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Durability of European Asphalt Mixtures Containing Reclaimed Asphalt and Warm Mix Additives

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ABSTRACT

This paper investigates the moisture susceptibility of European asphalt mixtures containing reclaimed asphalt (RA) and warm mix (WMA) additives. Test sections of a typical SMA mixture have been laid, from which cylindrical samples were cored and utilised for laboratory testing. Four variants of the SMA mixture were prepared; a control HMA mixture with 0% RA, a mixture with 30% RA and no WMA additive, a mixture with 30% RA in which a WMA additive was added and a mixture with 40% RA and a WMA additive. The coring procedure and testing were carried out in two phases; first field cores were taken 24 hrs after the construction of the test section was completed and then once again 12 months later. In this way, the influence of field ageing on the mechanical performance of the mixtures was considered. The samples were moisture conditioned at various combinations of water bath immersion and cyclic pore pressures by means of the Moisture Induced Sensitivity Tester (MiST). The degradation in strength due to moisture was quantified through indirect tensile strength tests. The results indicated that the use of RA in combination with WMA additives resulted to mixtures with improved durability characteristics, with respect to moisture damage, compared to the control HMA mixture. Based on the results, recommendations were made for characterizing and limiting moisture damage of asphalt pavements.

Keywords: Durability, Moisture damage, Ageing, Reclaimed asphalt, Warm mix additive

INTRODUCTION

Traditional technologies for asphalt mixture production are gradually being replaced by warm mix asphalt (WMA) and reclaimed asphalt (RA) technologies due to the associated environmental benefits. These benefits are usually listed as a combination of lower fuel consumption and greenhouse gases emissions, along with a reduction in virgin materials consumption and the amount of waste sent to landfills, all potentially contributing to the overall development of sustainable road infrastructure. The challenge for engineers is to develop environmental friendly pavement materials with similar mechanical performance to those of the conventional ones and, at the same time, to consider ways to make the most of such technologies by further increasing the RA content or lowering the temperatures in pavement mixture design and construction. Obviously, the benefits that arise from the use of RA and WMA can be compromised if the mixture performance is poor in the long-term. For this reason, further research is still needed to evaluate the performance and durability of WMA and RA mixtures.

Traffic loading and environment affect substantially the long-term performance and durability of asphalt pavements. Several environmental factors such as temperature variations, humidity, precipitation, oxygen, freeze-thaw cycles and ultraviolet radiation can degrade the mixture properties, thus decreasing its ability to sustain traffic loads. As a result, an increase in the operational and maintenance costs is needed in order to fulfil the expected service life of the pavement system. Of all possible damages, moisture and oxidative ageing have been identified as important contributors to various forms of damage such as ravelling, rutting and cracking.

Moisture damage is a result of various processes that occur when liquid water or moisture vapour interacts with asphalt mixtures. Moisture diffusion, binder erosion due to the scouring action of water and pressure development in the macro pores of the pavements due to repeated traffic loading are the most important moisture-induced damage processes found in literature *(1, 2)*. Moisture damage phenomena are particularly complex as they depend, among others, on mixture morphology (air voids percentage, size and interconnectivity and hence permeability) and on the physico-chemical properties of bituminous binders and aggregates (diffusivity and chemical affinity with water). Similarly, oxidative ageing of the binder is another cause of mixture degradation. It appears to be a complex phenomenon that alters the viscoelastic behaviour of the binder through chemical and/or physical processes in time and typically leads to embrittlement of the binder, making the pavements more prone to damage under the same loads and strains. Depending on the availability of oxygen for diffusion in a pavement, asphalt binders will harden in time and become brittle; consequently the propensity of asphalt pavements to cracking increases *(3)*.

The use of RA and WMA technologies can influence the aforementioned degradation mechanisms and hence, can further complicate an already complex situation. At the time of construction, it may be that the initial properties of these mixtures are comparable to those of traditional hot mix asphalt (HMA) mixtures; however, the changes in material properties with time may be greater (or lesser) for those mixtures than for HMA mixtures and consequently this will have an influence on their durability. WMA is a type of asphalt mixture that is produced, laid and compacted at temperatures lower than those for HMA. Typically, the mixing temperature for WMA ranges from 100°C to 140°C compared with 150°C to 180°C for HMA *(4)*. It is quite frequently noted, however, that the reduction in mixing temperatures for WMA could adversely affect the moisture resistance of asphalt mixtures *(5)*, because the reduced mixing temperature might lead to inadequate drying and/or coating of the aggregates. Additionally, the introduction of water into the production of the mixtures (for example when using foaming techniques) could also give unintended moisture damage issues.

In the recent past, several studies have been undertaken to evaluate moisture susceptibility of WMA mixtures. Kanitpong et al. *(5)* performed dynamic creep tests under water on HMA and WMA specimens produced by using a 60/70 asphalt binder combined with two aggregate types. For the WMA mixtures 3% Sasobit was used as an additive to allow production at a lower temperature of 110°C. The results indicated that WMA mixtures had a greater resistance to permanent deformation than HMA mixtures, probably due to the fact that Sasobit results in higher mixture stiffness. However, in terms of moisture susceptibility, WMA was more sensitive to moisture compared to HMA. Differences, between the WMA and HMA mixtures, were also found in relation to the gradation and aggregate type. Slag aggregates performed better against moisture for the HMA mixtures, while the WMA slag mixtures exhibited high sensitivity to moisture damage. This can be attributed to the fact that moisture entrapped within the slag aggregates, due to their high porosity, could not be thoroughly dried in WMA due to the lower production temperature. Therefore, to improve moisture susceptibility of WMA mixtures, aggregate types with desirable properties should be considered.

In another study, Xiao et al. *(6)* performed indirect tensile tests on WMA and HMA mixtures after moisture conditioning. They reported that HMA had a better performance compared to WMA mixtures regardless of the aggregate, storage duration and antistripping agent type. However, there exists also evidence that does not support the abovementioned results. Kavussi and Hashemian *(7)* reported that the addition of 2% hydrated lime improved significantly the performance of WMA mixtures in terms of their tensile strength and rutting potential under wet conditions. Nevertheless, a further reduction in mixing temperature resulted to a increase in moisture sensitivity. Moreover, Hurley and Prowell *(8)* reported that, depending on the aggregate and binder type, different WMA additives showed variability compared to the control mixture with respect to moisture susceptibility. From the above it is clear that more investigation is still required to achieve a better understanding of moisture-induced damage in WMA mixtures.

Apart from the low temperature mixtures, reclaimed asphalt technology, namely the use of old asphalt pavements that are milled up or ripped off the road *(9)*, is a useful alternative to virgin materials that can reduce the use of virgin aggregates and asphalt binders for HMA, WMA or cold mix asphalt mixtures *(10)*. To investigate the durability characteristics of RA mixtures, with respect to their moisture sensitivity, several research projects were undertaken. Aurangzeb et al. *(11)* performed the Illinois DOT's moisture susceptibility test on four mixtures with 0%, 30%, 40%, and 50% RA content produced with two aggregate types. The results showed that the tensile strength and tensile strength ratio (TSR) of all mixtures increased with increasing RA content, with the exception of the 40% RA mixture that failed to pass the minimum TSR criterion (TSR≥ 85%). Moreover, Hajj et al. *(12)* reported that overall the addition of RA to a mixture resulted in acceptable moisture resistance; however a reduction in the unconditioned and conditioned tensile strength was observed.

Another study by He and Wong *(13)* concluded that the bitumen type and ageing level of RA materials significantly affects moisture susceptibility. Also, they reported that the indirect tensile strength of fine aggregate mixtures decreased with increasing RA content under dry and wet conditions and that hard bitumen types were found to improve moisture susceptibility. West et al. *(14)* conducted performance related tests to determine the susceptibility of asphalt mixtures containing RA to various distresses. Thirty mixtures were designed and produced with different RA contents and virgin binders, using materials from contractors in New Hampshire, Utah, Minnesota, and Florida. The assessment of the mixtures for their susceptibility to moisture was performed using AASHTO T283. The results showed that mixtures with high RA content generally had higher tensile strength than virgin mixtures before and after moisture conditioning. In several cases, however, the high RA content mixtures did not initially meet the standard 0.80 TSR criterion and the addition of an antistripping additive was needed to improve their TSR values.

Other researchers investigated the moisture sensitivity of mixtures prepared with both WMA and RA technologies. A study by Zhao et al. *(15)* used laboratory performance tests to evaluate the effect of high RA percentages on WMA mixtures. The performance against rutting, fatigue and moisture damage was investigated for four WMA mixtures with 0%, 30%, 40%, and 50% RA. In addition, two HMA control mixtures were designed with 0% and 30% RA. Moisture susceptibility was evaluated using the Hamburg wheel tracking test and AASHTO T283 with one freeze-thaw cycle. It was found that the TSR values of WMA containing high percentages of RAP (30%, 40% and 50%) were higher compared to that of virgin WMA, which indicates that the addition of RA can potentially reduce significantly moisture susceptibility of WMAs. Similar observations were made for the HMA mixtures containing RA.

Moreover, Shu et al. *(16)* evaluated the moisture susceptibility of plant-produced foamed WMA containing high percentages of RA using multiple moisture conditioning procedures and laboratory performance tests. Testing involved the Superpave indirect test, the Hamburg wheel tracking test, and the dynamic modulus test on dry and moisture conditioned samples using two conditioning procedures i.e. the AASHTO T283 freeze–thaw procedure and the moisture induced stress tester (MIST). The findings showed that increasing the RA content in the mixtures generally led to the increase in the ratios of conditioned to dry samples for the various properties. Overall, it was observed that moisture susceptibility decreased with increasing RA content and that plant-produced foamed WMA showed similar moisture susceptibility to that of HMA. It was concluded that foamed WMA combined with RA could perform as well as HMA in terms of moisture damage.

From the above, it can be concluded that there is a need for further research regarding the moisture damage susceptibility of asphalt mixtures that use WMA and RA technologies. A better understanding of the moisture damage mechanisms themselves, but also in relation with the new mixture production technologies is essential.

OBJECTIVES

The main objective of this study was to evaluate the differences in moisture sensitivity that arise from the use of WMA and RA technologies in comparison to hot mix asphalt (HMA) mixtures. Moreover, an attempt was made to study the effect of ageing on the moisture sensitivity of HMA and WMA-RA mixtures. To this end, in this study, a moisture conditioning protocol that combines bath conditioning and pore pressure application by means of MiST was used to characterize moisture damage of WMA asphalt mixtures containing RA. The combined protocol takes into account the key moisture damage processes and allows the quantification of their contributions to moisture damage. For this, asphalt cores obtained from site trials at two distinct time intervals, namely after pavement construction and after one year of service. The evaluation of the moisture susceptibility characteristics of the various mixtures was made on the basis of their tensile strength and tensile strength ratio (TSR).

MIXTURE DESIGN AND SAMPLE COLLECTION

In this study, the effect of using reclaimed asphalt and WMA additives on the durability of asphalt pavements was studied on the basis of site trials. Four variants of a typical SMA surface course were produced according to the Irish and European standards and laid on the test sections, as shown in Figure 1.

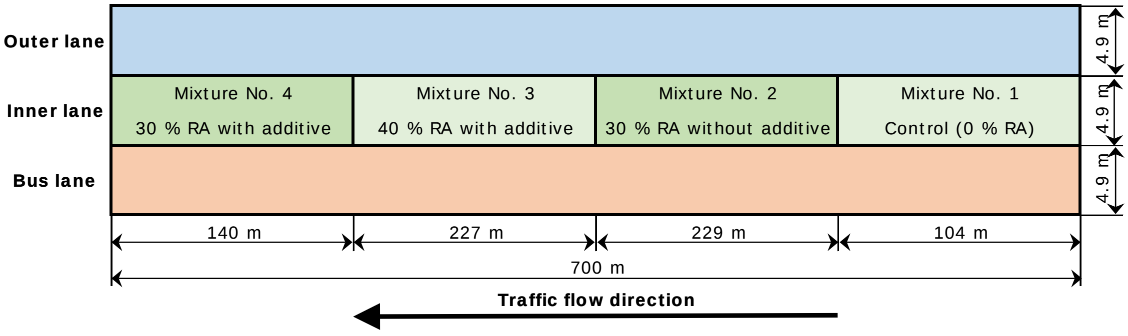

FIGURE 1 Schematic representation of the test sections. After Tabaković et al. *(17)*.

The selected test section is a dual carriage road with three traffic lanes on each direction (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 *(18)*. The mixture had a maximum aggregate size of 10 mm. The mix design target air voids content for all mixtures was 10% whereas the achieved air voids content ranged from 6.8% to 7.5 %. Four variants of the SMA mixture were prepared. Specifically, a control mixture with 0% RA, a mixture with 30% RA and no WMA additive and two more mixtures with Cecabase RT 945 warm mix additive and 30% and 40% of reclaimed asphalt. Table 1 shows the mix design of the four different mixtures. More information on the mixture design and construction of the site trials can be found in Taboković et al. *(17)*.

TABLE 1 Mixture design. After Taboković et al. *(17)*.

Mixture	Proportional content (%)					
	RA content (%)	Aggregates (10 mm)	CRF*	Filler	Fresh binder	WMA additive**
A	0	65.9	22.8	5.7	5.6	0
B	28.6	43.8	17	5.7	4.9	0
C	38.1	34.4	17.1	5.7	4.7	0.3
D	28.6	43.8	17	5.7	4.9	0.3

**Crushed rock fines*
***WMA additive added at 0.5% of the total binder content*

Overall, a total of 216 cores were collected and tested for their sensitivity to moisture damage. First, a total of 108 cores (27 from each trial section) were collected 24 hours after the construction of the site trial section was completed, while in order to consider the effect of ageing another 108 cores were taken nearly one year after the construction of the trial section. The asphalt field cores were 100 mm in diameter and approximately 60 mm in height. The cores consisted of two different layers, namely the SMA surface course and the underneath binder course. Therefore, prior to testing, the binder course was removed by sawing the asphalt cores using a diamond saw. Then the height of the samples was measured in accordance with the European standard EN 12697-29.

MOISTURE CONDITIONING AND TESTING PROTOCOL

Earlier, moisture diffusion and pumping action were identified as the dominant moisture-induced damage mechanisms. However, the time frame over which each mechanism occurs in the field differs significantly. Moisture diffusion occurs over a longer timeframe, while excess pore pressure development takes place in very short times. In order to address the individual mechanisms associated with these two damage processes, the field cores were subjected to a combination of two different conditioning methods: (a) immersion in water bath and (b) cyclic pore pressure application.

Bath conditioning was performed at elevated temperatures so as to facilitate moisture diffusion into the mixture, accelerating thus the long-term degradation of the material properties. Cyclic pore pressure was applied on the samples by means of the moisture induced sensitivity tester (MiST). MiST is a self-contained unit 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 pumped 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 *(19)*.

After delivery, the samples were subjected to the above mentioned combinations of bath and MiST conditioning. First the samples were immersed in a bath with distilled water at an elevated temperature of 60°C, in order to facilitate the diffusion of water into the asphalt samples. At specified time intervals of 3 and 6 weeks three samples per mixture were removed from the bath, placed in water at 20°C for 2 hours and then maintained in a climate chamber at 20°C until tested. An additional three samples per mixture were removed from the bath and further conditioned in MiST; 4000 cycles of pressure were applied at a temperature of 60°C and a pressure of 70 psi (0.48 MPa). After MiST conditioning, the samples were placed in a water bath at 20°C for 2 hours and then in a climate chamber until testing. More details on the moisture conditioning protocol and the selection of the various parameters are given in a previous study *(20)*.

The additional step of placing the samples in a water bath at room temperature (20°C) was found to be essential, considering that the samples were conditioned at high temperature and therefore, they became soft after bath or MiST application. This extra step allowed the stabilization and further handling of the samples. The degradation of the mechanical properties due to moisture conditioning was evaluated through indirect tensile tests (ITT), which were performed in accordance with the EN 12697-23 standard. The indirect tensile strength tests were performed at 20°C at a loading rate of 50 mm/min.

TEST RESULTS AND DISCUSSION

The susceptibility of the asphalt cores to moisture was evaluated on the basis of their indirect tensile strength (ITS) and indirect tensile strength ratio (ITSR). The mean ITSR values (out of three replicate samples), after bath and bath-MiST conditioning, for the unaged (fresh) and field aged samples are shown in Figures 2 and 3, respectively. Also, the coefficient of variation was calculated and presented on the top of the columns. The dashed line represents the threshold value below which an asphalt mixture is considered to be susceptible to moisture damage, according to Dutch and Irish standards.

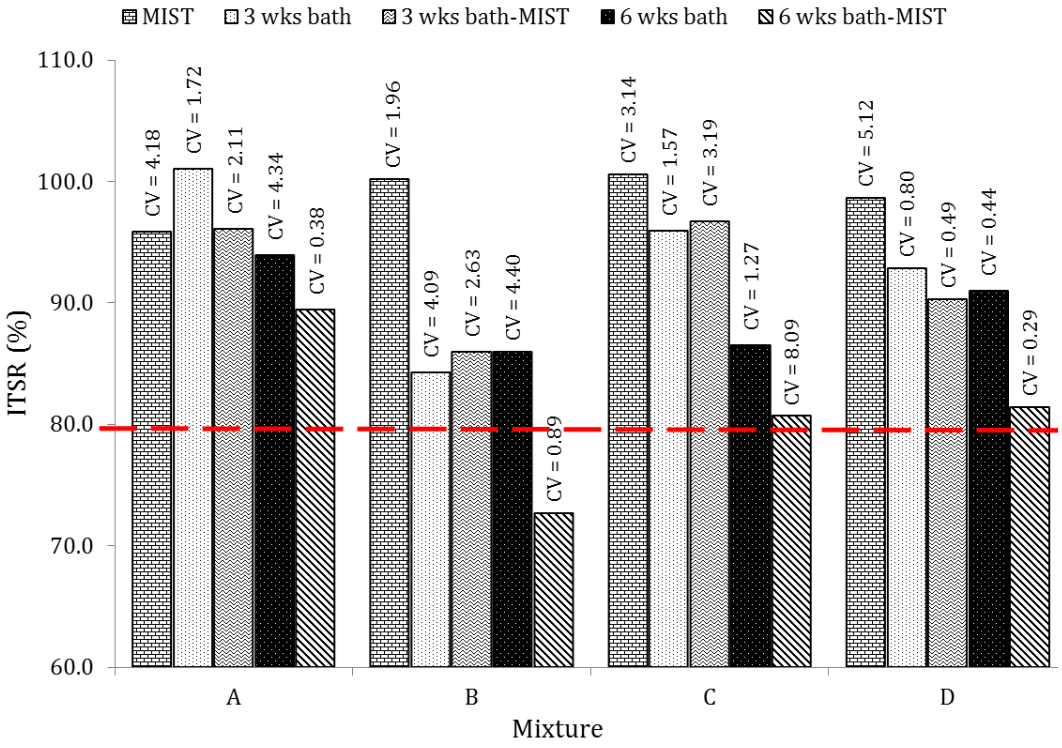

FIGURE 2 Mean ITSR values for unaged (fresh) samples.

Figure 2 shows that the tensile strength ratios of the RA mixtures, regardless of the addition of WMA, were found to be lower than the conventional HMA mixtures for the unaged samples. The addition of WMA additive appeared to improve the resistance of the RA mixtures against moisture as follows from the comparison between mixture B and D, which had the same amount of RA content but differed in terms of the addition of the WMA additive.

After field ageing, however, a different trend was observed as the ITSR values of the RA mixtures were found to be higher than those of the control HMA mixture (0% RA), as shown in Figure 3. The mechanical performance of the control mixture after moisture conditioning (0% RA) had significantly deteriorated for the samples that were collected after one year of field ageing, thus suggesting mixture A is sensitive to moisture damage. On the other hand, after field ageing, the moisture susceptibility of all RA mixtures improved significantly. Specifically, mixture B (30% RA; no WMA additive) was found to be susceptible to moisture damage both before and after field ageing; nevertheless its performance was slightly improved after ageing. Similarly, mixtures C (40% RA plus WMA additive) and D (30% RA plus WMA additive) had high tensile strength ratios before ageing, which were further improved after field ageing. In general, it was found that mixture D performed better against moisture damage compared to other mixture variants. The improvement of the ITS ratios after field ageing suggests that the RA mixtures (with and without WMA additives) underwent a curing process during field ageing that resulted to an increase in their wet tensile strength, thus exhibiting lower sensitivity to moisture damage.

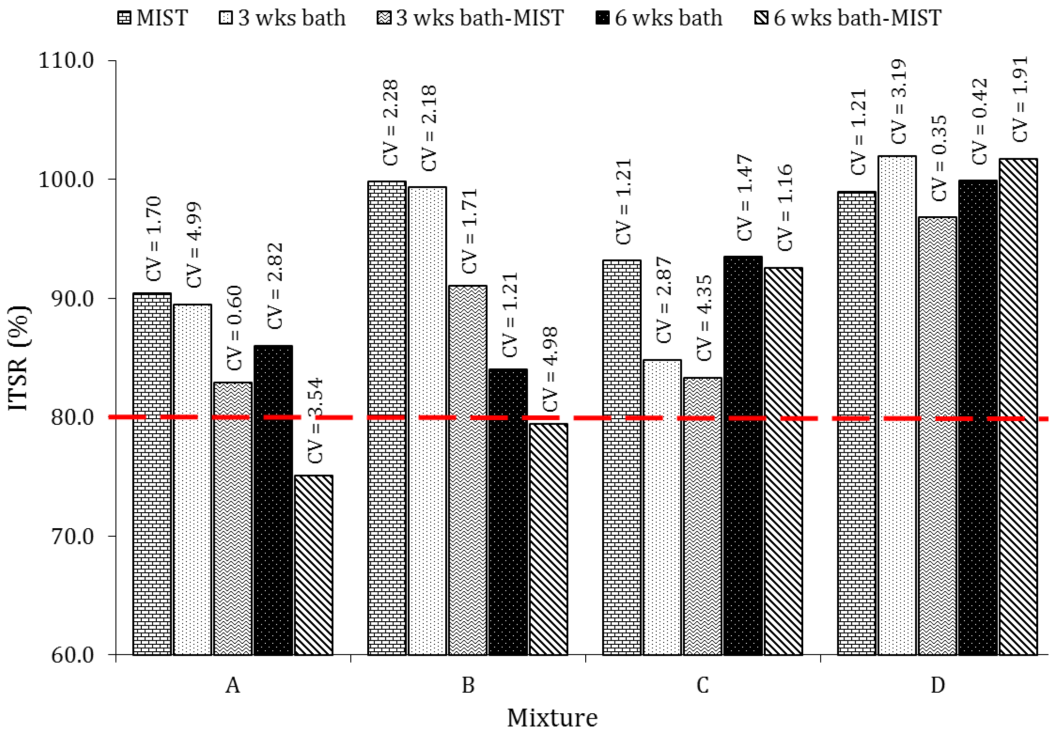

FIGURE 3 Mean ITSR values for the field aged samples.

Table 3 shows the reduction in strength for all mixtures after the application of the various conditioning regimes. From the results, the contributions of the short- and long-term moisture damage on the strength of the samples were quantified. The results for the samples obtained right after the construction of the test sections, show that the HMA control mixture was found to be less sensitive to both long- and short-term moisture conditioning. After three weeks of bath conditioning a slight increase in tensile strength was observed for the unaged samples, while six weeks of bath conditioning resulted to a minor reduction in strength of about 6%. On the other hand, the RA mixtures had higher reduction in strength after bath conditioning that ranged from 4% to 16%. Among the RA mixtures, the 30% RA mixture with a WMA additive showed the best performance, while mixture B that had no WMA additive (but the same RA content of 30%) was extremely sensitive to moisture. Furthermore, it was observed that an increase in the amount of RA content, from 30 % to 40 %, did not result to great differences in the moisture susceptibility of the mixtures, as follows from the comparison between mixture C and D. With respect to the short-term moisture damage, it was observed that MiST application, without any prior bath conditioning and after three weeks in the bath, had a greater effect on the HMA mixture than on the RA mixtures regardless of the addition of WMA additive. However, after six weeks of bath conditioning the samples containing RA weakened considerably and the application of pressure cycles resulted to a high decrease in strength compared to the control mixture.

TABLE 3 Average reduction in strength for the unaged (fresh) and aged samples

Conditioning method	Time (wks)	Strength reduction (%)							
		Mixture A		Mixture B		Mixture C		Mixture D	
		Fresh (unaged)	Aged	Fresh (unaged)	Aged	Fresh (unaged)	Aged	Fresh (unaged)	Aged
Long-term bath conditioning	0	na	na	na	na	na	na	na	na
	3	-1.01	10.50	15.75	0.70	4.05	15.20	7.12	-1.90
	6	6.08	14.00	14.00	16.00	13.51	6.50	9.01	0.10
Long-term bath conditioning & MiST	0	4.17	9.60	-0.21	0.20	-0.58	6.80	1.32	1.00
	3	3.92	17.10	14.03	9.00	3.31	16.70	9.68	3.20
	6	10.54	24.90	27.29	20.60	19.32	7.40	18.58	-1.70
MiST application*	0	4.17	9.60	-0.21	0.20	-0.58	6.80	1.32	1.00
	3	4.93	6.60	-1.72	8.30	-0.74	1.50	2.56	5.10
	6	4.46	10.9	13.29	4.60	5.81	0.90	9.57	-1.80

** The effect of MiST is given as the difference between bath and bath-MiST conditioning; na: not applicable*

After one year in the field, however, the mixtures containing RA exhibited a lower reduction in strength compared to the control mixture after the application of the different conditioning regimes. Specifically, mixture A (0% RA) had the highest reduction in strength for all conditioning protocols (maximum strength loss was 24.90%), suggesting that the mechanical properties of the HMA mixtures deteriorated significantly during a year of service that resulted to high moisture sensitivity. Moreover, similar levels of strength reduction were observed, after only bath conditioning, for the aged samples of mixture B (30% RA; no WMA additive) compared to the unaged ones. However, the performance of mixture B, subjected to the combined protocol, was slightly improved after field ageing. Furthermore, the results demonstrated the positive effect of using WMA additives on moisture susceptibility of both unaged and field aged mixtures. Mixture C (40% RA plus WMA additive) showed a decreasing strength with increasing bath conditioning time; however it appeared to be insensitive to the application of cyclic pressure, indicating that mixture C is more probable to fail cohesively, due to the weakening of the binder, rather than adhesively. This can be attributed to the antistripping effect of the Cecabase RT 945 WMA additive, which appeared to improve the adhesion properties of the aggregate-binder systems. Mixture D (30% RA plus WMA additive), exhibited the best performance against moisture damage. The rate of strength degradation was very low, particularly after field ageing; comparable strength levels were measured after the various conditioning scenarios.

The aforementioned observations are depicted in Figures 4 and 5. The degradation curves due to long- and short-term moisture induced damage mechanisms, i.e. moisture diffusion and cyclic pore pressures, are shown. The red (or blue) curve demonstrates the effect of moisture diffusion on tensile strength due to bath conditioning alone, while the green (or purple) curve shows the influence of the combined conditioning protocol (bath and MiST) on tensile strength. From the results, it can be observed that the dry strength of the control mixture increases significantly after field ageing, in contrast to the RA mixtures that were found to have comparable strength levels for both the unaged and aged samples. With respect to moisture damage susceptibility, the strength of the control mixture appeared to decrease with increasing bath conditioning. Similar observations were also made for mixture B, which did not contain a WMA additive.

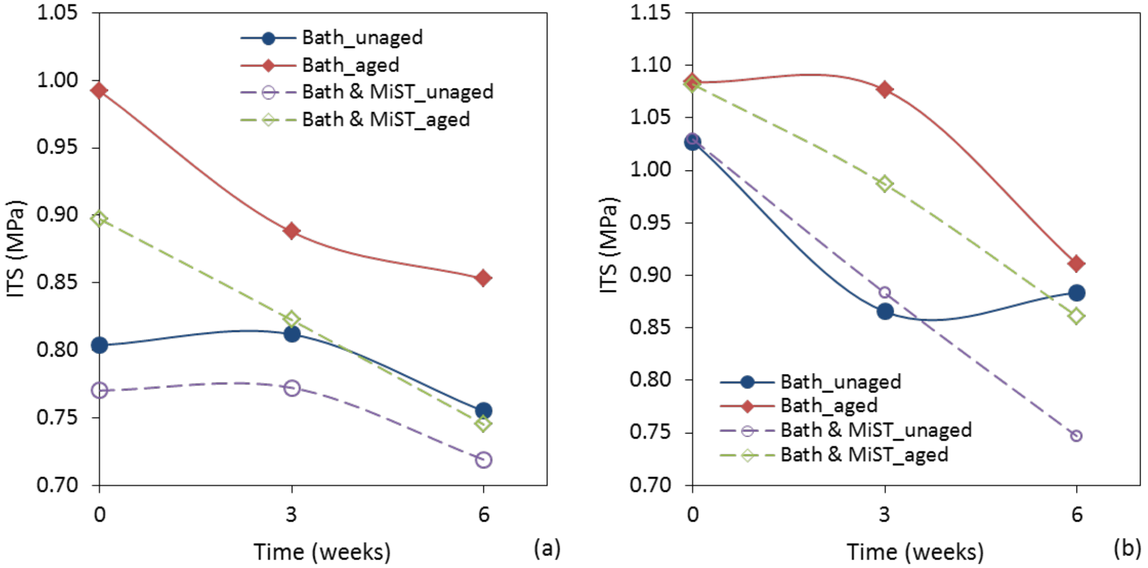

FIGURE 4 Strength degradation curves due to moisture conditioning for (a) mixture A (Control; 0% RA) and (b) mixture B (30% RA; no WMA additive).

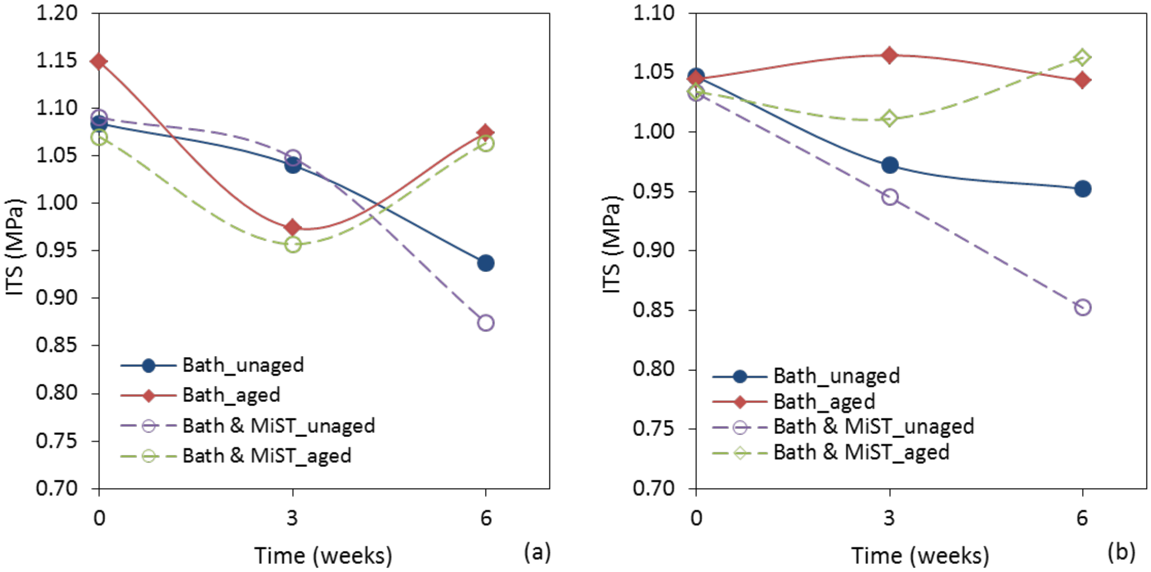

FIGURE 5 Strength degradation curves due to moisture conditioning for (a) mixture C (40% RA; WMA additive) and (b) mixture D (30% RA; WMA additive).

Regarding the influence of short-term moisture conditioning, it was found that MiST application resulted to additional strength loss for both mixtures A and B. The graphs show that the reduction in strength, which corresponds to the influence of pore pressure cycles, increases with bath conditioning time, suggesting that moisture diffusion, degraded further the properties of the mixtures, thus resulting in a greater reduction in strength for the same amount of MIST conditioning. On the contrary, the tensile strength of the mixtures containing reclaimed asphalt and a WMA additive were not significantly affected by pore pressure application. In general, the use of WMA additive resulted to mixtures with superior performance against moisture, especially with respect to the pressure-induced damage.

SUMMARY AND CONCLUSIONS

Overall, the objective of this work was to evaluate the moisture sensitivity of mixtures containing RA and WMA additives and investigate the effect of field ageing on their moisture damage susceptibility. Four variants of a typical European SMA mixture were prepared; a control HMA mixture with 0% RA, a mixture with 30% RA and no WMA additive, a mixture with 30% RA in which a WMA additive was added, as well as a mixture with 40% RA and a WMA additive. Test sections were laid using the four mixtures and a total of 216 samples were cored after 24 hours and one year after the construction of the test sections. The field cores were conditioned in combinations of water bath immersion and cyclic pore pressures by means of the moisture induced sensitivity tester (MiST). The degradation in strength was quantified through indirect tensile strength tests. Based on the results the contributions of long- and short-term moisture damage were quantified. On the basis of this study the following conclusions can be made:

- The inclusion of RA has a great effect on mixture strength. The tensile strength of the mixtures increased with increasing RA content.
- A change in the amount of RA content, from 30% to 40%, did not create great differences in the dry and wet ITS and ITSR values.
- The rate of strength degradation due to moisture damage was found to be lower for the mixtures containing RA and WMA additive compared to the control mixture. The RA mixtures, subjected to the various moisture conditioning regimes, had a lower reduction in strength, especially after field ageing.
- The results showed that mixtures with RA content generally had higher tensile strength than the control mixture before and after moisture conditioning. In a number of cases, however, the RA mixtures, with and without WMA additive, did not initially meet the standard 0.80 TSR criterion, but their TSR values were found to improve for the field aged samples. The results suggest that the mixtures underwent a curing process in the field that enhanced their response to moisture damage. Therefore it is recommended that ageing considerations are made when performance testing is necessary to validate the mix design with respect to moisture damage susceptibility.
- The use of warm mix additive increased the resistance to moisture damage induced both by bath and bath-MIST conditioning. A comparison between mixture B and D, which had the same amount of RA and only differed with respect to the addition of WMA additive, clearly demonstrates the positive effect of WMA additive on the moisture damage susceptibility of the mixtures.
- The results indicate that the two moisture damage inducing mechanisms had diverse effects on strength degradation. Mixtures with variable composition, but the same morphological characteristics (air void content, aggregate gradation etc.) can be susceptible to long- or short-term conditioning to a lesser or greater degree. Therefore

considerations of both moisture damage mechanisms should be made when evaluating asphalt mixtures for their susceptibility to moisture damage.

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