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Effects of Reclaimed Asphalt and Warm Mix Asphalt on the Availability of the Road Network

J.C. Nicholls & M. Wayman
TRL Limited, Wokingham, United Kingdom

A. Varveri
Technische Universiteit Delft, Delft, Netherlands

S. King & S. Cassidy
Lagan Asphalt, Dublin, Ireland

K. Mollenhauer
Universität Kassel, Kassel, Germany

C. McNally & A. Tabakovic
University College Dublin, Dublin, Ireland

ABSTRACT: This repot reviews the EARN project, which was undertaken under CEDR Call2012 in order to investigate the effects of using reclaimed asphalt (RA) and/or lower temperature asphalt on the road network. The work consisted of a review of existing data on service lifetime and availability of road materials and structures, a site trial to evaluate varying proportions of RA, experimental evaluation of moisture damage and ageing in asphalt mixtures and development of an impact assessment model. The site trial involved four different mixtures containing varying proportions of RA and warm mix additive and was monitored for international roughness index, mean profile depth, corrected SCRIM Coefficient, indirect stiffness modulus, water sensitivity and indirect tensile strength, the latter with and without artificial ageing. The monitoring was extended to 40 months with two extensions to the project, when monitoring of the binder mechanical and other properties were also made.

1 INTRODUCTION

There are many issues that the public has deep concerns about. These include the need for greater sustainability to ensure that succeeding generations have some resources left (although not all public think that far ahead). This issue of sustainability is one that engineers can help. The main drivers that are being used to increase the sustainability of asphalt road construction are replacing constituent materials (aggregates and binders) by reclaimed asphalt (RA) and/or secondary materials from other industries and the use of warm mix asphalt (WMA) or other lower temperature mixtures.

These techniques have been around for a long time, but their use is becoming more prevalent with pressure for greater sustainability. However, the long-term sustainability of these measures in construction, gained by using less fresh materials and energy and creating a reduced carbon footprint, will be lost if the durability of the pavement is sufficiently impaired to required more frequent replacement such that increased fresh materials and energy are used and the carbon footprint is greater in the longer term, as well increased traffic disruption.

The national road authorities are interested in both increasing the sustainability of the construction of their networks and limiting the disruption on them. As such, the Confederation of European Directors of Roads (EARN), in their Transnational Road Research Programme Call 2012 included a call for “Recycling: Road construction in a post-fossil fuel society” that was funded by Denmark, Finland, Germany, Ireland, Netherlands and Norway. One of the successful projects to this call was “Effects on Availability of Road Network” (CEDR) put forward by a consortium led by TRL Limited with Universität Kassel, University College Dublin, Technische Universiteit Delft, Lagan Asphalt and Shell Bitumen. The project subsequently got two extensions for longer-term monitoring of the trial site. This report summarises the findings from the EARN project carried out for CEDR.

2 REVIEW

A review was undertaken into existing data that could be used to assess the effect on durability of using RA, WMA or secondary aggregates (Mollenhauer et al. 2014). No databases were found that identified the influence of the use of recycled construction materials or secondary by-products on the durability of the road pavements despite there being many studies published on RA and WMA. Furthermore, the high number of parameters affecting the pavements durability, as shown in Table 1, do not allow a comprehensive model for calculating the durability in near future.

Table 1. Summary of effects on service lifetime and durability of pavements

Categories	Parameters
Environmental effects	Air temperature
	Wind Speed
	Sun exposure
	Frost-thaw cycles
	Precipitation, humidity
	High-depth frosting
Traffic loading	Tyre/axle weight and number
	Traffic speed (distribution)
	Axle configuration
Sub-base characteristics	Bearing capacity
	Moisture/drainage properties
Pavement type and structure	Type of pavement
	Number of structural layers
	Layer thickness
Unbound base layers	Composition (type of aggregates, grading)
	Degree of compaction
	Moisture
	Bearing capacity
Hydraulically base layers	Construction type
	Stiffness / strength
	Air voids content
	Grading of aggregates
	Binder type
	Binder content
	Construction conditions: Shrinkage / cracking
Bitumen stabilised base layers (Cold recycling mixtures)	Type of mixture (foam or emulsion; site or plant mixed)
	Aggregate grading
	Curing conditions
	Binder content (bitumen)
	Binder content (cement)
	Air voids content
	Stiffness / Strength
Asphalt layers (hot, half-warm and warm mix asphalts)	Type of mixture
	Binder content
	Binder type
	Aggregate grading
	Air voids content
	Volumetric properties
	Type and content of additives
	RA type, quality and content
	Construction conditions
	Performance properties

Furthermore, reliable data on the structural properties of the road network is still lacking which prohibits the empirical evaluation of long-term performance of various pavement material parameters on network level. What was concluded from a database evaluation conducted was that the application of RA in hot-mix asphalt can reduce the expected service lifetime, which would invalidate the main reason for using RA. Nevertheless, the evaluation showed large scatter and, therefore, no distinct statement could be drawn. From international literature, it was shown that the use of RA in new hot-mix asphalt mixtures generally results in adequate material durability performance. However, some researchers (Watson *et al*. 2008) have also identified reduced durability for mixtures containing RA.

3 TRIAL SITE

The main effort of the EARN project was to undertake a site trial to identify the effect of RA and WMA on the durability of asphalt (Mollenhauer *et al*. 2014b). A typical surface course of stone mastic asphalt (SMA) with a maximum nominal aggregate size of 10 mm and a target of 4 % to 6 % air voids content was produced according to the Irish and European standards with four variants. These variants are shown in Table 2.

The RA feedstock was supplied from a site on the M1 motorway in North County Dublin and was 14 mm porous asphalt derived from a single source. The acquisition of RA from a single source allows for more consistency on the grading and properties than the alternative procedure of mixing multiple sources. The RA was added to the mixture from an extra aggregate bin with the proportions taken from the other bins being adjusted to provide the required grading.

Five samples of RA were taken and the average binder content was found to be 5.3 % and the material particle size distribution after the binder burn-off procedure in EN 12697-39 is shown in Figure 1.

Table 2. Mixture design

Mix No.	Proportional content (%)					
	RA	10 mm	CRF*	Filler	Fresh Binder	WMA †
1	0	65.9	22.8	5.7	5.6	0
2	28.6	43.8	17.0	5.7	4.9	0
3	38.1	34.4	17.1	5.7	4.7	0.5
4	28.6	43.8	17.0	5.7	4.9	0.5

* Crushed Rock Fines

† Warm mix additive as a proportion of total binder content

In collaboration with the Irish National Roads Authority, a section of the N3 national road between Blanchardstown and Clonee Village was selected for the site trial experiment. The reasons were that the site had been scheduled for resurfacing, was only about 60 km from a suitable asphalt plant and was on a main commuter route into Dublin city with an average daily vehicle traffic count (one direction only) of 15,480 vehicles (including heavy goods vehicles). Subsequent measurements found that the southbound average daily traffic was c.35k in 2015 and closer to 60k in 2016/7.

The road is a dual carriageway with three traffic lanes on each side (bus lane and two traffic lanes). The middle lane was chosen as the test lane because it will be subjected to the most trafficking, particularly from heavy goods vehicles. The traffic direction is towards Dublin city. Figure 2 shows a schematic layout of the trial section.

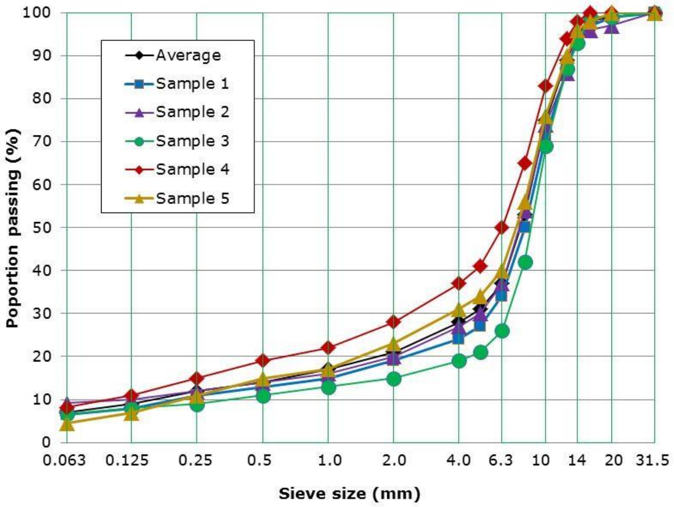


Figure 1. RA material grading after the binder removal

Just over 230 tonnes of asphalt material were required to cover the trial section area. The work started with removal of the existing surface course which was milled to a depth of 40 mm. An initial regulating course of SMA was then laid to a depth of 20 mm. The outer lane and bus lane (Figure 2) were resurfaced with a standard SMA, containing no RA or warm mix additive, to a depth of 40 mm.

The paving process started with laying Mixture 1 (control mixture). The asphalt material was hauled from the plant to the site by truck and unloaded to the material transfer vehicle before it was sent to the paver. The purpose of the material transfer vehicle was to remix the material before paving. The paving process is shown in Figure 3 and Figure 4.

The paving process passed as expected without any difficulties for Mixture 1. However, Mixture 2 proved to be more difficult because the material cooled down rapidly with the consequential reduction in workability of the mixture, although the reason for that cooling was not clear. The paving of Mixtures 3 and 4 passed without much difficulty, highlighting the improved workability of the mixtures incorporating the warm mix additive, even with up to 40 % RA.

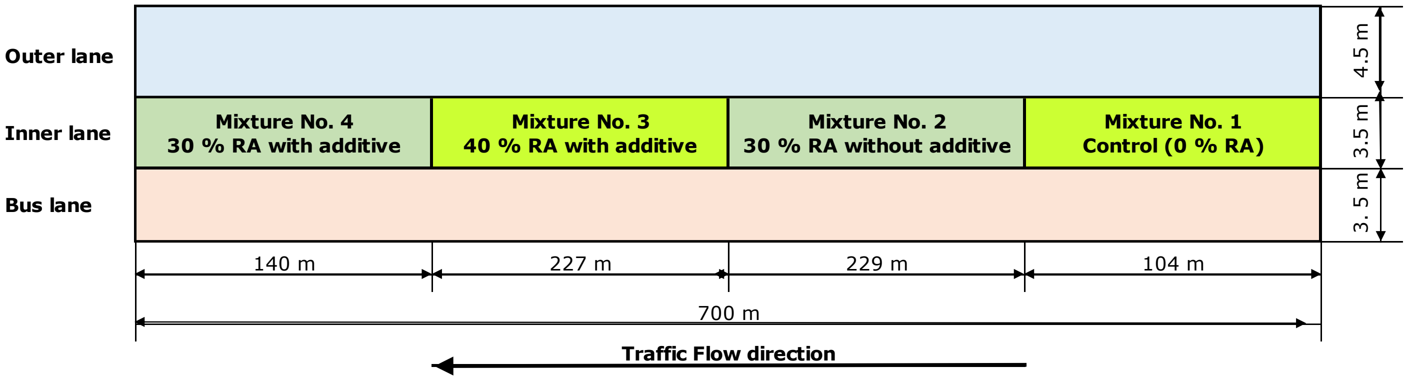


Figure 2. Schematic representation of the trail section

Figure 3. Paving process of the trial section (1)

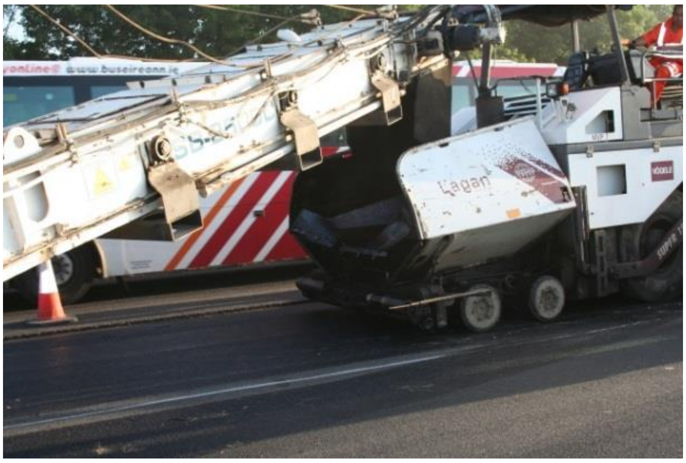


Figure 4. Paving process of the trial section (2)

4 CARBON FOOTPRINT

The trial site was monitored to develop a decision model for carbon foot-printing (Wayman *et al*. 2014). Data collection was tailored directly to the site trial with information from the plant batching records; mixture recipes; metered energy consumption (gas oil and electricity); laying records; and cost data for mixture components, haulage and energy the being collated on the day of the trial or directly after the trial was carried out.

Real time energy monitoring was not routinely carried out at the batch plant so it was necessary to collect data on the day of the trial. Electricity consumption, which was independent of mixture or burner temperature, was recorded directly before and directly after the trial mixtures had been batched. Gas oil consumption, which was assumed to have a direct relationship with burner temperature and the temperature of individual batches as they were mixed were recorded at 30 s intervals throughout batching of the trial mixtures.

The CO_2e generated for the asphalts investigated are covered by "cradle-to-gate" default emissions factors. The values used are presented in Table 3 with the cost data being provided directly by Lagan Asphalt. For the modelling, all material costs are assumed to remain constant throughout the 60-year investigation period.

Table 3. Cradle to gate constituent CO_2e values and costs

Constituent	$kgCO_2e/t$	Cost €/t
Aggregates	4.4	16.75
Crushed rock fines	4.4	16.75
RA planings	0.31	11.00
Imported filler	4.4	20.00
Polymer-modified bitumen	370	730.87
CECABASE™ additive	2,100	5,583.20

The cradle-to-gate, cradle-to-site and total CO_2e footprints were calculated for the works carried out at the trial site and are presented in Table 4 in which the values in brackets are the proportion difference from Mixture 1 (Control).

Table 4. Calculated CO_2e footprints per tonne for the four mixtures used

Component	Mixture			
	1	2	3	4
Cradle-to-gate CO_2e footprint ($kgCO_2e/t$)	49.25	47.64 (3.3 %)	45.20 (8.2 %)	43.97 (10.7 %)
Cradle-to-site CO_2e footprint ($kgCO_2e/t$)	60.83	59.22 (2.6 %)	56.78 6.7 %)	55.54 (8.7 %)

The decision model that was developed is reproduced as Figure 5.

5 MONITORING

The site properties of international roughness index (IRI), mean profile depth (MPD) and corrected SCRIM Coefficient (SC) were monitored initially and after 6 months, 12 months (Nicholls *et al*. 2014) and 23 months (Nicholls *et al*. 2015). No measurements were made at 40 months because of the short notice given for the second project extension and because the surface had been disrupted by the extraction of so many cores, particularly for measuring IRI on the remaining surface.

After two years in service, the IRI, MPD and SC results showed good asphalt material performance, although the MPD values were slightly lower than usual national value for Ireland of 1.4 mm. Furthermore, all the trial materials continue to perform after two years in service, with acceptable values obtained with respect to ride quality, skid resistance and mechanical performance.

However, there were indications that the material had undergone densification due to traffic loading and ageing of the binder, with the possibility of densification being supported by the increased bulk density of extracted cores and the ageing being supported by the increased stiffness and tensile strength over the limited time that the trial was monitored.

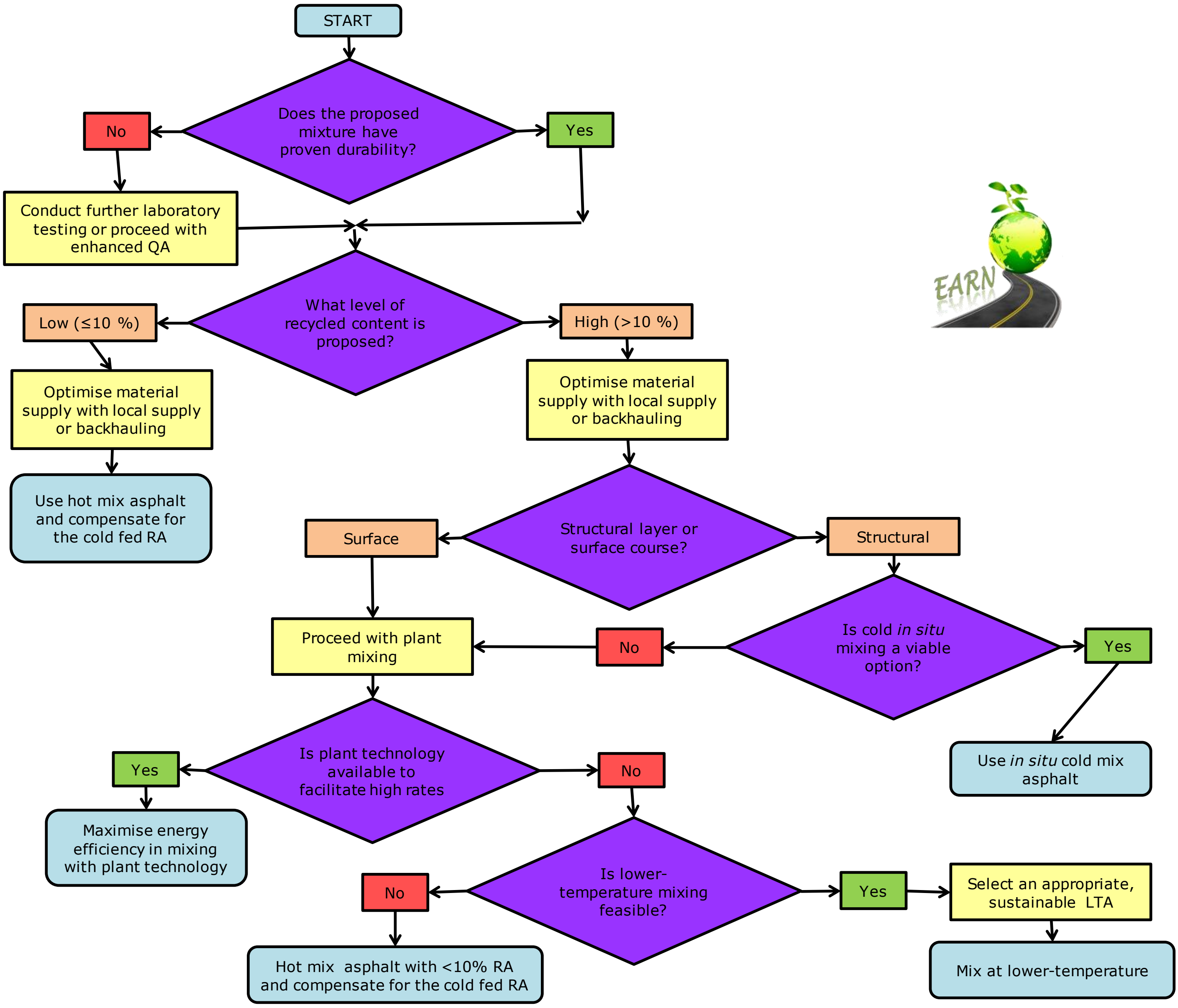
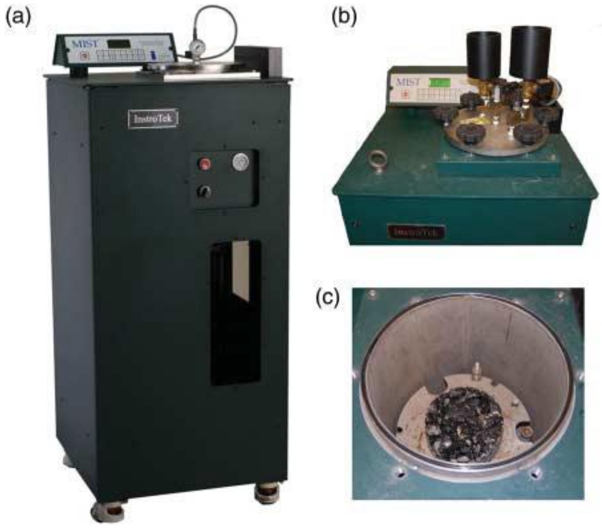


Figure 5. EARN decision model for choice of mixture type

The mechanical properties of indirect tensile stiffness modulus (ITSM) and indirect tensile strength ratio for water sensitivity were measured on cores extracted initially and after 12 months (Nicholls *et al*. 2014) and 23 months (Nicholls *et al*. 2015). The results showed that the water sensitivity test on Mixture 3 (40 % RA with additive) failed to meet the 80 % threshold, dropping from 87.6 % after 12 months to 77.6 % after 23 months.

More cores were taken for an extensive programme of testing for indirect tensile strength (ITS) with and without ageing by immersion in a water-bath and/or the MIST procedure (Varveri *et al*. 2014). All the results were compared with the unaged ITS result of the cores taken at that time; as such, these ratios were not the same as the usual ITSR values with a standard soaking period. These tests were carried out on cores extracted initially and after 12 months (Nicholls *et al*. 2014), 23 months (Nicholls *et al*. 2015) and 40 months (Nicholls *et al*. 2017). The MIST procedure includes both long-term moisture conditioning in the water bath and short-term cyclic pore pressure application using MIST. MIST is a self-contained unit (Figure 6), which includes a hydraulic pump and a piston mechanism that is designed to cyclically apply pressure inside a sample chamber. Moisture conditioning is performed by placing a compacted asphalt sample in the chamber and filling it with water. Then the water is pushed and pulled through the sample, thus creating pressure cycles between zero and the chosen pressure. One can choose the pressure, temperature and the number of conditioning cycles to replicate different combinations of traffic and environmental conditions.

The findings from the laboratory sensitivity testing showed that the inclusion of RA affects the tensile strength of a mixture with the ITS values increasing with increasing RA content although the change in the amount of RA content, from 30 % to 40 % did not change the dry and wet ITS and ITSR values significantly.



Key:
(a) MIST machine
(b) Chamber with specimen
(c) Chamber sealed from top

Figure 6. Moisture induced sensitivity tester

After one year in service, the ITSR and ITS values of the RA mixtures (both with and without WMA additive) improved, indicating that the mixtures underwent a curing process that increased the strength with time and enhanced their performance with respect to moisture damage. Also, the use of warm mix additive was found to increase the resistance to moisture damage induced both by bath and by bath plus MIST conditioning and the control mixture showed a poor performance with respect to moisture in comparison with the performance of the freshly-laid mixtures.

After two years in service, the performance of the RA mixtures with a WMA additive deteriorated considerably. The ITSR results failed to meet the specification requirements and the reduction in the wet ITS values compared to the dry values indicate that the mixtures are highly susceptible to moisture damage, which implies loss of resistance to water damage. The performance of RA mixtures without a WMA additive, however, was similar to that of the control mixture. Also, the control mixture had a steady performance with respect to moisture damage compared to the previous years and the RA mixtures were more sensitive to long-term moisture conditioning than to the application of pore pressures; the reverse was observed for the control mixture.

After over three years in service, Mixture 1 (control) presented a consistent behaviour with respect to its moisture susceptibility in time, after the initial decrease in strength and ITSR values after the first year. Therefore, the drop after two years could be just testing variability. Mixture 2 displayed a similar performance to the control mixture, appearing to be sensitive to longer periods of bath conditioning at each specified time interval. Mixtures 3 and 4 showed high variability in their moisture sensitivity with time in that, after showing poor performance at two years in service, both mixtures were observed to have similar performance to the control mixture after three years in the field. Meanwhile, the dry strength of Mixtures 3 and 4 decreased substantially, their wet strength values were higher than Mixtures 1 and 2.

With the two extensions, in addition to the site and laboratory tests, the dynamic shear rheometer (DSR) frequency and temperature sweeps (-20 °C to 90 °C) and force ductility measurements were obtained from the binder extracted from RA and the freshly produced mixtures and after 23 months (Nicholls *et al*. 2015) and 40 months (Nicholls *et al*. 2017) of ageing. The mechanical binder tests were complemented by the following chemical binder properties, conducted on fresh binder, binder extracted from the RA, binder extracted the four mixtures, the four core samples and the four samples after MIST conditioning (but not after soaking in a water-bath):

- Fourier Transform Infrared (FTIR) spectroscopy.
- Saturates Aromatics Resins Asphaltenes (SARA) analysis by Asphaltene-extraction and TLC-FID (Iatroscan).
- Proportions of asphaltenes.

Some ageing effects were observed on the bitumen samples recovered from the asphalt mixtures and core samples from the mixtures after 23 and 40 months of service life in terms of increasing shear modulus, decreasing softening point and increasing phase angle. There were also unusual changes of softening point and phase angle observed during ageing that can be explained by oxidative degradation of the polymer used for binder modification as also shown by decreasing SBS peak area values within FTIR tests. The changes observed in mechanical bitumen tests cannot be clearly explained by changes in the colloidal properties obtained by applied chemical test methods.

The WMA mixtures showed a lower resistance against ageing identified by higher shear moduli, changes in asphaltenes compositions as well as by the asphalt properties increased stiffness and decreased dry strength. Meanwhile, MIST conditioning had no systematic oxidative ageing effect on the bitumen. However, non-specific differences were observed within binders recovered from MIST-conditioned asphalt specimens.

6 ANALYSIS

The data were analysed with a computer program using the multi-variant linear regression option (Nicholls et al. 2017). The data for all the variables was analysed using Model 1 but with any data measured after artificial ageing by water-bath or MIST being excluded. The assumed relationship for Model 1 is shown in Equation 1.

$$Property = A \times Age + B \times RA + C \times RA \qquad (1)$$

Model 1 was used to identify the extent to which *RA* and *WMA* affect any change of the property with time but not artificial ageing by water-bath and/or MIST and, if so, whether they accelerate or decelerate any change.

For those properties measured after artificial ageing by water-bath and/or MIST, the data were also analysed against Model 2 using the assumed relationship in Equation 2. For the binder, FTIR spectroscopy and SARA analysis properties, the artificial ageing was only undertaken using MIST, so the *D* x *Bath* term is not used.

$$Property = A \times Age + B \times RA + C \times RA + D \times Bath + E \times MIST \qquad (2)$$

Model 2 was used to identify the extent to which *RA* and *WMA* affect any change of the property with time and with artificial ageing by water-bath and/or MIST and, if so, whether they accelerate or decelerate any change. It was also hoped to be able to estimate the calibration of artificial ageing by water-bath and/or MIST in terms of time in-situ, which will be *D*/*A* months ageing per week in a water-bath and *E*/*A* months for MIST conditioning.

The values showed great variability in many of the relationships. The correlation, as indicated by the Adjusted R^2 value, ranges from negative values (no confidence) to 0.93 (high confidence). However, most relationships had correlations of between 0.20 and 0.60, showing that moderate confidence can be put on them. Nevertheless, to ensure that those values weaker correlations do not over-influence the results, the weighted mean results were used rather than the standard means.

The age parameter did not consistently increase or decrease the values of the properties being analysed, but that is to be expected because the requirement for the properties measured are also in terms of whether an increase is "good", as for ITS or ITSM, or "bad", as for IRI. Furthermore, there are several properties, particularly in the binder categories, that are not inherently of a nature that "more" is inherently "good" or "bad". The difference between the two models showed that extra parameter and data significantly affected the proportionate effect of the age.

The inclusion of reclaimed asphalt did not consistently have the same sign as for the age but in around two thirds of the relationships (but not for the important mechanical properties) the signs were opposite, indicating that the inclusion had the reverse effect and, hence, reduced ageing.

The use of warm mix asphalt also did not consistently have the same sign as for the age with around half being opposite, although the signs were opposite in all the relationships for the mechanical properties, again indicating that the use tends to reduce mechanical ageing.

Water-bath ageing was only used for the mechanical tests with same signs as for age, implying that it is an effective method of artificial ageing.

The MIST procedure did not consistently have the same sign as for the age, although all the coefficients for the mechanical are the same sign, implying that it is an effective method of artificial ageing for those properties but not necessarily for all properties.

7 CONCLUSIONS

The main overall conclusions from the EARN project were:

- The use of the WMA system and/or RA can affect the durability of flexible pavements, but that effect is not always adverse and may not be great. Furthermore, extrapolating from 40 months to (possibly) 20 years is not ideal.
- The effect of using the WMA systems, RA, secondary by-products and/or binder additives can be modelled in the expected service life of mixtures (but only to a limited extent).
- Data on the effect of each specific components and the extent to which they are incorporated into the mixture need to be collected to make the model more accurate.
- The MIST procedure is suitable for standardisation as an asphalt moisture conditioning procedure in the EN 12697 series (applicable to more situations than EN 12697-45).

8 ACKNOWLEDGEMENTS

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