

Wu, 2009 also concluded that the presence of mineral filler delays the age-stiffening of the bitumen. He also attributed the mitigating effect to the adsorption of bitumen polar functional groups on the fillers' surface. Moreover, he suggested that upon extraction and recovery of bitumen a substantial portion of these adsorbed components cannot be recovered, which is in line with the findings of Petersen et al., 1974. Similar, observations are also reported by BASt Hirsch, 2017c as shown in Figure 3.42. In this case, it is hypothesized that it is the chemical interaction between the bitumen and the active filler with hydroxide that causes bitumen to be bound to calcium hydroxide and to calcium carbonate, to such an extent that it is not completely removed by the normal reclaiming processes.

Moreover, Moraes et al., 2015 made a comparison between mastics with limestone (calcium carbonate) and granite (at equal mineral filler concentration by volume). The ageing index was given as the ratio of |G*| after 24 h of PAV ageing at 20 atm and 100°C and at fresh conditions. Two ageing indices were calculated: the first with |G*| at 10°C and 30 Hz (representing lower temperature or higher traffic speed) and the second at 40°C and 0.1 Hz (representing higher temperature or slower traffic speed). The study showed that granite delayed the ageing process more effectively (Figure 3.35). This was attributed to the larger (by a factor two) specific surface area of granite filler leading to a more pronounced asphaltenes adsorption effect. Specifically, they concluded that when the contact area between the filler particles and bitumen increases, by either a higher specific surface area or increased mineral filler volume fraction, the asphaltenes (polar groups) adsorption on the fillers' surface becomes more intense and leads to an overall softening of the bulk material.

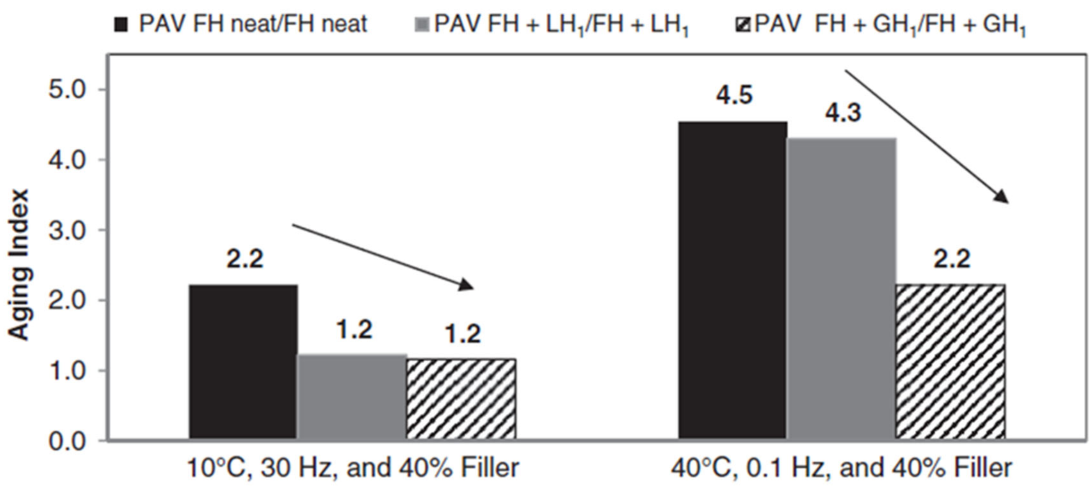



Figure 3.35: Ageing indices of neat bitumen (FH: Flint Hills PG64-22) and mastics prepared with FH neat bitumen and limestone ($LH_1$ at 40% by volume) or granite ($GH_1$ at 40% by volume) filler (Moraes & Bahia 2015a).

Numerous laboratory studies and field evaluations have demonstrated the ability of calcium hydroxide to reduce the ageing susceptibility of bitumen, amongst other special features it provides to asphalt mixtures (Lesueur et al., 2012). Plancher et al., 1976 explained the mechanism through the adsorption of highly polar functional groups of bitumen on the fillers' surface as described above.

More recently, Alfaqawi et al., 2017 studied the effect of three types of mineral fillers namely granite, limestone and hydrated lime (all three fillers were substantially finer than 63µm in particle size) on the ageing susceptibility of mastics. The mastics were prepared using a pen grade 40/60 bitumen and granite or limestone fillers in 1:1 ratio by mass. Moreover, 10% and 20% by mass of the filler (granite or limestone) was replaced by hydrated lime to investigate the influence of lime addition. The mastics were evaluated by means of ageing indices calculated through the complex shear modulus values at 20°C and 0.4 Hz before and after ageing (Figure 3.36). The results demonstrated that mastics containing limestone were less aged than mastics with granite. When hydrated lime was added to either of the two base fillers, the ageing indices reduced even more which is in line with the statement of Lesueur et al., 2012 regarding the effectiveness of hydrated lime in decelerating the ageing process. This seems contradictory to the results of Moraes et al. (2015) discussed above, which found the opposite: granite mastics were less aged. However, the fillers used for both studies had different surface areas. In Moraes et al., granite filler has double the surface area of the limestone, while in Alfaqawi et al., it is the granite which has a slightly lower surface area than the limestone filler. Considering the importance of the surface area in relation to the physicochemical interactions, it makes the studies incomparable.

In a recent study Mastoras, 2019, concluded that the mineral fillers Wigro 60K (limestone + 25wt% calcium hydroxide) and Wigro (limestone) led to similar ageing levels for the mastics (Figure 3.37). The positive effect of the addition of calcium hydroxide on ageing was not confirmed in this study. However, the results of these two studies can, unfortunately, also not be directly compared. In this case for two reasons:

- first in the study by Mastoras, 2019 the mastics were not subjected to short-term ageing before PAV ageing, and
- the results are reported at the same temperature but at different frequencies.

This shows that the bitumen-filler interaction is determined by a number of interacting variables, of which filler composition is only one.

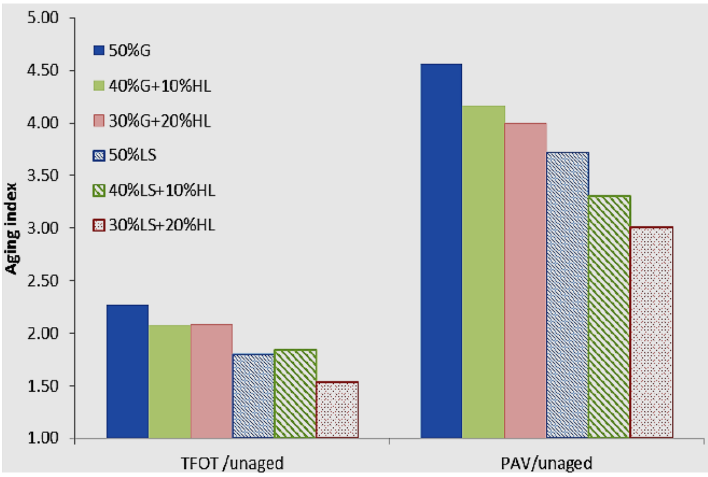



Figure 3.36: Ageing indices of granite and limestone mastics with and without the addition of hydrated lime. Two ageing conditions were considered: TFOT ageing at 163°C for 5 hours and PAV ageing for 20 hours at 90°C following the TFOT27 oven ageing. (Alfaqawi et al., 2017).

27 The TFOT is basically an oven, it simulates short-term aging by heating a film bitumen for 5 hours at 163 C

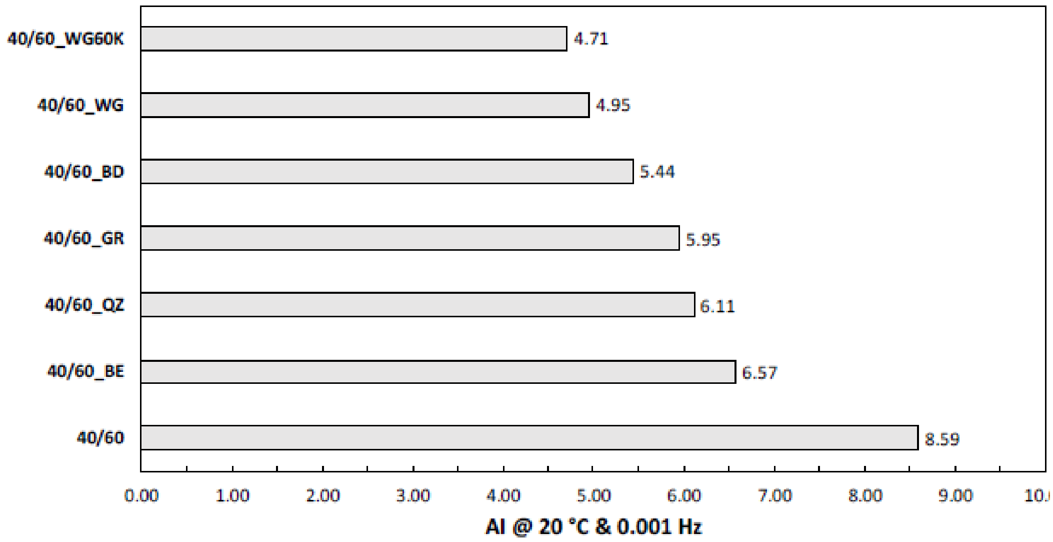



Figure 3.37: Ageing indices (AI) for mastics prepared with pen grade 40/60 bitumen and Wigro 60k (WG60K), Wigro (WG), Baghouse dust (BD), Granite (GR), Quartz (QZ) and Bestone (BE) fillers in a 1:1 ratio by mass28.

Calcium hydroxide can degrade over time due to the chemical interaction with the bitumen or with air ($CO_2$). Specifically, calcium hydroxide can react with ($CO_2$) at ambient conditions to form calcium carbonate (and release water) according to the following equation:

$$Ca(OH)_2 + CO_2 \rightarrow CaCO_3 + H_20 \quad (3.1)$$

Sibelco, the filler supplier company, has studied the loss of $Ca(OH)_2$ over time of a hydrated lime "filler" with 95% m/m $Ca(OH)_2$ exposed to the air. Figure 3.38 shows that 70% of the calcium hydroxide is lost after two months of exposure in air at room temperature, probably due to the reaction with $CO_2$ in the air. Hirsch, 2017c performed a similar test on a Wigro 60K filler with 25% $Ca(OH)_2$ by mass. The filler was stored in air under ambient laboratory conditions for 22 days. At various time intervals the filler was tested using thermogravimetric analysis. Figure 3.39 shows that the exposure of Wigro 60K filler in open air does not lead to a noticeable reduction in the calcium hydroxide content at the specified time interval. According to the results of Sibelco, it can be observed that around 40% of $Ca(OH)_2$ is lost in the first month, which is not the case for the study done by Hirsch, 2017c. However, the materials used in the two studies were different; in Wigro 60K 75% is limestone particles mixed with 25% calcium hydroxide while the filler tested by Sibelco was almost pure (approx. 95%) $Ca(OH)_2$. The filler composition of the Wigro 60K (calcium hydroxide embedded in limestone particles), together with the different timeframe that the fillers were exposed in open air, can explain the minimal degradation process of $Ca(OH)_2$ due to $CO_2$ reaction for the study done by Hirsch, 2017c.

Mastoras, 2019 investigated the degradation of $Ca(OH)_2$ due to the physico-chemical interaction with bitumen. In his study, he has tested the recovered filler from mastics that were prior aged in PAV (Pressure Ageing Vessel) at 90°C temperature and 2.1 MPa (~300 psi) air pressure for 20 hours. The FT-IR results (Figure 3.40) showed no degradation of the $Ca(OH)_2$ after ageing as indicated by the characteristic peak (narrow absorption band at 3642 $cm^{-1}$ due to stretching mode of O-H) present in the original and recovered filler samples. These results are not in agreement with the reduced $Ca(OH)_2$ values that were found in the recovered fillers from field cores at the various locations. (Figure 3.38). This may be explained by the fact that the PAV ageing protocol involves conditioning at high

28 The ageing index used here is the ratio of the complex shear modulus at fresh (unaged) and aged conditions at 20°C and 0.001 Hz (Mastoras, 2019)

temperatures and pressures, but does not consider humidity, which is present in the atmosphere and is expected to affect the $Ca(OH)_2$ degradation. Also effects of loading (both by traffic and low temperatures), which may lead to damage and increased access of oxygen and moisture, is not included. It is therefore recommended that a combined moisture-ageing protocol is used to study $Ca(OH)_2$ degradation in mastics or asphalt mixtures.

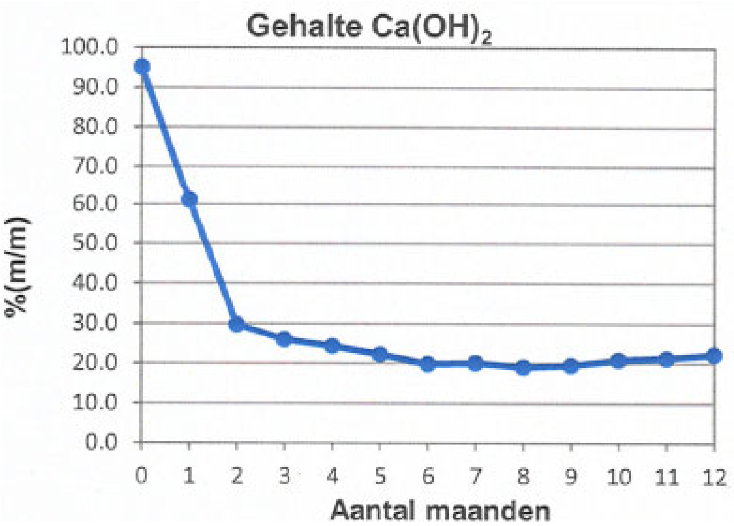



**Figure 3.38: Decrease of calcium hydrate (appox. 95% $Ca(OH)_2$) over time under laboratory conditions (Sibelco, 2014).**

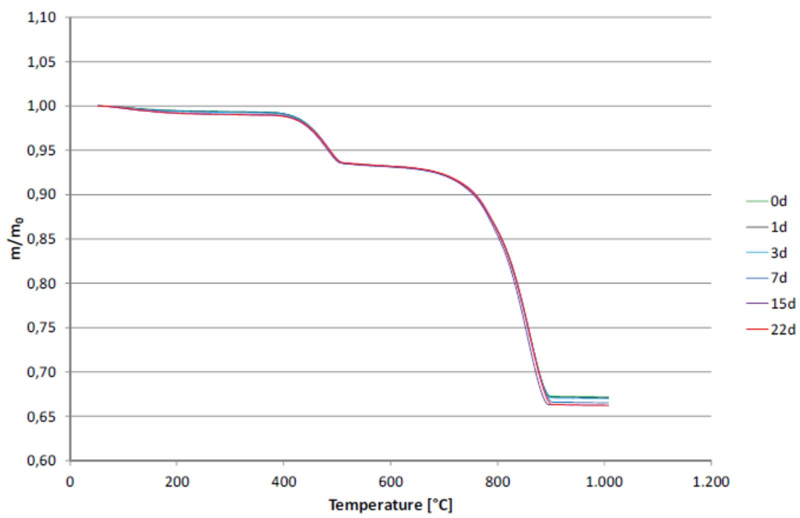



**Figure 3.39 Thermogravimetry (TGA) analysis results of Wigro 60K (25% $Ca(OH)_2$ over a period of 22 days under laboratory conditions Hirsch, 2017c**

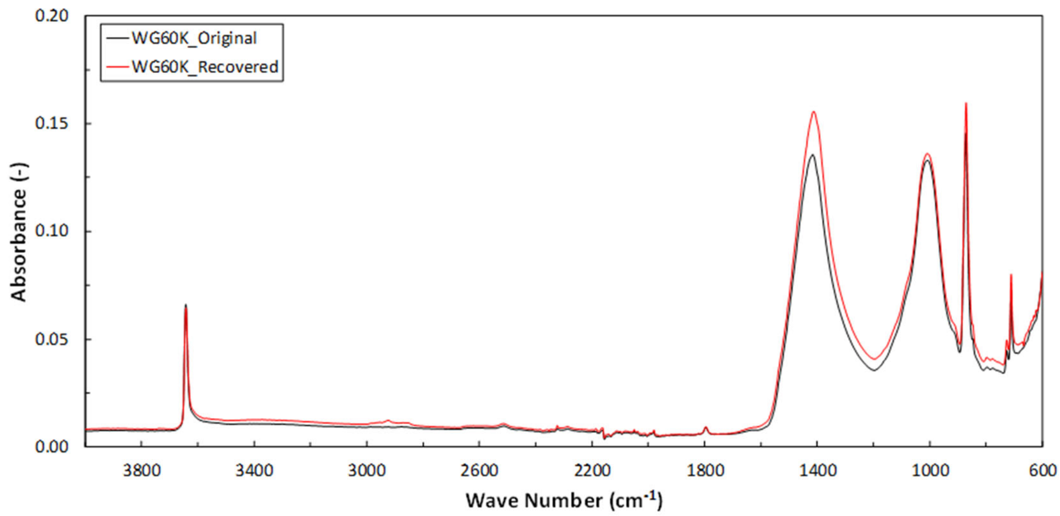



**Figure 3.40: Fourier Transform infrared (FT-IR) spectra of the original and recovered (after PAV ageing) mineral filler Wigro 60K Mastoras, 2019**

### 3.7.2.3.1.2 Moisture resistance

For moisture resistance, the effect of active versus non-active filler and the effect of the PMB has been studied in detail Kringos et al., 2010,Scarpas et al., 2007,Varveri, 2017. In the first of these studies, direct tension tests were carried out on specimens consisting of a thin layer of mastic (100 mm diameter, 4 mm thickness) attached to a stone disk (150 mm diameter and 20 mm of thickness).

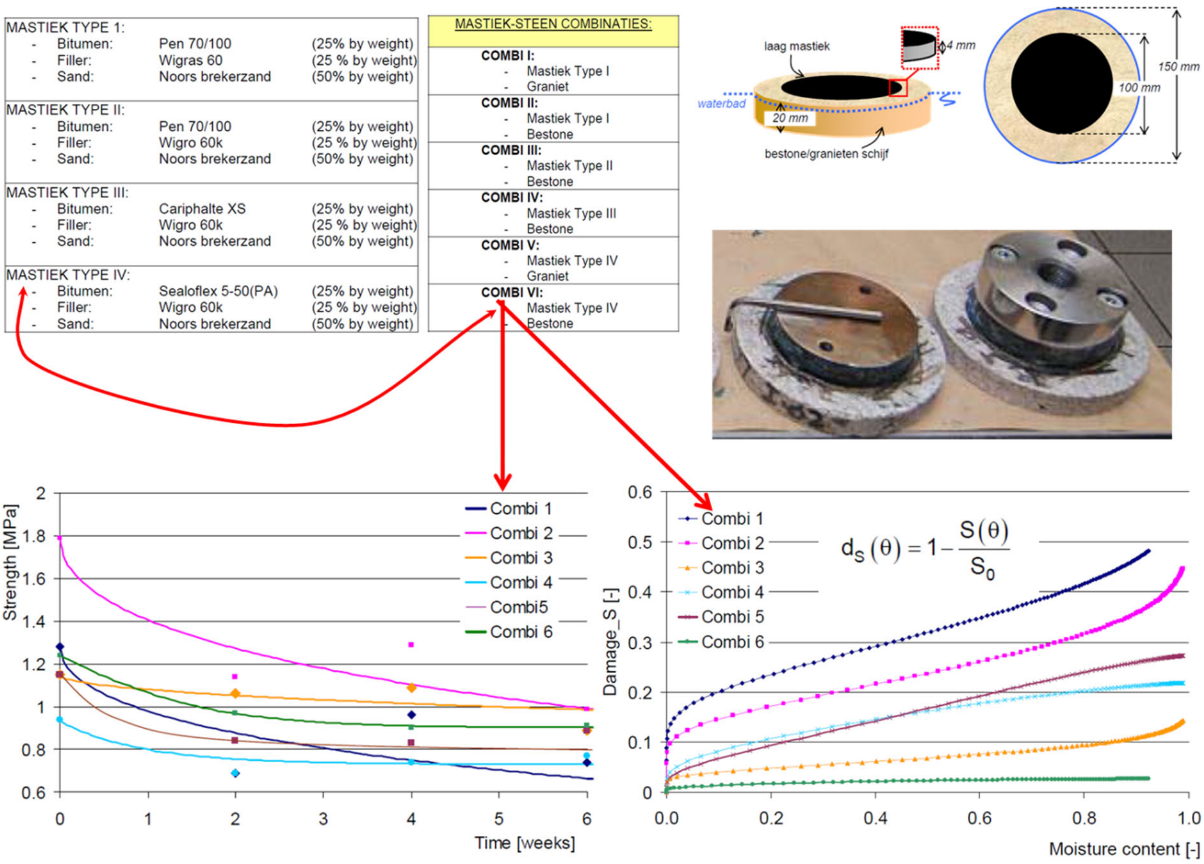



Figure 3.41: Effect of active filler on moisture sensitivity (compare combi II and III)

The stone disks were placed in a water bath, allowing water to penetrate the stone and eventually reach the stone-mastic contact surface. Various combinations of mastic and stone were used, two of the mastics used pen grade 70/100 bitumen and Wigras 60 or Wigro 60K filler, the other two were PMBs with Wigro 60K. These were combined with either Bestone of granite. Combi II and III exist of Bestone with either mastic I (pen grade 70/100 bitumen and Wigras 60) or mastic II (pen grade 70/100 bitumen with Wigro 60K). The graph on the left shows the tensile strength as a function of time in the water bath. As can be seen, combi's 1, 3,5 and 6 have comparable initial strengths, with Combi 2 higher and Combi 4 lower. The graph on the right shows the reduction of the initial strength (as a factor) as a function of the moisture content. It can be seen that the two combinations with mastic I lose strength faster due to moisture than the combinations with active filler.

The adsorption of polar molecules (acid groups) to the $Ca(OH)_2$ prevents them from diffusing to the bitumen/aggregate surface, leaving only non-acidic surfactants to move to this surface. These are usually amine-based and not easily displaced by water, which explains the decreased moisture sensitivity Lesueur et al., 2012. Although interesting and supporting both the previous work described and the attention for the presence of $Ca(OH)_2$ in this study, it does not relate directly to the materials studied here since their resistance to moisture has not been tested after sampling.The cores that were CT scanned are still available at TUD and could potentially be used to assess the moisture sensitivity to compare it to the $Ca(OH)_2$ values found.

### 3.7.2.4 Additional tests

The additional tests discussed in this section aim to determine the presence and quantity of $Ca(OH)_2$ in the filler reclaimed from the field cores. It is often hypothesized that bitumen and active filler with hydroxide have a strong chemical and/or physical interaction, which explains its beneficial effects, but also makes it hard to reclaim active filler from the asphalt mixture. In the course of this project this aspect was also investigated Hirsch, 2017c. This showed that bitumen is bound to calcium hydroxide and, to a lesser extent, calcium carbonate, to such an extent that it is not completely removed by the normal reclaiming processes, this is shown for example in Figure 3.42, where it can be seen that some parts of the pores in the filler retain bitumen, reducing the specific surface area. Obviously, this makes it both difficult and crucial to have a reliable and reproducible method of determining the calcium hydroxide content.

It is rather odd that, although there is a requirement to use active filler, there is no standard test available to assess this quantity. As such, any checks upon this part of the specification will currently be based on entrance control through the weighing information from the asphalt plant. This is unfortunate, since it prevents the development of insights and information about the reaction of $Ca(OH)_2$ and its effect on performance over time.

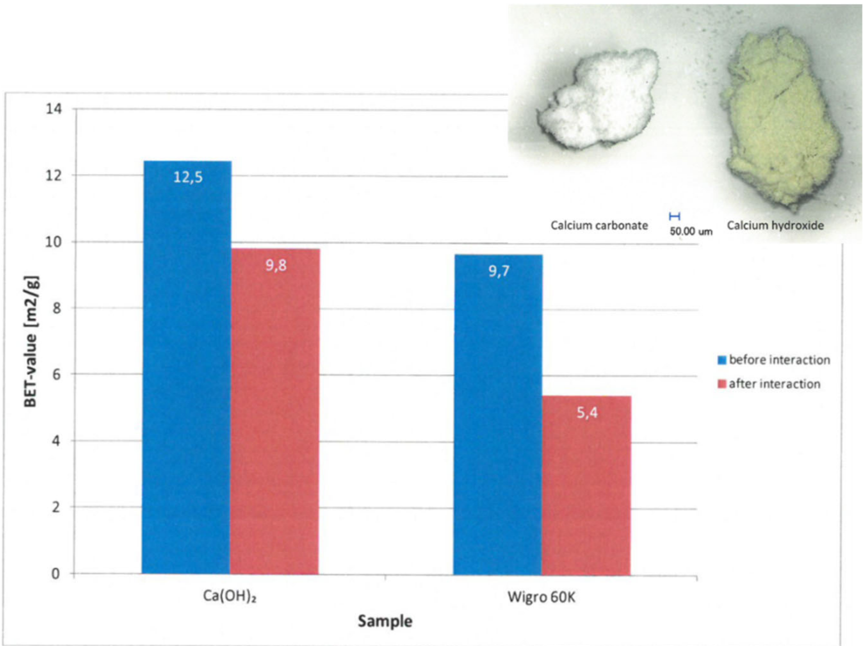



Figure 3.42: Change in surface area of the filler after interaction with bitumen and the visibly remaining bitumen coating on the filler particles Hirsch, 2017c

### 3.7.2.4.1 VOLUMETRY, GRAVIMETRY, THERMOGRAVIMETRY, FTIR AND XRPD-RIETVELD

These tests are used to identify or quantify calcium hydroxide or calcium carbonate, titrimetry is discussed in detail in Section 3.7.2.3. Together with volumetry and gravimetry it allows the various mineral fractions to be identified (Figure 3.43).

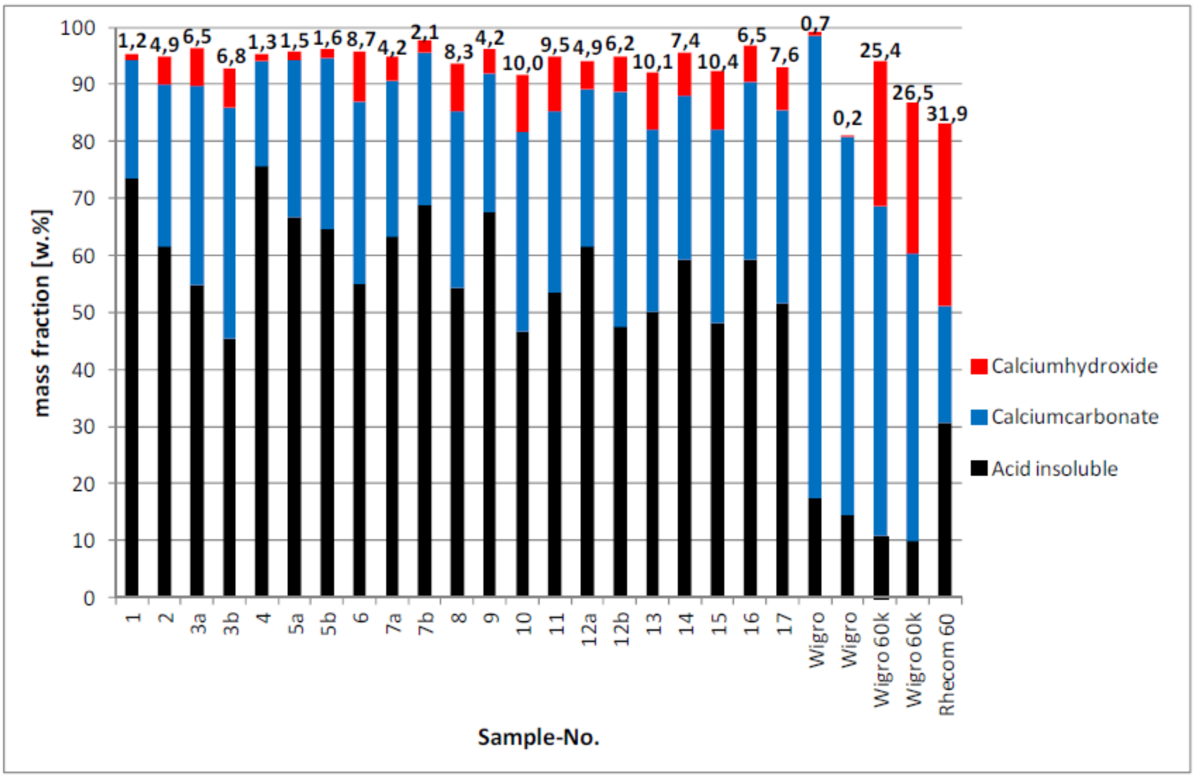



Figure 3.43: Filler composition as found from the combined titrimetric-volumetric-gravimetric methods (numbers above the columns refer to the calcium hydroxide content) Hirsch, 2017b

According to BASt this combined method is accurate, but time consuming, so additionally they applied FTIR and thermogravimetry, which are faster, separately. Unfortunately, no background information on the accuracy (i.e. inter-laboratory or other comparison studies) are cited and in light of the further experience with titrimetry, some caution is appropriate. The fast results are only reported in graphs, not in tables. They seem to give varying answers, see Figure 3.44 and Figure 3.45 for the comparison of thermogravimetry and FTIR determination, respectively, to titrimetry. For this reason and because the raw data is not available, only results are given and the methods are not described in detail (mostly in-house methods), the results are not further discussed here.

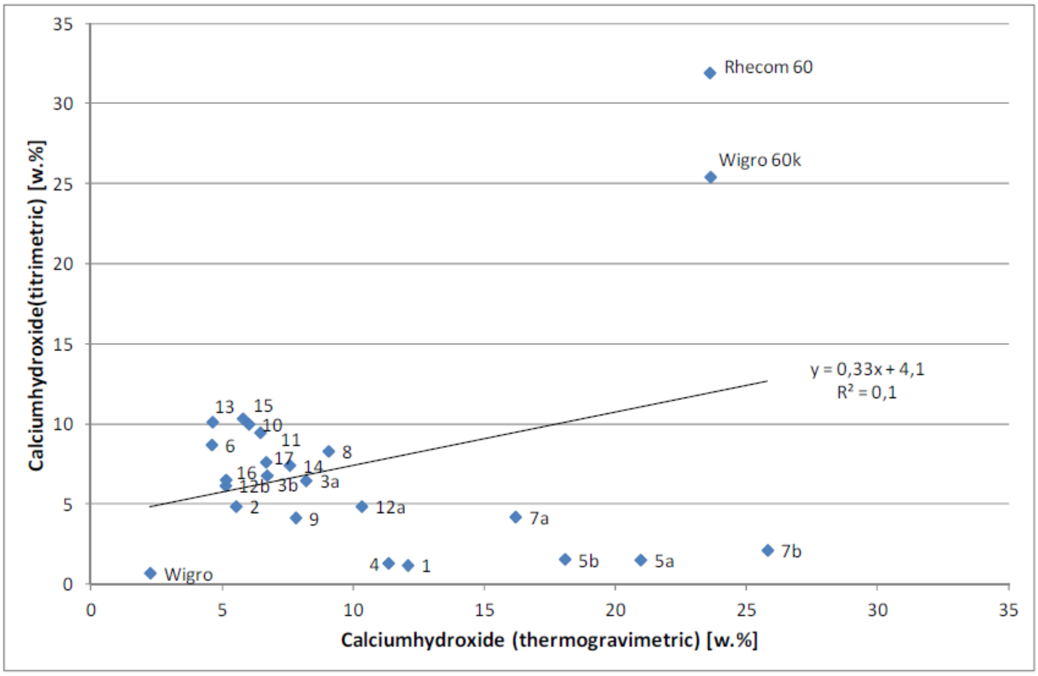



Figure 3.44: Comparison of the Ca(OH)2 content found using titrimetry and thermography Hirsch, 2017b

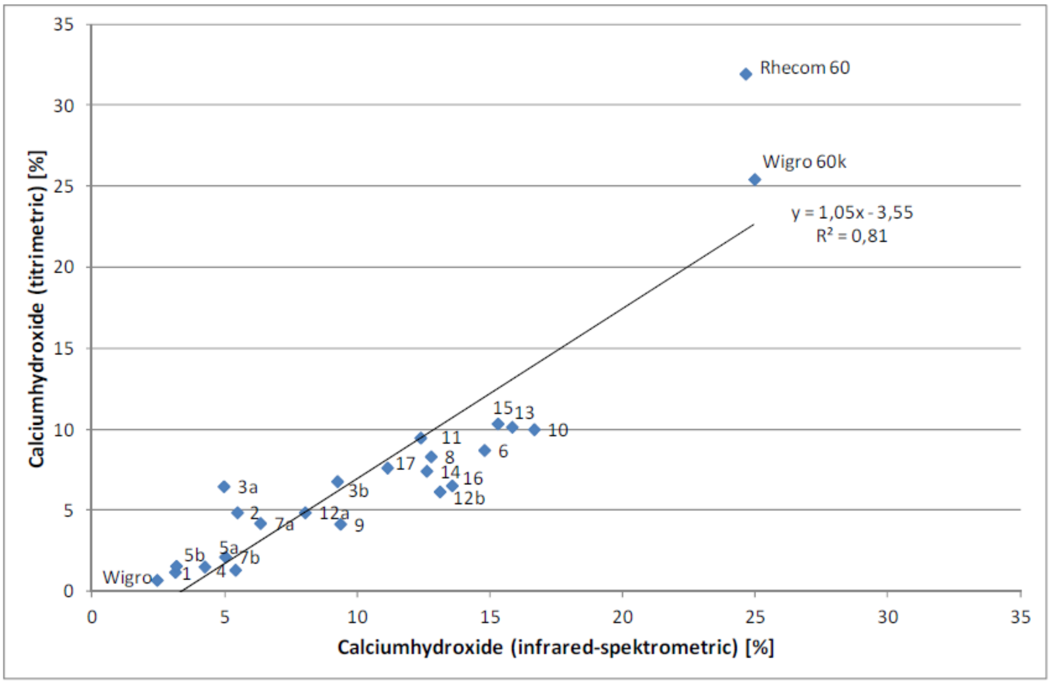



Figure 3.45: Comparison of Ca(OH)2 content found using titrimetry and FTIR Hirsch, 2017b

The overall conclusions by BASt were that the combined method (using titrimetry to determine the $Ca(OH)_2$ content) works well, that the thermogravimetric method is a fast and reliable method to determine the calcium carbonate content and the FTIR can do the same for calcium hydroxide (Figure 3.45).

CorePower conducted X-ray powder diffraction (XRPD) measurements using the Rietveld method (see also Section 3.7.2.5.2 on the Phase 2 filler tests) to interpret the results by linking the signals to specific crystal structures to identify minerals, as well as inductively coupled plasma mass spectrometry (ICP-MS) and inductively coupled plasma atomic emission spectroscopy (ICP-AES) for element analyses. Based on the results, they performed mass balance calculations (see Section 3.7.2.4.3). The XRPD results for the calcium hydroxide content appeared to have a good correlation with the titrimetry (Figure 3.46, left), but to give generally lower values. According to CorePower, this is probably the result of the preparation method used in the XRPD, where ethanol is used which can contain up to 4 volume-% of water, which can react with carbon dioxide in the air to form calcite. This seems to be confirmed by a small set of tests they did on dry-prepared specimens, which give a much closer match to the titrimetry results (Figure 3.46, right). Based on this, their conclusion is that more research is needed to prove the usefulness of the Rietveld method to determine the $Ca(OH)_2$ concentration.

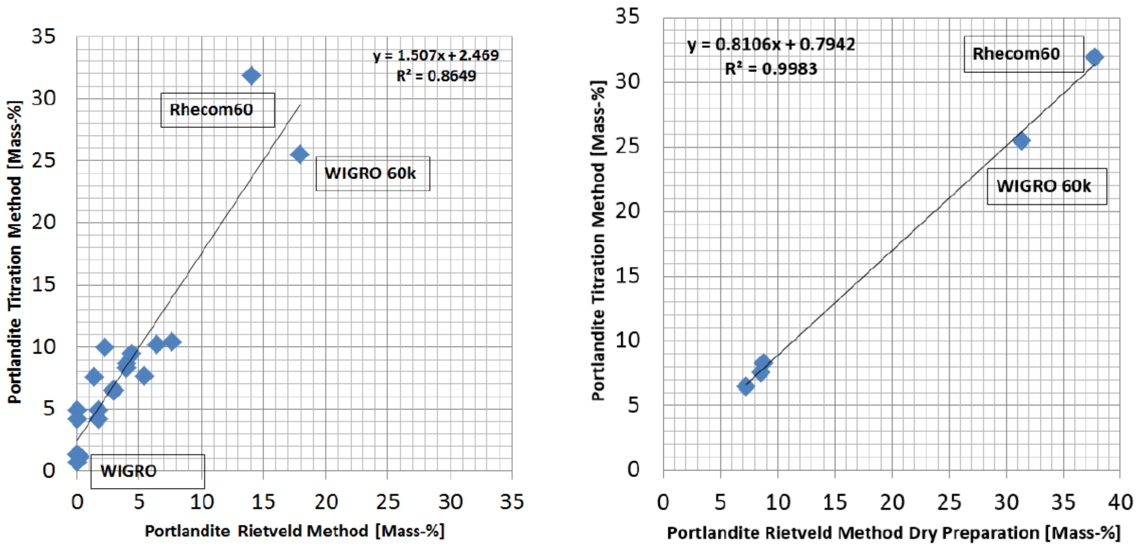



Figure 3.46: XRPD using Rietveld method comparison of $Ca(OH)_2$ content Hellman, 2018b compared to titration Hirsch, 2017b for the wet (left) and dry (right) preparation method in XRPD Hellman, 2018b

It would be interesting to know the protocols and results of especially the FTIR determination of the $Ca(OH)_2$, because it is a fast test and does not require much material. If a reliable quantification is possible, this would be a good test to add to quality control testing instead of or in addition to titrimetry.

Similarly, an indication of the robustness and the required amount of material, effort and costs of using the XRPD would be interesting for the same reasons.

### *3.7.2.4.2 Additional tests: Titrimetry*

For this project, the calcium hydroxide content was determined by two different laboratories, Kiwa KOAC in the Netherlands and BASt in Germany using titrimetry.

There is a European standard for the detection of calcium hydroxide in various lime-based construction materials Mouillet et al., 2014, which uses the alkalinity of calcium hydroxide to determine its quantity. However, what is done here, is the determination of calcium hydroxide in asphalt concrete cores. For this, there are two methods, one is a variation on the EN standard, the other is the use of FTIR on dust from an asphalt core, obtained by drilling a hole in it, developed by FHWA in the USA.

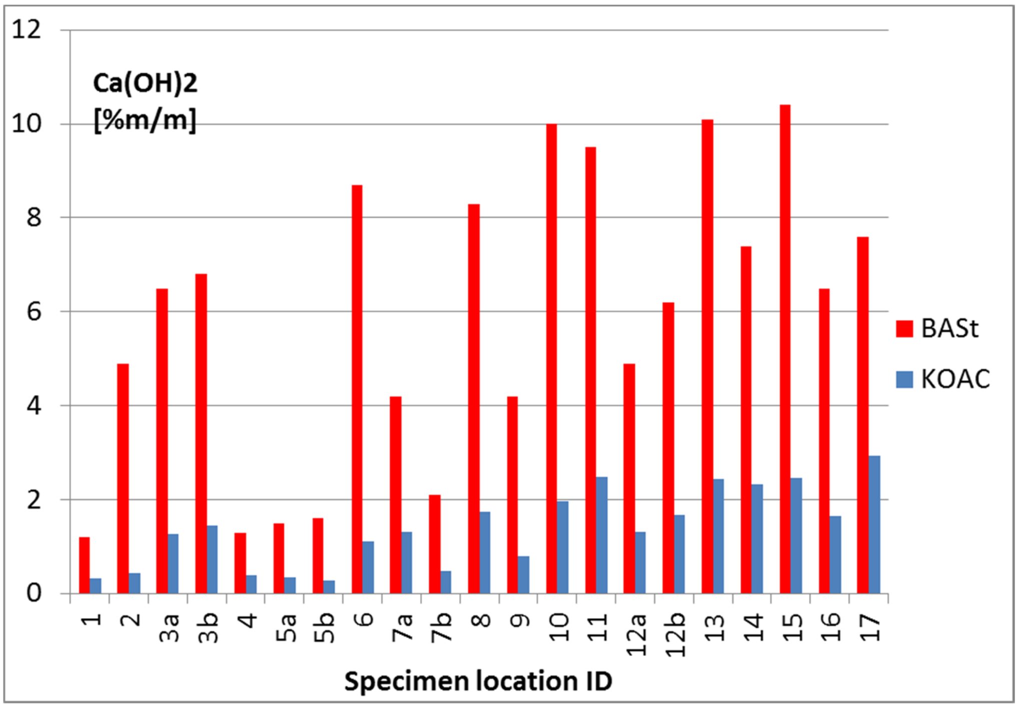



Figure 3.47: Results on the hydrated lime content determined with titrimetry from BASt and Kiwa KOAC

Both labs used the EN standard (EN 459-2) to determine the calcium hydroxide content in the reclaimed filler. The results are plotted in Figure 3.47, as can be seen they are very different. Roughly, there is a factor 4 between the results, but it is not a constant and for some samples (i.e. Location 2) the difference is much larger.

In Mouillet et al., 2014 it is described that to use the EN method on asphalt concrete, first the filler material is reclaimed through solvent extraction of the bitumen (EN 12697-1). Then, the titration from EN 459-2 is used, *but the acid solution is diluted to 0,5M* because of the reduced alkalinity of the filler from the asphalt concrete.

This article includes the description of a Round Robin test involving 37 laboratories from eight different European countries. The procedure was given as:

*The suspension to be titrated is then obtained by blending 1 g of recovered filler to 150 ml of water, 10 ml isobutanol and 5 ml of a surfactant solution (1 g sodium dodecylsulfate and 1 g polyethylene glycol dodecylether in 100 ml water). The surfactant solution is needed only when recovered filler is tested, in order to wash out the filler from remaining bitumen or solvent from bitumen extraction. The coloured indicator is phenolphthalein (0.5 g in 50 ml ethanol, completed to 100 ml by water). Titration rate is 12 ml/min initially, but decreases to 4 ml/min near the equivalence point.*

*Disperse the filler sample in a mixture of water, isobutanol and tenside solution in order to clean the filler (to remove the bitumen and/or the extraction solvent maybe still present). Titrate in the alkaline range the calcium hydroxide content with hydrochloric acid using a method adapted from EN 459-2. But, it has to be noted that for mixed fillers and recovered fillers, it is necessary to determine the blank value of the used filler material.*
*This test method is very simple, easy to perform by all laboratories and unexperienced operators. As 1 mol of $Ca(OH)_2$ reacts with 2 mol of HCl, the calcium hydroxide content expressed as ($Ca(OH)_2$) in mass fraction in %, is given by the following equation:*

$$\% \, Ca(OH)_2 = 100 \, F \, 37{:}05 \, (C_1 \;\; V_{eq})/(1000 \, m_1) \tag{3.2}$$

*where: C1 is the concentration of hydrochloric acid (mol/l) (note: as the concentration of solutions might deviate in time, a corrective factor has to be determined by titration with a base prepared by weighing), Veq is the volume equivalent of hydrochloric acid (ml), $m_1$ is the mass of taken filler sample (g), F is the factor of the acid, being 1 for an acid at the right purity at ambient temperature.*

There were quite a number of errors reported in applying the equation (3.1) in the article, but the determination of $V_{eq}$ was rather accurate over the labs. The overall average amount of reclaimed $Ca(OH)_2$ (28,2%) was, once the errors involving the equation were corrected, quite close to the amount used in producing the specimens (29,9%). This is, unfortunately, not what we see here and the details on the exact procedures used are limited. In the KOAC report only the reference to the EN standard (EN 459-2) is given, leaving it unclear if the lower acidity (0.5M) solution is used. From the BASt report, it is clear that a diluted acid is used and that they follow a procedure similar to that tested in the round robin described in Mouillet et al., 2014. The procedures were discussed in detail with BASt and Kiwa KOAC. Table 3.19 summarizes the steps taken from the two laboratories for the titration method and possible reasons for the differences in the determined calcium hydroxide content were provided.

Table 3.19: Differences and similarities between the titration procedures used by BASt and KIWA-KOAC.

| Influencing factor | BASt | Kiwa KOAC | Remarks |
|---|---|---|---|
| Tested filler | Same | Same | Filler was reclaimed by Kiwa KOAC and both labs used the same filler fraction passing the 63 µm sieve |
| Filler mass | 1 g | 1.3 g | - |
| Concentration of acid solution | 0.5 M (low acidity solution), according to Mouillet et al., 2014 | 1 M (high acidity) according to EN 459-2 | According to Mouillet et al. 2014, for reclaimed fillers with reduced alkalinity a lower acidity solution is used |
| Rate of titration[29] | Same before first colour change | Same before first colour change | • 12 ml/min before the first colour change<br>• For second colour change<br>- Kiwa KOAC: 4 ml/min (EN 459-2)<br>- BASt: not prescribed, up to laboratory technician (German standard) |
| Suspension of the analyte | Isobutanol was added and stirred for 30 mins to clean and disperse the filler particles[30] | Sugars were added | Good dispersion of the filler could lead to higher values of specific surface area (SSA). This, in turn, could explain the higher $Ca(OH)_2$ content for the BASt samples |
| Filtration of the solution | No | Yes | After titration the solution was filtered. |
| Equation for calculation | **7.2 Mixed filler and extracted filler**<br>$\omega(Ca(OH)_2) = \frac{18{,}525 \times V_2 \times F_2 \times 100}{1000 \times m_2} = \frac{1{,}8525 \times V_2 \times F_2}{m_2}$ (2) | $Ca(OH)_2 = \frac{37{,}05 \times V \times 100}{1000 \times m_{14}} = \frac{3{,}705 \times V}{m_{14}}$ | The equations are different by a factor of 2. However, the results are higher for BASt that has the lower factor. |

Independent of which numbers are correct, the amount of calcium hydroxide detected in the samples is much less than that specified for fillers. There are two possible explanations:

1. degradation of the $Ca(OH)_2$ over time due to i.e. the chemical interaction with the bitumen.
2. the wrong type of filler (with too less or no calcium hydroxide) was added.

Regarding the first explanation, BASt remarks that, based on the high calcium content found in the bitumen Hirsch, 2017a, the reaction of calcium hydroxide with acidic components of bitumen accounts for at the most 3-4% m/m reduction in the calcium hydroxide content Hirsch, 2017b. Starting from roughly the same level of $Ca(OH)_2$ in a mixture, this would indicate that acidic binders consume a little more $Ca(OH)_2$ then less acidic binders. As such, a relation between Ca level in the bitumen and reduction of $Ca(OH)_2$ is expected. Since the highest levels of Ca in the bitumen do not seem to occur in the samples with the lowest $Ca(OH)_2$ levels in the filler, this does not appear the be the complete explanation. However, this is hard to say without knowing how much $Ca(OH)_2$ was initially dosed, or what the initial Ca level (as a trace element) was in the fresh bitumen. In establishing titrimetry as a test method for the calcium hydroxide content of reclaimed filler, also the "consumption" over time for various types of bitumen and under various conditions (moisture) need to be studied. A first step

29 A weakness of the titration method is the accurate detection of colour change (from pink to clear) and thus the results is highly dependent on the laboratory personnel.

30 Suspension of the analyte was considered to be important, as agglomeration of the particles may have occurred during the filler reclamation process.

in this direction was taken in the Phase 2 study, looking at the effect of aging Hellman, 2019,Voskuilen, 2019 and that does not appear to have an effect (Section 3.7.2.5.2).
In Figure 3.48 the results are plotted versus the age of the materials (at the moment they were taken from the road).

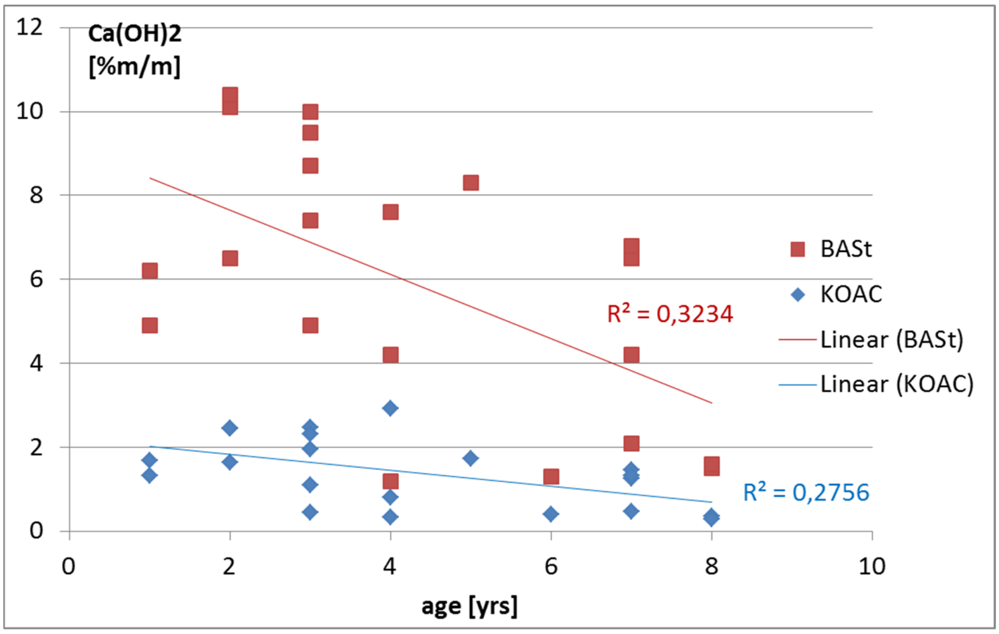


Figure 3.48: $Ca(OH)_2$ content from Kiwa KOAC and BASt plotted versus age

It can be seen that there is a downward trend with time, but also that the variation per age is considerable. Since this variation includes the variation in filler composition as well as that in bitumen composition, this is not surprising. Since there is no information found on the degradation of calcium hydroxide over time while in asphalt concrete, it is not possible to determine whether or not the samples are expected to have contained middle type filler with hydroxide or not. The most interesting locations to look at in more detail are Locations 1 (age 4 years, $Ca(OH)_2$ content 1,2%), Location 4 (6 yrs, 1,3%) and Location 12A and B (1 yr, 4,9 and 6,2%, respectively).

Textbox 1: *Potential Test Program to determine the $Ca(OH)_2$ content in reclaimed filler*

Considering the expected influence of $Ca(OH)_2$ on the properties of the mixture, it is strongly recommended to develop a standard test method to determine it for field cores, as well. For this reason, it is recommended to have the laboratories repeat the tests using both the standard EN 459-2 for fresh fillers and TP gestein (the 2010 and 2018 versions) for comparison. These tests should be done on fresh filler as well as filler reclaimed from an asphalt mixture. The reclaimed and new filler should be taken from the same batches, to ensure the same start position.
This will give an impression of the repeatability if the same procedures are used, of the difference between reclaimed and fresh filler and of the difference between the three different procedures when used on reclaimed filler, which will give information about the comparability of the results presented here. If the latter is not required, or to save time and effort, it is also possible to ask for background information on the development of the new TP Gestein and have the different labs use the most current version of that to see if it is repeatable and reproducible.

In a second stage, different combinations of bitumen (more and less acidic) and stone with the same type and amount of filler (think of two types of bitumen, two types of stones and active and inactive filler) should be used to assess the effect of the chemical consumption of $Ca(OH)_2$. Without that check, the assumption remains that the ca(OH)2 that goes in, should be recovered, but if it reacts with the bitumen to provide a better mastic some of the material will be used up.

Finally, the effect of reduction of $Ca(OH)_2$ over time, not just as an effect of bitumen aging, but including the presence of moisture needs to be taken into account. The current results (reduction of the $Ca(OH)_2$ content over time in lab conditions versus no reduction in PAV aging, seem contradictory.

###### *3.7.2.4.3 Mass balance calculations*

Rijkswaterstaat is interested to find out whether the original filler fraction used during the construction of the 17 ZOAB layers would differ from the prescribed recipes for the ZOAB produced for these locations.

Dr. Hellmann Hellman, 2018a investigated the recovered fines, sand and aggregate samples using XRF (to determine the elements present) and XRD to determine the mineralogical composition of these samples both qualitatively and quantitatively. The original commercial fillers that could have been used during the production of the mixtures were also analysed by XRD and XRF.

By the use of so-called Mass Balance calculations the results of XRD (mineralogical composition) and XRF (element composition) measurements of the original commercial filler, sand and aggregate were used to explain the mineralogical composition of the recovered fines fraction (grain size smaller than 63 µm), recovered sand fraction (63 µm – 2mm) and recovered aggregate/stone fraction (grain size > 2mm).

The procedure used to estimate/predict the amount (and type of) filler in the recovered fines fraction of the ZOAB samples is described in Chapter 2.3.2 of the Core Power report. It seems that there is a fundamental problem with the way the mass balance analysis has been done. There are several points that need attention:

1. The simplified input-output method suggested by Dr. Hirsch.
2. The mass balance calculation does not lead to a complete explanation of the recovered fines composition.
3. Assumptions have been made in the choice of values for parameters that are neither described nor explained. No sensitivity analysis to show the effect of assumptions and the effect of variability of parameters is made. It is believed that the quantitative mineral composition using the method described is not correct.

Arguments to support the doubts on the calculation method used are described in the following:

Ad 1. In Table 2 of the Core Power report gives the grainsize distribution of the recovered ZOAB materials. The table header wrongly uses the term “mass balance” and the column headers “filler”, “crushed sand” and “aggregate”. The header titles should be *recovered fines* or *recovered fraction ≤0,063mm*, *recovered sand* or *recovered fraction 0,063mm ≤D≤* 2mm and *recovered aggregate/stone* or *recovered fraction ≥ 2mm.* In the meeting of March 21, 2019 Dr Hellmann presented a revised table, which is given for clarity reasons as Table 3.20.

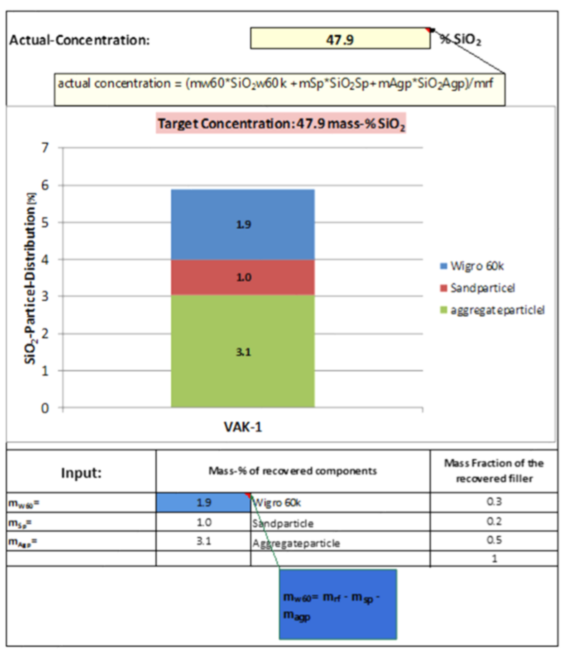
Table 3.20. Recovered fines, sand and aggregate from ZOAB after bitumen extraction for the selected samples (15.03.2018). The Ca(OH2) content is the mass of calcium hydroxide, contained in the recovered fines.

| VKA –No. Mass.-% | Recovered Fines Mass.-% | Recovered Sand Mass.-% | Recovered Aggregate Mass.-% | $Ca(OH)_2$ Mass.-% |
|---|---|---|---|---|
| VAK 1 | 5.9 | 11.1 | 83.0 | 0.33 |
| VAK 2 | 4.8 | 8.2 | 87.0 | 0.44 |
| VAK 3 (A) | 6.1 | 7.9 | 86.0 | 1.20 |
| VAK 4 | 5.3 | 9.7 | 85.0 | 0.40 |
| VAK 5 (A) | 6.4 | 11.4 | 82.2 | 0.35 |
| VAK 8 | 5.3 | 9.7 | 85.0 | 1.74 |
| VAK 9 | 6.2 | 10.8 | 83.0 | 0.80 |
| VAK 14 | 5.7 | 9.3 | 85.0 | 2.32 |
| VAK 17 | 5.7 | 10.3 | 84.0 | 2.93 |

The proposed mass balance concept as given in Figure 2.1 in the report (Core Power 2018-2), was explained again in the presentation of Dr. Hellmann during the meeting of March 21, 2019, see Figure 3.49.

The equations on the right-hand side of Figure 3.49 explain the mass of the recovered materials as follows:

- The mass of the recovered aggregate (*read the recovered stone fraction*) is the initial mass of aggregate minus the worn aggregate particles (*particles smaller than 2 mm*)
- The mass of the recovered sand is the mass of the initial crushed sand minus the worn sand (*particles smaller than 63 µm*). (*Note that this neglects the particles of sand -size that originate from the aggregate*)
- The mass of the recovered fines corresponds to the mass of the initial filler plus the mass of the particles produced from the stones and the sand (*smaller than 63 µm*)




$$m_{Sp,r} = m_{Sp,0} - m_{Sp,part}$$

The mass of the recovered aggregate ($m_{Sp,r}$) corresponds to the mass of the added aggregate ($m_{Sp,0}$) minus the mass of the particles resulting from the aggregate. ($m_{Sp,part}$)

$$.m_{S,r} = m_{S,0} - m_{S,part}$$

The mass of recovered sand ($m_{S,r}$) corresponds to the mass of sand added ($m_{S,0}$) minus the mass of particles produced from the sand ($m_{S,part}$)

$$m_{rf} = m_{Ref} + m_{Sp,part} + m_{S,part}$$

The mass of the recovered filler ($m_{rf}$) corresponds to the mass of the added reference filler ($m_{Sp,part}$ , e.g. Wigro 60k) plus the mass of the particles produced from sand and aggregate. ($m_{S,part}$).

Figure 3.49: Concept of Mass Balance calculation by Core Power (presentation 21 March 2019, in Delft)

Given the fact that the initial stones, sand and filler grain size distributions were not incorporated in the description of the composition of the filler, the mass calculation must be approximate, there is already an error in the mass of aggregate and sand derived particles coming from the aggregate and crushed sand. Furthermore, other sources of fines material are not known (backhouse dust could have been added to the filler, clogged dirt could be present in the ZOAB cores). Note that also the original commercial filler has a certain percentage of grains above 63µm.

Ad 2. The mass balance calculation procedure followed by Core Power is described in Chapter 2.3.2.1 in the Core Power report Hellman (2018a). The first step was to allocate the elements found by XRF analyses of the different possible components to the mineralogy of the recovered filler. This was done using the element $SiO_2$ only. The second step was to ascribe the aluminium to the Al-bearing minerals in the fines fraction. Dr. Hellmann reports that $AL_2O_3$ showed for most locations a mismatch.

*As an example, we give the results of location 1 (see above* Figure 3.49*).*
*In the commercial filler used, Wigro 60K, we have a* $SiO_2$ *concentration of 9.4 mass-%.*
*In the recovered filler we have an* $SiO_2$ *concentration of 47.9 mass-%.*
*For the analysis Dr. Hellmann assumed that the difference in* $SiO_2$ *was caused by the fact that during the production of the mixture in addition to the commercial filler the filler fraction < 0.063 mm (63 µm) from the aggregate/stone and sand was used. In his calculation, by iteration, he allocated percentage of filler coming from aggregate, from sand and commercial filler to get the* $SiO_2$ *concentration as measured in the recovered filler31.*

In summary, there are some serious issues that cast doubt on the validity of the approach used in the mass balance calculations. These will need to be resolved to be able to use this procedure in future studies. The issues are listed underneath:

- Not being able to distribute all elements over the mineral fractions shows that the mass balance calculations done are not accurate and cannot be relied upon in this stage of the investigation.

- The mass balance calculations assume that the non-commercial/factory filler part in the fines originates from the aggregate and sand used for the ZOAB. This assumption is doubtful. Other fines can be used, for instance baghouse dust. The $SiO_2$ used in the mass balance calculation can also originate from clogging material.

- The initial size distributions (PSD) of the source filler, sand and aggregate/stone fractions (i.e. the fines, sand and stone fraction of each of the three components) have not been determined, which seriously will influence the composition of the resulting recovered size fractions. Dr. Hellmann reported one mixing composition of filler from aggregate and sand but there are

31 For a mass balance calculation, the element composition (derived from the XRF measurement) and the mineral composition (derived from the XRD measurement) are used. The elemental composition of the substance is given in oxide percentages for each element. The XRD results give the mineral types present in the substance. A theoretical mineral composition is selected for each mineral. The procedure followed is then to allocate each element oxide to all minerals present in the substance and obtain a quantitative mineral composition for the substance which adds up to (about) 100 mass%. For example: a substance that consists of Quartz ($SiO_2$), Feldspar $(K,Na)[AlSi_3O_8]$ and Muscovite $K_2Al_4[Si_6Al_2O_{20}](OH,F)_4$. The procedure starts with allocating the measured $SiO_2$ quantity first to Quartz and the remaining $SiO_2$ is divided proportionally between the feldspar and muscovite chemical compositions. Then the $Al_2O_3$ is divided between the muscovite and feldspar, followed by the $K_2O$, $Na_2O$. When all the elements are distributed over the minerals and the mass % sums up to 100, then the resulting quantitative composition can be relied upon, with the annotation that the exact chemical composition of the minerals is not known and can explain deviations.

more compositions possible to get the measured concentration. A question still to be answered by Dr. Hellmann is why the reported values were chosen. This issue may be resolved in future research when initial PSDs are known and considered.

- Another example to illustrate these doubts is that some of the minerals present in the aggregates are not found in the recovered filler; for instance, the mineral Epidote in the aggregate of location 1 is not detected in the recovered fines.

#### *3.7.2.4.4 CALCIUM HYDROXIDE (PORTLANDITE) CONTENT FROM TESTS AND CALCULATIONS*

The $Ca(OH)_2$ content found from the various test methods and different protocols in the titrimitry show a large variation in the results. Before using these results to make statements on the nature of the original filler, it should become clear that the method of testing and analysis used is objective and reproducible.
Once a reliable method for determining the amount of $Ca(OH)_2$ in the reclaimed filler is established, it would be worthwhile to address the questions regarding the mass balance calculations, because if these can be resolved, it would theoretically allow the determination of the minimum amount of calcium hydroxide added to the mixture. Alternatively, if the questions cannot be resolved or if reactions between bitumen and filler and the amount of $Ca(OH)_2$ consumed in this reaction depends on the bitumen composition, guidelines or models will need to be developed to show the reduction over time.

#### *3.7.2.4.5 ACID NUMBER*

The conclusions from BASt Hirsch, 2017a addresses the fact that if $Ca(OH)_2$ acts as an aging inhibitor, the changes in acidity should be less. However, it is unclear what can be used/was used as a reference in this. Unless there is a material with the same bitumen and of similar age available where it is known that it did not contain a $Ca(OH)_2$ filler, there is no way to know what the reference level for the acidity would be.

### 3.7.2.5 Additional study: phase 2

From the previous sections it became clear that the various test methods do not result in the same or comparable results. This can be due to the test methods, but it is definitely also affected by the lack of consistent test protocols and inter-laboratory testing. However, those tests that did result in quantities all show considerably less $Ca(OH)_2$ than would be expected. Because of this, in the intermediate report written about this study (Ven et al., 2018), it was recommended to further investigate the development of the calcium hydroxide content over time.

This was done in the so-called Phase 2 study, where three of the mixture recipes were re-created and the loose mixtures were oven aged. In re-creating the mixtures, the same source materials are used but these were necessarily purchased a number of years after the original materials. The aim was to recreate the mixtures based on the target composition. For this reason the same materials were used. Obviously, several years had gone by, but the mixtures were reproduced as close as possible.
For the fines (≤0,063 mm) a detailed study was carried out to determine the fines added to the mixture from the fabricated filler, sand and stone fractions. From this is was found that on average 15% of the Wigro 60K filler consists of particles larger than 0,063 mm. In the remainder of this section, the amount of Wigro smaller than 0,063mm is calculated by multiplying the mass of Wigro added by a factor of 0,85.

For each of the three mixtures also the average amount of fines included in the stone and sand fractions were determined. And finally, based on experience with the materials, the expected amount of fines created in production was estimated. Because this study was looking into possible explanations for the low values of $Ca(OH)_2$ found in the overall research, it aimed to create a worst case scenario.

This was considered to be having 1,5% m/m of baghouse dust (made up out of fines attached to the stone and sand fractions and fines created during production) in the final mixture. For more information on why 1,5% baghouse dust was considered the worst case scenario, see Section 3.7.3 on page 144 and beyond. The amount of $Ca(OH)_2$ in the Wigro 60K was determined and turned out to be 29,8%, all of it in de fraction smaller than 0,063 mm. As such, the amount of calcium hydroxide can be determined through the following equation (Voskuilen, 2019):

$$[\%\ \mathrm{Ca(OH)_2}]_{\leq 63\mu m} = \frac{\%wigro\ 60Kx0{,}85\ x\ 0{,}298}{\left[\frac{m}{m}\%\right]_{\leq 63\mu m}} x100\% \qquad (3.3)$$

With:

$[\%\ \mathrm{Ca(OH)_2}]_{\leq 63\mu m}$= total percentage of $Ca(OH)_2$ in the fraction smaller than 63μm

$\%wigro\ 60K$=total dosed amount of Wigro 60K in m/m% in 100% mineral aggregates

0,85 = amount of Wigro 60K smaller than 63μm (85%)

0,298= amount of $Ca(OH)_2$ in Wigro 60K (29,8%)

$\left[\frac{m}{m}\%\right]_{\leq 63\mu m}$=total amount of material smaller than 63μm in m/m% in 100% mineral aggregates

Based on the fines from the stone and sand fractions and the expected wear during production, the total baghouse dust amount for the mixtures was around 1%m/m (Table 3.21, top). To get to the worst case scenario of 1,5%, additional fines obtained from sieving the stone fraction for that mixture were added to the mixture composition. To retain the target composition on the 0,063mm sieve, the fabricated filler amount was reduced accordingly (Table 3.21, bottom). Although it is understandable that the aim was to obtain a worst case scenario, replacing part of the target composition in fabricated filler with baghouse dust was over doing it. In the RAW requirements for ZOAB it is clearly stated that only fabricated must be dosed. Although fines from the aggregates will get into the mix, these should not be dosed on purpose and definitely not in the place of the fabricated filler (see also Section 3.7.3). In the ideal case, the extra fines would have been created during mixing and compaction, but the expectations were that this would not add up to 1,5%. The extra fines could have been added to the mixture without removing the fabricated filler, but that would have changed the grading and overall target composition. Alternatively, a number of plates could have been made using more or less extensive mixing to see how close to the worst case scenario of 1,5% baghouse dust, or alternatively the amount of fines from the field cores, they would come. But this would have required a lot of material and work, so it can be seen why the approach was used to replace part of the fabricated filler. However, this has affected the grading and properties of the fine material, such as the dosed amount of $Ca(OH)_2$.

Table 3.21: Original and adapted composition Phase 2 in order to meet target design and have 1,5% baghouse dust

| original composition | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Mix | target < 63 µm (%)* | Wigro 60K (%) | % < 63 µm Wigro 60K *** | % < 63 µm from stones | % < 63 µm from sand | expected production < 63 µm during production | total < 63 µm* | total % baghouse dust** | % $Ca(OH)_2$ |
| 1 | 5,0 | 4,5 | 3,8 | 0,5 | 0,2 | 0,5 | 5,0 | 1,2 | 22,7 |
| 8 | 4,4 | 4,0 | 3,4 | 0,4 | 0,1 | 0,5 | 4,4 | 1,0 | 23,0 |
| 11 | 5,5 | 5,1 | 4,3 | 0,6 | 0,0 | 0,6 | 5,5 | 1,2 | 23,3 |
| **adapted composition** | | | | | | | | | |
| Mix | additional % < 63 µm** | remaining Wigro 60K (%) | remaining % < 63 µm Wigro*** | % < 63 µm from stones | % < 63 µm from sand | expected production < 63 µm during production | adapted Total < 63 µm* | adapted total baghouse dust %** | % $Ca(OH)_2$ |
| 1 | 0,3 | 4,2 | 3,6 | 0,5 | 0,2 | 0,5 | 5,1 | 1,5 | 21,0 |
| 8 | 0,5 | 3,5 | 3,0 | 0,4 | 0,1 | 0,5 | 4,5 | 1,5 | 19,9 |
| 11 | 0,3 | 4,7 | 4,0 | 0,6 | 0,0 | 0,6 | 5,5 | 1,5 | 21,7 |

** Phase 2 aimed to reproduce the target compositions, including the total amounts of fines (< 63 µm)*
*** After accounting for the fines in the sand and stones (determined through sieving) and the estimated extra fines from production, the total baghouse dust content was still lower than the worst-case scenario of 1,5% m/m*
*Additional fines from the stones fraction was added to get to 1,5%, reducing the Wigro <( 63 µm) with the same amo*
**** The result is less wigro in the adapted design, while still meeting the target fines content and having 1,5% baghouse*

The material was produced with a pug mill in the laboratory, after which slabs were made and compacted with a roller. In all mixtures Arbocell type ZZ-8/1 was used as a drainage inhibitor (0.3%). After producing plates with the adapted composition, the material was reclaimed and analysed. The results from this analyses are shown in Table 3.22.

Table 3.22: adapted (intended) composition compared to the reclaimed composition for Phase 2

| adapted composition | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Mix | additional % < 63 µm** | remaining Wigro 60K (%) | remaining % < 63 µm Wigro 60K | % < 63 µm from stones | % < 63 µm from sand | expected extra < 63 µm during production** | adapted Total < 63 µm* | adapted total baghouse dust %*** | % $Ca(OH)_2$ | |
| 1 | 0,3 | 4,2 | 3,6 | 0,5 | 0,2 | 0,5 | 5,1 | 1,5 | 21,0 | |
| 8 | 0,5 | 3,5 | 3,0 | 0,4 | 0,1 | 0,5 | 4,5 | 1,5 | 19,9 | |
| 11 | 0,3 | 4,7 | 4,0 | 0,6 | 0,0 | 0,6 | 5,5 | 1,5 | 21,7 | |
| **reclaimed composition** | | | | | | | | | | |
| Mix | reclaimed < 63 µm (%)* | Wigro 60K (%) dosed | % < 63 µm Wigro 60K | % < 63 µm from stones & sand | expected extra < 63 µm during production*** | realized extra < 63 µm during production*** | Total < 63 µm * | Total % baghouse dust*** | % $Ca(OH)_2$ | % $Ca(OH)_2$ in % < 63 µm field cores |
| 1 | 6,6 | 4,2 | 3,6 | 0,7 | 0,8 | 2,3 | 6,6 | 3,0 | 16,3 | 5,8 |
| 8 | 6,2 | 3,5 | 3,0 | 0,5 | 1,0 | 2,7 | 6,2 | 3,2 | 14,4 | 5,3 |
| 11 | 7,7 | 4,7 | 4,0 | 0,6 | 0,9 | 3,1 | 7,7 | 3,7 | 15,5 | 6,2 |

** Reclaimed amount of fines higher than expected/aimed for*
*** The extra added and expected fines during production*
**** Because the extra fines created in production exceed the expectations, the total amount of baghouse dust and as a result the total amount of fines is higher than intended*

As can be seen, the amount of fines resulting from the production was considerably higher than expected, which, in hindsight, makes the addition of extra fines unnecessary. The resulting amount of fines was higher than that in the field cores (Figure 3.50). As such, it can be concluded that where it concerns the $Ca(OH)_2$ content, the composition does indeed give a worst case scenario, also in comparison to the field cores. A potential explanation for the large amount of fines created is, as mentioned by Voskuilen (2019), the rather long dry mixing time (from 1 minute and 27 second to 1 minute and 50 seconds).

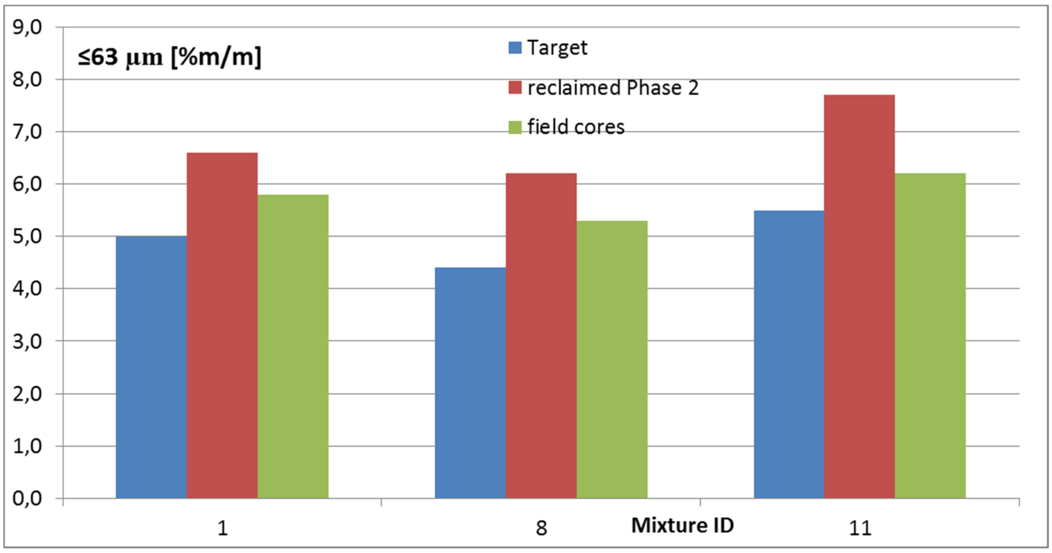


Figure 3.50: Target and realized amount of fines for Phase 2 and field cores

A detailed discussion of this study can be found in Voskuilen (2019). The test conditions and tests carried out are summarized in Table 3.23.

Table 3.23: Tests carried out in Phase 2

| protocol | time @155 [°C] in [hrs] | time @80 [°C] in [hrs] | Composition | penetration | TR&B | MSCR | DSR | FTIR | XRPD-Rietveld | titrimetry |
|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 2 | 0 | X | X | X | X | X | X | X | X |
| 2 | 2 | 24 | X | X | X | X | X | X | X | X |
| 3 | 2 | 48 | X | X | X | X | X | X | X | X |
| 4 | 2 | 72 | X | X | X | X | X | X | X | X |
| 5 | 2 | 96 | X | X | X | X | X | X | X | X |
| 6 | 2 | 168 (1 wk) | X | X | X | X | X | X | X | X |
| 7 | 2 | 504 (3wks) | X | X | | | | | | X |
| 8 | 2 | 1176 (7 wks) | X | X | | | | | | X |

Although the focus in this additional research was on the filler and especially the potential degradation of $Ca(OH)_2$ due to asphalt aging, the bitumen properties were also studied because of the strong inter-relation with calcium hydroxide. In the filler report by BASt Hirsch, 2017b, 2017c and the intermediate report of this study Ven et al., 2018, it was already stated that since calcium hydroxide reacts both with the carbon dioxide in the air and with bitumen components (the acidic components, polar aromatics and to a lesser extent asphaltenes), a lower content of calcium hydroxide is to be expected in recovered fillers than in the reference fillers.

In the next sections first the results from the bitumen tests and then the filler tests of this Phase 2 study are discussed.

#### *3.7.2.5.1 Bitumen tests*

The general trend of the bitumen properties with aging was as expected, a decrease in penetration (and increase in softening point) with aging time, fast increase initially and slowing over time. The results for the penetration for the first four aging protocols were only presented graphically, the final three protocols were also given numerically. After 2 hours at 155°C and 7 weeks of aging at 80 °C there was not yet any indication of a plateau value. In the report (Voskuilen, 2019) it is concluded that the results at 7 weeks are closest to the field data, but considering the variation found in the field data for the various sections (Figure 3.23), it may be misleading to look at the values only.

As such, an attempt was made at a more general comparison. For this, the rule of thumb32 that chemical reactions that occur at about room temperature double in speed with every 10 degree temperature rise was used. Basically, ten degrees higher gives a factor 2 in reaction rate, so with twenty degrees it is 2x2 or $2^2$ increase in rate. Assuming roughly an average annual asphalt temperature of 20°C33, the long term aging at 80°C gives a temperature difference of 60°C. This gives roughly an increase in reaction rate of $2^6 = 64$ times. Using this multiplication factor on the time that the material was placed at 80°C, assuming that the 2 hours at 155°C indeed mimics production, storage and transport in the field cores, the 1, 3 and 5 weeks become respectively 1,2 years, 3,7 and 8,6 years. It would be interesting to see what such a rough approximation would do to the measurements in the previous stages, but those are unfortunately not available as numbers.
Plotting the values for the longer time periods in the graph showing the development of the penetration over time (and removing all non 70/100 results from the original study) yields Figure 3.51. All markers are data from this study, the small ones are the results from the field cores in general and the large magenta (pink) ones the field core values for the three locations reproduced in Phase 2. The lines come from literature Voskuilen et al., 2004. The larger black ones are the results for the Phase 2 study, using the rule of thumb discussed above. Since this is obviously a rough approximation, this is shown in the graph by adding the results for Phase 2 also assuming an average annual asphalt temperature of 10 (blue) and 30 (red) degrees, respectively. As can be seen, the effect of changing the annual average asphalt temperature basically shifts the results in a horizontal direction.

As can be seen, especially considering the rough approach to obtain the corresponding field life times, the match between the Phase 2 results and the overall trends is not bad. Although it is correct that the individual values (pink markers) are mostly closer to the 7 weeks of aging, looking at the overall trend the 3 weeks are also reasonably representative. The three points of the field cores seem to lie almost on top of the trend line for the mixtures with 5,5% bitumen (=5,2% “in” 100% mix) and cellulose fibres.

32 https://www.chemguide.co.uk/physical/basicrates/arrhenius.html#top, accessed at 1-10-2019

33 The value of $20^0$C is only an assumption, not based on measurements or a literature review. It fits rather well for these data, but if another value was used, that would have a large effect on the results. It is known that mapping field aging to laboratory aging involves many variables, making the comparison tricky. As such, this exercise is used only to show that the values are within the range one would expect.

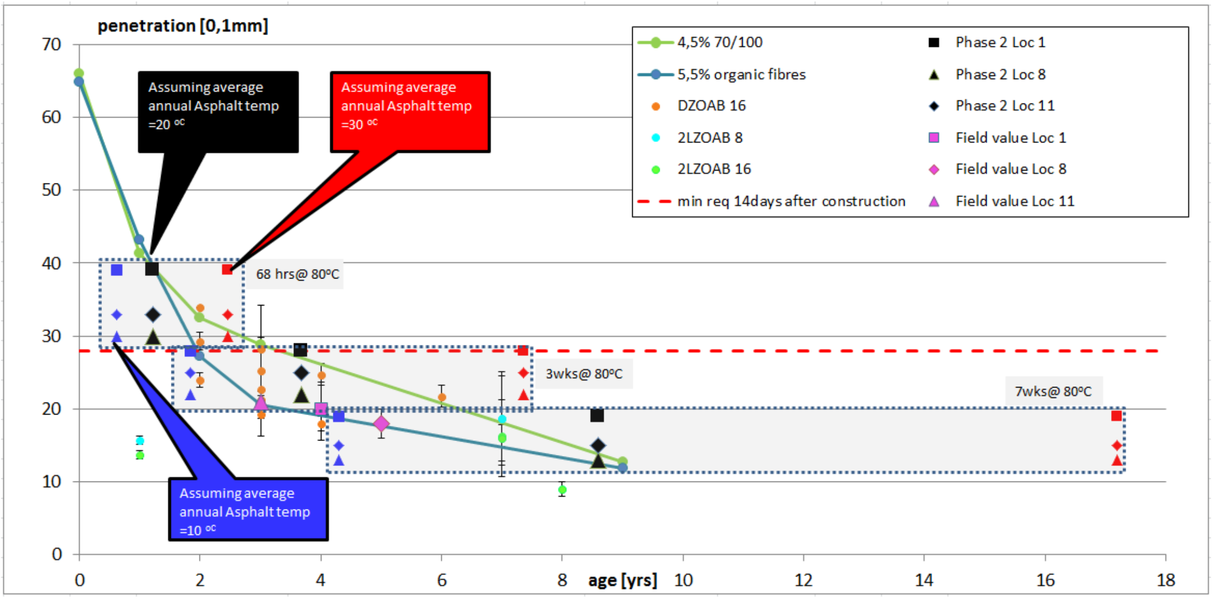



Figure 3.51: Adding the penetration values from phase 2 to Figure 3.2334

The other tests also show the expected kind of trends, but the results are not always in agreement with each other. For example, the DSR tests do show an increase in stiffness at lower frequencies (higher temperatures), but the field values that are close to the 3 or 7 week results for penetration and ring and ball temperature are for the DSR tests close to the results after 2 hours at 155 degrees (only production, storage and transport). For locations 1 and 8 the field results appear to be extrapolated relative to the test results, while the field results from location 11 deviates from the trend in phase 2 data. The RTFOT and PAV aged material is for Location 1 close to the field result, for location 8 it is an extrapolation of the Phase 2 results including the field result, while for Location 11 it is a considerable extrapolation of the Phase 2 results. This makes it difficult to interpret the results regarding it relation to the field properties. What it seems to indicate is that the laboratory aging procedure does capture some aspects of the chemical and physical changes with time, but not all or not in the same ratio as it occurs in the field. Since different tests address different properties, they are affected in different ways and the ranking of the aged materials in the tests will be different. As such, the tests are an indication of aging potential but do not give consistent results over various properties nor are they fully representative for field aging. Also, the three different pen grade 70/100 bitumens used in Phase 2, show different results under the same lab aging. The effect appears composition depended and, as such, it is unlikely that there is a lab aging method which is able to predict the field aging for all types of bitumen, let alone all mixture compositions. Although unpractical, this is something more often reported, for example by Besamusca et al. (2016), see Figure 3.52.

34 The 4,5% and 5,5% bitumen from literature (Voskuilen et al., 2004) are both for 70/100 bitumen, the first without and the second with drainage inhibitors. These percentages are “on” 100% mass of aggregate and correspond to 4,3% and 5,2% “in” 100% mixture as used in the current specifications. Because of the choices in the EN 13108-7 series, the former is now given as $B_{min}$=4,2% and the latter remains 5,2%

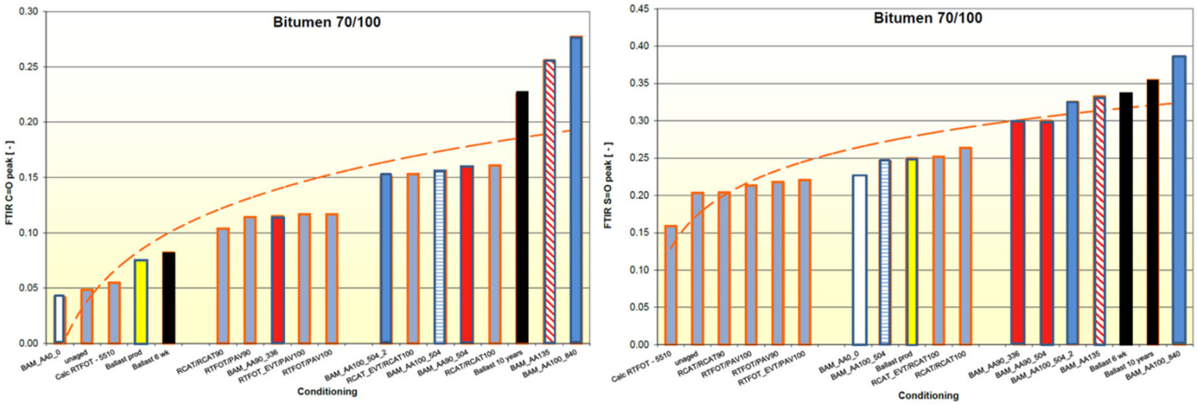



Figure 3.52: C=O and S=O ratio ranking for various aging conditions (lab and field), Besamusca et al. (2016)

This is further complicated because in the field there is an aging gradient present where the most aged material is concentrated at the top. Yet, depending on the type of specimen and amount of material needed for a test, a more or less homogenized sample over the height of the core is tested. Figure 3.53 shows for the same PA mixture the aging developments in the lab (left, @100°C and 1 atmosphere) and outside (un-trafficked pavement). The field results were obtained by separating the core in 3 layers, the results are for the top layer. As can be seen, the development over time is different from the field, but the results are of the same order of magnitude. By using a standard protocol for aging, a mixtures sensitivity to it can be assessed in a standardised way, even if the laboratory aging does not completely mimic field aging.

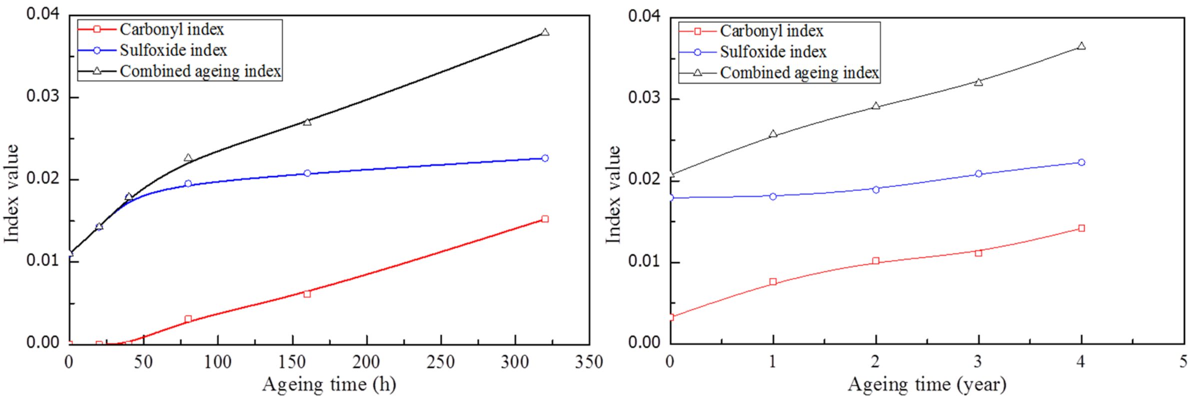



Figure 3.53: C=O and S=O development during aging in the lab (left) and in the field (right) Jing, 2019

The FTIR results from the Phase 2 study Voskuilen (2019) appear to show results that differ somewhat from what is commonly found. This may be due to differences in temperature, because higher temperatures speed up the chemical processes, but can also trigger different reaction mechanisms. The results could also be affected by the calculation method of the index values, a reference for the method used is included in Hirsch (2019a), but the method itself is unfortunately not given. Finally, a loose mixture was used for aging and that and the method used to reclaim the bitumen can also have an effect on the results found.

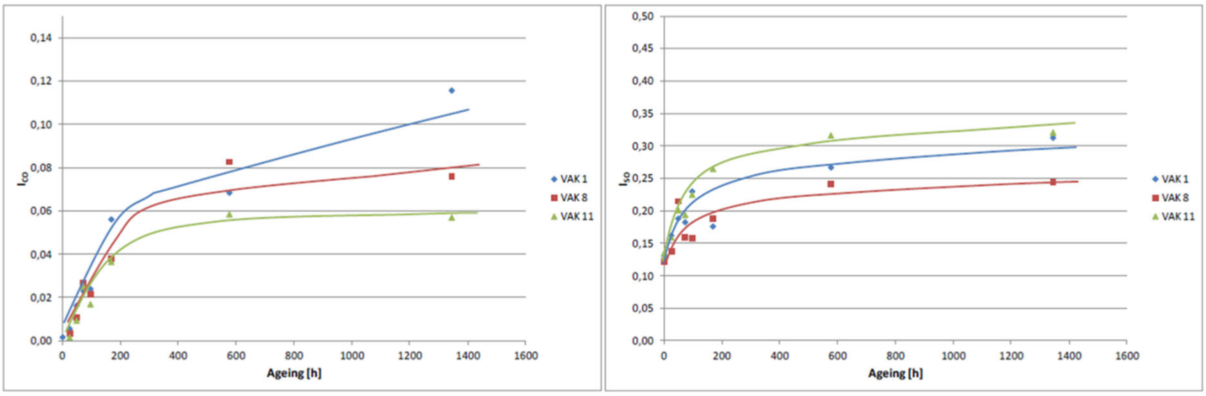



Figure 3.54: C=O (left) and S=O (right) development during lab aging according Voskuilen, 2019

Usually in laboratory aging S=O products are expected to form earlier on in the aging process and stabilize for the onset and stabilization of C=O. Also, the S=O and C=O indices are usually in the same order of magnitude, with C=O typically around half of the S=O index. In this case, both seem to occur early on and develop at the same rate, with rapid development until 200 hours and stabilization after 600 hours, although the results for C=O are somewhat variable in that range (note: look at the data points, not the lines connecting them). Also, the C=O development is about 1/3 of that of the S=O index.

#### *3.7.2.5.2 Filler tests*

The filler material was tested using XRPD Rietveld (X-Ray Powder Diffraction using Rietveld interpretation) measurements. X-ray powder diffraction is used for the identification of unknown crystalline materials. When a certain structure is found, interference leads to a peak in the signal. The overlapping of peaks in the signal, makes it difficult to determine the structure of an unknown material. The Rietveld technique allows for material identification through a comparison with a theoretical profile developed using instrumental and microstructural information and a crystal structure.

How the $Ca(OH)_2$ content of these results relates to that of other tests (Section 3.7.2.4.1) is not quite clear. Particularly, since in the previous phase it was found that the wet preparation method caused a deviation due to a reaction of the calcium hydroxide with the water in the ethanol, which led to the use of the dry preparation method Hellman, 2018a. In the new report, section 2.0 on page 6 of Hellman, 2019 first of all the method using ethanol is described, but in the final text block in the section it is stated that the samples were all prepared using the dry method. This statement is repeated in the conclusions, so that is probably what happened.
However, for this Phase 2 study the actual preparation method is not an issue, because it looks at changes in the content due to aging. Since it are the changes (relative data) that are used, the method is less relevant. As can be seen from the results, although some fluctuations were found (Figure 3.55), overall the amount seems to be stable during the aging process. This indicates that pure oxidative aging does not change the $Ca(OH)_2$ (= Portlandite) content.

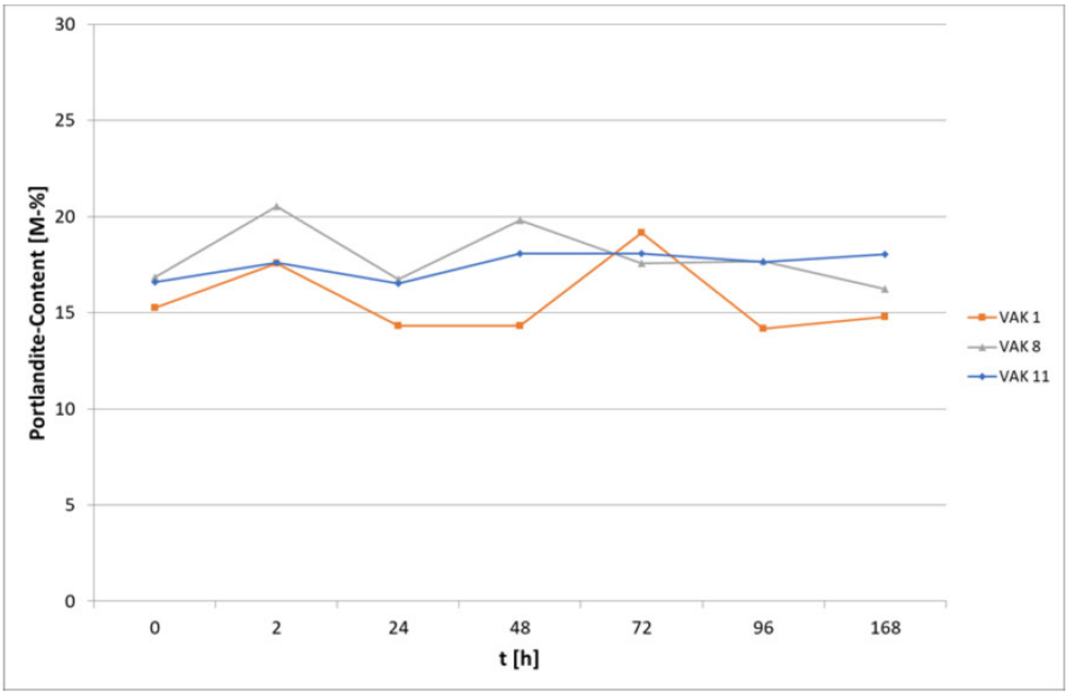



Figure 3.55: $Ca(OH)_2$ content found from XRPD on dry-prepared specimens in various stages of aging (Table 3.23) reproduced after Hellman, 2019

For the same samples also titration was used by BASt Hirsch, 2019b according to the procedure described in Section 3.7.2.4.2. These results are shown in Figure 3.56, including the values from the field cores.

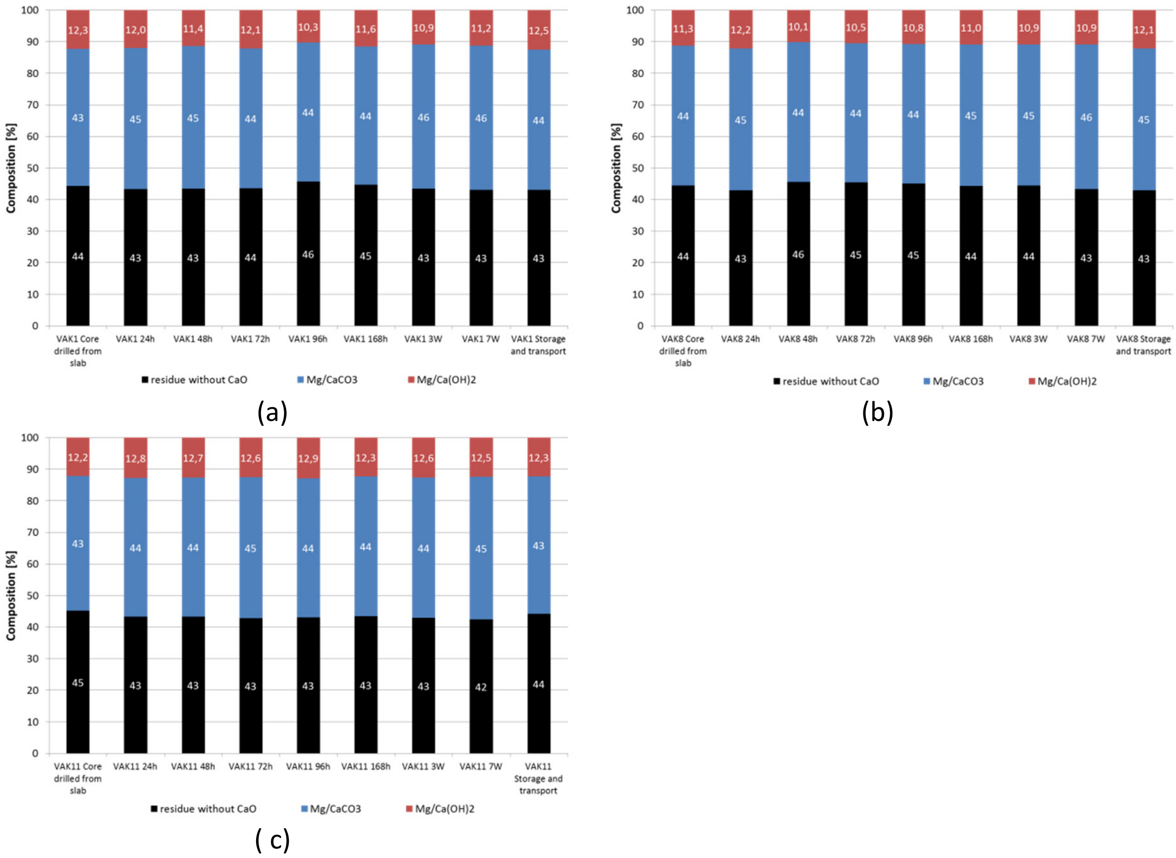


Figure 3.56: Titrimetry results for the lab aged mixtures and field cores for location 1 (a), 8 (b) and 11 (c)

The average results for the lab aged samples compared to the dosed amounts of $Ca(OH)_2$ and the results from the field cores are shown in Table 3.24 and for both XRPD and titrimetry. As can be seen, the titration results do not find all dosed $Ca(OH)_2$ .The XRPD finds amounts very close to what was dosed. However, as can be seen in this case for Location 8, actually more $Ca(OH)_2$ is found than was dosed, indicating that there is at least a margin of 7% in its accuracy. It is important to know if it is expected to find all dosed $Ca(OH)_2$ in reclaimed filler or not, if all remains present, its beneficial effects would be due to very low doses or because it acts as a catalyst. If the material itself is involved in chemical or physical reactions, one would expect that not all of it can be found.

Table 3.24: $Ca(OH)_2$ in the field cores (Hirsch, 2017b) and the dosed and recovered amounts in phase 2 (Hellman, 2019 and Hirsch, 2019b), reproduced from Voskuilen (2019), see also Figure 3.57

| | core from the field | lab aged | | |
|---|---|---|---|---|
| PA+ road section | recovered $Ca(OH)_2$ via titration of fraction <0,063mm | dosed $Ca(OH)_2$ fraction <0,063mm | recovered $Ca(OH)_2$ via titration | recovered $Ca(OH)_2$ via XRPD |
| 1 (4 years old) | 1,2 | 16,3 | 11,7 (72 %) | 15,7 (96 %) |
| 8 (5 years old) | 8,3 | 14,4 | 11,1 (77 %) | 17,9 (124 %) |
| 11 (3 years old) | 9,5 | 15,5 | 12,5 (81 %) | 17,5 (113 %) |

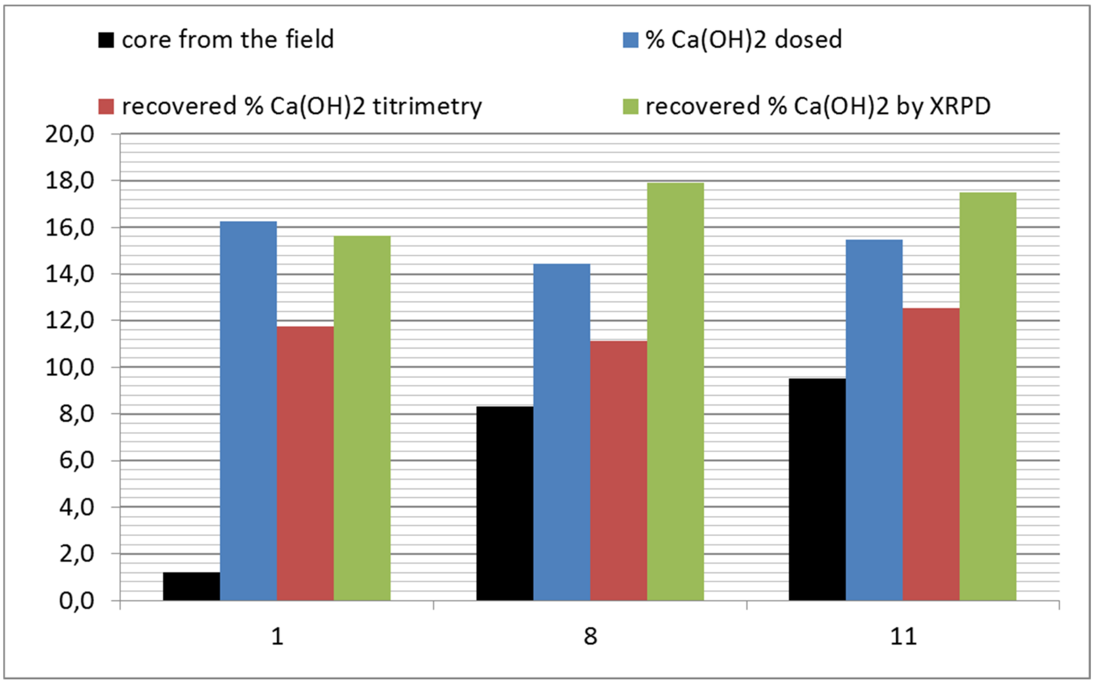



Figure 3.57: Dosed and reclaimed, through tritimetry and XRPD, respectively amounts of $Ca(OH)_2$ (Table 3.24)

Based on the results shown in the Table and Figure above, it would appear from the results for section 1 that XRPD is the better method to use to determine the amount of $Ca(OH)_2$ that is present. However, when taking into account the other two sections, this impression changes. Where a certain amount of loss of Ca(OH)2 in reacting with other component can explain a reduction, there is no explanation for finding more than the added amount. Voskuilen (2019) also mentions this and concludes that both

methods require additional study to determine whether they are suited as objective and reproducible methods to determine the $Ca(OH)_2$ content in reclaimed fines.
Additionally, in the earlier study Hellman (2018a), the wet-prepared samples under-estimated the $Ca(OH)_2$ content compared to the BASt titration method and the dry prepared samples gave almost equal results to those from titration. Since in this study again the same fresh and reclaimed filler materials were used and the methods used by both labs are the same as used previously, it is illogical that two test methods that in the first phase of the study matched almost completely would now show a 30% difference. This reinforces the conclusion by Voskuilen that it appears to be too early to arrive at any definite conclusions on the best method to assess the $Ca(OH)_2$ content in reclaimed filler.
It is therefore recommended to follow the test program proposed in the text box at the end of Section 3.7.2.4.2 (Page 127)Textbox 1, adding the XRPD method and the FTIR to this testing program. This should include a clear description on how the methods work (test protocol), allowing other institutes to also do the tests.

Also, based on the results from the XRPD in phase 2, it looks like no or very little $Ca(OH)_2$ is consumed during the production of a mixture. This raises some questions when regarded in combination with the explanation for the 30% "loss" of $Ca(OH)_2$ in titration expressed by Prof. Dr.-Ing. Kurt Schellenberg in a correspondence shown in Attachment 8 in Voskuilen (2019). He indicates several causes for the apparent loss of calcium hydroxide content in the titration method:

1. Different quantity of material < 0.063 mm due to crushing during mixing, which leads to a different ratio of $Ca(OH)_2$ and other particles
2. Presence of a monomeric layer of oily components on the filler particle after extraction, which defies full identification of calcium hydroxide
3. Chemical reaction of calcium hydroxide with the oleo components in the bitumen to form calcium naphthenates and calcium stearates

It is not quite clear if, and to what extent, the monomer layer would affect XRPD, but both other factors should also show up in the XRPD results. That fact that they do not, indicates that either the full reduction found in titration is due to the monomer layer or that there is an aspect in XRPD analyses that is not yet explained and causes an over estimation of the calcium hydroxide content. This is quite possible, since the XRPD results from Section 8 and 11 show a higher amount of $Ca(OH)_2$ than was dosed.

The latter explanation gains further plausibility due to some results from BASt presented in Attachment 7 of Voskuilen (2019) where titration was used to determine the calcium hydroxide content of the fraction < 0.063 mm of Wigro 60K filler35. The procedure was also carried out after mixing the heated (150ºC) filler material with the similarly heated sand and coarse minerals for three minutes and storing it for two hours (150ºC). A third determination was carried out, following the same procedure as for the second36, but now also adding bitumen. The dry mixing of the filler with the other aggregates can be seen as a worst case scenario for effect 1), since the crushing can be expected to be less extreme if bitumen is present in mixing, acting as a lubricant. The mixing with bitumen and recovering the filler should be representative of effects 2) and 3).

35 The average result of 29,8% is used in Equation 3.6 to calculate the $Ca(OH)_2$ content
36 The procedure is described as follows: For this research the mixture composition of mixture PA+ 1 was chosen. First the baghouse dust of the sand and stone fraction was removed by wet sieving on 63 µm. The filler, sand and stones were heated up to 150°C in an oven. The filler was sealed with aluminium foil to prevent reaction with CO2. Than the total mixture of stones, sand and filler was mixed for 3 minutes at 150°C followed by storage for 2 hours at 150°C. After that the fraction < 63 µm was recovered with the decant cup centrifugation method. The calcium hydroxide of the fraction < 63 µm was determined Voskuilen, 2019.

The results are shown in Table 3.25 and in Figure 3.58. Each of the three steps are carried out on two samples, which seem to give quite repeatable results. As can be seen, the $Ca(OH)_2$ content that is detected drops when the filler material is mixed with the other fine aggregates. The result of also mixing in bitumen is almost identical to that obtained when only the fine aggregates are mixed, which seems to indicate that mixing has a more pronounced effect than the interaction with bitumen. This is interesting, since the difference between the original material and the material after mixing with bitumen (-3,9%) is very close to the 3-4% that BASt found to be chemically bound to the bitumen (and unrecoverable) (Hirsch, 2017b). This indicates that more research into these aspects is needed. One crucial step would be to sieve the material obtained following the second and third preparation method, to account for the change in the amount of material smaller than 0,063 mm.
A potential explanation for a reduction in detectable $Ca(OH)_2$ beyond the increase in fines was raised by Hopman et al., 2006, where it is suggested that $Ca(OH)_2$ could form a bridge between (acidic) aggregates and bitumen groups via interaction of the H-atom of one OH-group with stone and a similar reaction of the other group with acidic components in the bitumen, thus providing a connection between both. Although this theory has as far as could be traced, not been investigated, it would indicate the possibility of having hydroxide chemically bonded to the surface of the other aggregates, thus reducing the traceable amount even without interaction with bitumen. This does not explain why there does not appear to be an effect of mixing with bitumen, either in chemical interaction or in the monomer layer affecting the measurements37.

Table 3.25: $Ca(OH)_2$ content found with titrimetry in fines, after mixing with aggregates and after mixing with aggregates and bitumen Voskuilen, 2019

| Sample number | Sample name | Calcium hydroxide content (m/m %) Single values | Average calcium hydroxide content (m/m %) |
|---|---|---|---|
| 62751 | Sieved fraction < 63 µm of Wigro 60 K | 29,8 | 29,8 |
| | | 29,7 | |
| 62752 | Recovered fraction < 63 µm (sample without bitumen) | 26,4 | 26,3 |
| | | 26,2 | |
| 62753 | Recovered fraction < 63 µm (sample with bitumen) | 25,7<br>26,0 | 25,9 |

These results are graphically represented in Figure 3.58.

37 Unless the titration was in this case done using the NEW version of the TP Gestein (2018), where instead of one washing with surfactants, six washings are carried out and where it is expected that this removes the bitumen monolayer completely, Attachment 8 Voskuilen, 2019

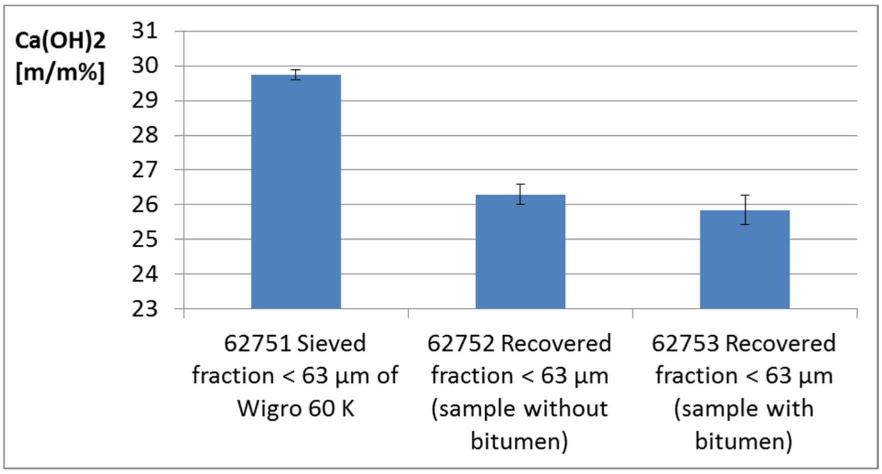


Figure 3.58: Graphical results showing Ca(OH)2 content in Wigro 60K, after dry mixing and after mixing with bitumen

It can be seen that in this test for the mix from Location 1 a reduction of about 4%m/m $Ca(OH)_2$ is found, which is just over 10% compared to the dosed percentage. When this is compared to Figure 3.56, Figure 3.57 and Table 3.24 it is clear that for XRPD in the various stages values of Ca(OH)2 content is between 15-20% m/m, while for titrimetry it is 10-15%. From the first to the last aging step, those values stay roughly the same, showing that oxidative aging does not appear to effect the calcium hydroxide content. Some material may be lost at the initial mix production, but how much and due to which processes is not known yet.

What is also not yet clear is what method is the most accurate and objective. As such, it is recommended to follow the test program proposed in Section 3.7.2.4.2 Textbox 1. Adding not only the XRPD method and the FTIR to this testing program as suggested on the previous page, but also the step of mixing only the (fine) aggregates, without bitumen. This will provide an overview of how the various methods are affected by the steps in production and reclaiming, which is crucial in selecting the optimal test method. As stated previously, this study should include a clear description on how the methods work (test protocols), in order to allow others to reproduce these tests but also to be able to address any remaining questions about test influences.

What is clear, is that the field values found are considerably lower than those found from the tritation tests in Phase 2, especially for Location 1. In this respect, it has to be noted that the Phase 2 tests address the effect of temperature aging on $Ca(OH)_2$, but they do not address the effect of moisture on the degradation of the $Ca(OH)_2$ content through carbonisation. Yet in the Phase 1 BASt study Hirsch, 2017b it is mentioned that under laboratory conditions the carbonation reaction is extremely slow, but that it will be faster at high humidity, something that is bound to occur in the road since there moisture and actual water will be present regularly. It seems unlikely that this would explain so large a difference as found for Location 1, but it could be worthwhile to determine if the location where these cores were taken has been exposed to considerably more moisture than other locations in this study. If it has, it may explain the difference. Either way, either field time lines for $Ca(OH)_2$ must be established, or additional testing including moisture is needed once a reliable test method has been developed. At that time, also testing the remaining cores for $Ca(OH)_2$ may be needed to be sure of the field core values.
This is further supported by Section 3.7.2.3 the results from BASt (hardly any degradation of $Ca(OH)_2$ content in Wigro 60K, with 25% $Ca(OH)_2$, under lab conditions over 22 days) were compared to those found by Sibelco (where a 95% m/m $Ca(OH)_2$ filler lost 40% of calcium hydroxide in the first month, stabilising at 80% loss after about a year). The calcium hydroxide content in both cases was different, which may have an effect, and possibly also the humidity was different. In order to resolve the

expected development of $Ca(OH)_2$ content in pavements over time this, the effect of moisture will need to be taken into account.

So the first step should be to determine which, if any, of the methods tried gives a reliable and reproducible result for the $Ca(OH)_2$ content of reclaimed fillers, as described above. In doing this, the effects of mixing, both with and without bitumen can be used to assess the objectivity and to further develop the theory on $Ca(OH)_2$ content degradation.
In determining a time line of $Ca(OH)_2$ content degradation in the field, it will be important to include the effect of moisture and water as well as the level of chemical interaction between calcium hydroxide, bitumen and maybe aggregates. If these reactions lead to conversion of $Ca(OH)_2$ they will affect the results and if the amount of reaction depends on the type of materials used, either a database will have to be established or determining the dosed as well as resulting calcium hydroxide content needs to become part of the standard tests.

### 3.7.3 Presence versus dosing of baghouse dust

As discussed in the previous section, the materials used in Phase 2 contained 1.5% of baghouse dust. In the introduction of the Phase 2 report by Voskuilen, 2019 this is explained on the basis of production practices. Currently, the hot air coming from the drum during the heating of the aggregates has to be filtered before it can be released to the outside. In this process, fine material from the aggregates gets caught in the baghouse and this is used as a filler when no specific requirements are set for the filler material, as is the case in almost all asphalt mixtures.

However, for ZOAB specific requirements are set, the filler must be middle type factory filler with at least 25% calcium hydroxide. Based on the VBW Asfalt (1995) guideline Voskuilen (2019) explains that up to 1,5% m/m difference in the material <0,063mm is allowed between target composition and composition after production (field cores). Indeed, the guideline (of which parts have been included in Appendix I*, in Dutch*) describes the various components that make up the fine fraction in the mixture:

- the dosed factory filler,
- dust adhering to the sand and coarse aggregates (between 1-5%) and
- dust produced due to crushing of coarser aggregates in production

For the latter source the guideline indicates that an amount between 0,5-2,5% is normal for Dutch conditions.
Adhering dust is (partially) removed from the process during heating in the drying drum, but afterwards there is no removal of any remaining or produced fine material, so some increase in the amount of dust will occur during the production. In the guideline it is stated that the properties of the baghouse dust are roughly equivalent to those of weak type factory fillers (based on bitumen number and void content) and that in principle it is possible to deal with the additional fines by reducing the amount of factory filler during production.
Because there is a difference in grading, this replacement may lead to more free bitumen in the mortar, which can have negative effects. Because of that, they arbitrarily limit the deviation of the designed factory filler content in production must not exceed 1,5% m/m. If more deviation occurs, the amount of factory filler has to be reduced and the baghouse dust must be added to the mixture during the mixture design procedure (precursor of the Type Test, used up to 2008) as a separate constituent material.

Based on this, Voskuilen, 2019 indicates that this is interpreted to mean that if x% of baghouse dust is declared as a constituent material in the Type Test, x+1,5% can be dosed in the production. However, the authors of this report do not agree with that interpretation of the guideline.

First of all, it should not be a matter of *dosing* an amount of baghouse dust in production, the guideline describes a method to deal with the amount of fines *created* in production. No baghouse dust should be deliberately *dosed* during production.
This does not mean baghouse dust cannot be added during production at all. In mixtures where no specific requirements are set for fillers, or where the baghouse dust fulfils the requirements that are set, it can be dosed in production as a constituent material. In that case, it should also be used as such in the target composition and type testing. An interesting question in that case is if the baghouse dust needs to be characterised according to the EN standard for aggregates, since it is being used as such. Apart from that issue, if baghouse dust is used as a filler in mixture, during production *additional* fines will still be produced and it is the amount of extra fines that is addressed in the guideline.

Secondly, the guideline does not discuss the specific requirements for fillers in ZOAB and SMA and how that would affect the way to deal with the production of fine materials in production. Yet this is an issue, since the standard specifically requires the use of middle type filler with hydroxide and this is not interchangeable with baghouse dust, which is (for some properties) similar to a weak filler. Obviously, in production of ZOAB and SMA also dust is added to the mixture, so the question is how to interpret it. It could be taken to mean that, since baghouse dust must be declared as a constituent material if the amount of filler shifts by more than 1,5% during production and the required filler material must be weak factory filler, that a ZOAB or SMA-NL cannot have a shift of more than 1,5% in filler size particles during production, because that keeps the baghouse dust under the limit allowed in production and does not require it to be considered a constituent material. Mixtures that do not stay below this threshold would be ZOAB or SMA mixtures, but they do not meet the RAW Standard requirements for ZOAB or SMA-NL.
It will be useful to discuss this in detail and make the interpretation explicit. Since the guideline is not a formal document, currently people will interpret and use it differently. One example is the interpretation Voskuilen thinks is being used, also some contractors do mention baghouse dust as a material on their list of constituent materials, typically in amounts less than 1,5% (0,5-1,5%).

According to the guideline, only amounts of more than 1,5% must be considered as a constituent material and then the full amount of the shift in production must be considered and taken into account in the mixture design/type test. However, according to the CEN standards, all constituent materials must be declared, for filler according to EN 13043 (Section 4.3.4 EN 13108-7) and for additives the nature and properties must be declared (Section 4.5, EN 13108-7).
The amount of any aggregate material not passing the 0,063 mm sieve must be declared to 1%, while the amount aggregates passing the 0,063 mm sieve, bitumen and additives must be specified to 0,1%. Grading is expressed as percentage by mass of total aggregate, additives and bitumen as percentages by mass of total mixture (Section 5.1 of EN 13108-7).

So these percentages of baghouse dust on the CE marking of PA mixtures could mean several things:

1. that this is the amount of shift that occurs for that material in that plant and
    a. it is declared to show it stays below the 1,5%, so it is not an issue
    b. the producer considers *all* shifts in fines as crucial for ZOAB quality and he uses this amount also in his type testing and declares it conform the EN 13108-7 requirements
    c. the producer interpreted the guidelines differently and declares the percentage of fines *above* the 1,5% threshold only (so the actual amount created in production is the declared value +1,5%, he also uses the declared amount of additional fines in his Type Test and has adapted his grading to allow for it
2. that the producer interpreted the guide line to mean that it is allowed to use up to 1,5% baghouse dust in the target composition and he declares what he adds during production and he
    a. adds the dosed percentage of baghouse dust from his storage also in type testing
    b. adds the total shift in fines (production effect plus dosed percentage) in type testing

c. does not use baghouse dust in his type testing

Anything under 2) takes the guideline to areas for which it was not meant, since it involves actively dosing baghouse dust, rather than dealing with any involuntarily produced shift in fines in such a way that it does not adversely affect the mixture properties. In the opinion of the authors, only 1a meets both the requirements for ZOAB and SMA-NL in the standard and the intention of the guideline, but others may well have reached the other interpretations or additional ones.
It would be advisable to set up a system to deal with such issues when they arise and improve the regulations accordingly.
An additional reason to limit the change in grading is that the fine materials that get added to the mixture in this way are, like baghouse dust, not tested and can have a wide variety of properties. The amount of such uncharacterised material in the mixture must be limited to prevent unwanted or unexpected effects.

## *3.8 Tests related to sand content and properties*

### 3.8.1 Comparing field data to overall mixture group requirements for sand

For the sand fraction only the grading is tested, the results are presented in Section 3.4 Tests related to grading. Some of the DZOAB 16 samples were close to the minimum boundary of the overall mixture group description. To know if they fulfil the specifics of their recipe, individual data sheets need to be consulted.

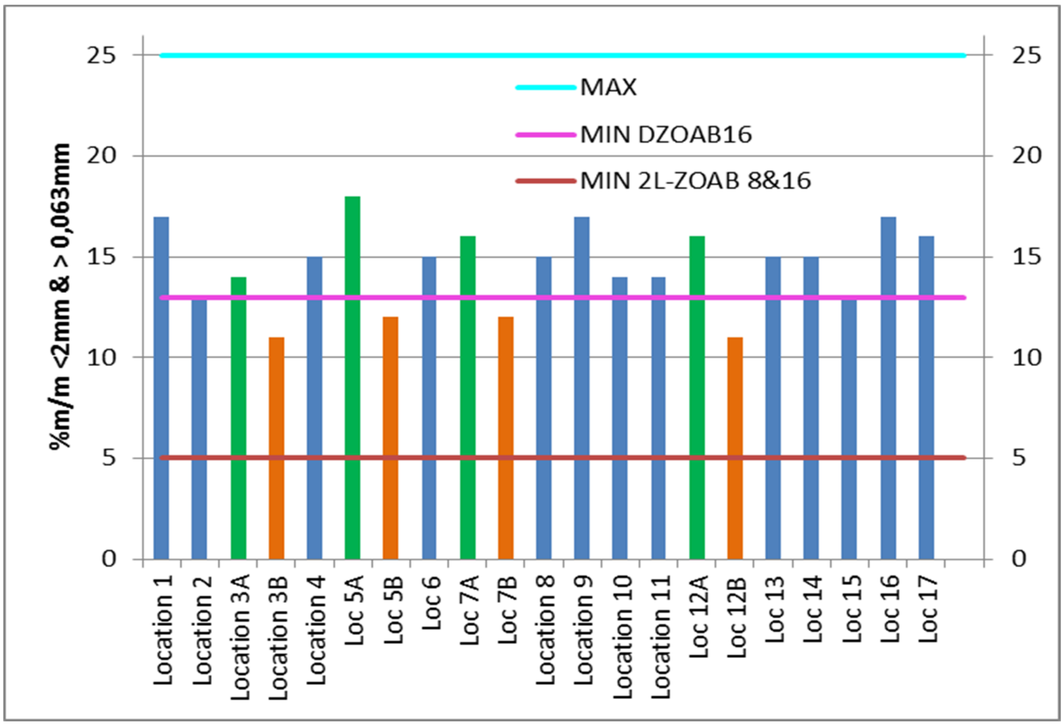



Figure 3.59: Average (n=3) sand fraction found for the various the locations (blue=DZOAB 16, green=2L-ZOAB 16, red = 2L-ZOAB 8) and the requirements for this fraction

Overall, all cores meet the general requirements set for this fraction for the various mixture groups, although a few of the DZOAB 16 results are quite close to the bottom limit.

### 3.8.2 Location specific data

Comparing the provided information on the sand fraction for Location 1 and 9 (where two DZOAB 16 data sheets were provided) illustrates the approach in the RAW Standard where there are sets of

requirements, besides the general mixture group limits discussed above. The first is the requirement for the maximum difference per sieve between the target grading on the CE information and the reference grading provided (art 81.22.01), for the 2 mm sieve this half of the tolerances for one sample from Figure 2.28, which comes to +/- 2,5% m/m.
The second is the maximum deviation between the reference grading and the grading found in the field, this for n=3 and ZOAB 3,5% m/m on the 2 mm sieve.

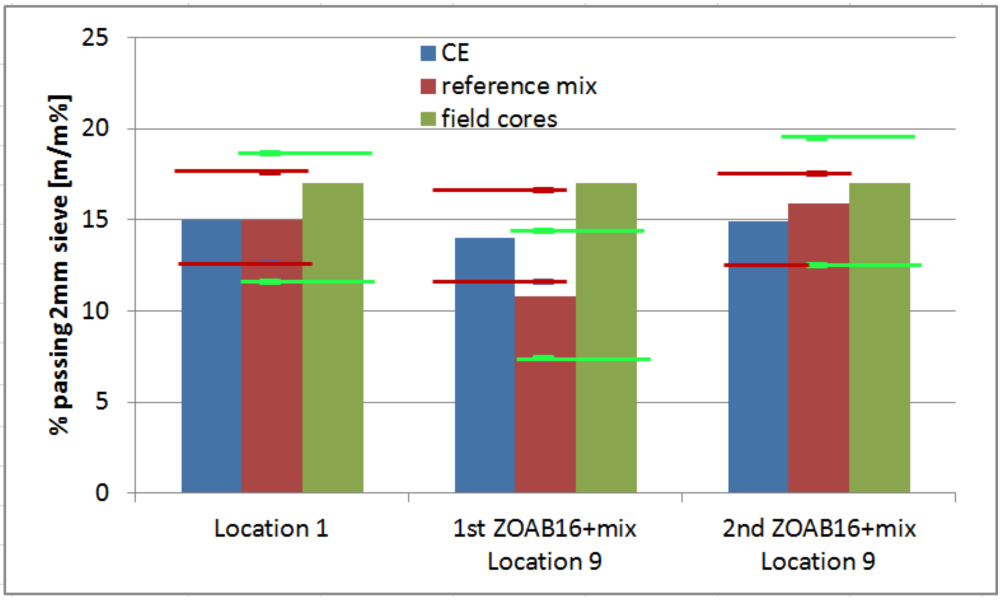



Figure 3.60: Individually declared and measured values compared to the boundaries between CE and reference composition (red) and reference composition and field values (for n=3, green)

As can be seen, the reference mixture value for the percentage passing the 2 mm sieve is too much smaller than the target composition for the 1 st DZOAB 16 mixture at Location 9, so this reference composition is not acceptable for this target composition. As a result, if this is the mixture used in this location, its variation found in the field cores is also too large. As a matter of fact, it would have been too large if the reference composition had been equal to the target value, as well. The 2nd DZOAB 16 mixture had a larger percentage passing the 2 mm sieve and this amount was increased in the reference composition. The value found in the field was even larger, but the differences between the three sets of values would, in this case, pass the requirements.

## *3.9 Tests related to coarse aggregate properties or content*

### 3.9.1 Standard tests

#### 3.9.1.1 Grading

The average grading of two of the locations failed to meet the general overall requirements for the mixture groups (DZOAB 16, 2L-ZOAB 8 and 2L-ZOAB 16) on one of the sieves for the coarse fraction. This is reported in Section 3.4 Tests related to grading. Detailed analyses of two locations (one of them a location with a deviation on the coarse sieves) showed that for the deviant location, the sieve that deviated in the field cores (the CSC which is the 11,2 mm sieve for DZOAB 16) was not declared, instead the CE info and the reference composition showed the D/2 (8 mm) sieve info. Although the specifications are limited to the 1,4D, D, CCS, 2 mm and 0,063 mm sieves in production and declaration the whole sieve curve should be declared.

### 3.9.1.2 PSV value

RWS requires Steenslag 3 for the coarse aggregate in wearing courses for motorways and as shown in Section 2.2.6, that means, among other aspects, 100% broken particles ($C_{100/0}$) and a Polished Stone Value (PSV) of 58 or more.

In Table 3.26 the PSV values found on the aggregates obtained from the field cores are given and in Figure 3.61 they are plotted Schulze et al., 2018. These data are only given for the top layer of the 2L-ZOAB locations, since the PSV=58 requirement applies to wearing courses only.

As can be seen, 10 of the 17 cases do not meet the requirement for PSV. Since the test is meant to be done on fresh material, the results obtained from tests on stones from field cores may lead to some discussion. However, as long as the stones used are not taken from the top surface of the core, they have not been exposed to polishing by traffic. In a previous study Fafie et al., 2005 stones from the pavement have been tested in the PSV test and the values obtained were of the expected order of magnitude. In this study, also a comparison was made where fresh stones were used in the test and, with material from the same batch, a PA core was made after which the stones were retrieved and tested. Both tests gave the same PSV (PSV=53[38]), indicating that, although lab production and field production are not exactly the same, it is unlikely that the production and subsequent recovery of the stones affect their resistance to polishing.

Table 3.26: PSV values found from the samples from the test sections

| location ID | mixture type | PSV | requirement | year | age |
|---|---|---|---|---|---|
| 1 | (D)ZOAB | 59 | 58 | 2012 | 4 |
| 2 | (D)ZOAB | 57 | 58 | 2013 | 3 |
| 3A | 2L_ZOAB8 | 57 | 58 | 2009 | 7 |
| 4 | (D)ZOAB | 64 | 58 | 2010 | 6 |
| 5A | 2L_ZOAB8 | 59 | 58 | 2008 | 8 |
| 6 | (D)ZOAB | 57 | 58 | 2013 | 3 |
| 7A | 2L_ZOAB8 | 58 | 58 | 2009 | 7 |
| 8 | (D)ZOAB | 56 | 58 | 2011 | 5 |
| 9 | (D)ZOAB | 58 | 58 | 2012 | 4 |
| 10 | (D)ZOAB | 56 | 58 | 2013 | 3 |
| 11 | (D)ZOAB | 57 | 58 | 2013 | 3 |
| 12A | 2L_ZOAB8 | 59 | 58 | 2015 | 1 |
| 13 | (D)ZOAB | 54 | 58 | 2014 | 2 |
| 14 | (D)ZOAB | 50 | 58 | 2013 | 3 |
| 15 | (D)ZOAB | 56 | 58 | 2014 | 2 |
| 16 | (D)ZOAB | 58 | 58 | 2014 | 2 |
| 17 | (D)ZOAB | 54 | 58 | 2012 | 4 |

38 At that time, the PSV requirement for highways in the Netherlands was 53

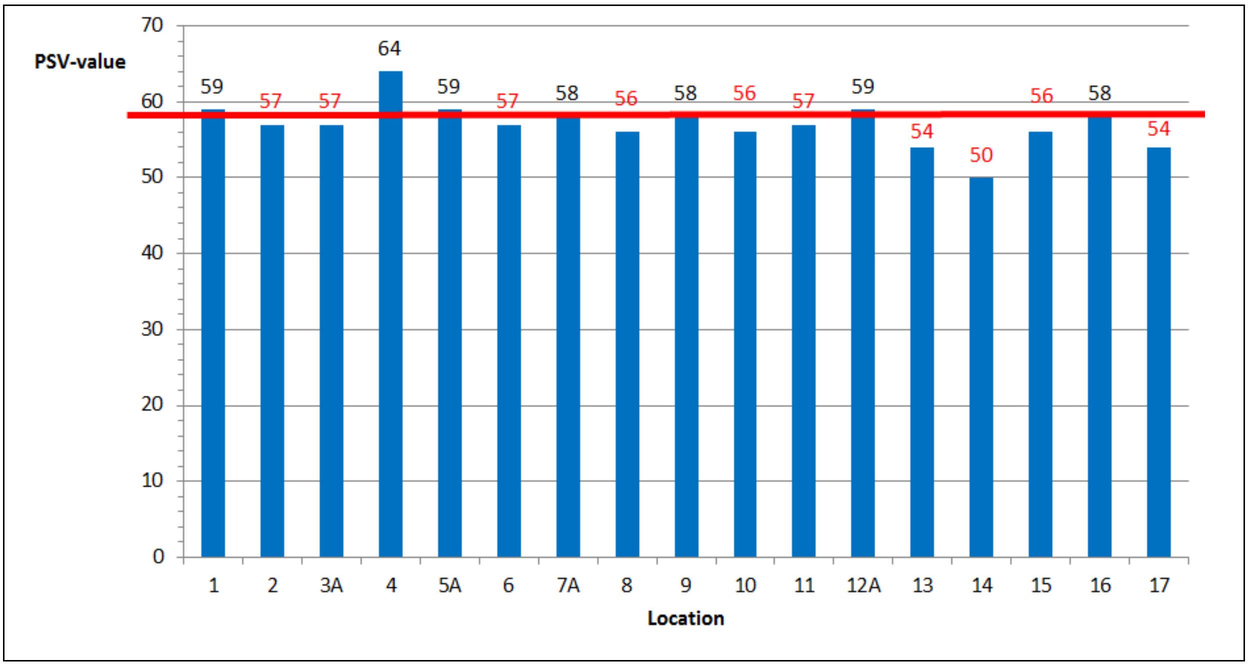



Figure 3.61: PSV values course aggregates relative to the PSV=58 requirement

As mentioned above, 10 of the 17 locations do not meet the PSV requirements, that is a lot. When we bring in the PSV values from the project documentation, first of all it is noted that for six out of the 21 materials no PSV is specified. Although 4 mixtures are not wearing courses, a general requirement for ZOAB is steenslag 2 and that means a PSV≥53. So in all cases, values should be specified. Furthermore, in all but one cases the declared PSV values are higher than the values actually found.

In this case, the CE system may be part of the problem. It is a generally accepted fact that the properties of stones in a quarry can vary considerable per location. In the current CE marking system, the producer has to re-test for the PSV value at least once per year, but this may not be sufficiently frequent to ensure the properties of these natural materials.
Considering the link to safety, road authorities and contractors may want to consider to make additional arrangements such as required entrance testing at the plant. If these tests show that the variation is indeed such that the client (in this case, the contractor) cannot rely on the CE information supplied, this should be taken up with CEN.

## 3.9.2 Additional tests

### 3.9.2.1 Petrography of aggregates

#### *3.9.2.1.1 Rock name and origin*

Delft University described the ZOAB core samples delivered by Kiwa KOAC microscopically. Kiwa KOAC provided the recovered coarse aggregate delivered from extraction (the stone fraction > 2 mm). Thin sections were prepared of sample particles from this stone fraction for microscopic examination by a petrographer (van Tooren, M. et al., 2017).

Core Power has studied polished thin sections of aggregate particles using optical microscopy. The petrographic descriptions were supplemented with XRD information including a Rietveld based quantitative analysis of the mineralogical composition Hellman, 2018b.

Both institutes allocated the rock types into clusters, based on the petrographic information obtained. The results of the cluster analysis and the rock names given for each cluster are shown in Table 3.27

The determination of the rock types by TU Delft and Core Power agree with each other, although the wording used is not always completely similar.

Additionally, an assessment of the likely origin of the aggregate was made (the likely geological formation and if possible, a source quarry was assessed). Although the petrographic descriptions are only from few stone particles per sample, some of the rock types identified are quite characteristic and can therefore be ascribed to a source rock formation with some confidence. The pinpointing to a quarry is less certain and depends on the experience of TU Delft and Core Power with the materials from these quarries.

Core Power compared the results of the assessment also with their in-house database of aggregate quarries. The results are given in Table 3.28.

Table 3.27: Rock names given by the involved institutes39

| **Location code** | **TU Delft** | **Core Power** |
|---|---|---|
| 2, 3, 8, 14 | Meta-sandstone | Feldspar bearing fine meta-sandstone |
| 4, 5, 6, 7, 11, 16 | Sandstone | Coarse meta-siltstone or fine meta sandstone |
| 10, 13, 15, 17 | Magmatic-basic: gabbro and basalt/basalt-variety | Metasomatically altered volcanic rock (“porphyrite”). |
| 1 | Magmatic – acid: possible rhyolite | Aalkali feldspar rhyolite or a rhyolite |
| 12 | Various composition: quartzite, schist, sandstone, limestone. | Part of cluster 4, 5, 6, 7, 11, 16 |
| 9 | Sandstone /siltstone | Fine grained meta-sandstone or a coarse meta-siltstone |

Table 3.28: Assessment of origin (quarry, area) by the two institutes40

| **Location code** | **TU Delft** | **Core power** |
|---|---|---|
| 2, 3, 8, 14 | Bremanger quarry - Norway | 2 and 3 Bremanger 8 and probably 14 Fjordstone |
| 4, 5, 6, 7, 11, 16 | Belgium Ardennes | Stentenberg quarry (Bergneustadt, Sauerland), |
| 10, 13, 15, 17 | Probably quarry Oberscheld (Dillenburg), Germany | most likely originates from the Lahn-Dill area near Oberscheld |
| 1 | Possible Flechtingen, Germany | Bierghes quarry Belgium |
| 12 | Quarry in river or moraine deposit | Part of cluster4, 5, 6, 7, 11, 16 |
| 9 | unknown | possible origin in the Ardennes |

39 The description of location code 12 in the TU Delft report was based on material from ZOAB core 121. Probably this core was not representative for the location; the variety of rock particles of differing lithology points to a river or moraine deposit. The description of Core Power based on material of location 12 from three ZOAB core samples is more in line with a class 3 aggregate as defined in the Dutch specifications RAW.

40 The locations 4,5,6,7,11 and 16 are from a Palaeozoic sandstone formation which runs from the Ardennes up to Sauerland in Germany.

Conclusions

- Based on the microscopic description from thin sections of the rocks in combination with the mineralogy determined by XRD analysis, it is clear that it is possible to build-up a database with typical petrographic and mineralogical characteristics of the aggregates.
- Comparison of data from an unknown aggregate with information in such a database will help to assess the origin of an aggregate. Accuracy of such assessments will improve when the database gets filled with more data.

#### *3.9.2.1.2 Assessment of the measured PSV value from petrographic information.*

Using the results of the petrographic description and the XRD analysis, Core Power determined the following characteristics of the rock aggregates Hellman, 2018b:

- Polymineralic rock composition
- Percentage of hard minerals against the percentage of soft minerals
- The ratio of hard minerals with good (well developed) cleavage to hard minerals with badly developed or no cleavage
- The Rosiwal rock polishing hardness for the rock, expressed in Quartz Equivalent Hardness (%).
- Mohs rock hardness number
- Remarks on petrographic aspects from which it is expected that they will influence the surface roughness, such as grain size and angularity of the minerals.

In appendix 2 of the Core Power report for each location a comment was given on the measured PSV value. Based on the mineralogical composition of the rock and considering the percentage of hard and soft minerals and the ratio hard/soft, a judgement was given on the measured PSV value. Most of the measured PSV values were considered likely and therefore “justified”. For one location, location 4, the measured PSV value of 64 was considered too high. An overview of the data is given in Table 3.29.

Paul Kuijper (2017) from RWS has used the mineralogical data for a multivariable regression analysis aimed at predicting the PSV value and moreover the behaviour of the ZOAB road surface during service life. The regression analysis uses only the mineral composition. When the rocks were grouped into a cluster igneous rock and a cluster sedimentary rock, the regression coefficient became better.

Tourenq et al., 1971 have found an empirical relationship between the PSV values measured on 84 rock types and the mineralogical composition of the rocks. They have used the differential hardness of the minerals composing the rock and the weighted Vickers Hardness of the rock as variables.

If dvi is the hardness of the ith mineral and pi the proportion of that mineral in the rock, then the mean Vickers Hardness of the rock, $D_{mp}$, is defined as:

$$D_{mp} = \sum_i p_i \ d_{vi} \qquad (3.4)$$

The differential hardness, $C_d$, is defined as:

$$C_d = \sum_i p_i \ |d_{vi} - d_{vb}| \qquad (3.5)$$

where $d_{vb}$ is the Vickers Hardness of the most abundant mineral.

The PSV regression equation based on the 84 rock types had a correlation coefficient of 0.928:

$$PSV = 33.42 + 10^{-2}\, D_{mp} + 6.10^{-2} C_d \tag{3.6}$$

Results of the Tourenq approximation of the PSV value are included in Table 3.29. The Vickers Hardness values of the minerals used come from Chapter 10 from Verhoef, 1997, an Excel spreadsheet calculation is available.

Despite the high correlation coefficient that Tourenq reports, for the rocks of this study the correlation is very low (see Figure 3.62). Apparently rocks from outside the rock database on which the regression equation is based do not fit the equation, which is therefore not generally applicable.

The poor results of the regression equations can be explained by other aspects that are known to influence resistance to polishing which are not included as variable in the regression analyses, such as the texture (microscopic structure) of the rock. Those aspects were considered in earlier research work done for Rijkswaterstaat DWW by Delft University (GEOMAT project; Pieters, W.E. , 1992, Pieters, W.E. et al., 1992, Van de Wall, 1992 and Verhoef et al., 1998). In that study the relationship of microscopic structure (texture), grainsize of minerals and PSV test results was investigated. There is a relationship, but this can be shown only within rock types of similar texture. Another outcome of this study is that using only the mineralogical composition is not enough for PSV estimation.

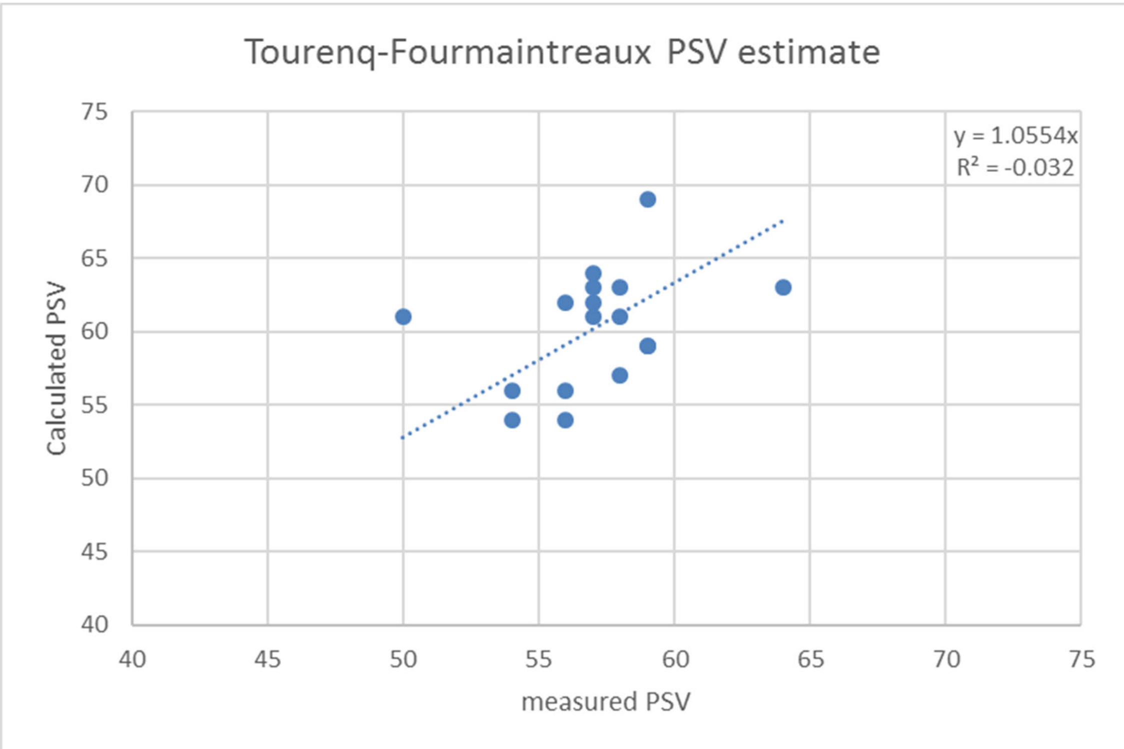



Figure 3.62: PSV calculated with the Tourenq regression equation (Tourenq et al., 1971) compared with the measured values.

Table 3.29: Summary of the mineralogical data from Core Power (2018-2)41. HM=hard minerals, SM=soft minerals, GC=good cleavage, LC=low cleavage. The last column gives the PSV values calculated using the Tourenq & Fourmaintreaux (1972) equation.

| Location | Rock name | Origin | Hard Min HM | Soft Min SM | HM+SM %(mass) | Ratio HM/SM | HM-GC %(mass) | HM-LC %(mass) | SM-GC %(mass) | Ratio HM-GC/HM-LC | Rosiwal Hardness | Mohs Hardness | Mean grain size µm | Self sharpening | PSV measured | PSV Tourenq |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | meta-microgranite | Bierghes | Quartz<br>Feldspars | Muscovite<br>Chlorite | 63+37= 100 | 1.7 | 32 | 31 | 37 | 1.03 | 45 | 5 | ? | yes | 59 | 69 |
| 2 | Meta-sandstone | Bremanger<br>Bestone | Quartz<br>Feldspars | Muscovite<br>Chlorite<br>carbonate | 69.2+30.2=99.4 | 2.3 | 27 | 43 | 30 | 0.61 | 53 | 5.4 | 97 | yes | 57 | 64 |
| 3 | Meta-sandstone | Bremanger<br>Bestone | Quartz<br>Feldspars | Muscovite<br>Chlorite<br>carbonate | 71.8+28.2= 100 | 2.5 | 29 | 43 | 29 | | 54 | 5.5 | 103 | yes | 57 | 63 |
| 4 | quartzitic graywacke<br>fine sandstone | stentenberg | Quartz<br>Feldspars | carbonate<br>Muscovite<br>Chlorite | 67+33=100 | 2 | 12 | 55 | 33 | 0.23 | 60 | 5.4 | 65 | yes | 64 | 63 |
| 5 | quartzitic graywacke<br>fine sandstone | stentenberg | Quartz<br>Feldspars | carbonate<br>Muscovite<br>Chlorite | 74+26=100 | 2.9 | 14 | 61 | 26 | 0.22 | 66 | 5.8 | 46 | yes | 59 | 59 |
| 6 | quartzitic graywacke<br>fine sandstone | stentenberg | Quartz<br>Feldspars | carbonate<br>Muscovite<br>Chlorite | 72+28=100 | 2.6 | 14 | 58 | 28 | 0.24 | 64 | 5.7 | 52 | yes | 57 | 61 |
| 7 | quartzitic graywacke<br>fine sandstone | stentenberg | Quartz<br>Feldspars | carbonate<br>Muscovite<br>Chlorite | 72+28=100 | 2.6 | 14 | 58 | 28 | 0.24 | 64 | 5.7 | 46 | yes | 58 | 61 |
| 8 | meta sandstone | fjordstone | Quartz<br>Feldspars | Muscovite<br>Chlorite<br>carbonate | 74.3+25.7=100 | 2.9 | 25 | 49 | 26 | 0.51 | 59 | 5.6 | 81 | yes | 56 | 62 |
| 9 | fine sandstone to<br>coarse siltstone | Bois d'Antthisune | Quartz | Muscovite | 77+23=100 | 3.3 | 4 | 72 | 23 | 0.06 | 74.2 | 5.8 | 48 | ? | 58 | 57 |
| 10 | coarse grained<br>meta-sandstone | Herhof Basalt- und<br>Diabas | Feldspars<br>pyroxene | Chlorite<br>calcite | 64+36=100 | 1.8 | 61 | 3 | 36 | 18.6 | 28.4 | 5 | 105 | yes | 56 | 54 |
| 11 | Quartzitic Greywacke<br>fine sandstone | Stentenberg | Quartz<br>Feldspars | carbonate<br>Muscovite<br>Chlorite | 69+31=100 | 2.2 | 13 | 55 | 31 | 0.24 | 61 | 5.5 | 33 | yes | 57 | 62 |
| 12 | Quartzitic Greywacke<br>fine sandstone | Stentenberg | Quartz<br>Feldspars | carbonate<br>Muscovite<br>Chlorite | 74+26=100 | 2.9 | 12 | 62 | 26 | 0.19 | 66 | 5.8 | 49 | yes | 59 | 59 |
| 13 | Diabase | werk Obenscheld | Feldspars<br>pyroxene | Chlorite<br>calcite | 60.6+39.4=100 | 1.5 | 57 | 3 | 39 | 17.19 | 27.4 | 4.9 | 165 | yes | 54 | 56 |
| 14 | meta sandstone | fjordstone | Quartz<br>Feldspars | Muscovite<br>Chlorite<br>carbonate | 79.6+20.4=100 | 3.9 | 38 | 41 | 20 | 0.92 | 56 | 5.8 | 95 | yes | 50 | 61 |
| 15 | Diabase | Obenscheld | Feldspars<br>pyroxene | Chlorite<br>calcite | 61.1+38.9=100 | 1.6 | 55 | 6 | 39 | 9.93 | 28 | 4.9 | 96 | yes | 56 | 56 |
| 16 | quartzitic graywacke<br>fine sandstone | stentenberg | Quartz<br>Feldspars | carbonate<br>Muscovite<br>Chlorite | 66+34=100 | 2 | 12 | 54 | 34 | 0.23 | 59 | 5.5 | 46 | yes | 58 | 63 |
| 17 | Diabase | Obenscheld | Feldspars<br>pyroxene | Chlorite<br>calcite | 64.3+35.7=100 | 1.8 | 61 | 3 | 36 | 18.64 | 28 | 5 | 55 | yes | 54 | 54 |

Conclusions:

- There is a relationship between PSV value and the mineral composition of aggregate, but this can be shown only within rock types of similar texture.
- The resistance to polishing is sensitive to the microscopic structure (texture) of the rock aggregate particles; i.e. the distribution of hard and soft minerals in the rock.

### 3.9.2.2 CT-scans

With a computed tomography scan (CT-scan) it is possible to create a three-dimensional volume from the scanned sample (in this case a ZOAB core). The objects can be 3D visualised and allow inspection of the inside structure of the sample. From the digital data the overall composition (such as bulk voids content, stone fraction, mortar) or composition of selected areas can be calculated.
From each location two cores with diameters of 150 mm, have been scanned with a medical CT-scanner at Delft University. In addition, one core sample with a diameter of 45 mm was cored out of one of the 150 mm diameter cores. This 45 mm diameter core has been scanned with a high-resolution scanner. From the data void-, mortar- (including clogging) and coarse aggregate content were determined and the distribution of these properties over the height of the samples van Tooren, M. M. et al., 2017.

Visual observations of the presence of cracks in grains, the distribution of voids and clogging are given in Table 3.30.

41 In the Core Power (2018-2) appendices the PSV values measured and "justified" are in several cases lower than 58. This is amazing and of concern, because all the certificates from the CE marking showed that the PSV value was always at least 58, as required.

**Table 3.30: Summary of visible observations of cracks, voids and clogging from the CT scan results.**

| Location | Presence of cracks in aggregate grains | Distribution of voids over the height | Clogging present in the core |
|---|---|---|---|
| 1 | In upper part | Dip close to the surface<br>Decreasing with depth | Some |
| 2 | No | Constant over the height | Some |
| 3 upper layer | Some | | Some |
| 3 lower layer | No | Low at the surface<br>Increasing with depth | |
| 4 | Some | One core, low at the surface,<br>Increasing with depth | In top part |
| 5 upper layer | Upper part frequently<br>Less in the lower part.<br>Grains missing in top part | | Yes |
| 5 lower layer | Grains missing in lower part Some Grains are not connected to the mortar, this could be a 2D effect(connected elsewhere) | Increasing with depth | |
| 6 | No | Low at the surface<br>Increasing with depth | Some |
| 7 upper layer | Some cracking over the whole sample, some grains are totally crushed | | Some in the lower part |
| 7-lower layer | Chattered grains at the top, the mortar is coming loose from the grains (stripping??) | Low at the surface | |
| 8 | Some in the upper part | Low at the surface<br>decreasing with depth | Some in lower part |
| 9 | Grains in upper and lower part are frequently cracked | | Some in the lower part |
| 10 | Some grains especially at the surface show a weathering pattern resulting in degradation of the grain | Low at the surface,<br>increasing with depth | No |
| 11 | Cracks in a few grains | Low at the surface | No |
| 12 upper layer | | | Present through the whole sample |
| 12 lower layer | | | |
| 13 | Some grains especially at the surface show a weathering pattern resulting in degradation of the grain | Low at the surface | No |
| 14 | No | Uniform over the height | No |
| 15 | Some grains especially at the surface show weathering patterns resulting in degradation of the grain | Dip close to the surface,<br>increasing with depth | No |
| 16 | Some grains at the surface are cracks | Dip close to the surface | In lower part |
| 17 | Some grains especially at the surface show weathering patterns resulting in degradation of the grain | | Some |

As can be seen in this table, in 15 locations (>70%) some form of cracks are noticed in the stones. Since CT-scanning and especially micro CT-scanning are not standard tests, there is no way to know if this is usual or not. However, cracks would seem to indicate weak spots and as such, to be unwanted. Having cracks present in so many cases, does not seem to be a good sign. It is recommended to use CT-scanning to look into the presence of cracks and their development over time.

An example of cracks such as mentioned at location 10, 13, 15 and 17 is given in Figure 3.63. In practice, such cracks will result in degradation of the aggregate grain causing an open space at the road surface, which may be the initiation of raveling.

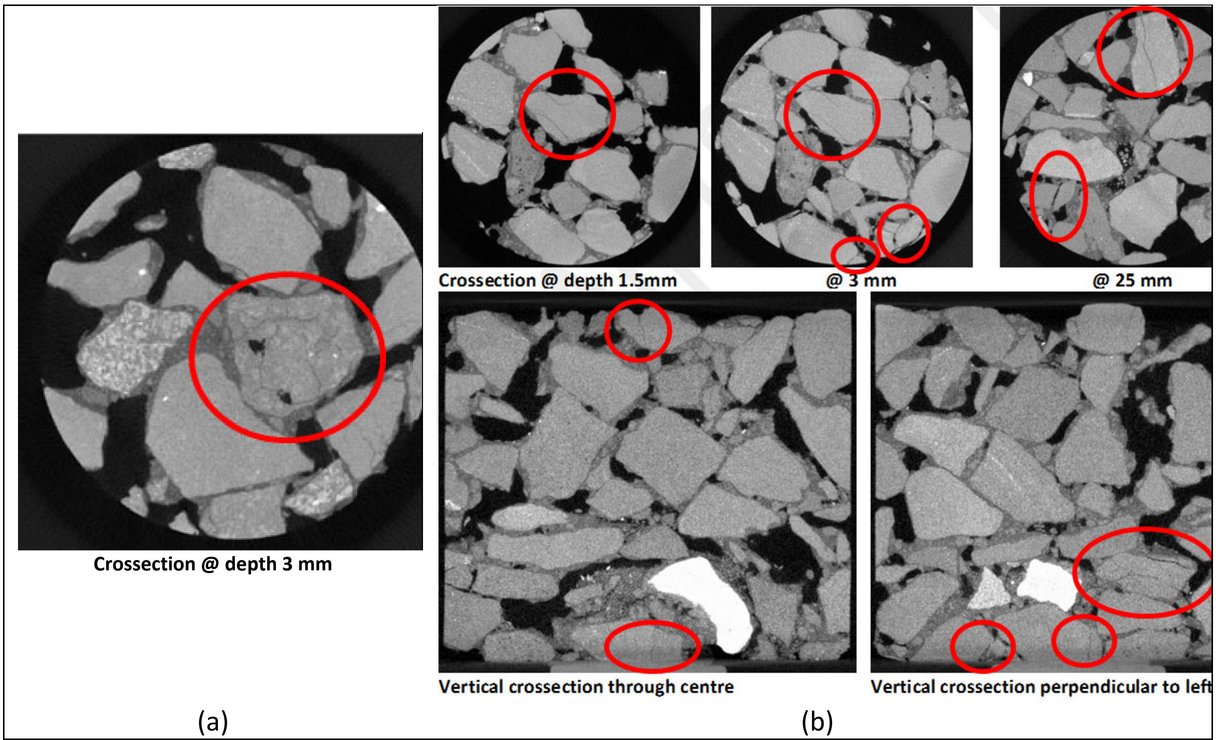



**Figure 3.63: Example of (a) weathering patterns (location 17) and (b) cracks (location 9)**

This leads to the following conclusions:

- CT-Scanning makes it possible to visualise pavement samples in 3D, which allows the studying of
    - voids over the height (Section 3.5.2 on page 89),
    - aggregate structure and individual aggregates (shapes, size, cracked or not)
    - clogging (visually, by trained experts for now)
    - as well as the binding between mortar and grains
- without damaging or disturbing the specimen, the core can still be used for other tests after scanning it to get detailed info

The recommendations are:

- The high-resolution scans give a lot of information but on small diameter samples. It would be an important improvement if it was possible to scan larger diameter core samples with a resolution of about 50 microns. Based on these scans stronger conclusions can be formulated than now, on i.e. :
    - Clogging, currently, experts are needed to visually distinguish clogging from mortar. With the higher resolution on larger course, it may be possible to automate this
    - Bitumen/mortar drainage: it may prove difficult to detect mortar drainage, because of the small differences over the height of the specimen but this might eventually be possible
    - Grain shape and grain size analyses of the aggregates in a core

## 3.10 Tests related to moisture sensitivity

This is not tested, so it is not further discussed here. It is, however, recommended to consider using cores that are still available to determine the moisture sensitivity to see if this can in any way be linked to the results on bitumen and (especially) $Ca(OH)_2$ presence.

## 3.11 Overview of the requirements and how well they are met

In the previous sections the requirements are treated per property. In this section, they are summarized to give an overall impression. This is done in a number of different ways, firstly by using the information obtained from the field cores without any documentation, purely comparing them to the overall RAW Standard requirements for each mixture group (Section 3.11.1). This was done because the detailed documentation was not present for all locations (Section 3.1).

In Section 3.11.2 the detailed information, where available, is compared to the average values (n=3) from the field cores using the requirements in the RAW Standard and finally, the detailed information was also compared to the individual results per location (Section 3.11.3).

The aim of this approach is to give an impression on how the requirements work out at various levels of detail and to help answer the research question regarding in what stages of a project various variations occur.

### 3.11.1 Comparing averages of field cores to RAW overall mixture specifications

In this section, the RAW specifications on group level are used to assess the average results from the cores. This means that the average bitumen content, void content, grading and PSV value are compared to the requirements for DZOAB 16, 2L-ZOAB 16 and 2L-ZOAB 8. In this comparison initially no margins are taken into account. Usually, margins are taken into account when assessing field cores, but that is relative to the reference composition. In that case, for the average core composition, the number of requirements reduces. This is because no margins are specified for the coarse aggregate fractions (and the degree of compaction).

This comparison is different and basically addresses whether the average results from the cores immediately allow the determination of the mixture group to which the cores belong. Since the target density is not part of the RAW specfications for a mixture group, no check on density or degree of compaction is included.

The results are shown in Table 3.31. The requirements for the penetration after construction and the amount of calcium hydroxide in the filler are included in the table, but as was discussed in Section 3.6.2.1 and Sections 3.7.2.3 and 3.7.2.5.2 these cannot be assessed. The penetration because it is typically not determined as part of the controls after construction, so no data on that was available. The field cores taken for this project were tested, but had over time lost more of their initial penetration value, making a direct link to the requirements difficult. For the $Ca(OH)_2$ content a similar issue occurs, where it is not quite clear if and if so, how the amount changes over time in field conditions. This is made even more complex, because currently there is no standard test method to assess the $Ca(OH)_2$ content after construction. For this reason, these checks show up in black, they cannot yet be carried out in an objective, validated way.
As can be seen, this way of assessing the data shows a limited number of deviations from the grading requirements, but considerable deviations from the minimum binder content, void content and PSV value required for the mixture groups under consideration. Only one out of twenty one mixtures (5%) do not show any deviation from the group specifications.

Table 3.31: Comparing field core averages (n=3) to mixture group requirements RAW Standard without any margins

| | | bit% | | voids | | PSV | | 1,4D | | D | | CCS | | | 2mm | | 0,063mm | | Ca(OH)2 | | pen after | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| location II | mixture group | RAW >= | cores | RAW >= | cores | RAW >= | cores | RAW>= | cores | RAW | cores | RAW | | cores | RAW | cores | RAW | cores | RAW >=* | cores | RAW >=** | cores |
| 1 | (D)ZOAB | 5,2 | 5,3 | 20 | 14,4 | 58 | 59 | 100 | 100 | 93-100 | 99 | 11,2 | 70-85 | 77 | 13-25 | 17 | 2,0-10,0 | 5,2 | 25 | - | 28 | 19,7 |
| 2 | (D)ZOAB | 5,2 | 4,7 | 20 | 17,7 | 58 | 57 | 100 | 100 | 93-100 | 99 | 11,2 | 70-85 | 74 | 13-25 | 13 | 2,0-10,0 | 4,8 | 25 | - | 28 | 28,3 |
| 3A | 2L_ZOAB8 | 5,4 | 5,3 | 20 | 20,9 | 58 | 57 | 100 | 100 | 90-100 | 94 | 5,6 | NR | 43 | 5-25 | 14 | 2,0-10,0 | 6,1 | 25 | - | 28 | 18,7 |
| 3B | 2L-ZOAB16 | 4,2 | 4,1 | 25 | 22,6 | | | 100 | 100 | 90-100 | 98 | 11,2 | DV | 40 | 5-25 | 11 | 2,0-10,0 | 4,8 | 25 | - | 28 | 16,3 |
| 4 | (D)ZOAB | 5,2 | 4,8 | 20 | 17,8 | 58 | 64 | 100 | 100 | 93-100 | 99 | 11,2 | 70-85 | 74 | 13-25 | 15 | 2,0-10,0 | 5,3 | 25 | - | 28 | 21,7 |
| 5A | 2L_ZOAB8 | 5,4 | 5,4 | 20 | 20,7 | 58 | 59 | 100 | 100 | 90-100 | 100 | 5,6 | NR | 95 | 5-25 | 18 | 2,0-10,0 | 6,6 | 25 | - | 28 | 9 |
| 5B | 2L-ZOAB16 | 4,2 | 4,2 | 25 | 21,9 | | | 100 | 100 | 90-100 | 94 | 11,2 | DV | 41 | 5-25 | 12 | 2,0-10,0 | 5 | 25 | - | 28 | 9 |
| 6 | (D)ZOAB | 5,2 | 5,2 | 20 | 15,4 | 58 | 57 | 100 | 100 | 93-100 | 99 | 11,2 | 70-85 | 80 | 13-25 | 15 | 2,0-10,0 | 5,8 | 25 | - | 28 | 22,7 |
| 7A | 2L_ZOAB8 | 5,4 | 5,0 | 20 | 21,7 | 58 | 58 | 100 | 100 | 90-100 | 98 | 5,6 | NR | 46 | 5-25 | 16 | 2,0-10,0 | 6,7 | 25 | - | 28 | 18,7 |
| 7B | 2L-ZOAB16 | 4,2 | 4,0 | 25 | 22,1 | | | 100 | 100 | 90-100 | 94 | 11,2 | DV | 41 | 5-25 | 12 | 2,0-10,0 | 2,6 | 25 | - | 28 | 16 |
| 8 | (D)ZOAB | 5,2 | 5,1 | 20 | 15,9 | 58 | 56 | 100 | 100 | 93-100 | 98 | 11,2 | 70-85 | 67 | 13-25 | 15 | 2,0-10,0 | 5,3 | 25 | - | 28 | 18 |
| 9 | (D)ZOAB | 5,2 | 5,2 | 20 | 17 | 58 | 58 | 100 | 100 | 93-100 | 100 | 11,2 | 70-85 | 98 | 13-25 | 17 | 2,0-10,0 | 6,2 | 25 | - | 28 | 24,7 |
| 10 | (D)ZOAB | 5,2 | 5,7 | 20 | 19,7 | 58 | 56 | 100 | 100 | 93-100 | 98 | 11,2 | 70-85 | 76 | 13-25 | 14 | 2,0-10,0 | 5,4 | 25 | - | 28 | 25,3 |
| 11 | (D)ZOAB | 5,2 | 5,3 | 20 | 19,2 | 58 | 57 | 100 | 100 | 93-100 | 99 | 11,2 | 70-85 | 81 | 13-25 | 14 | 2,0-10,0 | 6,2 | 25 | - | 28 | 21,3 |
| 12A | 2L_ZOAB8 | 5,4 | 5,3 | 20 | 21,9 | 58 | 59 | 100 | 100 | 90-100 | 96 | 5,6 | NR | 46 | 5-25 | 16 | 2,0-10,0 | 7,5 | 25 | - | 28 | 15,7 |
| 12B | 2L-ZOAB16 | 4,2 | 4,1 | 25 | 20 | | | 100 | 100 | 90-100 | 96 | 11,2 | DV | 38 | 5-25 | 11 | 2,0-10,0 | 5 | 25 | - | 28 | 13,7 |
| 13 | (D)ZOAB | 5,2 | 6,5 | 20 | 18,9 | 58 | 54 | 100 | 100 | 93-100 | 99 | 11,2 | 70-85 | 83 | 13-25 | 15 | 2,0-10,0 | 6,8 | 25 | - | 28 | 34 |
| 14 | (D)ZOAB | 5,2 | 5,3 | 20 | 16,1 | 58 | 50 | 100 | 100 | 93-100 | 98 | 11,2 | 70-85 | 75 | 13-25 | 15 | 2,0-10,0 | 5,7 | 25 | - | 28 | 19,3 |
| 15 | (D)ZOAB | 5,2 | 6,3 | 20 | 19 | 58 | 56 | 100 | 100 | 93-100 | 99 | 11,2 | 70-85 | 83 | 13-25 | 13 | 2,0-10,0 | 5,6 | 25 | - | 28 | 29,3 |
| 16 | (D)ZOAB | 5,2 | 5,3 | 20 | 16,1 | 58 | 58 | 100 | 100 | 93-100 | 100 | 11,2 | 70-85 | 84 | 13-25 | 17 | 2,0-10,0 | 6 | 25 | - | 28 | 24 |
| 17 | (D)ZOAB | 5,2 | 6,4 | 20 | 17,8 | 58 | 54 | 100 | 100 | 93-100 | 99 | 11,2 | 70-85 | 82 | 13-25 | 16 | 2,0-10,0 | 5,7 | 25 | - | 28 | 18 |
| 1 (5%) | OK | 12 (57%) | | 4 (19%) | | 11 (65%) | | 21 (100%) | | 21 (100%) | | 19 (90%) | | | 21 (100%) | | 21 (100%) | | | | | |
| 20 (95%) | NOT OK | 9 (43%) | | 17 (81%) | | 6 (35%) | | 0 (0%) | | 0 (0%) | | 2 (10%) | | | 0 (0%) | | 0 (0%) | | | | | |

**>=25% m/m in the filler, only use of middle type factory filler with hydroxide allowed, currently no standard test to assess this after production*

***: requirement 40% of lower limit penetration grade or value from TT max 14 days after construction, 28=40%x70. Current info much later in time*

Even if the requirement on the PSV is not considered, the overall result stays the same in only 1 out of 21 cases the average of the field cores meets the mixture group requirements. Most of the deviations occur in the void content (80% fails the mix group specification). In over 40% the minimum bitumen content is not met and in two cases (15% of the cases for which a requirement can be checked) the amount of material going through the characteristic course sieve (CCS) is not conform requirements.

What is interesting to notice, is that the deviations on average bitumen content as shown in Table 3.12 is that the deviations shown there, do not show up here and vice versa. The reason for this is that in this table only the basic RAW requirements are used, without margins. For bitumen this is a *minimum requirement*, which means that only the values that are too low show up as deviations in this table. In Table 3.12 (page 95) the minimum requirements are used to compare to the average values of the field cores, but here the margins are applied to this minimum. These margins are -0,5% and +0,4% and as a result, you get a minimum and maximum value here. None of the average results are lower than the minimum minus the margin, but several are higher than the minimum plus the margin. So although the approach in both tables is similar, it is not the same. For Table 3.12 the results show if the average core result would meet the specifications *if the target value for that mix is equal to the minimum requirement*. In YY it is shown if the average field core results fit into the overall requirements of the mixture group in the RAW 2015. For example, for Location 10 the average bitumen content of the field cores is 5,7%. This is well above the $B_{min}$ required DZOAB16 (5,2%) and as a result, this value shows as conforming to specification in Table 3.31. If, however, 5,2% would be the actual target value for $B_{min}$ for this mixture, the average core value would have to be between 5,2-0,5=4,7% and 5,2+0,4=5,6%. In that case, 5,7% exceeds 5,6% and as a result it shows as a deviation in Table 3.12.

### 3.11.2 Field core averages and detailed project information

In Table 3.2 and Table 3.3 an overview of the present documentation was shown. In this section, the content of that documentation is taken into account. In Table 3.32 it is shown if the project documentation contains a target and/or reference composition. If present, the target composition is checked versus the group requirements of the mixture under consideration in the RAW standard, a check which is also separated into the various aggregate groups (fines/sand/coarse). The reference composition, if present, is compared to the maximum allowed deviation from the target composition42. The results are shown in Table 3.32 and Table 3.33. The first two columns in both tables are the same, since they address the location ID and type of mixture.

The difference with the overview in the previous section is that there the average results of the field cores were compared to the RAW mix group requirements, by-passing the complications that arose because not all the required documentation was available for all materials/locations.

In this section, the target composition is compared to the RAW mix group requirements, the reference composition (or composition after extraction, if available) is compared to the target composition of the specific mixture using the margins specified in the standard. And finally, the average of the field cores is compared to the reference composition for each specific mixture. If required information is missing, that is considered a deviation and listed as such.

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42 In principle the reference composition should be compared to the composition after extraction (c.a.e., see art. 81.22.01 of the CROW, Standaard 2015, 2015), however, there is only one location for which all three compositions are available. For this reason, for all locations with a reference composition but no c.a.e. the comparison is done between target and reference composition. In case there is a c.a.e. provided, but no reference composition, the c.a.e. is used for the comparisons. If no reference composition is given either, this is counted as a deviation.

As can be seen, in quite a number of cases, the target composition does not meet the RAW Standard requirements for the mixture group. This basically means that these materials cannot be considered or shown to be a DZOAB 16 etc., *since in their design composition they do not meet the requirements for that mixture group*.
This is the case for nearly 50% of the materials. In most cases the coarse sieve and especially the CCS (characteristic coarse sieve) do not meet the requirements or the grading on that sieve is not given. The RAW Standard specifies, since the introduction of the EN standards in 2008, the 11,2 mm sieve as the characteristic sieve of ZOAB 16. For DZOAB 16 there is a requirement linked to the 11,2 mm sieve, for 2L-ZOAB 16 there is not, but a value must be declared (DV) and will later on be used to compare the various compositions to the target composition of each specific mixture. In 10 out of the 21 mixtures, this or one or more other deviations are present in the gradation information for the target composition.

It should be noted here that the checks were carried out only on the sieves for which there are requirements. In some cases the whole grading is provided in the target composition and since this is what is used and needed in production, that makes sense. However, in those cases checks should still be carried out on the sieves for which there are requirements only, to prevent putting a punishment on providing additional information.

Table 3.32: Comparing average field core results to project details – part I

| | | target composition vs RAW | | | | | reference vs target comp/c.a.e. | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| location ID | mixture group | overall | fines | sand | coarse | bit | fines | sand | coarse | ref bit% | target density? | overall |
| 1 | DZOAB16 | Y | Y | Y | Y | Y | N | Y | Y | Y | Y | N |
| 2 | DZOAB16 | N | Y | Y | N | Y | Y | Y | Y | Y | Y | Y |
| 3A | 2L_ZOAB8 | Y | Y | Y | Y | Y | Y | Y | N | Y | Y | N |
| 3B | 2L-ZOAB16 | N | Y | Y | N | Y | Y | Y | N | Y | Y | N |
| 4 | DZOAB16 | Y | Y | Y | Y | Y | Y | Y | Y | Y | Y | Y |
| 5A | 2L_ZOAB8 | Y | Y | Y | Y | Y | N | N | N | N | Y | N |
| 5B | 2L-ZOAB16 | Y | Y | Y | Y | Y | N | N | N | N | Y | N |
| 6 | DZOAB16 | N | Y | Y | N | Y | N | Y | N | Y | Y | N |
| 7A | 2L_ZOAB8 | Y | Y | Y | Y | Y | N | N | N | N | Y | N |
| 7B | 2L-ZOAB16 | Y | Y | Y | Y | Y | N | N | N | N | Y | N |
| 8 | DZOAB16 | Y | Y | Y | Y | Y | Y | Y | N | Y | N | N |
| 9 | DZOAB16 | N | Y | Y | N | N | N | Y | N | N | Y | N |
| 10 | DZOAB16 | N | Y | Y | N | N | N | Y | N | N | Y | N |
| 11 | DZOAB16 | N | Y | Y | N | Y | N | Y | N | Y | Y | N |
| 12A | 2L_ZOAB8 | N | Y | Y | Y | N | Y | Y | Y | Y | Y | Y |
| 12B | 2L-ZOAB16 | Y | Y | Y | Y | Y | N | Y | Y | Y | Y | N |
| 13 | DZOAB16 | N | Y | Y | N | Y | N | Y | N | Y | Y | N |
| 14 | DZOAB16 | Y | Y | Y | Y | Y | Y | Y | N | Y | N | N |
| 15 | DZOAB16 | N | Y | Y | N | N | N | Y | N | N | Y | N |
| 16 | DZOAB16 | N | Y | Y | N | Y | N | Y | N | Y | Y | N |
| 17 | DZOAB16 | N | Y | Y | N | N | N | Y | N | N | Y | N |
| 0 | OK | 10 | 21 | 21 | 11 | 16 | 7 | 17 | 5 | 13 | 19 | 3 |
| 20 | NOT OK | 11 | 0 | 0 | 10 | 5 | 14 | 4 | 16 | 8 | 2 | 18 |
| 1 | UNCLEAR | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

Regarding the bitumen content, corrections for the average weights of the aggregates were taken into account when assessing whether the bitumen content met the requirements. Despite this, nearly 25% of the mixtures do not meet the basic specifications in the RAW Standard, or do not provide information on the target bitumen content.

As indicated in Article 81.21.01d and e and 81.21.04 the (reference) composition consists of the grading and the bitumen content, so these should both be specified. A such, the overall composition (3$^{rd}$ column in Table 3.32) combines the results from the grading and the bitumen content. From the five mixtures where the bitumen content does not meet the specifications, four occur in mixtures where also the course aggregate gradation was incomplete or out of specification, in one case (mix 12A) the grading was complete and met the RAW requirements, but the bitumen content does not. As a result, for the overall composition, 11 out of 21 mixtures are incomplete or do not meet the mix group specifications of the RAW standard.

Although not labelled as part of the composition, the RAW standard states that for porous asphalt the void content must be equal to that determined in the Type Test (Section 81.22.14-05) and in the Type Test description it is indicated that for PA the void content must be determined (Test 62, section 2.3) and that this void content is the average of four determinations using NEN-EN 12697-8a (Test 62, section 4.2 of the RAW Standard 2015). Although it might seem logical to specify a target void content and also specify the void content actually found in determining the reference composition, this is not specifically required. For that reason, if either the reference or target composition provided a void content, this is counted as providing void content information for the mix composition. In thirteen cases one void content was provided, in six cases void contents for both target and reference composition were given and in two cases no void content was specified. In one case the given void content did not meet the specified requirement, so three mixtures failed to meet, or demonstrate to meet, the requirements for the void content. These three (8, 12B and 14) are all mixtures that did meet all grading requirements, so if void content is taken into account, 14 of the 21 mixtures (33%) do not meet the mix group specifications of the RAW standard.

In the right hand side of Table 3.32, the reference composition is compared to the target composition provided for each material. According to the RAW, a target and reference composition should always be provided, and since 2010 also the composition after extraction (c.a.e.) is required. However, there is only one location for which all three compositions are provided. In cases where only a reference or only a composition after extraction is provided, that one is used for the comparison to both target composition and field cores, without counting it as a deviation. If neither composition is provided, this is counted as a deviation and it effectively precludes any comparisons. Overall, in 85% of the cases there are one of more omissions or deviations between the target and reference (or c.a.e) composition that exceed the margins. Most of these errors are, again, caused by missing information on the CCS (11,2 mm) sieve.

Table 3.33: Comparing average field core results to project details – part II

| | | ave. cores vs reference | | | | | | | voids | | | | PSV | | density |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | bitumen type | | | | | | | | | |
| location ID | Mixture group | fines | sand | coarse | cores bit% | ref comp | cores | overall | $V_{req}$ | $V_{target}$ | $V_{ref}$ | cores | ref comp | cores | cores |
| 1 | DZOAB16 | Y | Y | NR | Y | 70/100 | 70/100 | Y | 20 | - | 20 | 14,4 | 62 | 59 | 2128 |
| 2 | DZOAB16 | Y | Y | NR | Y | 70/100 | 70/100 | Y | 20 | 21,5 | - | 17,7 | 61 | 57 | 2055 |
| 3A | 2L_ZOAB8 | Y | Y | NR | Y | PMB | PMB | Y | 20 | 20 | 23,7 | 20,9 | 62 | 57 | 1949 |
| 3B | 2L-ZOAB16 | Y | Y | NR | Y | 70/100 | 70/100 | Y | 25 | 20 | 28,2 | 22,6 | | | 1960 |
| 4 | DZOAB16 | Y | Y | NR | Y | 70/100 | 70/100 | Y | 20 | - | 20,4 | 17,8 | | 64 | 2055 |
| 5A | 2L_ZOAB8 | N | N | NR | N | PMB | PMB | N | 20 | 22 | - | 20,7 | 62 | 59 | 1953 |
| 5B | 2L-ZOAB16 | N | N | NR | N | 70/100 | 70/100 | N | 25 | 24,9 | - | 21,9 | 62 | | 1964 |
| 6 | DZOAB16 | Y | Y | NR | Y | 70/100 | 70/100 | Y | 20 | 20 | - | 15,4 | 58 | 57 | 2091 |
| 7A | 2L_ZOAB8 | N | N | NR | N | PMB | PMB | N | 20 | 22 | - | 21,7 | 62 | 58 | 1946 |
| 7B | 2L-ZOAB16 | N | N | NR | N | 70/100 | PMB | N | 25 | 24,9 | - | 22,1 | 62 | | 1973 |
| 8 | DZOAB16 | Y | Y | NR | Y | 70/100 | 70/100 | Y | 20 | - | - | 15,9 | | 56 | 2101 |
| 9 | DZOAB16 | Y | Y | NR | Y | 70/100 | 70/100 | Y | 20 | 20 | 21,7 | 17 | 58 | 58 | 2042 |
| 10 | DZOAB16 | Y | Y | NR | N | 70/100 | 70/100 | N | 20 | 20 | 23,1 | 19,7 | 58 | 56 | 2053 |
| 11 | DZOAB16 | Y | Y | NR | Y | 70/100 | 70/100 | Y | 20 | 20 | - | 19,2 | 58 | 57 | 2003 |
| 12A | 2L_ZOAB8 | Y | Y | NR | N | PMB | PMB | N | 20 | 22 | - | 21,9 | 60 | 59 | 1934 |
| 12B | 2L-ZOAB16 | Y | Y | NR | Y | PMB | 70/100 | N | 25 | 24 | - | 20 | 60 | | 1982 |
| 13 | DZOAB16 | Y | Y | NR | N | 70/100 | 70/100 | N | 20 | 20 | 23,1 | 18,9 | 58 | 54 | 2049 |
| 14 | DZOAB16 | Y | Y | NR | Y | 70/100 | 70/100 | Y | 20 | - | - | 16,1 | | 50 | 2093 |
| 15 | DZOAB16 | Y | Y | NR | N | 70/100 | 70/100 | N | 20 | 20 | 23,1 | 19 | 58 | 56 | 2050 |
| 16 | DZOAB16 | Y | Y | NR | Y | 70/100 | 70/100 | Y | 20 | 20 | - | 16,1 | 58 | 58 | 2081 |
| 17 | DZOAB16 | Y | Y | NR | N | 70/100 | 70/100 | N | 20 | - | 23,1 | 17,8 | 58 | 54 | 2077 |
| 0 | OK | 17 | 17 | 21 | 12 | | 19 | 11 | | 18 | | 15 | 17 | 2 | 4 |
| 20 | NOT OK | 4 | 4 | 0 | 9 | | 2 | 10 | | 3 | | 6 | 4 | 10 | 17 |
| 1 | UNCLEAR | 0 | 0 | 0 | 0 | | 0 | 0 | | 0 | | 0 | 0 | 9 | 0 |

When moving on to the next table (Table 3.33), the average of the field cores is compared to the reference composition. Here one would expect all the missing information in the reference composition to have an effect. This is, however, not the case. Mostly this is because there are no requirements for the deviation between cores and the reference composition on the coarse sieves if more than one core is tested. As a result, the number of deviations from the specifications for the grading is only 4 (out 21), those that have no reference composition at all. This shows that it is important to check separately for the completeness of the required information and not just use what is provided for checks.

Considering the bitumen content, the four locations for which there is no reference composition cannot be checked and therefore they are labelled as deviations. There are another five deviations where the average core values fail to meet the requirement set by the reference composition. Strikingly, only one has a bitumen that is too low, the others are too high compared to their reference.

The void content is too low in three locations, according to RAW Standard requirements. Another 3 locations do not meet the contractual requirements (RWS requires >=15% for individual cores, >=18% for the average, note that the requirements are not 18,0%, so i.e. location 2 does meet the requirement). As a result, a total of six (6) locations fail to meet the requirements.

Finally, it can be seen that in only two locations the declared PSV for the aggregates is realized in the cores. In all other cases, the cores result in a lower value than was declared. In ten locations, the value found from the cores is even lower than the minimum required value from the RAW Standard (58 for wearing courses/DZOAB16 and 2L-ZOAB8). In four cases (locations 3B, 4, 7B and 14) no PSV values are declared. Although the bottom layer of 2L-ZOAB can contain steenslag 2 instead of steenslag 3, that still requires the declaration of a PSV value higher than or equal to 53. The variation between declared and measured values is worrying, considering the relation to safety. And although determining the PSV on reclaimed aggregates is not a standard test, it raises some questions regarding the reliability of the CE-system when it comes to PSV value.

For density what is reported here is the presence of a declared target density in the project information. So Y means a value is given, N means it is not there.

All in all, none of the locations studied meets all the requirements, even taking into account that there are no requirements on the coarse fractions for this check.

### 3.11.3 Individual field core results and detailed project information

An example of the individual comparison of the field cores is shown in table 3.28. For all locations, this information is shown in Appendix II. On top of the table an explanation of the colour codes in the table is given. In this table the target composition is compared to the overall RAW Standard requirements. The reference composition is compared to the composition after extraction (c.a.e.), if available. Otherwise it is compared to the target composition. Similarly, if only a c.a.e. is present in the documentation and no reference composition, the c.a.e is compared to the target composition. In all these cases the maximum deviations specified between reference composition and c.a.e. are used as the criterion.
Individual and average core values are compared to the reference composition, when available. If there is no reference composition, but there is a c.a.e., that is used. The exception is the void content. If no void content was given in the short report/with the reference composition or c.a.e, but there was a value given in with the target composition, that one is used. The reason for this is that it is not explicitly stated that the reference composition should contain a value for void content and that this is the basis for the assessment of the cores.

Basically, this means that as long as a target composition (grading, bitumen content) and void content are given and either a c.a.e. or reference composition with a target density, all checks are carried out and no deviations due to missing information are registered. It must be noted that formally, this is not correct because under the RAW 2015 all three compositions (target, c.a.e. and reference composition) must be provided. However, since only one location came with all three compositions this would have increased the number of deviations considerably. At the top of the columns for the target composition, c.a.e. and reference composition it is indicated if that specific composition is provided and contains all required components. A green cell means provided and complete (not necessarily correct/fulfilling the requirements), orange means one or more required components are missing and red means that no information is provided for that composition. For example, in Table 3.34 for location 2 all three compositions are provided and complete, so the top cells in the three columns are green. It can also be seen that this doesnot necessarily mean the compositions meet all requirements, because the target composition does not (the value on the characteristic coarse sieve, CCS, (11,2mm) is too low), so that value is printed in red. For Location 3(A) the c.a.e. is not provided, so the top cell of that column is red, while the reference composition is provided, but lacks the information on the D (8mm) sieve. As a result the top cell in this column is orange.

Table 3.34: Example of the check on the individual core values versus target and reference composition

text/nr: point of attention/worry
not provided in documentation
no requirement
no Vmin given, DV provided and used

text: outside margin, inside acceptance interval
text: doesnot meet requirement
text: no requirement
text: meets requirement

c.a.e. = composition after extraction
target/c.a.e./ref present & complete
ref/c.a.e. present but incomplete
Bmin selected from Table 3 EN 13108-7:2006 based on conversion target Bmin from "on" to "in"

RWS contract specs: V>=15% individual cores, >=18% on average

| | overall requirement RAW | | | | | | | c.a.e. vs reference | | | | reference vs field cores (n=1) | | | | | ref vs av. field cores (n=3) | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| sieve | DZOAB16 | | 2L-ZOAB16 | | 2L-ZOAB8 | | target | min | max | c.a.e. | reference | min | max | 1 | 2 | 3 | min | max | average |
| Location 2 | | | | | | | | | | | | | | | | | | | |
| 31,5 | | | | | | | | | | | | | | | | | | | |
| 22,4 | 100 | 100 | 100 | 100 | | | 100 | | | 100 | 100 | | | 100 | 100 | 100 | | | 100 |
| 16 | 93 | 100 | 90 | 100 | | | 97 | 95 | 101 | 98 | 98 | 92 | 104 | 98 | 98 | 100 | | | 99 |
| 11,2 | 70 | 85 | DV | DV | 100 | | 69 | 70,5 | 77,5 | 74 | 74 | 67 | 81 | 75 | 72 | 75 | | | 74 |
| 8 | | | | | 90 | 100 | | | | | | | | 42 | 38 | 40 | | | 40 |
| 5,6 | | | | | NR | NR | | | | | | | | 25 | 21 | 23 | | | 23 |
| 4 | | | | | | | | | | | | | | | | | | | |
| 2 | 13 | 25 | 5 | 25 | 5 | 25 | 13 | 10,5 | 15,5 | 13 | 13 | 8 | 18 | 14 | 12 | 13 | 9,5 | 16,5 | 13 |
| 0,5 | NR | NR | NR | NR | NR | NR | 8 | | | 8 | 8 | | | | | | | | |
| 0,18 | | | | | | | - | | | | - | | | | | | | | |
| 0,063 | 2 | 10 | 2 | 10 | 2 | 10 | 4,5 | 4,725 | 5,875 | 5,3 | 5,3 | 3,0 | 7,6 | 5,2 | 4,5 | 4,8 | 4,0 | 6,6 | 4,8 |
| Mbit | 5,2 | | 4,2 | | 5,4 | | 5,2 | | | | 5,1 | 4,5 | 5,7 | 4,9 | 4,6 | 4,7 | 4,60 | 5,50 | 4,7 |
| voids %V/V | 20 | | 25 | | 20 | | 21,5 | | | | | 16,5 | 26,5 | 16,0 | 18,5 | 18,6 | 17,50 | 25,50 | 17,70 |
| degree of compaction [%] | | | | | | | | | | | | 97,0% | 103,0% | 106,1% | 103,5% | 103,4% | | | 104,3% |
| density [kg/m3] | | | | | | | | | | | 1970 | | | 2090 | 2039 | 2037 | | | 2055 |
| | overall requirement RAW | | | | | | | target vs reference | | | | reference vs field cores (n=1) | | | | | ref vs av. field cores (n=3) | | |
| sieve | DZOAB16 | | 2L-ZOAB16 | | 2L-ZOAB8 | | target | min | max | c.a.e. | reference | min | max | 1 | 2 | 3 | min | max | average |
| Location 3 (A) | | | | | | | | | | | | | | | | | | | |
| 31,5 | | | | | | | | | | | | | | | | | | | |
| 22,4 | 100 | 100 | 100 | 100 | | | - | | | | - | | | | | | | | |
| 16 | 93 | 100 | 90 | 100 | | | - | | | | - | | | | | | | | |
| 11,2 | 70 | 85 | DV | DV | 100 | | 100 | | | | | | | 100 | 100 | 100 | | | 100 |
| 8 | | | | | 90 | 100 | 91,5 | 88,5 | 94,5 | | | | | 95 | 94 | 93 | | | 94 |
| 5,6 | | | | | NR | NR | 32,4 | | | | 32,4 | | | 45 | 43 | 41 | | | 43 |
| 4 | | | | | | | - | | | | - | | | | | | | | |
| 2 | 13 | 25 | 5 | 25 | 5 | 25 | 11,5 | 9 | 14 | | 11,5 | 6,5 | 16,5 | 14 | 14 | 14 | 8 | 15 | 14 |
| 0,5 | NR | NR | NR | NR | NR | NR | 8,8 | | | | - | | | | | | | | |
| 0,18 | | | | | | | - | | | | - | | | | | | | | |
| 0,063 | 2 | 10 | 2 | 10 | 2 | 10 | 5 | 4,425 | 5,575 | | 5 | 2,7 | 7,3 | 6 | 6,3 | 6 | 3,7 | 6,3 | 6,1 |
| Mbit | 5,2 | | 4,2 | | 5,4 | | 5,5 | | | | 5,7 | 5,1 | 6,3 | 5,4 | 5,4 | 5,2 | 5,20 | 6,10 | 5,3 |
| voids %V/V | 20 | | 25 | | 20 | | 20 | | | | 23,7 | 15 | 25 | 19,6 | 21,6 | 21,6 | 16,00 | 24,00 | 20,9 |
| degree of compaction [%] | | | | | | | | | | | | 97,0% | 103,0% | 105,0% | 102,2% | 102,5% | | | 103,2% |
| density [kg/m3] | | | | | | | - | | | | 1888 | | | 1982 | 1930 | 1936 | | | 1949 |

Since the RAW standard specifies the a composition as grading and bitumen content, if either of these is missing for the target provided compositions, this is considered a deviation. Because these values are used to assess whether the c.a.e./reference or core compositions meet the requirements, missing grading or bitumen content information makes it impossible to carry out these checks, which is considered a deviation in itself. For example, the missing information on the D-sieve for Location 3(A) makes it impossible to assess if the D-values for the individual cores fall within the margins allowed between core and reference composition. For this reason, although there are values there, they have a red background and count as deviations.

The numbers shown in the table are either printed in black, which means it is an active requirement or margin, like the requirements for DZOAB16 in the 2nd and 3rd column for Location 2 or those for 2L-ZOAB8 in columns 6 and 7. Or it is composition information for no requirement is specified, such as the 0,5mm sieve in all three compositions for Location 2.
If they are printed in green, it means they fulfil the requirement (i.e. the 16mm sieve in the target composition for Location 2), red means they do not (the 11,2mm sieve for the target composition of Location 2). Orange is used when there are two levels of requirements: a tolerance interval (which is not met, if the value is orange, i.e. the degree of compaction for core 2 and three of Location 2) and an interval for withholding approval (which if not met means the value is printed in red, like for the degree of compaction of core 1 of Location 2).

As can be seen, for the average of the field cores there are no margins specified for the course sieves or the degree of compaction. This seems odd, because usually the requirements for averages are stricter than for individual values. In the table, as an indication, also the density of the individual cores and their average are given. The requirement used here is the maximum variation in density specified in the type test (+/- 30kg/m$^3$). This is not currently a formal requirement in the standard, but it provides some extra information.

In a few cases (for example the bitumen content for the target composition of Location 3(A)), the number is printed on a yellow background. This indicates locations produced shortly after the introduction of the EN standards for Asphalt Concrete Mixtures (EN 13108-series). These mixtures could be delivered based on recent old-style mix designs (vooronderzoeken in Dutch). In those, the target bitumen content was expressed as a percentage "on" 100% aggregate mass. In Table 3 of the EN 13108-7 bitumen content "in" 100% mixture mass was defined in steps of 0,5%. In some cases, after calculating the $B_{min}$ the producer selected the closest lower value from the table, rather than just giving the value. The table in the standard should be used by clients, to specify requirements. A producer would, in case of the mixture from Location 3(A) be able to change 6,0% bitumen "on" to 5,7% "in" and declare that. If instead the closest value from Table 3 in the standard was selected this resulted in $B_{min}$5,5. In this case, it still fulfils the requirement (5,4%), but in cases that it doesn't, this is *not* counted as a deviation for these first generation EN standard mixtures.

Finally, an orange/pink background indicates a void content for an individual core or the average of the cores that does meet the RAW requirement, but fails the additional RWS requirements, since RWS requires for (D)ZOAB 16 that all individual cores have a void content of at least 15% and that the average value of cores is no lower than 18%. In relation to the RAW Standard requirements, this means that the requirement for the individual cores is set at the level of the tolerance, excluding the extra margin the RAW Standard allows before refusing acceptance. For the average of the cores, the RWS requirement is more stringent than the RAW Standard for mixtures whose design void content is close to the minimum required void content and limited numbers of cores. In determining the number of deviations, not meeting this contractual RWS requirement is also counted as a deviation.

#### 3.11.3.1 Check versus RAW 2015 requirements

The results of the detailed check for all locations is included in Appendix II. An overview is given in Table 3.35. Here the total number of deviations is compared to the total number of checks in this overview. For example, for the target and individual field core composition there are seven requirements to check for both D16 mixtures (*1,4D, D, CCS, 2 mm, 0,063 mm, bitumen content and void content* for the target composition and *D, CCS, 2 mm, 0,063 mm, bitumen content, void content and degree of compaction* for the field cores). For the reference composition/c.a.e. there are six requirements for the D16 mixtures (*D, CCS, 2 mm, 0,063 mm, bitumen contention and (target) density*) and for the average of the field cores there are formally four (*2 mm, 0,063 mm, bitumen content and void content*), five if also the density is compared to the target density. For the 2L-ZOAB8 mixture the numbers for all compositions are smaller by one, since there is no CCS requirement. See also Table 3.5, Table 3.6 and Table 3.7 on pages 70 to 72.
With 17 D16 and 4D8 mixtures, this yields a total of 143 requirements to check for both the target and the individual core compositions, 122 for the c.a.e./reference composition and either 84 or 105 (depending on whether density is taken into account) for the average of the field cores, using the current RAW requirements (2015).

Table 3.35: Overview of the numbers of checks met per type of composition (considering density for average)

| | | | field cores | | | |
|---|---|---|---|---|---|---|
| | total number of requirements met | | | | | |
| | target | reference | 1 | 2 | 3 | average |
| meets req | 125 (87%) | 75 (61%) | 86 (60%) | 86 (60%) | 91 (64%) | 65 (62%) |
| fails req | 18 (13%) | 47 (39%) | 57 (40%) | 57 (40%) | 52 (36%) | 40 (38%) |

In the overview in Table 3.35 for each composition (target composition, reference composition, the individual cores and the average of three cores) it is shown how many of these checks are met. This is a similar approach to determining the total number of deviations from the requirements as used in the DIAK reports (Table 1.2). The total percentage of deviations in the requirements that were checked, were in that case 13% and 11%, one versus RAW 1990 and the other for RAW 1995.

More importantly, even the target and c.a.e./reference composition fail to meet the requirements in a number of cases. For c.a.e./ reference composition there are deviations or missing information in nearly 40% of the cases. Even the target composition fails the requirements in over 10% of the mixtures. This should not occur at all, since in writing down these compositions, a check against the requirements would show they do not meet them. As such, materials with target and c.a.e. or reference compositions that do not fulfil the requirements should never leave the lab or plant to go into production.

Individual core results fail to meet roughly 40% of the requirements, for the average of the field cores, the percentage is of the same order if density is taken into account. If it is not (Table 3.36), deviations are about 10% less. The numbers and percentages between the two versions of the table differ only for the average of the field cores, the rest stays the same.

Table 3.36: : Overview of the numbers of checks met per type of composition (ignoring density for average)

| | | | field cores | | | |
|---|---|---|---|---|---|---|
| | total number of requirements met | | | | | |
| | target | reference | 1 | 2 | 3 | average |
| meets req | 125 (87%) | 75 (61%) | 86 (60%) | 86 (60%) | 91 (64%) | 60 (71%) |
| fails req | 18 (13%) | 47 (39%) | 57 (40%) | 57 (40%) | 52 (36%) | 24 (29%) |

Deviations between field cores and requirements are to be expected, since here production and construction conditions play a role. However, in determining the number of deviations the margins in the standard are already taken into account and only mixtures deviating more than the margins allowed for are listed. So in about 40% of the locations deviations occur.

When this 40% is compared to the DIAK controls (Rijkswaterstaat, 2001a, 2001b and Table 1.2), where the order of magnitude of deviations was 10% (11 and 13%, respectively), it appears that the number of deviations has increased considerably. The overall number of deviations is of the order of magnitude of the highest number of deviations found in those DIAK reports (36% for deviations from the grading).

Another way to look at the deviations is not taking into account the individual requirements, but consider it per material. Because these requirements are obligatory, so the aim is for any material in a project to meet all requirements. For this reason, the number of materials/locations for which all requirements were met are gathered (Table 3.37). This is done per composition and overall.

Table 3.37: Overview of the number of locations that meet all requirements per composition if density is taken into account for the average

| | number of locations meeting all requirements | | | | | | |
|---|---|---|---|---|---|---|---|
| | target | reference | 1 | 2 | 3 | average | total |
| meets all | 7 (33%) | 3 (14%) | 1 (5%) | 0 (0%) | 1 (5%) | 1 (5%) | 0 (0%) |
| fails >=1 r | 14 (67%) | 18 (86%) | 20 (95%) | 21 (100%) | 20 (95%) | 20 (95%) | 21 (100%) |

Table 3.38: Overview of the number of locations that meet all requirements per composition if density is not considered

| | number of locations meeting all requirements | | | | | | |
|---|---|---|---|---|---|---|---|
| | target | reference | 1 | 2 | 3 | average | total |
| meets all | 7 (33%) | 3 (14%) | 1 (5%) | 0 (0%) | 0 (0%) | 5 (24%) | 0 (0%) |
| fails >=1 r | 14 (67%) | 18 (86%) | 20 (95%) | 21 (100%) | 21 (100%) | 16 (76%) | 21 (100%) |

As can be seen, only about 30% of all target compositions and not even 15% of all reference compositions are complete and meet all requirements. That is extremely low.

For the individual cores hardly any material meets all requirements, for the average this increases to just over 15% if density is not considered. If it is, the score is as low as for the individual cores. This is still extremely low, it would be expected that the majority of the materials fulfil all requirements.

The final column shows the number of materials/locations that meet all requirements for all compositions (target, reference, core 1, 2 and 3 and their average). As can be seen, none of the locations do this, which is shocking.

As shown in Figure 3.64, only two of the 21 mixtures fail to meet less than 5 requirements. All others fail (considerably) more often, independent of whether density is taken into account or not.

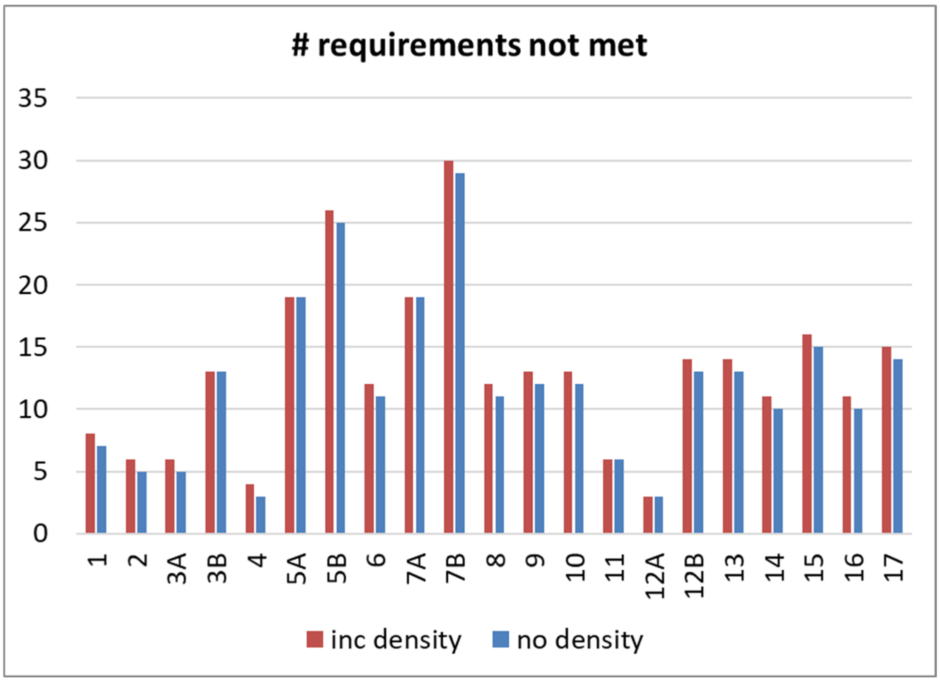

Figure 3.64: Overview of the number of requirements not met overall per project/location

### 3.11.3.2 Check versus requirements at time of construction

As discussed in Section 3.2, the requirements used to assess the materials here (RAW Standard 2015), were not the criteria valid at the moment of construction. At that time, these materials were not part of the RAW Standard. Particularly for the 2L-ZOAB mixtures, no grading requirements were available. DZOAB 16 was specified as ZOAB16, but with extra bitumen, which is stricter than the current requirements on the 2mm sieve (minimum value 15% instead of 13%). For 2L-ZOAB the required binder contents, transformed from the original percentage “on” (6,0% and 4,5%) to “in” were higher than the current ones (5,7 instead of 5,4% and 4,3 instead of 4,2%). Also, some of the tolerances and margins used in determining when penalties or additional research were needed, changed over time (Table 3.39).

Table 3.39: Differences in tolerances and margins between RAW 2015, 2010 and 2008

| | | | V% | DC% | Bmin% | D | CCS | 2 | 0,063 |
|---|---|---|---|---|---|---|---|---|---|
| **RAW 2008** | n=1 | tolerances | +/- 5,0 | +/- 3,0 | +/- 0,5 | +/- 4,5 | +/- 6,0 | +/- 5,0 | +/- 1,5 |
| | | no approval/add research | +/- 7,4 | +/-5 ,4 | +/- 0,8 | +/- 4,5 | +/- 6,0 | +/- 5,0 | +/- 1,5 |
| | n=3 | no approval/add research | +/- 4,00 | NR | +0,4 /-0,5 | NR | NR | +/- 3,50 | +/- 1,30 |
| **RAW 2010** | n=1 | tolerances | +/- 6,0 | +/- 4,0 | +/- 0,6 | +/- 6 | +/- 7 | +/- 5,0 | +/- 2,3 |
| | | no approval/add research | +/- 7,4 | +/-5 ,4 | +/- 0,8 | +/- 6 | +/- 7 | +/- 5,0 | +/- 2,3 |
| | n=3 | no approval/add research | +/- 4,00 | NR | +0,4 /-0,5 | NR | NR | +/- 3,50 | +/- 1,30 |
| **RAW 2015** | n=1 | tolerances | +/- 5,0 | +/- 3,0 | +/- 0,6 | +/- 6 | +/- 7 | +/- 5,0 | +/- 2,3 |
| | | no approval/add research | +/- 7,4 | +/-5 ,4 | +/- 0,8 | +/- 6 | +/- 7 | +/- 5,0 | +/- 2,3 |
| | n=3 | no approval/add research | +/- 4,00 | NR | +0,4 /-0,5 | NR | NR | +/- 3,50 | +/- 1,30 |

All in all, although the differences are limited, assessing the results versus the actual requirements per situation could conceivably lead to some changes. It must be noted here that "actual requirements" here means the requirements in place at the time of construction. This means the RAW Standard 2008 (CROW, Standaard 2008 (2008)) together with the RWS specifications for Asphalt Pavements (Rijkswaterstaat (2009)) and the VBW design guide for two layer PA (VBW Asfalt et al., 2002) for the locations constructed in 2008 and 2009. For locations constructed between 2010 and 2015 it means the RAW Standard 2010 (CROW, Standaard 2010 (2010)) in combination with the previously mentioned documents, the updates of these documents did not change the specified properties. Finally, for the section constructed in 2015 only the RAW Standard 2015 (CROW, Standaard 2015 (2015)) is needed.

Applying these requirements and tolerances results in the following overall results regarding the number of requirements met (or failed) and the number of Locations where all requirements for a given composition are met (Table 3.40). As can be seen, the differences with the results found using the criteria of the RAW 2015 (Table 3.35 through Table 3.38) are very limited. It must be noted here that in this new assessment, deviations of the DZOAB16 and 2LZOAB16 mixtures with regard to the lower limit of sieve 2mm were not counted. The reason for this is that that requirement was changed in the RAW 2015 for the reason that it was difficult to adhere to with the higher bitumen content. If that requirement were to be used strictly, it would add 8 more deviations to the target (versus RAW specifications) overview.

Table 3.40: Total numbers of requirements at the time of construction and number of requirements met either taking into account a density requirement for the average of the field cores (top) or without (bottom)

**inc density requirement average field cores**

| | | field cores | | | | |
|---|---|---|---|---|---|---|
| total number of requirements | | | | | | |
| target | reference | 1 | 2 | 3 | average | |
| 98 (84%) | 58 (57%) | 72 (59%) | 72 (59%) | 77 (63%) | 56 (60%) | |
| 18 (16%) | 43 (43%) | 50 (41%) | 50 (41%) | 45 (37%) | 37 (40%) | |
| number of locations meeting all requirements | | | | | | |
| target | reference | 1 | 2 | 3 | average | total |
| 8 (38%) | 3 (14%) | 1 (5%) | 1 (5%) | 2 (10%) | 1 (5%) | 0 (0%) |
| 13 (62%) | 18 (86%) | 20 (95%) | 20 (95%) | 19 (90%) | 20 (95%) | 21 (100%) |

**no density required for average field cores**

| | | field cores | | | | |
|---|---|---|---|---|---|---|
| total number of requirements | | | | | | |
| target | reference | 1 | 2 | 3 | average | |
| 98 (84%) | 58 (57%) | 71 (58%) | 70 (57%) | 74 (61%) | 51 (71%) | |
| 18 (16%) | 43 (43%) | 51 (42%) | 52 (43%) | 48 (39%) | 21 (29%) | |
| number of locations meeting all requirements | | | | | | |
| target | reference | 1 | 2 | 3 | average | total |
| 8 (38%) | 3 (14%) | 1 (5%) | 1 (5%) | 1 (5%) | 5 (24%) | 0 (0%) |
| 13 (62%) | 18 (86%) | 20 (95%) | 20 (95%) | 20 (95%) | 16 (76%) | 21 (100%) |

# 4. Effect of deviations on the life time

Because of the large number of variables that determine pavement performance, it is usually difficult to link a deviation in composition directly to a life time reduction. This was also clear from the early failures that triggered this study. In those cases extremely early failure was linked to a number of deviations in mixture composition. As such, it is difficult to indicate how the deviations found in this study will quantitatively affect the life time.

There are, however, generally accepted relations for how the various composition parameters affect performance in a qualitative way. Unfortunately, most of these are based on the experience with dense asphalt concrete, not with PA. Since it is used to get a general impression, this is considered sufficient for now. Therefore, these generally accepted relations are discussed in this chapter.

In the most general form it can be stated that asphalt mixture design is meant to establish the optimal composition for a type of material (say a DZOAB 16), with the materials selected (type of stones, filler, bitumen). This leads to a certain grading, void content and density. Because of the variability of the materials and the process involved, margins are allowed on this optimal composition. However, too much deviation (i.e. parameters that go outside the margins) from the designed, optimal, composition can have un-identified and therefor unwanted effects on the mixture properties.

A general overview of which constituent material property is considered to affect what mixture properties is given in (CROW, 2010) and this is reproduced here (in Dutch).

Table 4.1: Overview of the relation between constituent material and mixture properties (Table 20 from CROW, 2010)

| **Bouwstof** | **Eigenschap** | **Invloed op mengselgedrag** |
|---|---|---|
| Gebroken materiaal | Oppervlakteruwheid | Hogere stabiliteit (inwendige wrijving), moeilijker te verdichten |
| % grof aggregaat > 2mm | Steenskelet | Goede stabiliteit, weerstand tegen vervorming |
| Soort zand: grof-fijn enz. | Specifiek oppervlak-filmdikte bitumen | Levensduur, verwerking |
| Zandgradering | Stabiliteit zandfractie<br>Opvulling van het steenskelet | Stabiliteit |
| Type en soort vulstof | Hechting bitumen/omhulling<br>Grof aggregaat invloed op mortelstijfheid | Levensduur<br>Stabiliteit, verwerking/verdichting |
| % vulstof + bitumen (mortel) | Opvulling holle ruimte grof aggregaat<br>Omhulling/hechting grof aggregaat | Stabiliteit/vervorming<br>Verwerking/verdichting<br>Levensduur |
| Verhouding vulstof/bitumen | Stijfheid mortel | Viscositeit mengsel, stabiliteit, verwerking/verdichting |
| Gradering mineraal aggregaat | Filmdikte bitumen<br><br>Stabiliteit-opneemvermogen | Levensduur, verwerkbaarheid, scheurweerstand<br>Stabiliteit |

Over the decades, many studies have been carried out to link various mixture properties, such as the stiffness to composition parameters. In this case, volumetric mixture information is used, not mass percentages as is the case in production, since it are the relative amounts of the materials that determine the properties.

In most cases, the actual relation works well for the group of mixtures for which it is derived, but not for other mixtures. Most of the time, however, the set of parameters used is quite consistent for a group of mixtures. For example, Bonnaure, 1977 published the work he did with Ugé on predicting the

AC stiffness using the stiffness of the bitumen, bitumen and aggregate volume percentages. This relation shows that the stiffness increases if the bitumen stiffness increases (harder bitumen), if the volume percentage of bitumen becomes less and if the volume content of stones increases. Similarly, the stiffness decreases with softer bitumen, more bitumen and less stones.

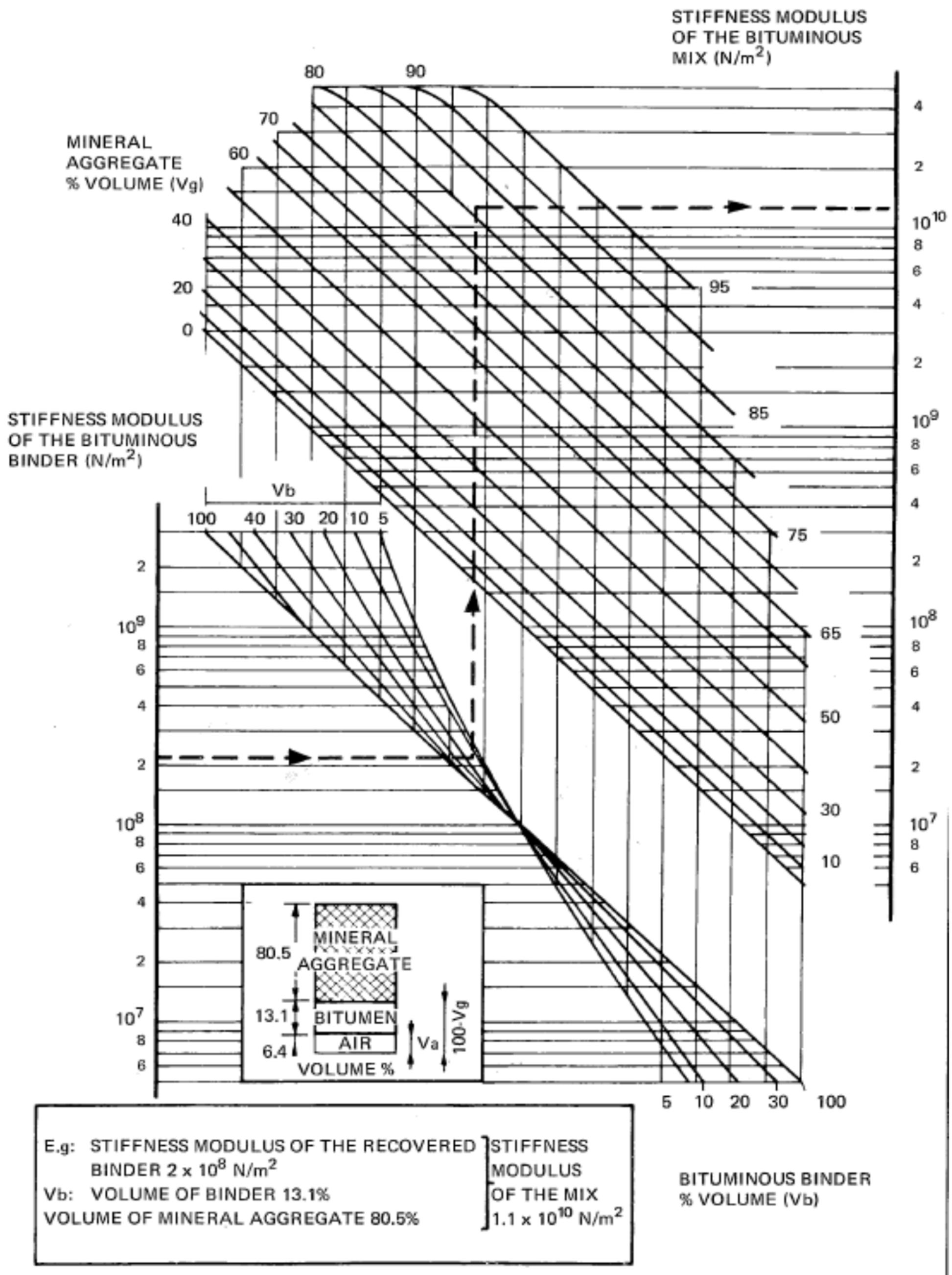


Figure 4.1: Uge nomograph, linking stiffness to volumetric mixture composition (Bonnaure, 1977)

## 4.1 Coarse aggregates

Coarse aggregates make up the bearing skeleton of the PA mixture, hence they carry a heavy load, if they are sensitive to crushing, it will lead to a change in gradation (more fines) during production and damage to the stones (cracking or crushing) in compaction (VBW Asfalt, 1997). This makes the mixture more vulnerable to damage. The resistance against crushing for the stones in the cores has not been investigated, but damage to the coarse aggregates (cracks) have been observed in some of the CT scans.

Also the acidity of the stones can have an effect of the life time, specifically lack of acidity, allowing for a better adhesion with the, generally acidic, bitumen (VBW Asfalt, 1997). Information on the acidity of the aggregate is not part of the standard specifications and has not been tested here.

## 4.2 Filler

Filler is part of the aggregate grading, improves the adhesion between stone and bitumen and stiffens and strengthens the bitumen (VBW Asfalt, 2005). If deviations occur in the amount of filler, the intended grading is not realized.

The beneficial efforts in adhesion promotion are ensured specifically by prescribing middle type filler with hydroxide (Bouwend Nederland, 2012 and CROW, 1996), which is why this is prescribed for ZOAB and SMA-NL. Specifically, the improved adhesion is found to affect the moisture sensitivity (Hopman et al., 2006).

In this study, several deviations on the amount of filler were found, this will affect both the grading and the mortar properties.

For the presence and amount of $Ca(OH)_2$ no standard test exists yet. Also, time lines for the development over time of this parameter are not available and since it seems feasible that the material reacts with bitumen (and stones) initially and with moisture throughout, such information will be needed to deal with any observations over time. As such, no conclusions on this aspect or its effect on performance are possible.
These observations do reinforce the importance of establishing test methods and reference frames for this property.

## 4.3 Bitumen

As shown above, more bitumen reduces the stiffness. Other effects of more bitumen are a thicker bitumen film on the aggregates, which slows aging and improves moisture sensitivity (VBW Asfalt, 1997). As a result, the life time (and resistance to ravelling) is improved (CROW, 1996), provided that drainage of the bitumen in the construction phase is prevented (using a drainage inhibitor). In the same study it was mentioned that PMB can also improve the life time and that less than 4,5% m/m (on 100% aggregates, so 4,3% m/m “in mixture”) leads to an unacceptable reduction of the life time.

Another study (infoblad_960_ontmenging_van_zoab) indicates that a higher bitumen content at the surface of the mixture has a positive effect on the ravelling resistance and, through that, the life time of ZOAB and because of this the suggest to use a maximum variation of 0,7 %m/m between the top and bottom half of a ZOAB core. This has, however, only recently become a standard test.

In this study several deviations from the design bitumen content were found, but these were all higher than designed for. Although any deviation from the design beyond the margins is unwanted, this is a relatively benign deviation for ZOAB and not expected to have a negative impact on its performance.

In two cases it was found that the mixture information specified either a PMB or a penetration binder, while the study of the cores indicated that this was not what was used. Such a change in binder will have a major effect on the mixture properties and workability and is to be avoided at all times. Also, it means the mixture is not as indicated on the CE mixture information, which is not allowed.

The penetration of the recovered bitumen was for most of the pen grade bitumen samples in line with what is known about the reduction of the penetration over time. For the PMB's in two cases deviations seemed to appear. However, the available reference frame is limited and needs to be extended. Adding the determination of penetration to the standard tests in QA during construction would be a good start, along with testing a selection of locations over time to establish a time line.

## *4.4 Density, compaction, void content*

In general, compaction is seen to have a significant impact on the durability of a pavement, particularly on its rutting resistance (CROW, 2010).

VBW Asfalt (VBW Asfalt, 1997) states that higher void contents (30%) can be beneficial in improving resistance to clogging, but that generally this is not to be aimed for because of the increased damage sensitivity and increased noise levels due to the increased surface roughness. Regarding the durability and water transport capacity, it is said that the pores in a ZOAB must be as high as possible, with large pores and large connecting openings between them. This can be achieved through a gap graded, coarse aggregate mixture.

In this study several deviations from the void content, all of them towards lower void contents, were found. Generally, the void contents for the D16 mixtures were on the low side. Although not bad for ravelling, this can potentially affect the noise reduction and water transport capacity. The latter could lead to moisture staying in the material for longer and as a secondary effect, this could affect the durability.

# 5. Conclusions and recommendations

## *5.1 Overall conclusions and recommendations*

### 5.1.1 General observations on the available data

The key conclusion from all the information gathered for this study is that the system that was established to deal with the administrative side of the material qualification and quality control does not appear to be working. From the amount, type and recurrence of errors, from missing forms, through incomplete forms, materials specifications that do not meet the requirements to materials that do not meet their own specifications, it is clear that the paper system is a separate entity from the production and construction process. Also, it appears that there are insufficient checks and balances to ensure improvement over time. The current RWS quality control system is risk based and focusses on the major (top ten) risks. For other risks, and asphalt concrete usually falls in this category, RWS relies on the contractual requirement that the contractor carries out his quality control and will report any deviations and propose solutions to ensure sufficient quality. This project was initiated by a number of very early failures, where a combination of deviations from the specifications were found in the subsequent study to determine the cause. It led to the conclusion that, for these projects the contractual quality control system did not work out and deviations were not noticed, mentioned and resolved. The aim of this project was, among others, to determine if such deviations occurred more often. Based on the results it can be concluded that they do and that the system of noticing, deviations, bringing them to the attention of the client and proposing solutions, both for the deviation that occurred and to prevent similar deviations in the future, is currently not functioning properly.

Since for several of the mixtures used in this study the date of the Type Test is now more than 5 years ago, it is recommended to check if these have been used more recently in RWS projects and if the information regarding them has been improved. If it has, that step is working and will lead to gradual improvements. However, since this happens only once every 5 years (or earlier if the constituent materials change), it is further recommended to establish some form of a “complaints and observations” procedure where issues regarding the quality and completeness of the paper work as well as problems in the procedures, such as requirements that lead to practical issues, can be reported. This should then lead to an improvement of the formal procedures as well as to generally accepted guidelines in how to interpret and deal with the regulations. Ideally, the experiences with assessment of the completeness and quality of the provided information and the delivered work should be part of an overall quality assurance system used by both contractors and clients.

An important underlying general conclusion is that the dossiers on these construction projects are far from complete. The documentation that is there, varies considerably in layout and content, sometimes providing measured properties, sometime categories or minimum or maximum values. This variation makes it hard to assess it, but must also make it difficult to determine what is wanted.
Based on the information provided for this study, it would in many cases be impossible to determine whether or not the materials offered meets the requirements, let alone whether the actually constructed material does.
Part of the problem here is likely to be the various documents that are involved in setting the requirements, from EN standards, via RAW Standards to contract specifications. With the introduction of the European standards for Asphalt Concrete (EN 13108-series) in 2008, a public law component was introduced in a system that, until that time was fully based on private law. The resulting situation with both legal and contractual requirements, the former upheld by a national inspection agency (Inspectie Luchtvaart en Transport) and the latter by the client, is, to this day, causing confusion and discussion. Keeping track of all requirements and interpreting what they say and how this all holds together gets complicated. On the other hand, the actual composition requirements have not changed

much over time, yet even the target compositions provided do often not meet the mixture group requirements in the RAW Standard.
Since proper and complete documentation is the key to both quality control and the development of insights and knowledge which spurs improvements, it is highly recommended to facilitate proper documentation and quality control, i.e. through developing a standard, national overview of what documents are required, what information they should contain and, preferably, what format they should have. If these requirements are linked to the background documents, they can be easily updated if any of the background documents change. Also, it will allow for automating assessing the documentation to a large degree. This will go a long way in helping to establish generally accepted guidelines on how to interpret and deal with the guidelines.

Another improvement would be a counter where issues or disputes regarding the proper interpretation of the specifications can be registered and settled as well as shared with the Dutch pavement engineering community at large. The results from such disputes could then be implemented in the overall quality assurance system to ensure continuous development and improvements.

Finally, it is recommended to consider gathering not only pre-construction information on the materials, but also production and construction information (i.e. delivery sheets) and post-construction data preferably out of tests on cores drilled at the construction itself. Combining this kind of information will provide a data-rich environment which will enable new developments.

### 5.1.2 Standard requirements and tests

In the current situation, if controls are carried out after construction, it is typically limited to void content, thickness, grading, bitumen content and degree of compaction. There are, however, also requirements on the remaining penetration, the use of filler with a minimum amount of calcium hydroxide and moisture sensitivity. The first and last can be checked based on samples from the road, but were not tested by RWS for this study. It is unknown if contractors carry out these tests as part of their quality control. It is highly recommended to include testing for this, if a control measurement is done.

For the presence and quantity of calcium hydroxide, currently no standard test is available. Considering its relevance, it is recommended to adopt or develop one. Suggestions on how to approach this are given in Sections 3.7.2.4.2 and 3.7.2.5.2.

For these and the other properties, bringing together the results from all projects will help to establish a reference frame for quality purposes.
Designating random projects as test sections and sampling them over time to carry out these tests will further establish the development of these properties over time, which can be helpful in disputes but will be invaluable in order to assess innovations and learn from particularly well or poor performing sections.

### 5.1.3 Non-standard tests

The challenge with non-standard tests is to assess their relevance for the issue at hand. In this case, it was clear that for a number of tests it would not be possible to assess this without more work, see also the previous Section.

Two exceptions are the CT-scans and several techniques used to assess the presence of PMB in the material. The CT-scan is non-destructive and provides more detailed information on the state of the aggregates and void structure. It is recommended to use them on a regular basis and to assess the match with the traditional methods on cores of various materials, to allow for a detailed assessment of the core structure and the assessment of pores over the height without the need to separate the various layers. This is of particular importance for 2L-ZOAB, also because it gives information about the void content in the interface between the top and bottom layer.

The various tests used to indicate the presence of PMBs all give the same result, where the FTIR tests require little material and are able to identify the type of PMB in very short amount of time. As such, it is worth considering the use of FTIR for this purpose in quality control.

### 5.1.4 Recommended follow-up

As a follow-up from the study summarised in this report, it is recommended to initiate a number of steps. First and foremost is to set up a system of product checks that consistently samples the delivered pavements on the basis of the requirements. The results of these tests can be used in the actual projects, to provide annual overviews of the deviations found so they form both a track record and an indication of changes and as a basis to link quality to performance. This latter step will provide a better understanding of the contribution of various requirements to the performance in practice.

In parallel to this step, the information provided in the various projects should be stored centrally and checked for completeness. This way, recurring issues like not providing information on the required CCS (11,2) for DZOAB 16 can be identified, discussed and remedied. To allow this system to work, it should be part of an escalation procedure understood and supported by both contractor and client. Such a system should ideally support the contractors own quality control system through a realistic approach to deviations that are found and reported and solutions proposed, while setting penalties on insufficient checks and deliberate repression of deviations. Recurring problems should be brought to the attention of the management of both clients and contractors.

It is also recommended to review the current requirements for the average of the field cores and to determine whether requirements/margins for the coarse sieves and the degree of compaction or density should be included.

Regarding the tests carried out in this study, it is recommended to add determining the penetration of the bitumen after construction to the standard tests, since this is part of the requirements. Additionally, random sections of various asphalt mixtures should be labelled as test sections and samples throughout their life time to determine the penetration in order to develop and maintain time lines for the development of this property. Having information on this kind of time dependent properties improves the understanding of pavement performance, provides objective background knowledge in case of disputes and forms a frame work to help in the assessment of innovative materials.

As similar advice holds for the determination of $Ca(OH)_2$ after construction and over time, but to develop this first a reliable test method needs to be established. Carrying out a study along the lines of the procedure I the text box at the end of Section 3.7.2.4.2 (page 127) would accomplish this. It is recommended to compare not only various titrimetry procedures in this test program, but to include the FTIR and XRPD Rietveld methods.

Additionally, extending the current quality control checks with FTIR to determine the bitumen composition and especially whether it is polymer modified or not as well as with CT-scans to determine the void content over the height and the presence of clogging and cracked stones is recommended. Particularly for 2LZOAB, doing the scans before the classical determination of void content adds information regarding the transition zone between the layers.

Finally, apart from just using these tests as additional sources of information, research programs to identify if they can be used in other ways to add to or replace existing tests, is useful. FTIR, for example, added to tracking the penetration over time would provide insight in the development of aging. With the current changes in bitumen and with the application of in-situ rejuvenation, this could proof very valuable. Using CT scans in parallel to classical void content determination would show whether this could be an alternative and could allow for developing automated methods to determine clogging and cracking of stones, which would provide useful additional information. Additionally, this would, if a careful multiyear sampling is used to compensate for the inherent spatial variation (Figure 3.15), provide information on the variation of void content over time. As discussed in Section 3.5.1 ( Page 85) it appear unlikely in ZOAB mixtures, but the only way to be sure it to collect data.

## 5.2 Conclusions in relation to the research questions and hypotheses

In Chapter 1 the following research questions and hypotheses were formulated:

1. ***How often do deviations from the specifications occur?***
    a. *When and where do they occur, between design (target composition) and the project specifications (reference composition) and/or between project specifications (reference composition) and actual composition after construction (field core composition)?*
    b. *How and when can deviations be determined?*
2. ***Do deviations always lead to a reduction in life time?***
    a. *Do all deviations have the same impact on performance/life time reduction, or do some have more effect than others?*
    b. *Are single deviations enough to reduce the life time, or does it require multiple deviations/specific combinations of deviations?*
    c. *Can we link specific deviations to a given reduction in life time?*

These research questions were translated into the following hypotheses, which led to a research approach meant to see if the hypotheses would be falsified or validated.

1. Deviations exceeding the margins allowed between target[43] and reference composition occur at least 5% of the time, deviations exceeding the margins between reference composition and field cores occur in 20% of the cases.
2. Deviations in composition cause a reduction of life time and/or functional characteristics.

From the results we see that deviations do indeed occur, but that this already occurs between the target composition and overall specifications for the mixture group, which was not expected beforehand. In most cases, these deviations are omissions, mostly of the percentage passing the specified CCS (11,2 mm for DZOAB 16 and 2LZOAB16).
In 10 out of 21 mixtures, the provided grading information is either incomplete or does not meet the RAW requirements (Table 3.32). If bitumen content is taken into account (assuming that a negative difference of 0,1%m/s is due to corrections for aggregate density), this becomes 11 out of 21. And if also the minimum design void content is taken into account, 14 out of 21 mixtures (nearly 70%) do not meet the basic RAW requirements for DZOAB 16, 2LZOAB 8 and 2LZOAB 16 (Section 3.11.2, starting on page 158).

Looking at the deviations between reference and target composition that exceed the margins, less than 15% meets the requirements on all sieves. So 85% does not or cannot be checked because of incomplete information in the target composition. This is considerably more than the 5% from the hypothesis. As such, the hypothesis is disproved, the actual number of deviations is considerably higher than expected.

43 Or composition after extraction of a core made according to the target composition, depending on the valid standard, see Chapter 2 and 3

When comparing the results from the field cores to the reference composition, if the average of the field cores is considered, there is no requirement for the maximum deviation on the coarse sieves. This effectively reduces the number of requirements which are not met or cannot be checked, because in many cases the CCS (11,2 mm sieve) information is missing for the D16 mixtures. As a result, the number of mixtures where the deviation between the average field core result and the reference composition exceeds the acceptable margins (or cannot be checked because of missing information in the reference composition) reduces to just under 20% (4 out of 21).
If besides the grading also the bitumen content and type are considered, the deviations increase again to just under 50%. If void content and density are taken into account, deviations occur in 95% of the cases. If density is left out, because it is not a formal requirement in the RAW 2015 for the average field cores, over 75% of the locations show one or more deviations. This is again considerably more than the hypothesized 20%.
On an individual core basis, the level of deviations between the composition of the core and the reference composition44 is of the same magnitude as for the average if density is taken into account (>95%).
So this hypothesis is also disproven, the number of deviations is considerably higher than expected.

This analysis shows that deviations do occur, both *more* and *earlier in the process* than initially hypothesized. The amount of deviations is also considerably larger than expected and higher than it used to be (Rijkswaterstaat, 2001a, 2001b and Table 1.2).

In a project deviations can be registered at the first registration of the mixture specifications prior to type testing, since it really does not serve a purpose to even type test for example a DZOAB16 mixture if its composition does not fulfil the RAW Standard requirements for a DZOAB16. The next check should be in writing down the mixture properties in the TT report, DoP and other documentation. In doing this, at least checking these specifications against the requirements is a required step. These points of control are solely within the sphere of influence of the producer/contractor. The first opportunity for a client to check things is upon the first delivery of documents for a project. At this point, a check against the overall requirements should not be needed, but considering the results from this project, it is advisable to at least do random checks. What the client should always check is whether all required documents are provided, allowing for checks later on.
From that point on, product tests (standard by the contractor or separately by of for the client) during the various stages of the project for all materials can be used to determine deviations beyond the allowed variation. As can be seen from the results of this study, it worthwhile checking individual as well as average results, particularly for the course sieves. Upon transferring the project dossiers to the pavement management organisation, a check on completeness and, at least occasionally on the data within also allows the assessment of deviations.

Regarding the effect on life time, the results are more diffuse, lower void content and more bitumen are expected to be positive, lack of $Ca(OH)_2$ is expected to be negative, but cannot be assessed reliably at the moment. Cracks in the stones, uneven distribution of voids and deviations from the original gradation due to construction effects are also expected to have a negative effect on the life time. Using a different type of bitumen (penetration versus PMB or vice versa) will also have an effect on workability and the resulting properties, especially because this will result in an incorrect production and construction temperature.

As such, the second hypothesis is neither confirmed or disproven, only a general impression could be obtained. However, it can be said that the sheer number of deviations found in this study means that

44 taking into account grading, bitumen type and content, void content and degree of ompaction

the material in the pavement is not that which was designed and this will in all probability have a negative impact on the performance.

## *5.3 Sub conclusions and recommendations per topic*

### 5.3.1 Completeness and correctness of available information

#### 5.3.1.1 Completeness of documentation

Documentation on composition and properties are not only useful to build data sets and obtain insights, it is crucial in assessing the quality of the delivered work and wrapping up the project. As such, an inventory of the required documentation was done. This showed that in 10% of the cases the project documentation available at RWS did not include CE marking. Double that number did not include the short report and of the mixtures that required a DoP (construction date later than July 1st 2013) this was also present in only 40% of the cases (Table 3.1, Table 3.2 and Table 3.3).

All in all, all required documents are present in less than 60% (57%) of the cases, in over 20% (24%) they are not, or not conclusively (~20%). This is a shocking result, particularly since this is required documentation and this check addresses only **if** such documents were present. It does not include an assessment of the completeness or correctness of the information provided in these documents. The key issue is that such a check on completeness and correctness is not possible if the documentation is not there to begin with!

#### 5.3.1.2 Completeness and correctness of the information

In addition to the observations regarding the presence of required documentation discussed in the previous section, it was found that in a large number of cases even the target and reference composition do not meet the requirements in the RAW Standard. For the target composition (grading and bitumen content) about 50% of cases (11 out of 21) the information is either incomplete or the provided target composition fails to meet the requirements for grading and bitumen content. If the RAW design criterion for the (minimum) void content is also taken into account, nearly 70% (14 out of 21) of the mixtures does not meet the criteria (Table 3.32 and Table 3.33, combined).
For the reference composition 85% fails the grading requirements or does not provide the required information. This stays the same if also bitumen content (8 out of 21 missing or incorrect) and a declaration of the target density is considered (2 out of 21 cases did not have a target density declared).

A similar result is found when the results of field cores are compared to the reference composition. Over 95% fails to meet the standard or contract criteria, or required information is missing, obtained, both for the individual cores and average over three cores, if for the latter density is taken into account (Table 3.37). If it is not, for the average of the field cores still over 75% of the locations fall outside the specified margins for one or more requirements (Table 3.38).

This is much higher than the expected deviations. If the total number of deviations is divided by the total number of checks carried out, over 10% of the requirements for the target composition fails and about 40% of those for the other compositions (Table 3.35). This is more than three times as high as in 2000 (Rijkswaterstaat (2001a), Rijkswaterstaat (2001b) and Table 1.2). Even if density of the average field cores is not taken into account (as it is not currently required in the standard), the nearly 30% of the requirements for the average of the field cores is not met or cannot be checked.
When comparing these percentages to those found in 2000, it has to be taken into account that the total number and type of checks is not completely the same between these two cases, but the overall percentage of deviations is in this case higher than the highest percentage for a single category (grading, 36% and 23%, respectively) in the 2000 reports.

### 5.3.2 Tests related to grading

#### 5.3.2.1 Overall requirements

In summary, in 10 out of 21 (48%) of the cases one of the general overall RAW sieve requirements for the mixture type is not met or required information is missing. Considering that this is not a comparison to the mixture specific grading compared, but to the overall boundaries of the mixture types, this can be considered a considerable deviation. In one out of the ten cases it is a requirement that is not met, in 9 cases the information for the Characteristic Course Sieve (CCS, for (D)ZOAB16 defined as the 11,2 mm sieve) is not provided.

For the coarser sieves, there are requirements for the maximum deviation of a single field core from the reference composition, but not for the average of more cores. This seems odd, in one core having one more coarse aggregate can actually affect the percentages of grading, but this affect diminishes with multiple specimens. If you have more cores, the differences should average out and you should get closer to the intended overall grading. The effect of crushing in production and construction will be found through a higher content on the fine sieves, but other problems such as dosing the wrong amounts or segregation during transport are not covered this way. It is not quite clear why there are no requirements set for the course sieves, but this was already the case before the introduction of the EN standards (CROW, Standaard 2005 (2005)).

#### 5.3.2.2 Mixture specific requirements

From the two locations initially selected for an indepth check, both show deviations from the requirements. It must be kept in mind that location 9 was selected because it showed a deviant grading based on the analyses in the previous paragraph. However, considering the fact that a DZOAB 16 is delivered without providing the required grading information (specifically the CCS), a mixture more over that does not even appear to meet the requirements for the DZOAB 16 mixture group, suggests that quality control is necessary. Somekind of interaction between clients, contractors and regulatory bodies sharing the errors made and generally improving the knowledge about and quality of the delivered information would be worthwhile.

Finally, for Location 9 two DZOAB 16 (intended) mixtures where available. It would be make sense to request and store information on which mixture is used where in the actual project, both in planning, but definitely in practice.

The total overview on mixture specific properties in relation to the requirements (Section 3.11.3 on page 162), confirms the impression obtained from these two mixtures. In many cases deviations from the requirements occur, indicating a need to change the current system.

### 5.3.3 Tests related to void content

From Figure 3.10 the low void contents do not seem to have a relation with the age of the specimens. This is in line with the expectations, since there are no indications that PA mixtures are further compacted by traffic to this extend. However, there has also been little study into this. To be absolutely sure, it is recommended to randomly follow the void content development over time in a number of these mixtures (see Section 3.5 for suggestions on the sampling details). Generally, it is useful to know the development of crucial properties over time in standard materials, both in case of disputes and to speed up the assessment of innovations.

From the overall results it seems that generally, the void contents for the 2L-ZOAB mixtures quite close to the required void content. For the standard PA mixtures, they are on the low side. For raveling resistance a lower void content is beneficial, if all other parameters remain unchanged. The effect on the noise reduction remains to be seen.

In order to illustrate the shift to lower void contents in the DZOAB16 and 2L-ZOAB16 mixture, the distribution of the void contents found is plotted versus that based on the general requirements and the margins allowed. From these curves, it can be seen that the variation found in the void contents found for this project (13 or 4 separate projects for DZOAB and 2L-ZOAB, respectively) is less than that allowed for a single core in one project (based on the individual values). This may indicate that the current margins are rather wide.

#### 5.3.3.1 Void content from CT scans

From the CT scans it is seen that most ZOAB16 cores have a more or less uniform distribution of void content over the height, indicating proper timing in the laying and compaction. However, that also means that the required compaction effort is often overestimated, since overall too low a void content is realized.

In most cases, the distribution of void content over the height is similar for the two or three cores tested, indicating continuity in the compaction process. Location 2 is the exception in this sense.

For the top-layer of 2L-ZOAB 8 the distribution over the height is not uniform, it is higher at the top and the bottom and lower in the middle of the layer. This is the case for all top-layers of 2L-ZOAB 8, so it seems that compactability of these thin top-layers is an issue.

Regular control on the void content, including its distribution over the height, is to be recommended. None of the sections meet the design criterion (≥20%) for these mixtures, although in many cases the results do fall within the acceptable margins. However, if only deviations to the lower margin are found, this indicates a bias rather than the expected variation in construction. Somehow, during construction, the material gets to be less porous (and more dense) the intended in the mixture design. Particularly, a study comparing the initial to eventual void content, proofing or disproving the reduction of voids after construction, either through compaction or by clogging. If the ability to distinguish clogging from mastic could be automated, that would provide a great advantage.

Regarding the voids it is often seen that we have less voids just below the road surface (first 5 to 7 mm). The reason can be compaction during construction or by traffic. An example of this phenomenon is shown in Figure 3.16, where the voids content reduces very fast from 100% to below 10% in the first 4 mm. After this the voids content increases to a stable higher value around 15%. This “dip” in void content is not due to clogging. Although the distinction between mortar and clogging cannot (yet) be made automatically, experienced research can make the distinction visually. A possible explanation could be that the top layer of stones, tends to be flattened out during laying and compaction. If this is the case, the effect should occur only in materials with somewhat elongated particles. A visual analyses of the current scans does not confirm this suspicion. Scanning with a higher resolution in combination with image recognition techniques could help to study this in more detail in order to find an explanation.

### 5.3.4 Tests related to bitumen content or properties

#### 5.3.4.1 Bitumen content

The results are summarized in Table 3.12 and Figure 3.19. As can be seen, in most cases the bitumen content is reasonably close to the target content. Surprisingly, there are four locations where the bitumen content of the DZOAB 16 mixtures exceeds the upper limit for the binder content. This is surprising, since bitumen is the most expensive component in the material, so usually attention is paid to ensure that no more than needed is used. To exceed the upper boundary is therefore unexpected. It would be worthwhile to discuss this with contractors, because it either points to a lack of control during production, or there is a reason to increase the bitumen content in production relative to characterisation. In the latter case, it can either be standardized, or used to improve understanding.

## 5.3.4.2 Bitumen properties

### *5.3.4.2.1 Penetration*

This is one of the potential checks during quality control at or around the time of delivery, but it is hardly ever done. RWS should consider including it in product checks.

In this report, the results are compared to data from literature and most samples appear to perform as expected regarding the penetration development. The exception is the 2L-ZOAB mixtures that are one year old (Location 12) and possibly the 8 year old (Location 5).

### *5.3.4.2.2 Additional properties*

#### 5.3.4.2.2.1 MSR Test

Although the method of reporting deviates from the usual approach and raises some questions regarding the actual values, the trend in data is similar and recognizable and allows PMBs to be separated from non-PMB’s.

#### 5.3.4.2.2.2 FTIR

The FTIR tests are carried out by two institutions, addressing among others the presence of PMB. They give the same results, where the TNO report shows that it is even possible to identify the type of PMB used.

#### 5.3.4.2.2.3 Acid number

What is unclear in this analysis is how relevant this test is for non-fresh bitumen. Once mixed with the filler, reaction with the $Ca(OH)_2$ would take place. It is unclear if this would lead to a reduction in the acid groups detected in the test after reclaiming the bitumen. If so, low acid numbers in the reclaimed bitumen samples can indicate a high content of reactive filler or a low natural acid content. If it matches with a low carbon hydroxide of the reclaimed filler, it could point to a less acidic bitumen that interacted with an active filler, or an acidic bitumen combined with a low amount of active filler.

### *5.3.4.2.3 Summary of the non-standard tests regarding PMB detection*

All methods used indicate that 3A, 5A and B, 7A and B and 12A were polymers.

As can be seen in the comparison with the project documentation, in one case (7B) the tests all indicate the presence of PMB while the project documentation says it does not contain modification. In another case (12B) the project documentation states that PMB is used, while none of the tests indicate the presence of the polymer. It is unlikely that this is due to an error in the tests, since they do pick up the PMB modification in the top layer (12A), which is the same type of PMB according to the project documentation.

Based on these results, it is highly recommended to include testing for PMB in case they are part of the mixture design. FTIR seems the best choice, based on the level of detail, the limited amount of material required and the lack of issues regarding the interpretation.

### 5.3.5 Tests related to filler content or properties

#### 5.3.5.1 Standard tests

##### *5.3.5.1.1 Quantity of filler-sized material*

The quantity requirements for the general mixture groups are met by all locations. When looking into the details for two locations, allowing a comparison to mixture specific information, in two cases too large deviations between the target composition and reference composition are found.
This illustrates the need for and usefulness of detailed checks.

#### 5.3.5.2 Additional tests

##### *5.3.5.2.1 Filler to bitumen ratio*

Based on literature, no specific interval for an optimum f/b ratio, either by mass or volume, can be given. In several studies f/b by mass is given as around 1 (m/m%), which is also close to the average values found based on the requirements in the RAW Standard. Based on this, the value from Location 7B is very low, both compared to the 1% and when comparing the field values to the design.

What is clear from literature, is that there are many factors other than f/b that effect the interaction between bitumen and filler, from the filler composition to its specific surface.

##### *5.3.5.2.2 Calciumhydroxide content of the filler fraction*

In the studies on which this report is based, however, it would be interesting to know the protocols and results of especially the FTIR determination of the $Ca(OH)_2$, because it is a fast test and does not require much material. If a reliable quantification is possible, this would be a good test to add to quality control testing. The same goes for XRPD-Rietveld tests, as used in both Phase 1 and Phase 2 of this study. In the first phase, it was found that the wet specimen preparation introduced deviations, but the dry method was very close to the results of the titrimetry. However, in the second phase study, there was a considerable difference between the two. Based on the available reports the cause of this is not clear, so additional research comparing the various test methods and their reliability and reproducibility is needed. Besides FTIR and XRPD this study should include (various test protocols in) tritimetry.

Besides a reliable test method also a time line for degradation of calcium hydroxide in PA is missing. Attempts to address this show different results. The study of degradation of $Ca(OH)_2$ in the mastics after PAV (Pressure Ageing Vessel) ageing using FT-IR results (Figure 3.40) showed that there is no degradation of the $Ca(OH)_2$ after ageing as indicated by the characteristic peak (narrow absorption band at 3642 $cm^{-1}$ due to stretching mode of O-H) present in the original and recovered filler samples. These results are not in agreement with the degradation curve shown by Sibelco (Figure 3.38). This may be explained by the fact that the PAV ageing protocol involves conditioning at high temperatures and pressures, but does not consider moisture, which is expected to also affect the $Ca(OH)_2$. Also effects of loading, which may lead to damage and increased access of oxygen and moisture, is not included. It is therefore recommended that a combined moisture-ageing protocol is used to study $Ca(OH)_2$ degradation in mastics or asphalt mixtures.

Although there is, as yet, no standard method to test for the Ca(OH)2 content of reclaimed filler, there are a number of promising tests that should be further studied to arrive at a standard. Once that is in place, it should be used to develop a time line of the Ca(OH)2 content in mixtures in the field as well as for quality control. Despite the differences found in the various test methods, in all cases the values from the field cores appear to be low compared to the requirements for the dosed amounts. From the Phase 2 study it appears that the values are not affected by temperature (oxidative) aging only.

#### 5.3.5.2.2.1 Titrimetry

For the determination of $Ca(OH)_2$ in filler there exists an EN standard (EN 459-2).
However, it became clear that this standard is not suited to assess the $Ca(OH)_2$ in reclaimed filler, due to the high affinity of bitumen to active filler (a thin bitumen layer remains). As such, it turned out that different labs used different techniques, resulting in large difference in the results.
Considering the expected influence of $Ca(OH)_2$ on the properties of the mixture, it is highly recommended to develop (or adopt) a standard test method to determine it for field cores, as well.

For this reason, it is recommended to have the laboratories repeat the tests using both the standard EN 459-2 for fresh fillers and TP gestein (the 2010 and 2018 versions) for comparison. These tests should be done on fresh filler as well as filler reclaimed from an asphalt mixture. The reclaimed and new filler should be taken from the same batches, to ensure the same start position.
This will give an impression of the repeatability if the same procedures are used, of the difference between reclaimed and fresh filler and of the difference between the three different procedures when used on reclaimed filler, which will give information about the comparability of the results presented here. If the latter is not required, or to save time and effort, it is also possible to ask for background information on the development of the new TP Gestein and have the different labs use the most current version of that to see if it is repeatable and reproducible.

In a second stage, different combinations of bitumen (more and less acidic) and stone with the same type and amount of filler (think of two types of bitumen, two types of stones and active and inactive filler) should be used to assess the effect of the chemical consumption of $Ca(OH)_2$. Without that check, the assumption remains that the $Ca(OH)_2$ that goes in, should be recovered, but if it reacts with the bitumen to provide a better mastic some of the material will be used up.

Finally, the effect of reduction of $Ca(OH)_2$ over time, not just as an effect of bitumen aging, but including the presence of moisture needs to be taken into account. The current results (reduction of the $Ca(OH)_2$ content over time in lab conditions versus no reduction in PAV aging, seem contradictory.

#### 5.3.5.2.2.2 Mass balance calculations

There are some serious issues that cast doubt on the validity of the approach used in the mass balance calculations.

- Not being able to distribute all elements over the mineral fractions shows that the mass balance calculations done are not accurate and cannot be relied upon in this stage of the investigation.

- The mass balance calculations assume that the non-commercial/factory filler part in the fines originates from the aggregate and sand used for the ZOAB. This assumption is doubtful. Other fines can be used, for instance backhouse dust. The $SiO_2$ used in the mass balance calculation can also originate from clogging material.

- The initial size distributions (PSD) of the source filler, sand and aggregate/stone fractions (i.e. the fines, sand and gravel/stone fraction of each of the three components) have not been determined, which seriously will influence the composition of the resulting recovered size fractions. Dr. Hellmann reported one mixing composition of filler from aggregate and sand but there are more compositions possible to get the measured concentration. A question still to be answered by Dr. Hellmann is why the reported values were chosen. This issue may be resolved in future research when initial PSDs are known and considered.

- Another example to illustrate our doubts is that some of the minerals present in the aggregates are not found in the recovered filler; for instance, the mineral Epidote in the aggregate of location 1 is not detected in the recovered fines.

These issues need to be resolved before continuing with this method.

#### *5.3.5.2.3 Acid number*

The conclusions from BASt Hirsch, 2017a addresses the fact that if $Ca(OH)_2$ acts as an aging inhibitor, the changes in acidity should be less. However, it is unclear what can be used/was used as a reference in this. Unless there is a material with the same bitumen and of similar age available where it is known that it did not contain a $Ca(OH)_2$ filler, there is no way to know what the reference level for the acidity would be.

### 5.3.6 Tests related to sand content and properties

For the sand fraction only the grading is tested, the results are presented in Section 3.4 Tests related to grading. Some of the DZOAB 16 samples did not meet the lower limit of the overall requirements in the RAW. When assessing the values based on the detailed product information, all but one of the materials for which all information was provided met the requirements. This is based on the fact that cores can have a certain variation with regard to the specified properties. If the specified value is close to a requirement, within the variation the core values can actually fall outside the overall mixture requirements. It may be worth considering having hard requirements on certain properties related to the overall requirements rather than variation with regard to the design.

### 5.3.7 Tests related to coarse aggregate properties or content

#### *5.3.7.1.1 PSV value*

As can be seen from the results, 10 of the 17 locations do not meet the overall PSV requirement of Steenslag 3 (PSV≥58 for wearing courses). If the values from the cores are compared to those given in the mixture documentation, it can be seen that for locations 4, 8 and 14 no PSV is specified. Since a minimum PSV of 58 is a requirement, this information must be provided and documented by the underlying information about the aggregate. For the other wearing courses, the declared PSV value meets or exceeds the requirement (≥58).

For the locations 3B, 5B, 7B and 12B the PSV requirement is ≥53, since for ZOAB steenslag 2 is required (81.26.4-2). For these locations, also, no information on the PSV is found in the project dossiers. This is not correct, this information must be provided since it is a requirement.

In all cases where a PSV is given, the actual measured value is lower. In this case, the CE system may be part of the problem. It is a generally accepted fact that the properties of stones in a quarry can vary considerable per location. In the current CE marking system, a Type Test has a long. The producer has to re-test for the PSV at least once per year, but this may not be sufficiently frequent to ensure the properties of these natural materials.

Considering the link to safety, road authorities and contractors may want to consider to make additional arrangements such as required entrance testing at the plant. If these tests show that the variation is indeed such that the client (in this case, the contractor) cannot rely on the CE information supplied, this should be taken up with CEN.

For location 14, the PSV found is even too low for non-wearing course PA mixtures. This pavement was constructed in 2013, so it still falls within the warranty. A check on the current skid resistance and potentially requesting additional information on the PSV of this material is recommended.

## 5.3.7.2 Additional tests

### *5.3.7.2.1 Petrography of aggregates*

The determination of the rock types by TU Delft and Core Power agree with each other, although the wording used is not always completely similar.

Based on the microscopic description from thin sections of the rocks in combination with the mineralogy determined by XRD analysis, it is clear that it is possible to build-up a database with typical petrographic and mineralogical characteristics of the aggregates.

Comparison of data from an unknown aggregate with information in such a database will help to assess the origin of an aggregate. Accuracy of such assessments will improve when the database gets filled with more data.

#### 5.3.7.2.1.1 Assessment of the measured PSV value from petrographic information.

There is a relationship between PSV value and the mineral composition of aggregate, but this can be shown only within rock types of similar texture.

The resistance to polishing is sensitive to the microscopic structure (texture) of the rock aggregate particles; i.e. the distribution of hard and soft minerals in the rock.

### *5.3.7.2.2 CT-scans*

CT-Scanning makes it possible to visualise pavement samples in 3D, which allows the studying of

- voids over the height (Section 3.5.2 on page 89),
- aggregate structure and individual aggregates (shapes, size, cracked or not)
- clogging (visually, by trained experts for now)
- as well as the binding between mortar and grains

without damaging or disturbing the specimen, so the core can still be used for other tests after scanning it to get detailed info on specific properties. This also allows to establish exact comparisons between the void content from scans (first) and the standard approach.

Additionally, from the high-resolutions CT-scans it was found that in 15 locations (>70%) some form of cracks are present in the stones (Table 3.30). Having cracks present in so many cases, does not seem to be a good sign. It is recommended to use CT-scanning to look into the presence of cracks and their development over time.

The high-resolution scans give a lot of information but on small diameter samples. It would be an important improvement if it was possible to scan larger diameter core samples with a resolution of about 50 microns. Based on these scans stronger conclusions can be formulated than now, on i.e. :

- Clogging, currently, experts are needed to visually distinguish clogging from mastic. With the higher resolution on larger course, it may be possible to automate this

- Bitumen/mastic drainage: it may prove difficult to detect mastic drainage, because the higher resolution shows up the filler in the mastic, making it harder to distinguish mastic and aggregates, this might eventually be possible.

It is therefore recommended to do further research into these possibilities.

### 5.3.8 Tests related to moisture sensitivity

This is not tested, so it is not further discussed here. It is, however, recommended to consider using cores that are still available to determine the moisture sensitivity to see if this can in any way be linked to the results on bitumen en (especially) $Ca(OH)_2$ presence.

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# APPENDICES

# I. Text on baghouse dust (in Dutch)

Text taken from VBW VBW Asfalt, 1995.

## 2.4 Vulstoffractie < 63 µm

De fractie < 63 µm in een asfaltmengsel is samengesteld uit drie componenten:

a. voor een deel is deze afkomstig uit de apart gedoseerde fabrieksvulstof (in de Europese terminologie "filler");

b. voor een deel is deze afkomstig uit het aangevoerde mineraal aggregaat ("eigenstof"; in de Europese terminologie: "fines");

c. en voor een deel ontstaat deze in het asfaltproduktieproces ten gevolge van slijtage van het mineraal aggregaat (met name in de droogtrommel, in de warme silo's en tijdens de droge menging). Dit materiaal behoort gezien zijn aard ook tot de "fines". (NB: Dit deel wordt hier aangeduid met de term "produktiestof".)

Ad a: De eisen voor de fabrieksvulstof zijn opgenomen in de Ontw.NEN 3975:1995. De fabrieksvulstof wordt per 01/01/1996 geleverd onder KOMO-certificaat: de SVC-certificatie is vanaf dat moment ondergebracht in de algemene structuur voor de certificatie in de GWW, die in C.R.O.W-verband in ontwikkeling is.
Het aandeel fabrieksvulstof wordt bij het vooronderzoek afzonderlijk in rekening gebracht.

Ad b: Aan de fractie < 63 µm die in het aangevoerde mineraal aggregaat aanwezig is worden geen aparte eisen gesteld: alleen de hoeveelheid is gelimiteerd (1,0 tot 5,0%, afhankelijk van de aard van het aggregaat). Bij deze fractie gaat het om materiaal dat qua aard en herkomst identiek is aan het aangevoerde aggregaat: het is steenmeel. Het gaat dus om "gezond" materiaal: voor aspecten als hechting etcetera behoeft niet te worden gevreesd.
Ook het aandeel "eigen stof" wordt altijd bij het vooronderzoek in rekening gebracht.

Ad c: Aan dit materiaal worden geen aparte eisen gesteld. Dit materiaal is steenmeel, volledig afkomstig van het aangevoerde aggregaat. Qua mineralogische samenstelling is het dus identiek aan het "eigen stof".
Het aandeel produktiestof wordt normaliter bij het vooronderzoek niet in rekening gebracht. De hoeveelheid produktiestof die ontstaat is sterk afhankelijk van de totale inrichting van het produktieproces, van de aard van het mineraal aggregaat en van de procesvoering. Het is niet bekend welke factoren bepalend zijn voor de totale hoeveelheid; wel is bekend dat deze hoeveelheid onder normale Nederlandse omstandigheden varieert tussen 0,5 en 2,5% van het totale aggregaat. De hoeveelheid produktiestof die op een bepaald moment is ontstaan is in principe

zichtbaar via de registratie van de dosering van de fabrieksvulstof: deze moet op basis van de produktiecontrole worden verlaagd om het gewenste aandeel < 63 $\mu$m in het mengsel te realiseren. De afwijking ten opzichte van de bij het vooronderzoek gedoseerde hoeveelheid is afhankelijk van de korrelverdeling van de fabrieksvulstof cq van het aandeel < 63 $\mu$m in de fabrieksvulstof.

De fractie < 63 $\mu$m uit het aangevoerde aggregaat en het produktiestof kunnen niet apart uit het produktieproces worden afgezonderd.
Het stof uit het aangevoerde aggregaat wordt -met een hoeveelheid fijn zand- deels afgezogen uit de droogtrommel, waarna het via de ontstoffingsinstallatie in de "eigen stof"-silo wordt opgeslagen.
De rest van het stof uit het aangevoerde aggregaat wordt meegevoerd met het overige aggregaat in de hoofdstroom van het aggregaat.
Het produktiestof ontstaat onder andere in de droogtrommel, in de zeefstraat, in de opslagsilo's en tijdens de (droge) menging. Het produktiestof dat ontstaat in de droogtrommel zal deels via de afzuiging in de "eigen stof"-silo terechtkomen en zal deels met de hoofdstroom worden meegevoerd. Een belangrijk deel van het produktiestof ontstaat nà de droogtrommel en wordt dus niet afgezogen. Het een en ander betekent dat het eigen stof uit het mineraal aggregaat en het produktiestof volledig worden vermengd.

*NB: In de zogenaamde "Eigen stof"-silo bevindt zich dus een mengsel van "eigen stof", produktiestof en fijn zand. Het zandaandeel (materiaal > 63 $\mu$m) kan daarbij aanzienlijk zijn: gehaltes tot 50% en meer komen voor. Men dient zich te realiseren dat de op de registratie weergegeven hoeveelheid "eigen stof" feitelijk uit stof èn zand bestaat. Deze verwarrende vermenging van terminologie is sterk ingeburgerd!*

De "vulstof"-karakteristieken van "eigen stof" en produktiestof (met name bitumengetal en holle ruimte Rigden) worden sterk bepaald door hun korrelverdeling. Gebleken is dat dit stof bij de gangbare steensoorten globaal overeenkomt met zwakke vulstof: het bitumengetal bedraagt circa 40-45, de holle ruimte circa 35-40 %(v/v).
In principe kan een toename van de fractie < 63 µm ten gevolge van het produktiestof dus eenvoudig worden gecompenseerd door verlaging van het aandeel fabrieksvulstof. In het algemeen heeft dat geen technologische bezwaren. Er bestaat echter een kans dat door verandering van de totale korrelopbouw van het asfaltmengsel de holle ruimte in het asfaltmengsel kleiner wordt cq de vullingsgraad hoger. Bij qua vullingsgraad kritische mengsels is dat uiteraard ongewenst. Om ongewenste effecten te voorkomen is daarom arbitrair vastgesteld dat bij de asfaltproduktie de verschuiving van de hoeveelheid fabrieksvulstof (fractie < 63 µm) ten opzichte van het vooronderzoek niet meer mag bedragen dan 1,5 %(m/m). Zal blijkens ervaring van de asfaltproducent deze verschuiving groter zijn, dan moet bij het vooronderzoek de ver-

wachte hoeveelheid "eigen stof" (in zijn totaal) in rekening worden gebracht.

*NB: Men dient zich te realiseren dat het vooronderzoek geen doel op zich is, maar een hulpmiddel om te komen tot een goed asfalt in de weg. Een belangrijk instrument voor de beoordeling van de aanvaardbaarheid van verschuivingen in de samenstelling van het asfaltmengsel als hier bedoeld is de dichtheid/holle ruimte bij de produktie. Deze parameter dient daarom nauwlettend te worden beoordeeld, ook indien bij het vooronderzoek een hoeveelheid eigen stof is verrekend!*

In Hoofdstuk 4, Uitvoering proeven staat in paragraaf 4.1 Voorbereiding bouwstoffen (pg 28) vervolgens:

*Vulstof*

Indien uit ervaring bekend is dat tijdens de asfaltproduktie zóveel produktiestof ontstaat dat de hoeveelheid fabrieksvulstof (aandeel < 63 μm) tijdens deze produktie met meer dan 1,5% zou moeten worden verlaagd om de gewenste grootte van de fractie < 63 μm in het asfaltmengsel te realiseren, dient het produktiestof als aparte fractie bij het vooronderzoek volledig te worden ingewogen (en bij de berekening van de mengverhouding van de bouwstoffen in rekening te worden gebracht, zie par. 3.2).
Het produktiestof kan niet als afzonderlijke fractie uit de asfaltmenginstallatie worden afgezonderd. Materiaal zo goed mogelijk overeenkomend met produktiestof kan bijvoorbeeld worden verkregen door afzeving over zeef 63 μm van materiaal uit de "Eigen stof"-silo of door maling van steen. Gezien de aard van het produktiestof en het effect op het asfaltmengsel kan voor alle soorten asfalt worden volstaan met gebruik van één soort afgezogen materiaal uit een willekeurig brekerzandmengsel.

# II. Composition of the individual cores versus requirements RAW 2015

text/nr — point of attention/worry
not provided in documentation
no requirement
no Vmin given, DV provided and used

text: outside margin, inside acceptance interval
text: doesnot meet requirement
text: no requirement
text: meets requirement

c.a.e. = composition after extraction
target/c.a.e./ref present & complete
ref/c.a.e. present but incomplete
Bmin selected from Table 3 EN 13108-7:2006 based on conversion
target Bmin from "on" to "in"

RWS contract specs:
V>=15% individual
cores, >=18% on average

| sieve | DZOAB16 | | 2L-ZOAB16 (overall requirement RAW) | | 2L-ZOAB8 | | target | target vs reference min | max | c.a.e. | reference | reference vs field cores (n=1) min | max | 1 | 2 | 3 | ref vs av. field cores (n=3) min | max | average |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Location 1 | | | | | | | | | | | | | | | | | | | |
| 31,5 | | | | | | | - | | | | | | | | | | | | |
| 22,4 | 100 | 100 | 100 | 100 | | | 100 | | | | 100 | | | 100 | 100 | 100 | | | 100 |
| 16 | 93 | 100 | 90 | 100 | | | 98 | 95 | 101 | | 99 | 93 | 105 | 100 | 100 | 98 | | | 99 |
| 11,2 | 70 | 85 | DV | DV | 100 | | 72,5 | 69 | 76 | | 73 | 66 | 80 | 79 | 78 | 75 | | | 77 |
| 8 | | | | | 90 | 100 | 35 | | | | 36 | | | 54 | 52 | 52 | | | 53 |
| 5,6 | | | | | NR | NR | 24 | | | | 25 | | | 29 | 28 | 27 | | | 28 |
| 4 | | | | | | | 19 | | | | 19 | | | | | | | | |
| 2 | 13 | 25 | 5 | 25 | 5 | 25 | 15 | 12,5 | 17,5 | | 15 | 10 | 20 | 17 | 17 | 16 | 11,5 | 18,5 | 17 |
| 0,5 | NR | NR | NR | NR | NR | NR | 9 | | | | 9,6 | | | | | | | | |
| 0,18 | | | | | | | 6,6 | | | | 7,4 | | | | | | | | |
| 0,063 | 2 | 10 | 2 | 10 | 2 | 10 | 5 | 4,43 | 5,58 | | 6,0 | 3,7 | 8,3 | 6,1 | 5,7 | 5,5 | 4,7 | 7,3 | 5,8 |
| Mbit | 5,2 | | 4,2 | | 5,4 | | 5,2 | | | | 5,1 | 4,5 | 5,7 | 5,5 | 5,3 | 5,0 | 4,60 | 5,50 | 5,3 |
| voids %V/V | 20 | | 25 | | 20 | | - | | | | 20,0 | 15,0 | 25,0 | 14,1 | 12,6 | 16,5 | 16,00 | 24,00 | 14,40 |
| degree of compaction [%] | | | | | | | | | | | | 97,0% | 103,0% | 107,0% | 109,1% | 104,6% | | | 106,9% |
| density [kg/m3] | | | | | | | | | | | 1990 | | | 2130 | 2172 | 2082 | | | 2128 |
| sieve | DZOAB16 | | 2L-ZOAB16 (overall requirement RAW) | | 2L-ZOAB8 | | target | c.a.e. vs reference min | max | c.a.e. | reference | reference vs field cores (n=1) min | max | 1 | 2 | 3 | ref vs av. field cores (n=3) min | max | average |
| Location 2 | | | | | | | | | | | | | | | | | | | |
| 31,5 | | | | | | | | | | | | | | | | | | | |
| 22,4 | 100 | 100 | 100 | 100 | | | 100 | | | 100 | 100 | | | 100 | 100 | 100 | | | 100 |
| 16 | 93 | 100 | 90 | 100 | | | 97 | 95 | 101 | 98 | 98 | 92 | 104 | 98 | 98 | 100 | | | 99 |
| 11,2 | 70 | 85 | DV | DV | 100 | | 69 | 70,5 | 77,5 | 74 | 74 | 67 | 81 | 75 | 72 | 75 | | | 74 |
| 8 | | | | | 90 | 100 | | | | | | | | 42 | 38 | 40 | | | 40 |
| 5,6 | | | | | NR | NR | | | | | | | | 25 | 21 | 23 | | | 23 |
| 4 | | | | | | | | | | | | | | | | | | | |
| 2 | 13 | 25 | 5 | 25 | 5 | 25 | 13 | 10,5 | 15,5 | 13 | 13 | 8 | 18 | 14 | 12 | 13 | 9,5 | 16,5 | 13 |
| 0,5 | NR | NR | NR | NR | NR | NR | 8 | | | 8 | 8 | | | | | | | | |
| 0,18 | | | | | | | - | | | | - | | | | | | | | |
| 0,063 | 2 | 10 | 2 | 10 | 2 | 10 | 4,5 | 4,73 | 5,88 | 5,3 | 5,3 | 3,0 | 7,6 | 5,2 | 4,5 | 4,8 | 4,0 | 6,6 | 4,8 |
| Mbit | 5,2 | | 4,2 | | 5,4 | | 5,2 | | | | 5,1 | 4,5 | 5,7 | 4,9 | 4,6 | 4,7 | 4,60 | 5,50 | 4,7 |
| voids %V/V | 20 | | 25 | | 20 | | 21,5 | | | | | 16,5 | 26,5 | 16,0 | 18,5 | 18,6 | 17,50 | 25,50 | 17,70 |
| degree of compaction [%] | | | | | | | | | | | | 97,0% | 103,0% | 106,1% | 103,5% | 103,4% | | | 104,3% |
| density [kg/m3] | | | | | | | | | | | 1970 | | | 2090 | 2039 | 2037 | | | 2055 |
| sieve | DZOAB16 | | 2L-ZOAB16 (overall requirement RAW) | | 2L-ZOAB8 | | target | target vs reference min | max | c.a.e. | reference | reference vs field cores (n=1) min | max | 1 | 2 | 3 | ref vs av. field cores (n=3) min | max | average |
| Location 3 (A) | | | | | | | | | | | | | | | | | | | |
| 31,5 | | | | | | | | | | | | | | | | | | | |
| 22,4 | 100 | 100 | 100 | 100 | | | - | | | | - | | | | | | | | |
| 16 | 93 | 100 | 90 | 100 | | | - | | | | - | | | | | | | | |
| 11,2 | 70 | 85 | DV | DV | 100 | | 100 | | | | | | | 100 | 100 | 100 | | | 100 |
| 8 | | | | | 90 | 100 | 91,5 | 88,5 | 94,5 | | | | | 95 | 94 | 93 | | | 94 |
| 5,6 | | | | | NR | NR | 32,4 | | | | 32,4 | | | 45 | 43 | 41 | | | 43 |
| 4 | | | | | | | - | | | | - | | | | | | | | |
| 2 | 13 | 25 | 5 | 25 | 5 | 25 | 11,5 | 9 | 14 | | 11,5 | 6,5 | 16,5 | 14 | 14 | 14 | 8 | 15 | 14 |
| 0,5 | NR | NR | NR | NR | NR | NR | 8,8 | | | | - | | | | | | | | |
| 0,18 | | | | | | | - | | | | - | | | | | | | | |
| 0,063 | 2 | 10 | 2 | 10 | 2 | 10 | 5 | 4,43 | 5,58 | | 5 | 2,7 | 7,3 | 6 | 6,3 | 6 | 3,7 | 6,3 | 6,1 |
| Mbit | 5,2 | | 4,2 | | 5,4 | | 5,5 | | | | 5,7 | 5,1 | 6,3 | 5,4 | 5,4 | 5,2 | 5,20 | 6,10 | 5,3 |
| voids %V/V | 20 | | 25 | | 20 | | 20 | | | | 23,7 | 15 | 25 | 19,6 | 21,6 | 21,6 | 16,00 | 24,00 | 20,9 |
| degree of compaction [%] | | | | | | | | | | | | 97,0% | 103,0% | 105,0% | 102,2% | 102,5% | | | 103,2% |
| density [kg/m3] | | | | | | | - | | | | 1888 | | | 1982 | 1930 | 1936 | | | 1949 |
| sieve | DZOAB16 | | 2L-ZOAB16 (overall requirement RAW) | | 2L-ZOAB8 | | target | target vs reference min | max | c.a.e. | reference | reference vs field cores (n=1) min | max | 1 | 2 | 3 | ref vs av. field cores (n=3) min | max | average |
| Location 3 (B) | | | | | | | | | | | | | | | | | | | |
| 31,5 | | | | | | | | | | | | | | | | | | | |
| 22,4 | 100 | 100 | 100 | 100 | | | 100 | | | | | | | 100 | 100 | 100 | | | 100 |
| 16 | 93 | 100 | 90 | 100 | | | 93,4 | 90,4 | 96,4 | | | | | 98 | 98 | 98 | | | 98 |
| 11,2 | 70 | 85 | DV | DV | 100 | | | -3,5 | 3,5 | | | 14,8 | 28,8 | 39 | 43 | 39 | | | 40 |
| 8 | | | | | 90 | 100 | 13,3 | | | | 13,4 | | | 17 | 21 | 17 | | | 18 |
| 5,6 | | | | | NR | NR | - | | | | 12,9 | | | 14 | 16 | 12 | | | 14 |
| 4 | | | | | | | - | | | | - | | | | | | | | |
| 2 | 13 | 25 | 5 | 25 | 5 | 25 | 11,5 | 9 | 14 | | 11,5 | 6,5 | 16,5 | 11 | 13 | 9 | 8 | 15 | 11 |
| 0,5 | NR | NR | NR | NR | NR | NR | 7,8 | | | | - | | | | | | | | |
| 0,18 | | | | | | | - | | | | - | | | | | | | | |
| 0,063 | 2 | 10 | 2 | 10 | 2 | 10 | 4 | 3,43 | 4,58 | | 4 | 1,7 | 6,3 | 5,1 | 5,1 | 4,2 | 2,7 | 5,3 | 4,8 |
| Mbit | 5,2 | | 4,2 | | 5,4 | | 4 | | | | 4,3 | 3,7 | 4,9 | 4,1 | 4,1 | 4,2 | 3,80 | 4,70 | 4,1 |
| voids %V/V | 20 | | 25 | | 20 | | 20 | | | | 28,2 | 15 | 25 | 21,0 | 24,3 | 22,6 | 16,00 | 24,00 | 22,6 |
| degree of compaction [%] | | | | | | | | | | | | 97,0% | 103,0% | 111,8% | 107,4% | 110,0% | | | 109,7% |
| density [kg/m3] | | | | | | | | | | | 1786 | | | 1996 | 1918 | 1965 | | | 1960 |
| sieve | DZOAB16 | | 2L-ZOAB16 (overall requirement RAW) | | 2L-ZOAB8 | | target | target vs reference min | max | c.a.e. | reference | reference vs field cores (n=1) min | max | 1 | 2 | 3 | ref vs av. field cores (n=3) min | max | average |
| Location 4 | | | | | | | | | | | | | | | | | | | |
| 31,5 | | | | | | | | | | | | | | | | | | | |
| 22,4 | 100 | 100 | 100 | 100 | | | 100 | | | | 100 | | | 100 | 100 | 100 | | | 100 |
| 16 | 93 | 100 | 90 | 100 | | | 98 | 95 | 101 | | 97,5 | 91,5 | 103,5 | 100 | 98 | 100 | | | 99 |
| 11,2 | 70 | 85 | DV | DV | 100 | | 72 | 68,5 | 75,5 | | 72 | 65 | 79 | 79 | 66 | 77 | | | 74 |
| 8 | | | | | 90 | 100 | - | | | | 38 | | | 48 | 34 | 44 | | | 42 |
| 5,6 | | | | | NR | NR | - | | | | 21,4 | | | 26 | 20 | 25 | | | 24 |
| 4 | | | | | | | - | | | | - | | | | | | | | |
| 2 | 13 | 25 | 5 | 25 | 5 | 25 | 15 | 12,5 | 17,5 | | 15 | 10 | 20 | 16 | 13 | 15 | 11,5 | 18,5 | 15 |
| 0,5 | NR | NR | NR | NR | NR | NR | 6 | | | | 6,2 | | | | | | | | |
| 0,18 | | | | | | | - | | | | - | | | | | | | | |
| 0,063 | 2 | 10 | 2 | 10 | 2 | 10 | 4,5 | 3,93 | 5,08 | | 4,5 | 2,2 | 6,8 | 5,6 | 4,9 | 5,5 | 3,2 | 5,8 | 5,3 |
| Mbit | 5,2 | | 4,2 | | 5,4 | | 5,2 | | | | 5,2 | 4,6 | 5,8 | 5,3 | 4,2 | 5,0 | 4,70 | 5,60 | 4,8 |
| voids %V/V | 20 | | 25 | | 20 | | - | | | | 20,4 | 15,4 | 25,4 | 15,9 | 21,2 | 16,4 | ##### | ###### | 17,8 |
| degree of compaction [%] | | | | | | | | | | | | 97,0% | 103,0% | 105,0% | 99,7% | 104,8% | | | 103,2% |
| density [kg/m3] | | | | | | | | | | | 1992 | | | 2091 | 1987 | 2087 | | | 2055 |
| sieve | DZOAB16 | | 2L-ZOAB16 (overall requirement RAW) | | 2L-ZOAB8 | | target | target vs reference min | max | c.a.e. | reference | reference vs field cores (n=1) min | max | 1 | 2 | 3 | ref vs av. field cores (n=3) min | max | average |

| | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Location 5 (A) | | | | | | | | | | | | | | | | | | | |
| 31,5 | | | | | | | | | | | | | | | | | | | |
| 22,4 | 100 | 100 | 100 | 100 | | | | | | | | | | | | | | | |
| 16 | 93 | 100 | 90 | 100 | | | | | | | | | | | | | | | |
| 11,2 | 70 | 85 | DV | DV | 100 | | 100 | | | | | | | 100 | 100 | 100 | | | 100 |
| 8 | | | | | 90 | 100 | 92 | 89 | 95 | | | | | 95 | 95 | 94 | | | 95 |
| 5,6 | | | | | NR | NR | 27 | | | | | | | 49 | 48 | 48 | | | 48 |
| 4 | | | | | | | - | | | | | | | | | | | | |
| 2 | 13 | 25 | 5 | 25 | 5 | 25 | 13 | 10,5 | 15,5 | | | | | 17 | 18 | 18 | | | 18 |
| 0,5 | NR | NR | NR | NR | NR | NR | 9 | | | | | | | | | | | | |
| 0,18 | | | | | | | - | | | | | | | | | | | | |
| 0,063 | 2 | 10 | 2 | 10 | 2 | 10 | 6 | 5,43 | 6,58 | | | | | 6,3 | 7,2 | 6,3 | | | 6,6 |
| Mbit | 5,2 | | 4,2 | | 5,4 | | 5,6 | | | | - | #VALUE! | #VALUE! | 5,5 | 5,3 | 5,4 | ##### | ###### | 5,40 |
| voids %V/V | 20 | | 25 | | 20 | | 22 | | | | | 17 | 27 | 19,8 | 20,3 | 22,1 | 18,00 | 26,00 | 20,7 |
| degree of compaction [%] | | | | | | | | | | | | 97,0% | 103,0% | 102,3% | 102,1% | 99,4% | | | 101,3% |
| density [kg/m3] | | | | | | | | | | | 1929 | | | 1974 | 1969 | 1917 | | | 1953 |
| | | | overall requirement RAW | | | | | target vs reference | | | | reference vs field cores (n=1) | | | | | ref vs av. field cores (n=3) | | |
| sieve | DZOAB16 | | 2L-ZOAB16 | | 2L-ZOAB8 | | target | min | max | c.a.e. | reference | min | max | 1 | 2 | 3 | min | max | average |

| | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Location 5 (B) | | | | | | | | | | | | | | | | | | | |
| 31,5 | | | | | | | | | | | | | | | | | | | |
| 22,4 | 100 | 100 | 100 | 100 | | | 100 | | | | | | | 100 | 100 | 100 | | | 100 |
| 16 | 93 | 100 | 90 | 100 | | | 91 | 88 | 94 | | | | | 94 | 92 | 97 | | | 94 |
| 11,2 | 70 | 85 | DV | DV | 100 | | 19 | 15,5 | 22,5 | | | | | 41 | 39 | 42 | | | 41 |
| 8 | | | | | 90 | 100 | 12 | | | | | | | 20 | 19 | 20 | | | 20 |
| 5,6 | | | | | NR | NR | 12 | | | | | | | 16 | 15 | 16 | | | 16 |
| 4 | | | | | | | - | | | | | | | | | | | | |
| 2 | 13 | 25 | 5 | 25 | 5 | 25 | 11 | 8,5 | 13,5 | | | | | 12 | 12 | 13 | | | 12 |
| 0,5 | NR | NR | NR | NR | NR | NR | 8 | | | | | | | | | | | | |
| 0,18 | | | | | | | - | | | | | | | | | | | | |
| 0,063 | 2 | 10 | 2 | 10 | 2 | 10 | 4,5 | 3,93 | 5,08 | | | | | 5 | 4,8 | 5,3 | | | 5 |
| Mbit | 5,2 | | 4,2 | | 5,4 | | 4,3 | | | | - | #VALUE! | #VALUE! | 4,1 | 4,0 | 4,4 | ##### | ###### | 4,2 |
| voids %V/V | 20 | | 25 | | 20 | | 24,9 | | | | | 19,9 | 29,9 | 20,8 | 21,2 | 23,6 | 20,90 | 28,90 | 21,9 |
| degree of compaction [%] | | | | | | | | | | | | 97,0% | 103,0% | 105,9% | 105,4% | 100,2% | | | 103,8% |
| density [kg/m3] | | | | | | | | | | | 1891 | | | 2003 | 1993 | 1895 | | | 1964 |
| | | | overall requirement RAW | | | | | target vs c.a.e. | | | | reference vs field cores (n=1) | | | | | ref vs av. field cores (n=3) | | |
| sieve | DZOAB16 | | 2L-ZOAB16 | | 2L-ZOAB8 | | target | min | max | c.a.e. | reference | min | max | 1 | 2 | 3 | min | max | average |

| | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Location 6 | | | | | | | | | | | | | | | | | | | |
| 31,5 | | | mismatch target comp CE and summary report | | | | | | | | | | | | | | | | |
| 22,4 | 100 | 100 | 100 | 100 | | | 100 | | | 100 | | | | 100 | 100 | 100 | | | 100 |
| 16 | 93 | 100 | 90 | 100 | | | 100 | 97 | 103 | 99,7 | | 93,7 | 105,7 | 99 | 99 | 100 | | | 99 |
| 11,2 | 70 | 85 | DV | DV | 100 | | | -3,5 | 3,5 | | | -7 | 7 | 82 | 79 | 79 | | | 80 |
| 8 | | | | | 90 | 100 | 40 | | | 41,8 | | | | 44 | 43 | 44 | | | 44 |
| 5,6 | | | | | NR | NR | - | | | - | | | | 22 | 22 | 23 | | | 22 |
| 4 | | | | | | | - | | | - | | | | | | | | | |
| 2 | 13 | 25 | 5 | 25 | 5 | 25 | 14 | 11,5 | 16,5 | 15,3 | | 10,3 | 20,3 | 15 | 16 | 15 | 11,8 | 18,8 | 15 |
| 0,5 | NR | NR | NR | NR | NR | NR | 9 | | | 7,6 | | | | | | | | | |
| 0,18 | | | | | | | - | | | - | | | | | | | | | |
| 0,063 | 2 | 10 | 2 | 10 | 2 | 10 | 5,5 | 4,93 | 6,08 | 6,1 | | 3,8 | 8,4 | 6 | 5,3 | 6,1 | 4,8 | 7,4 | 5,8 |
| Mbit | 5,2 | | 4,2 | | 5,4 | | 5,1 | | | | 5,1 | 4,5 | 5,7 | 5,1 | 5,4 | 5,2 | 4,60 | 5,50 | 5,2 |
| voids %V/V | 20 | | 25 | | 20 | | 20 | | | | | 15 | 25 | 16,9 | 14,3 | 15,1 | 16,0 | 24,0 | 15,4 |
| degree of compaction [%] | | | | | | | | | | | | 97,0% | 103,0% | 104,0% | 106,9% | 106,3% | | | 105,7% |
| density [kg/m3] | | | | | | | | | | | 1978 | | | 2057 | 2115 | 2102 | | | 2091 |
| | | | overall requirement RAW | | | | | target vs reference | | | | reference vs field cores (n=1) | | | | | ref vs av. field cores (n=3) | | |
| sieve | DZOAB16 | | 2L-ZOAB16 | | 2L-ZOAB8 | | target | min | max | c.a.e. | reference | min | max | 1 | 2 | 3 | min | max | average |

| | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Location 7 (A) | | | | | | | | | | | | | | | | | | | |
| 31,5 | | | | | | | | | | | | | | | | | | | |
| 22,4 | 100 | 100 | 100 | 100 | | | | | | | | | | | | | | | |
| 16 | 93 | 100 | 90 | 100 | | | | | | | | | | | | | | | |
| 11,2 | 70 | 85 | DV | DV | 100 | | 100 | | | | | | | 100 | 100 | 100 | | | 100 |
| 8 | | | | | 90 | 100 | 92 | 89 | 95 | | | | | 96 | 99 | 98 | | | 98 |
| 5,6 | | | | | NR | NR | 27 | | | | | | | 45 | 47 | 45 | | | 46 |
| 4 | | | | | | | - | | | | | | | | | | | | |
| 2 | 13 | 25 | 5 | 25 | 5 | 25 | 13 | 10,5 | 15,5 | | | | | 17 | 16 | 15 | | | 16 |
| 0,5 | NR | NR | NR | NR | NR | NR | 9 | | | | | | | | | | | | |
| 0,18 | | | | | | | - | | | | | | | | | | | | |
| 0,063 | 2 | 10 | 2 | 10 | 2 | 10 | 6 | 5,43 | 6,58 | | | | | 7,3 | 6,6 | 6,1 | | | 6,7 |
| Mbit | 5,2 | | 4,2 | | 5,4 | | 5,6 | | | | | -0,6 | 0,6 | 4,9 | 5,2 | 4,9 | -0,50 | 0,40 | 5,00 |
| voids %V/V | 20 | | 25 | | 20 | | 22 | | | | | 17 | 27 | 21,7 | 21,3 | 22,2 | 18,0 | 26,0 | 21,7 |
| degree of compaction [%] | | | | | | | | | | | | 97,0% | 103,0% | 100,8% | 101,0% | 100,9% | | | 100,9% |
| density [kg/m3] | | | | | | | | | | | 1929 | | | 1944 | 1949 | 1946 | | | 1946 |
| | | | overall requirement RAW | | | | | target vs reference | | | | reference vs field cores (n=1) | | | | | ref vs av. field cores (n=3) | | |
| sieve | DZOAB16 | | 2L-ZOAB16 | | 2L-ZOAB8 | | target | min | max | c.a.e. | reference | min | max | 1 | 2 | 3 | min | max | average |

| | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Location 7 (B) | | | | | | | | | | | | | | | | | | | |
| 31,5 | | | | | | | | | | | | | | 70/100 acc to CE, PMB acc to tests | | | | | |
| 22,4 | 100 | 100 | 100 | 100 | | | 100 | | | | | | | 100 | 100 | 100 | | | 100 |
| 16 | 93 | 100 | 90 | 100 | | | 91 | 88 | 94 | | | | | 95 | 94 | 94 | | | 94 |
| 11,2 | 70 | 85 | DV | DV | 100 | | 19 | 15,5 | 22,5 | | | | | 41 | 41 | 40 | | | 41 |
| 8 | | | | | 90 | 100 | 12 | | | | | | | 20 | 18 | 21 | | | 20 |
| 5,6 | | | | | NR | NR | 12 | | | | | | | 15 | 15 | 16 | | | 15 |
| 4 | | | | | | | - | | | | | | | | | | | | |
| 2 | 13 | 25 | 5 | 25 | 5 | 25 | 11 | 8,5 | 13,5 | | | | | 13 | 12 | 12 | -3,5 | 3,5 | 12 |
| 0,5 | NR | NR | NR | NR | NR | NR | 8 | | | | | | | | | | | | |
| 0,18 | | | | | | | - | | | | | | | | | | | | |
| 0,063 | 2 | 10 | 2 | 10 | 2 | 10 | 4,5 | 3,93 | 5,08 | | | | | 2,7 | 2,6 | 2,4 | -1,3 | 1,3 | 2,6 |
| Mbit | 5,2 | | 4,2 | | 5,4 | | 4,3 | | | | | -0,6 | 0,6 | 4,0 | 4,0 | 4,1 | -0,50 | 0,40 | 4 |
| voids %V/V | 20 | | 25 | | 20 | | 24,9 | | | | | 19,9 | 29,9 | 23,6 | 21,5 | 21,3 | 20,90 | 28,90 | 22,1 |
| degree of compaction [%] | | | | | | | | | | | | 97,0% | 103,0% | 103,3% | 104,8% | 104,9% | | | 104,3% |
| density [kg/m3] | | | | | | | | | | | 1891 | | | 1954 | 1981 | 1984 | | | 1973 |
| | | | overall requirement RAW | | | | | target vs c.a.e. | | | | reference vs field cores (n=1) | | | | | ref vs av. field cores (n=3) | | |
| sieve | DZOAB16 | | 2L-ZOAB16 | | 2L-ZOAB8 | | target | min | max | c.a.e. | reference | min | max | 1 | 2 | 3 | min | max | average |

| | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Location 8 | | | | | | | | | | | | | | | | | | | |
| 31,5 | | | | | | | | | | | | | | | | | | | |
| 22,4 | 100 | 100 | 100 | 100 | | | 100 | | | 100 | | | | 100 | 100 | 100 | | | 100 |
| 16 | 93 | 100 | 90 | 100 | | | 97,6 | 94,6 | 100,6 | 95,5 | | 89,5 | 101,5 | 98 | 98 | 98 | | | 98 |
| 11,2 | 70 | 85 | DV | DV | 100 | | 70 | 66,5 | 73,5 | 74 | | 67 | 81 | 69 | 66 | 67 | | | 67 |
| 8 | | | | | 90 | 100 | 35 | | | 0 | | | | 35 | 34 | 36 | | | 35 |
| 5,6 | | | | | NR | NR | 19,1 | | | 0 | | | | 21 | 21 | 22 | | | 21 |
| 4 | | | | | | | - | | | 0 | | | | | | | | | |
| 2 | 13 | 25 | 5 | 25 | 5 | 25 | 15 | 12,5 | 17,5 | 16,5 | | 11,5 | 21,5 | 15 | 15 | 15 | 13 | 20 | 15 |
| 0,5 | NR | NR | NR | NR | NR | NR | 8,4 | | | 8,4 | | | | | | | | | |
| 0,18 | | | | | | | 5,9 | | | | | | | | | | | | |
| 0,063 | 2 | 10 | 2 | 10 | 2 | 10 | 4,5 | 3,93 | 5,08 | 5 | | 2,7 | 7,3 | 5,3 | 5,4 | 5,3 | 3,7 | 6,3 | 5,3 |
| Mbit | 5,2 | | 4,2 | | 5,4 | | 5,2 | | | | 5,2 | 4,6 | 5,8 | 5,1 | 5,2 | 5,1 | 4,70 | 5,60 | 5,1 |
| voids %V/V | 20 | | 25 | | 20 | | - | | | | | #VALUE! | #VALUE! | 15,4 | 16,7 | 15,7 | ##### | ###### | 15,9 |
| degree of compaction [%] | | | | | | | | | | | | 97,0% | 103,0% | | | | | | #DIV/0! |
| density [kg/m3] | | | | | | | | | | | - | | | 2115 | 2083 | 2106 | | | 2101 |
| | | | overall requirement RAW | | | | | target vs reference | | | | reference vs field cores (n=1) | | | | | ref vs av. field cores (n=3) | | |
| sieve | DZOAB16 | | 2L-ZOAB16 | | 2L-ZOAB8 | | target | min | max | c.a.e. | reference | min | max | 1 | 2 | 3 | min | max | average |
| Location 9 | | | | | | | | | | | | | | | | | | | |
| 31,5 | | | | | | | | | | | | | | | | | | | |
| 22,4 | 100 | 100 | 100 | 100 | | | 100 | | | | 100 | | | 100 | 100 | 100 | | | 100 |
| 16 | 93 | 100 | 90 | 100 | | | 95 | 92 | 98 | | 95,5 | 89,5 | 101,5 | 100 | 100 | 100 | | | 100 |
| 11,2 | 70 | 85 | DV | DV | 100 | | | -3,5 | 3,5 | | | -7 | 7 | 99 | 97 | 98 | | | 98 |
| 8 | | | | | 90 | 100 | 45,2 | | | | 49,3 | | | 53 | 52 | 47 | | | 51 |
| 5,6 | | | | | NR | NR | | | | | | | | 27 | 25 | 24 | | | 25 |
| 4 | | | | | | | | | | | | | | | | | | | |
| 2 | 13 | 25 | 5 | 25 | 5 | 25 | 14,9 | 12,4 | 17,4 | | 15,9 | 10,9 | 20,9 | 18 | 17 | 17 | 12,4 | 19,4 | 17 |
| 0,5 | NR | NR | NR | NR | NR | NR | 10,2 | | | | 11,1 | | | | | | | | |
| 0,18 | | | | | | | | | | | - | | | | | | | | |
| 0,063 | 2 | 10 | 2 | 10 | 2 | 10 | 5,5 | 4,93 | 6,08 | | 6,1 | 3,8 | 8,4 | 6,2 | 6,2 | 6,1 | 4,8 | 7,4 | 6,2 |
| Mbit | 5,2 | | 4,2 | | 5,4 | | 5,1 | | | | 5,1 | 4,5 | 5,7 | 5,4 | 5,2 | 5,1 | 4,60 | 5,50 | 5,2 |
| voids %V/V | 20 | | 25 | | 20 | | 20 | | | | 21,7 | 15 | 25 | 15,9 | 16,7 | 18,4 | 16,00 | 24,00 | 17,00 |
| degree of compaction [%] | | | | | | | | | | | | 97,0% | 103,0% | 106,0% | 104,8% | 103,3% | | | 104,7% |
| density [kg/m3] | | | | | | | | | | | 1950 | | | 2067 | 2043 | 2015 | | | 2042 |
| | | | overall requirement RAW | | | | | target vs reference | | | | reference vs field cores (n=1) | | | | | ref vs av. field cores (n=3) | | |
| sieve | DZOAB16 | | 2L-ZOAB16 | | 2L-ZOAB8 | | target | min | max | c.a.e. | reference | min | max | 1 | 2 | 3 | min | max | average |
| Location 10 | | | | | | | | | | | | | | | | | | | |
| 31,5 | | | | | | | | | | | | | | | | | | | |
| 22,4 | 100 | 100 | 100 | 100 | | | 100 | | | | 100 | | | 100 | 100 | 100 | | | 100 |
| 16 | 93 | 100 | 90 | 100 | | | 97 | 94 | 100 | | 97 | 91 | 103 | 98 | 98 | 98 | | | 98 |
| 11,2 | 70 | 85 | DV | DV | 100 | | | -3,5 | 3,5 | | | -7 | 7 | 76 | 77 | 74 | | | 76 |
| 8 | | | | | 90 | 100 | 42,5 | | | | 47,5 | | | 46 | 45 | 41 | | | 44 |
| 5,6 | | | | | NR | NR | | | | | | | | 24 | 22 | 20 | | | 22 |
| 4 | | | | | | | | | | | | | | | | | | | |
| 2 | 13 | 25 | 5 | 25 | 5 | 25 | 14 | 11,5 | 16,5 | | 15,5 | 10,5 | 20,5 | 15 | 13 | 13 | 12 | 19 | 14 |
| 0,5 | NR | NR | NR | NR | NR | NR | 8,8 | | | | 10,8 | | | | | | | | |
| 0,18 | | | | | | | | | | | - | | | | | | | | |
| 0,063 | 2 | 10 | 2 | 10 | 2 | 10 | 5,5 | 4,93 | 6,08 | | 6,6 | 4,3 | 8,9 | 5,5 | 5,2 | 5,5 | 5,3 | 7,9 | 5,4 |
| Mbit | 5,2 | | 4,2 | | 5,4 | | 5,1 | | | | 5,1 | 4,5 | 5,7 | 5,8 | 5,9 | 5,5 | 4,60 | 5,50 | 5,7 |
| voids %V/V | 20 | | 25 | | 20 | | 20 | | | | 23,1 | 15 | 25 | 17,5 | 20,4 | 21,3 | 16,00 | 24,00 | 19,7 |
| degree of compaction [%] | | | | | | | | | | | | 97,0% | 103,0% | 106,8% | 103,0% | 102,1% | | | 104,0% |
| density [kg/m3] | | | | | | | | | | | 1974 | | | 2109 | 2034 | 2015 | | | 2053 |
| | | | overall requirement RAW | | | | | target vs c.a.e. | | | | reference vs field cores (n=1) | | | | | ref vs av. field cores (n=3) | | |
| sieve | DZOAB16 | | 2L-ZOAB16 | | 2L-ZOAB8 | | target | min | max | c.a.e. | reference | min | max | 1 | 2 | 3 | min | max | average |
| Location 11 | | | | | | | | | | | | | | | | | | | |
| 31,5 | | | mismatch target comp CE and summary report | | | | | | | | | | | | | | | | |
| 22,4 | 100 | 100 | 100 | 100 | | | 100 | | | 100 | | | | 100 | 100 | 100 | | | 100 |
| 16 | 93 | 100 | 90 | 100 | | | 100 | 97 | 103 | 99,7 | | 93,7 | 105,7 | 100 | 99 | 99 | | | 99 |
| 11,2 | 70 | 85 | DV | DV | 100 | | | -3,5 | 3,5 | | | -7 | 7 | 80 | 81 | 82 | | | 81 |
| 8 | | | | | 90 | 100 | 40 | | | 41,8 | | | | 43 | 46 | 52 | | | 47 |
| 5,6 | | | | | NR | NR | - | | | | | | | 22 | 22 | 26 | | | 23 |
| 4 | | | | | | | | | | | | | | | | | | | |
| 2 | 13 | 25 | 5 | 25 | 5 | 25 | 14 | 11,5 | 16,5 | 15,3 | | 10,3 | 20,3 | 14 | 14 | 13 | 11,8 | 18,8 | 14 |
| 0,5 | NR | NR | NR | NR | NR | NR | 9 | | | 7,6 | | | | | | | | | |
| 0,18 | | | | | | | | | | - | | | | | | | | | |
| 0,063 | 2 | 10 | 2 | 10 | 2 | 10 | 5,5 | 4,93 | 6,08 | 6,1 | | 3,8 | 8,4 | 6,7 | 5,6 | 6,4 | 4,8 | 7,4 | 6,2 |
| Mbit | 5,2 | | 4,2 | | 5,4 | | 5,1 | | | | 5,1 | 4,5 | 5,7 | 5,3 | 5,5 | 5,2 | 4,60 | 5,50 | 5,3 |
| voids %V/V | 20 | | 25 | | 20 | | 20 | | | | - | 15 | 25 | 19,7 | 18,9 | 19,1 | 16,00 | 24,00 | 19,2 |
| degree of compaction [%] | | | | | | | | | | | | 97,0% | 103,0% | 100,5% | 101,7% | 101,6% | | | 101,2% |
| density [kg/m3] | | | | | | | | | | | 1978 | | | 1987 | 2011 | 2010 | | | 2003 |
| | | | overall requirement RAW | | | | | target vs c.a.e. | | | | reference vs field cores (n=1) | | | | | ref vs av. field cores (n=3) | | |
| sieve | DZOAB16 | | 2L-ZOAB16 | | 2L-ZOAB8 | | target | min | max | c.a.e. | reference | min | max | 1 | 2 | 3 | min | max | average |
| Location 12 (A) | | | | | | | | | | | | | | | | | | | |
| 31,5 | | | | | | | | | | | | | | | | | | | |
| 22,4 | 100 | 100 | 100 | 100 | | | | | | | | | | | | | | | |
| 16 | 93 | 100 | 90 | 100 | | | | | | | | | | | | | | | |
| 11,2 | 70 | 85 | DV | DV | 100 | | 100 | | | 100 | | | | 100 | 100 | 100 | | | 100 |
| 8 | | | | | 90 | 100 | 95 | 92 | 98 | 95,5 | | 89,5 | 101,5 | 97 | 96 | 96 | | | 96 |
| 5,6 | | | | | NR | NR | 27 | 23,5 | 30,5 | 30 | | | | 47 | 45 | 45 | | | 46 |
| 4 | | | | | | | - | | | - | | | | | | | | | |
| 2 | 13 | 25 | 5 | 25 | 5 | 25 | 13 | 10,5 | 15,5 | 14 | | 9 | 19 | 16 | 16 | 17 | 10,5 | 17,5 | 16 |
| 0,5 | NR | NR | NR | NR | NR | NR | 9 | | | 8,8 | | | | | | | | | |
| 0,18 | | | | | | | - | | | - | | | | | | | | | |
| 0,063 | 2 | 10 | 2 | 10 | 2 | 10 | 6 | 5,43 | 6,58 | 6,3 | | 4 | 8,6 | 7,4 | 7,7 | 7,5 | 5 | 7,6 | 7,5 |
| Mbit | 5,2 | | 4,2 | | 5,4 | | 5,2 | | | | 4,8 | 4,2 | 5,4 | 5,1 | 5,5 | 5,3 | 4,30 | 5,20 | 5,30 |
| voids %V/V | 20 | | 25 | | 20 | | 22 | | | | - | 17 | 27 | 23,7 | 20,8 | 21,3 | 18,00 | 26,00 | 21,9 |
| degree of compaction [%] | | | | | | | | | | | | 97,0% | 103,0% | 99,3% | 101,9% | 102,0% | | | 101,1% |
| density [kg/m3] | | | | | | | | | | | 1914 | | | 1900 | 1951 | 1952 | | | 1934 |
| | | | overall requirement RAW | | | | | target vs c.a.e. | | | | reference vs field cores (n=1) | | | | | ref vs av. field cores (n=3) | | |
| sieve | DZOAB16 | | 2L-ZOAB16 | | 2L-ZOAB8 | | target | min | max | c.a.e. | reference | min | max | 1 | 2 | 3 | min | max | average |
| Location 12 (B) | | | | | | | | | | | | | | | | | | | |
| 31,5 | | | | | | | | | | | | | PMB on CE, no PMB acc to tests | | | | | | |
| 22,4 | 100 | 100 | 100 | 100 | | | 100 | | | 100 | | | | 100 | 100 | 100 | | | 100 |
| 16 | 93 | 100 | 90 | 100 | | | 96 | 93 | 99 | 97 | | 91 | 103 | 96 | 95 | 97 | | | 96 |
| 11,2 | 70 | 85 | DV | DV | 100 | | 21 | 18 | 24 | 21 | | 14 | 28 | 41 | 38 | 35 | | | 38 |
| 8 | | | | | 90 | 100 | - | | | | | | | 18 | 16 | 16 | | | 17 |
| 5,6 | | | | | NR | NR | - | | | | | | | 14 | 13 | 13 | | | 13 |
| 4 | | | | | | | - | | | | | | | | | | | | |
| 2 | 13 | 25 | 5 | 25 | 5 | 25 | 10 | 7,5 | 12,5 | 11,2 | | 6,2 | 16,2 | 11 | 11 | 11 | 7,7 | 14,7 | 11 |
| 0,5 | NR | NR | NR | NR | NR | NR | 7 | | | 8,7 | | | | | | | | | |
| 0,18 | | | | | | | - | | | - | | | | | | | | | |
| 0,063 | 2 | 10 | 2 | 10 | 2 | 10 | 4,5 | 3,93 | 5,08 | 5,6 | | 3,3 | 7,9 | 5 | 5 | 4,9 | 4,3 | 6,9 | 5 |
| Mbit | 5,2 | | 4,2 | | 5,4 | | 4,5 | | | | 4,4 | 3,8 | 5,0 | 4,4 | 4,3 | 3,7 | 3,90 | 4,80 | 4,1 |
| voids %V/V | 20 | | 25 | | 20 | | 24 | | | | - | 19,0 | 29,0 | 18,6 | 20,6 | 20,7 | 20,00 | 28,00 | 20 |
| degree of compaction [%] | | | | | | | | | | | | 97,0% | 103,0% | 106,9% | 104,4% | 104,8% | | | 105,4% |
| density [kg/m3] | | | | | | | | | | | 1881 | | | 2011 | 1964 | 1971 | | | 1982 |

| sieve | DZOAB16 | | 2L-ZOAB16 | | 2L-ZOAB8 | | target | min | max | c.a.e. | reference | min | max | 1 | 2 | 3 | min | max | average |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Location 13 | | | | | | | | | | | | | | | | | | | |
| 31,5 | | | | | | | | | | | | | | | | | | | |
| 22,4 | 100 | 100 | 100 | 100 | | | 100 | | | | 100 | | | 100 | 100 | 100 | | | 100 |
| 16 | 93 | 100 | 90 | 100 | | | 97 | 94 | 100 | | 97 | 91 | 103 | 100 | 99 | 99 | | | 99 |
| 11,2 | 70 | 85 | DV | DV | 100 | | | -3,5 | 3,5 | | | -7 | 7 | 84 | 81 | 83 | | | 83 |
| 8 | | | | | 90 | 100 | 42,5 | | | | 47,5 | | | 54 | 53 | 53 | | | 53 |
| 5,6 | | | | | NR | NR | | | | | | | | 26 | 26 | 26 | | | 26 |
| 4 | | | | | | | | | | | - | | | | | | | | |
| 2 | 13 | 25 | 5 | 25 | 5 | 25 | 14 | 11,5 | 16,5 | | 15,5 | 10,5 | 20,5 | 15 | 15 | 15 | 12 | 19 | 15 |
| 0,5 | NR | NR | NR | NR | NR | NR | 8,8 | | | | 10,8 | | | | | | | | |
| 0,18 | | | | | | | | | | | - | | | | | | | | |
| 0,063 | 2 | 10 | 2 | 10 | 2 | 10 | 5,5 | 4,93 | 6,08 | | 6,6 | 4,3 | 8,9 | 6,8 | 6,8 | 6,9 | 5,3 | 7,9 | 6,8 |
| Mbit | 5,2 | | 4,2 | | 5,4 | | 5,1 | | | | 5,1 | 4,5 | 5,7 | 6,3 | 6,6 | 6,6 | 4,60 | 5,50 | 6,50 |
| voids %V/V | 20 | | 25 | | 20 | | 20 | | | | 23,1 | 15 | 25 | 19,3 | 18,4 | 18,9 | 16,00 | 24,00 | 18,9 |
| degree of compaction [%] | | | | | | | | | | | | 97,0% | 103,0% | 103,2% | 104,5% | 103,6% | | | 103,8% |
| density [kg/m3] | | | | | | | | | | | 1974 | | | 2038 | 2063 | 2046 | | | 2049 |
| | | | overall requirement RAW | | | | | target vs c.a.e. | | | | reference vs field cores (n=1) | | | | | ref vs av. field cores (n=3) | | |
| sieve | DZOAB16 | | 2L-ZOAB16 | | 2L-ZOAB8 | | target | min | max | c.a.e. | reference | min | max | 1 | 2 | 3 | min | max | average |
| Location 14 | | | | | | | | | | | | | | | | | | | |
| 31,5 | | | | | | | | | | | | | | | | | | | |
| 22,4 | 100 | 100 | 100 | 100 | | | 100 | 97 | 103 | 100 | | | | 100 | 100 | 100 | | | 100 |
| 16 | 93 | 100 | 90 | 100 | | | 97,6 | 94,6 | 100,6 | 95,5 | | 89,5 | 101,5 | 99 | 98 | 97 | | | 98 |
| 11,2 | 70 | 85 | DV | DV | 100 | | 70 | 66,5 | 73,5 | 74 | | 67 | 81 | 74 | 78 | 74 | | | 75 |
| 8 | | | | | 90 | 100 | 35 | | | 0 | | | | 36 | 38 | 39 | | | 38 |
| 5,6 | | | | | NR | NR | 19,1 | | | 0 | | | | 21 | 21 | 23 | | | 22 |
| 4 | | | | | | | - | | | 0 | | | | | | | | | |
| 2 | 13 | 25 | 5 | 25 | 5 | 25 | 15 | 12,5 | 17,5 | 16,5 | | 11,5 | 21,5 | 15 | 15 | 16 | 13 | 20 | 15 |
| 0,5 | NR | NR | NR | NR | NR | NR | 8,4 | | | 8,4 | | | | | | | | | |
| 0,18 | | | | | | | 5,9 | | | 0 | | | | | | | | | |
| 0,063 | 2 | 10 | 2 | 10 | 2 | 10 | 4,5 | 3,93 | 5,08 | 5 | | 2,7 | 7,3 | 5,5 | 5,6 | 6 | 3,7 | 6,3 | 5,7 |
| Mbit | 5,2 | | 4,2 | | 5,4 | | 5,2 | | | | 5,2 | 4,6 | 5,8 | 5,2 | 5,2 | 5,4 | 4,70 | 5,60 | 5,3 |
| voids %V/V | 20 | | 25 | | 20 | | | | | | - | -5 | 5 | 16,1 | 16,9 | 15,2 | -4,00 | 4,00 | 16,1 |
| degree of compaction [%] | | | | | | | | | | | | 97,0% | 103,0% | | | | | | #DIV/0! |
| density [kg/m3] | | | | | | | | | | | - | | | 2095 | 2076 | 2107 | | | 2093 |
| | | | overall requirement RAW | | | | | target vs reference | | | | reference vs field cores (n=1) | | | | | ref vs av. field cores (n=3) | | |
| sieve | DZOAB16 | | 2L-ZOAB16 | | 2L-ZOAB8 | | target | min | max | c.a.e. | reference | min | max | 1 | 2 | 3 | min | max | average |
| Location 15 | | | | | | | | | | | | | | | | | | | |
| 31,5 | | | | | | | | | | | | | | | | | | | |
| 22,4 | 100 | 100 | 100 | 100 | | | 100 | | | | 100 | | | 100 | 100 | 100 | | | 100 |
| 16 | 93 | 100 | 90 | 100 | | | 97 | 94 | 100 | | 97 | 91 | 103 | 99 | 99 | 99 | | | 99 |
| 11,2 | 70 | 85 | DV | DV | 100 | | | -3,5 | 3,5 | | | -7 | 7 | 80 | 84 | 84 | | | 83 |
| 8 | | | | | 90 | 100 | 42,5 | | | | 47,5 | | | 47 | 46 | 50 | | | 48 |
| 5,6 | | | | | NR | NR | 0 | | | | 0 | | | 21 | 20 | 21 | | | 21 |
| 4 | | | | | | | | | | | 0 | | | | | | | | |
| 2 | 13 | 25 | 5 | 25 | 5 | 25 | 14 | 11,5 | 16,5 | | 15,5 | 10,5 | 20,5 | 13 | 13 | 13 | 12 | 19 | 13 |
| 0,5 | NR | NR | NR | NR | NR | NR | 8,8 | | | | 10,8 | | | | | | | | |
| 0,18 | | | | | | | 0 | | | | - | | | | | | | | |
| 0,063 | 2 | 10 | 2 | 10 | 2 | 10 | 5,5 | 4,93 | 6,08 | | 6,6 | 4,3 | 8,9 | 5,4 | 5,4 | 5,9 | 5,3 | 7,9 | 5,6 |
| Mbit | 5,2 | | 4,2 | | 5,4 | | 5,1 | | | | 5,1 | 4,5 | 5,7 | 6,2 | 6,3 | 6,3 | 4,60 | 5,50 | 6,3 |
| voids %V/V | 20 | | 25 | | 20 | | 20 | | | | 23,1 | 15 | 25 | 18,5 | 19,6 | 19,0 | 16,00 | 24,00 | 19 |
| degree of compaction [%] | | | | | | | | | | | | 97,0% | 103,0% | 104,6% | 103,1% | 103,8% | | | 103,8% |
| density [kg/m3] | | | | | | | | | | | 1974 | | | 2064 | 2036 | 2049 | | | 2050 |
| | | | overall requirement RAW | | | | | target vs c.a.e. | | | | reference vs field cores (n=1) | | | | | ref vs av. field cores (n=3) | | |
| sieve | DZOAB16 | | 2L-ZOAB16 | | 2L-ZOAB8 | | target | min | max | c.a.e. | reference | min | max | 1 | 2 | 3 | min | max | average |
| Location 16 | | | | | | | | | | | | | | | | | | | |
| 31,5 | | | mismatch target comp CE and summary report | | | | | | | | | | | | | | | | |
| 22,4 | 100 | 100 | 100 | 100 | | | 100 | | | 100 | | | | 100 | 100 | 100 | | | 100 |
| 16 | 93 | 100 | 90 | 100 | | | 100 | 97 | 103 | 99,7 | | 93,7 | 105,7 | 100 | 100 | 100 | | | 100 |
| 11,2 | 70 | 85 | DV | DV | 100 | | | -3,5 | 3,5 | | | -7 | 7 | 83 | 86 | 82 | | | 84 |
| 8 | | | | | 90 | 100 | 40 | | | 41,8 | | | | 44 | 49 | 50 | | | 48 |
| 5,6 | | | | | NR | NR | - | | | | | | | 23 | 24 | 24 | | | 24 |
| 4 | | | | | | | - | | | - | | | | | | | | | |
| 2 | 13 | 25 | 5 | 25 | 5 | 25 | 14 | 11,5 | 16,5 | 15,3 | | 10,3 | 20,3 | 17 | 16 | 17 | 11,8 | 18,8 | 17 |
| 0,5 | NR | NR | NR | NR | NR | NR | 9 | | | 7,6 | | | | | | | | | |
| 0,18 | | | | | | | - | | | - | | | | | | | | | |
| 0,063 | 2 | 10 | 2 | 10 | 2 | 10 | 5,5 | 4,93 | 6,08 | 6,1 | | 3,8 | 8,4 | 6,1 | 5,8 | 6 | 4,8 | 7,4 | 6 |
| Mbit | 5,2 | | 4,2 | | 5,4 | | 5,1 | | | | 5,1 | 4,5 | 5,7 | 5,2 | 5,3 | 5,4 | 4,60 | 5,50 | 5,30 |
| voids %V/V | 20 | | 25 | | 20 | | 20 | | | | - | 15 | 25 | 16,4 | 16,1 | 15,7 | 16,00 | 24,00 | 16,1 |
| degree of compaction [%] | | | | | | | | | | | | 97,0% | 103,0% | 105,0% | 105,1% | 105,6% | | | 105,2% |
| density [kg/m3] | | | | | | | | | | | 1978 | | | 2076 | 2079 | 2088 | | | 2081 |
| | | | overall requirement RAW | | | | | target vs reference | | | | reference vs field cores (n=1) | | | | | ref vs av. field cores (n=3) | | |
| sieve | DZOAB16 | | 2L-ZOAB16 | | 2L-ZOAB8 | | target | min | max | c.a.e. | reference | min | max | 1 | 2 | 3 | min | max | average |
| Location 17 | | | | | | | | | | | | | | | | | | | |
| 31,5 | | | | | | | | | | | | | | | | | | | |
| 22,4 | 100 | 100 | 100 | 100 | | | 100 | | | | 100 | | | 100 | 100 | 100 | | | 100 |
| 16 | 93 | 100 | 90 | 100 | | | 97 | 94 | 100 | | 97 | 91 | 103 | 99 | 99 | 99 | | | 99 |
| 11,2 | 70 | 85 | DV | DV | 100 | | | -3,5 | 3,5 | | | -7 | 7 | 83 | 80 | 83 | | | 82 |
| 8 | | | | | 90 | 100 | 42,5 | | | | 44,1 | | | 50 | 48 | 48 | | | 49 |
| 5,6 | | | | | NR | NR | - | | | | 0 | | | 26 | 26 | 25 | | | 26 |
| 4 | | | | | | | - | | | | - | | | | | | | | |
| 2 | 13 | 25 | 5 | 25 | 5 | 25 | 14 | 11,5 | 16,5 | | 14,7 | 9,7 | 19,7 | 17 | 16 | 16 | 11,2 | 18,2 | 16 |
| 0,5 | NR | NR | NR | NR | NR | NR | 8,8 | | | | 10,8 | | | | | | | | |
| 0,18 | | | | | | | - | | | | - | | | | | | | | |
| 0,063 | 2 | 10 | 2 | 10 | 2 | 10 | 5,5 | 4,93 | 6,08 | | 6,6 | 4,3 | 8,9 | 5,9 | 5,9 | 5,3 | 5,3 | 7,9 | 5,7 |
| Mbit | 5,2 | | 4,2 | | 5,4 | | 5,1 | | | | 5,1 | 4,5 | 5,7 | 6,5 | 6,4 | 6,3 | 4,60 | 5,50 | 6,40 |
| voids %V/V | 20 | | 25 | | 20 | | - | | | | 23,1 | #VALUE! | #VALUE! | 19,4 | 17,6 | 16,4 | ##### | ###### | 17,8 |
| degree of compaction [%] | | | | | | | | | | | | 97,0% | 103,0% | 102,6% | 105,6% | 107,4% | | | 105,2% |
| density [kg/m3] | | | | | | | | | | | 1974 | | | 2026 | 2084 | 2120 | | | 2077 |
| meets requirement | | | | | | | 146 (89%) | | | | 111 (68%) | | | 104 (56%) | 103 (56%) | 109 (59%) | | | 63 (60%) |
| doesnot meet requirement/not provided | | | | | | | 18 (11%) | | | | 53 (32%) | | | 81 (44%) | 82 (44%) | 76 (41%) | | | 42 (40%) |
| # location meeting all reqs | | | | | 0 (0%) | | 7 (33%) | | | | 3 (14%) | | | 1 (5%) | 0 (0%) | 0 (0%) | | | 1 (5%) |
| #location not meeting 1 or more reqs | | | | | 21 (100%) | | 14 (67%) | | | | 18 (86%) | | | 20 (95%) | 21 (100%) | 21 (100%) | | | 20 (95%) |

| | | | overall requirement RAW | | | | | target vs reference | | | reference vs field cores (n=1) | | | | | ref vs av. field cores (n=3) | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| sieve | DZOAB16 | | 2L-ZOAB16 | | 2L-ZOAB8 | | target | min | max | reference | min | max | 1 | 2 | 3 | min | max | average |
| Location 13 | | | | | | | | | | | | | | | | | | |
| 31,5 | | | | | | | | | | | | | | | | | | |
| 22,4 | 100 | 100 | 100 | 100 | | | 100 | | | 100 | | | 100 | 100 | 100 | | | 100 |
| 16 | 93 | 100 | 90 | 100 | | | 97 | 94 | 100 | 97 | 91 | 103 | 100 | 99 | 99 | | | 99 |
| 11,2 | 70 | 85 | DV | DV | 100 | | | -3,5 | 3,5 | | -7 | 7 | 84 | 81 | 83 | | | 83 |
| 8 | | | | | 90 | 100 | 42,5 | | | 47,5 | | | 54 | 53 | 53 | | | 53 |
| 5,6 | | | | | NR | NR | | | | | | | 26 | 26 | 26 | | | 26 |
| 4 | | | | | | | | | | - | | | | | | | | |
| 2 | 13 | 25 | 5 | 25 | 5 | 25 | 14 | 11,5 | 16,5 | 15,5 | 10,5 | 20,5 | 15 | 15 | 15 | 12 | 19 | 15 |
| 0,5 | NR | NR | NR | NR | NR | NR | 8,8 | | | 10,8 | | | | | | | | |
| 0,18 | | | | | | | | | | - | | | | | | | | |
| 0,063 | 2 | 10 | 2 | 10 | 2 | 10 | 5,5 | 4,925 | 6,075 | 6,6 | 4,3 | 8,9 | 6,8 | 6,8 | 6,9 | 5,3 | 7,9 | 6,8 |
| Mbit | 5,2 | | 4,2 | | 5,4 | | 5,1 | | | 5,1 | 4,5 | 5,7 | 6,3 | 6,6 | 6,6 | 4,6 | 5,5 | 6,5 |
| voids %V/V | 20 | | 25 | | 20 | | 20 | | | 23,1 | 15 | 25 | 19,3 | 18,4 | 18,9 | 19,1 | 27,1 | 18,9 |
| degree of compaction [%] | | | | | | | | | | | | | 103,2% | 104,5% | 103,6% | | | 103,8% |
| density [kg/m3] | | | | | | | | | | 1974 | | | 2038 | 2063 | 2046 | | | 2049 |
| | | | overall requirement RAW | | | | | target vs reference | | | reference vs field cores (n=1) | | | | | ref vs av. field cores (n=3) | | |
| sieve | DZOAB16 | | 2L-ZOAB16 | | 2L-ZOAB8 | | target | min | max | reference | min | max | 1 | 2 | 3 | min | max | average |
| Location 14 | | | | | | | | | | | | | | | | | | |
| 31,5 | | | | | | | | extraction comp, not reference | | | | | | | | | | |
| 22,4 | 100 | 100 | 100 | 100 | | | 100 | 97 | 103 | 100 | | | 100 | 100 | 100 | | | 100 |
| 16 | 93 | 100 | 90 | 100 | | | 97,6 | 94,6 | 100,6 | 95,5 | 89,5 | 102 | 99 | 98 | 97 | | | 98 |
| 11,2 | 70 | 85 | DV | DV | 100 | | 70 | 66,5 | 73,5 | 74 | 67 | 81 | 74 | 78 | 74 | | | 75 |
| 8 | | | | | 90 | 100 | 35 | | | 0 | | | 36 | 38 | 39 | | | 38 |
| 5,6 | | | | | NR | NR | 19,1 | | | 0 | | | 21 | 21 | 23 | | | 22 |
| 4 | | | | | | | - | | | 0 | | | | | | | | |
| 2 | 13 | 25 | 5 | 25 | 5 | 25 | 15 | 12,5 | 17,5 | 16,5 | 11,5 | 21,5 | 15 | 15 | 16 | 13 | 20 | 15 |
| 0,5 | NR | NR | NR | NR | NR | NR | 8,4 | | | 8,4 | | | | | | | | |
| 0,18 | | | | | | | 5,9 | | | 0 | | | | | | | | |
| 0,063 | 2 | 10 | 2 | 10 | 2 | 10 | 4,5 | 3,925 | 5,075 | 5 | 2,7 | 7,3 | 5,5 | 5,6 | 6 | 3,7 | 6,3 | 5,7 |
| Mbit | 5,2 | | 4,2 | | 5,4 | | 5,2 | | | 5,2 | 4,6 | 5,8 | 5,2 | 5,2 | 5,4 | 4,7 | 5,6 | 5,3 |
| voids %V/V | 20 | | 25 | | 20 | | 20 | | | - | 15 | 25 | 16,1 | 16,9 | 15,2 | 16 | 24 | 16,1 |
| degree of compaction [%] | | | | | | | | | | | | | | | | | | #DIV/0! |
| density [kg/m3] | | | | | | | | | | - | | | 2095 | 2076 | 2107 | | | 2093 |
| | | | overall requirement RAW | | | | | target vs reference | | | reference vs field cores (n=1) | | | | | ref vs av. field cores (n=3) | | |
| sieve | DZOAB16 | | 2L-ZOAB16 | | 2L-ZOAB8 | | target | min | max | reference | min | max | 1 | 2 | 3 | min | max | average |
| Location 15 | | | | | | | | | | | | | | | | | | |
| 31,5 | | | | | | | | | | | | | | | | | | |
| 22,4 | 100 | 100 | 100 | 100 | | | 100 | | | 100 | | | 100 | 100 | 100 | | | 100 |
| 16 | 93 | 100 | 90 | 100 | | | 97 | 94 | 100 | 97 | 91 | 103 | 99 | 99 | 99 | | | 99 |
| 11,2 | 70 | 85 | DV | DV | 100 | | | -3,5 | 3,5 | | -7 | 7 | 80 | 84 | 84 | | | 83 |
| 8 | | | | | 90 | 100 | 42,5 | | | 47,5 | | | 47 | 46 | 50 | | | 48 |
| 5,6 | | | | | NR | NR | 0 | | | 0 | | | 21 | 20 | 21 | | | 21 |
| 4 | | | | | | | | | | 0 | | | | | | | | |
| 2 | 13 | 25 | 5 | 25 | 5 | 25 | 14 | 11,5 | 16,5 | 15,5 | 10,5 | 20,5 | 13 | 13 | 13 | 12 | 19 | 13 |
| 0,5 | NR | NR | NR | NR | NR | NR | 8,8 | | | 10,8 | | | | | | | | |
| 0,18 | | | | | | | 0 | | | - | | | | | | | | |
| 0,063 | 2 | 10 | 2 | 10 | 2 | 10 | 5,5 | 4,925 | 6,075 | 6,6 | 4,3 | 8,9 | 5,4 | 5,4 | 5,9 | 5,3 | 7,9 | 5,6 |
| Mbit | 5,2 | | 4,2 | | 5,4 | | 5,1 | | | 5,1 | 4,5 | 5,7 | 6,2 | 6,3 | 6,3 | 4,6 | 5,5 | 6,3 |
| voids %V/V | 20 | | 25 | | 20 | | 20 | | | 23,1 | 18,1 | 28,1 | 18,5 | 19,6 | 19 | 19,1 | 27,1 | 19 |
| degree of compaction [%] | | | | | | | | | | | | | 104,6% | 103,1% | 103,8% | | | 103,8% |
| density [kg/m3] | | | | | | | | | | 1974 | | | 2064 | 2036 | 2049 | | | 2050 |
| | | | overall requirement RAW | | | | | target vs reference | | | reference vs field cores (n=1) | | | | | ref vs av. field cores (n=3) | | |
| sieve | DZOAB16 | | 2L-ZOAB16 | | 2L-ZOAB8 | | target | min | max | reference | min | max | 1 | 2 | 3 | min | max | average |
| Location 16 | | | | | | | | | | | | | | | | | | |
| 31,5 | | | mismatch target comp CE and summary report | | | | | extraction comp, not reference | | | | | | | | | | |
| 22,4 | 100 | 100 | 100 | 100 | | | 100 | | | 100 | | | 100 | 100 | 100 | | | 100 |
| 16 | 93 | 100 | 90 | 100 | | | 100 | 97 | 103 | 99,7 | 93,7 | 106 | 100 | 100 | 100 | | | 100 |
| 11,2 | 70 | 85 | DV | DV | 100 | | | -3,5 | 3,5 | | -7 | 7 | 83 | 86 | 82 | | | 84 |
| 8 | | | | | 90 | 100 | 40 | | | 41,8 | | | 44 | 49 | 50 | | | 48 |
| 5,6 | | | | | NR | NR | - | | | | | | 23 | 24 | 24 | | | 24 |
| 4 | | | | | | | - | | | - | | | | | | | | |
| 2 | 13 | 25 | 5 | 25 | 5 | 25 | 14 | 11,5 | 16,5 | 15,3 | 10,3 | 20,3 | 17 | 16 | 17 | 11,8 | 18,8 | 17 |
| 0,5 | NR | NR | NR | NR | NR | NR | 9 | | | 7,6 | | | | | | | | |
| 0,18 | | | | | | | - | | | - | | | | | | | | |
| 0,063 | 2 | 10 | 2 | 10 | 2 | 10 | 5,5 | 4,925 | 6,075 | 6,1 | 3,8 | 8,4 | 6,1 | 5,8 | 6 | 4,8 | 7,4 | 6 |
| Mbit | 5,2 | | 4,2 | | 5,4 | | 5,1 | | | 5,1 | 4,5 | 5,7 | 5,2 | 5,3 | 5,4 | 4,6 | 5,5 | 5,3 |
| voids %V/V | 20 | | 25 | | 20 | | 20 | | | - | 15 | 25 | 16,4 | 16,1 | 15,7 | 16 | 24 | 16,1 |
| degree of compaction [%] | | | | | | | | | | | | | 105,0% | 105,1% | 105,6% | | | 105,2% |
| density [kg/m3] | | | | | | | | | | 1978 | | | 2076 | 2079 | 2088 | | | 2081 |

| | overall requirement RAW | | | | | | | target vs reference | | | reference vs field cores (n=1) | | | | | ref vs av. field cores (n=3) | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| sieve | DZOAB16 | | 2L-ZOAB16 | | 2L-ZOAB8 | | **target** | min | max | **reference** | min | max | *1* | *2* | *3* | min | max | **average** |
| Location 17 | | | | | | | | | | | | | | | | | | |
| 31,5 | | | | | | | | | | | | | | | | | | |
| 22,4 | 100 | 100 | 100 | 100 | | | **100** | | | **100** | | | *100* | *100* | *100* | | | **100** |
| 16 | 93 | 100 | 90 | 100 | | | **97** | 94 | 100 | **97** | 91 | 103 | *99* | *99* | *99* | | | **99** |
| 11,2 | 70 | 85 | DV | DV | 100 | | | -3,5 | 3,5 | | -7 | 7 | ***83*** | ***80*** | ***83*** | | | **82** |
| 8 | | | | | 90 | 100 | **42,5** | | | **44,1** | | | *50* | *48* | *48* | | | **49** |
| 5,6 | | | | | NR | NR | - | | | **0** | | | *26* | *26* | *25* | | | **26** |
| 4 | | | | | | | - | | | - | | | | | | | | |
| 2 | 13 | 25 | 5 | 25 | 5 | 25 | **14** | 11,5 | 16,5 | **14,7** | 9,7 | 19,7 | *17* | *16* | *16* | 11,2 | 18,2 | **16** |
| 0,5 | NR | NR | NR | NR | NR | NR | **8,8** | | | **10,8** | | | | | | | | |
| 0,18 | | | | | | | - | | | - | | | | | | | | |
| 0,063 | 2 | 10 | 2 | 10 | 2 | 10 | **5,5** | 4,925 | 6,075 | **6,6** | 4,3 | 8,9 | *5,9* | *5,9* | *5,3* | 5,3 | 7,9 | **5,7** |
| Mbit | 5,2 | | 4,2 | | 5,4 | | **5,1** | | | **5,1** | 4,5 | 5,7 | *6,5* | *6,4* | *6,3* | 4,6 | 5,5 | **6,4** |
| voids %V/V | 20 | | 25 | | 20 | | **0** | | | **23,1** | 18,1 | 28,1 | *19,4* | *17,6* | *16,4* | 19,1 | 27,1 | **17,8** |
| degree of compaction [%] | | | | | | | | | | | | | *102,6%* | *105,6%* | *107,4%* | | | **105,2%** |
| density [kg/m3] | | | | | | | | | | **1974** | | | 2026 | 2084 | 2120 | | | 2077 |
| **meets requirement** | | | | | | | **147 (90%)** | | | **115 (70%)** | | | **107 (58%)** | **109 (59%)** | **112 (61%)** | | | **60 (57%)** |
| **doesnot meet requirement/not provided** | | | | | | | **17 (10%)** | | | **49 (30%)** | | | **78 (42%)** | **76 (41%)** | **73 (39%)** | | | **45 (43%)** |
| **# location meeting all reqs** | | | | | **0 (0%)** | | **6 (29%)** | | | **2 (10%)** | | | **1 (5%)** | **0 (0%)** | **0 (0%)** | | | **2 (10%)** |
| **#location not meeting 1 or more reqs** | | | | | **21 (100%)** | | **15 (71%)** | | | **19 (90%)** | | | **20 (95%)** | **21 (100%)** | **21 (100%)** | | | **19 (90%)** |

not provided in documentation
no requirement
no ref V%, target value used

text: doesnot meet requirement
text: no requirement
text: meets requirement

RWS contract specs: V>=15% individual cores, >=18% on average

# III. Version overview

Version 1.0-1.x: concept versions of varied completeness from summer 2018 until late 2019, when the final concept was finished

Version 2.0: December 2019:

While finalizing the report random checks of the information underlying product information sheets revealed that the overview provided contained a number of errors. After consultation with RWS, it was decided that RWS would have a check done on all the information provided on the basis of the underlying documents

Version 2.1: May 2020:

RWS provided TUD with an updated, detailed check of the underlying project information. Although a number of individual data points (appendix II) changed, which affected the numbers in the overview tables, the order of magnitude of the overall results did not change. As part of this update, also the effect of assessing the information on the basis of the RAW 2015 versus using the requirements at the time of construction were included. In this update changes from bitumen content “on” to “in” were taken into account and deviations on lower margin of the 2mm sieve for the DZOAB 16 mixture that still met the RAW 2015 requirements were not counted as deviations.

Version 2.2 July 2020: updated management summary, more (numerical) details were included to support the general conclusions mentioned in the management summary.

Additionally, separate headers were added to separate the checks versus requirements RAW 2015 and those at time of construction were added to make it easier for the reader to differentiate.

Version 2.3 November 2021: In preparing for the meeting wit the contractors about the report, it was noticed that a number of tables were not corrected for the May 2020 numbers. This concerned Table 3.32, 3.33 (where also a link was corrected, showing two sets of PSV values and the specimen density where before a third incorrect PSV value was shown, 3.38 where an error in the core 3 numbers was corrected and 3.40 were the top part was correct but the bottom part not, the only difference between these should be in the average values). These errors were corrected.

Also, a footnote was added to the management summary on the basis of some of the comments made in this meeting.

Finally, this appendix listing the changes between the different versions of the report was added.