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Report on the results of laboratory tests for the RA mixtures after field ageing

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Executive summary

The objective of Work Package 3 (WP3) is to investigate the combined effect of ageing and moisture damage on the mechanical performance of selected asphalt mixtures containing various proportions of reclaimed asphalt (RA). For this study, site trials have been laid of mixtures both without and with RA in Dublin, Ireland, from which cylindrical samples were cored and utilised for laboratory testing. The coring procedure and the laboratory testing are carried out in two stages: in the first stage, field cores were taken 24 h after the construction of the trial section was completed and were evaluated for their propensity to moisture damage, while in the second stage asphalt cores were taken 12 months later and the same testing programme was undertaken. In this manner, apart from the moisture damage susceptibility, the effect of field ageing on the mechanical response of the selected mixtures will be evaluated.

This deliverable report summarises the findings of the laboratory tests carried out during the second phase of testing in WP3 and aims to investigate the effect of RA on the moisture damage susceptibility of asphalt mixtures considering the effect of field ageing. In the following sections, the experimental methodology utilised for the evaluation of the mixtures is described and the test results are presented.

1 Introduction

The development of sustainable road infrastructure requires, among others, the construction of asphalt pavements with enhanced durability characteristics. From the moment of construction and continuing during their service life, asphalt pavements are continuously exposed to a combination of traffic loading and environmental influences. Environmental conditions such as fluctuating temperature, humidity, precipitation, oxygen, freeze-thaw cycles and ultraviolet radiation influence the material properties constantly. To counteract these influences, an increase in the operational and maintenance costs is needed in order to fulfil the desired service life of the pavement system. Global warming and climate change events such as temperature extremes, high mean precipitation and rainfall intensity may further increase the probability and rate of pavement deterioration. Thus, there is a strong need to obtain an improved understanding of the influence of environmental factors on the long term performance of asphalt pavements.

In the EARN project, moisture damage and ageing due to oxygen diffusion were assumed to be the two important parameters that can shorten the pavement life and accelerate pavement distresses. The use of reclaimed asphalt, secondary materials and lower temperatures will affect the various factors in different ways, further complicating an already complex situation.

Regardless of the mix composition, asphalt mixtures will suffer from moisture damage at some time during their service life. In reality, a dislodging process of the aggregates occurs, which is known as ravelling or stripping of the asphalt mixture. The loss of the aggregates from the mixture may exhibit either a cohesive (i.e. within the binder which consists of bitumen and filler) or an adhesive (i.e. at the binder-aggregate bond) failure pattern. Even though not necessarily initiated by the presence of water, most pavement distress mechanisms (cracking, permanent deformation, ravelling, etc.) will be increased in extent and severity with the presence of water or other forms of moisture (Miller and Bellinger, 2003). For an asphalt mixture that is exposed to moisture and/or to a constant movement of water through it, there are several moisture damage phenomena that can be identified, in particular moisture diffusion, mastic erosion and pumping action. Details on the moisture damage mechanisms can be found in Varveri *et al.* (2014a).

Another important process that can cause slow alteration of the mechanical properties is ageing due to oxygen diffusion. The performance and durability of a pavement is significantly influenced by the performance of asphalt binders. As asphalt binders oxidise, their rheological and adhesion properties change, thus leading to a decrease in pavement durability. Therefore, binder ageing is a key factor for the design of long-lasting and better performing asphalt pavements. Depending on the availability of oxygen for diffusion in an asphalt pavement, asphalt binders will harden in time and become brittle; consequently the propensity of asphalt pavements to cracking increases (Ruan *et al*., 2003).

All the above failure mechanisms can be affected by the use of reclaimed asphalt, secondary materials and/or warm mix technology. Even when the initial properties of the asphalt are the same at the time of construction, the change in material properties with time may be greater (or lesser) for those mixtures than for traditional hot mix asphalt and, therefore, this will have an influence on their durability. It is this potential difference that the project will investigate.

This deliverable report summarises the results of task 3.2.2. It aims to quantify the degradation of mechanical properties due to moisture damage and field ageing and investigate the effect of RA on moisture susceptibility and ageing of asphalt mixtures.

In section 2, a description of the experimental method employed in this study is given. In section 3, the results of the tests for the second phase of the laboratory programme (considering the effect of ageing) are reported and the influence of RA on the durability of asphalt mixtures is evaluated.

2 Experimental work

2.1 *Mixture design*

In the EARN project, the effect of reclaimed asphalt and warm mix technology on the durability is studied on the basis of site trials. A typical surface course, SMA 10 mm with a target of 4 % to 6 % air voids content, was produced according to the Irish and European standards. The variations of the 10 mm SMA mixture are 0 % RA as control; 30 % RA and no additive; 40 % RA and Cecabase RT 945 warm mix additive; and 30 % RA and Cecabase RT 945 warm mix additive, as shown in Table 1. More information on the mixture design is given in Tabaković *et al.* (2014).

Table 1. Mixture design

Mixture No.	Proportional content (%)					
	RA	10 mm	CRF*	Filler	Fresh Binder	Warm Mix Additive**
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	0.3
4	28.6	43.8	17.0	5.7	4.9	0.3

**Crushed Rock Fines, **Warm mix additive added to mixtures 3 & 4 at 0.5 % of the total binder content*

2.2 *Collection of samples*

For the second phase of WP3, a total of 108 cores (27 from each trial section) were collected nearly 1 year after the construction of the test sections. The field aged cores were used for subsequent testing for their sensitivity to moisture damage in the laboratory. The asphalt cores, collected from the field, were 100 mm in diameter and 60 mm in height. Before testing, the asphalt cores had to be trimmed by sawing in order to remove the regulating material. Then the height and the bulk density measurements were performed in accordance with the European standards EN 12697-29 and EN 12697-6, Method B (SSD), respectively. The results are summarised in Table 2.

Table 2. Bulk density and height of the samples

Sample code	Height (mm)	Bulk density (kg/m^3)	Sample code	Height (mm)	Bulk density (kg/m^3)
1-1	42.1	2381	**3-1**	38.0	2347
1-2	37.1	2316	**3-2**	37.9	2348
1-3	36.9	2347	**3-3**	37.9	2383
1-4	37.0	2371	**3-4**	38.9	2358
1-5	36.2	2410	**3-5**	40.2	2329
1-6	35.1	2355	**3-6**	38.8	2372
1-7	36.1	2374	**3-7**	37.8	2354
1-8	35.9	2363	**3-8**	38.6	2368
1-9	36.0	2369	**3-9**	37.5	2091
1-10	35.0	2354	**3-10**	38.6	2332
1-11	36.1	2394	**3-11**	37.2	2346
1-12	36.3	2381	**3-12**	39.0	2342
1-13	35.9	2399	**3-13**	38.1	2396
1-14	37.0	2305	**3-14**	39.9	2337
1-15	36.8	2321	**3-15**	35.1	2322
1-16	37.5	2378	**3-16**	38.9	2346
1-17	34.5	2370	**3-17**	38.1	2367
1-18	35.0	2351	**3-18**	38.0	2363
1-19	38.1	2339	**3-19**	36.2	2408
1-20	35.9	2316	**3-20**	37.9	2405
1-21	34.2	2355	**3-21**	36.0	2376
1-22	33.5	2368	**3-22**	38.1	2367
1-23	37.0	2322	**3-23**	37.2	2370
1-24	37.1	2327	**3-24**	40.3	2372
1-25	36.5	2343	**3-25**	40.5	2353
1-26	36.1	2361	**3-26**	37.5	2392
1-27	36.0	2334	**3-27**	36.0	2391
2-1	37.1	2325	**4-1**	38.1	2272
2-2	38.1	2349	**4-2**	37.0	2297
2-3	37.9	2337	**4-3**	38.2	2305
2-4	36.0	2318	**4-4**	38.5	2330
2-5	38.1	2320	**4-5**	38.0	2318
2-6	36.2	2297	**4-6**	37.6	2336
2-7	38.9	2373	**4-7**	36.9	2380
2-8	36.0	2384	**4-8**	38.0	2355
2-9	39.0	2330	**4-9**	38.1	2398
2-10	38.5	2330	**4-10**	37.5	2376
2-11	38.9	2374	**4-11**	37.1	3076
2-12	37.2	2357	**4-12**	37.2	2396
2-13	38.1	2366	**4-13**	37.0	2365
2-14	38.0	2373	**4-14**	37.0	2398
2-15	38.1	2364	**4-15**	36.8	2345
2-16	38.5	2368	**4-16**	36.9	2370
2-17	38.0	2343	**4-17**	37.2	2398
2-18	38.1	2356	**4-18**	36.1	2383
2-19	36.0	2372	**4-19**	38.1	2378
2-20	37.5	1779	**4-20**	37.9	2369
2-21	39.0	2339	**4-21**	37.7	2179
2-22	38.1	2333	**4-22**	37.8	2375
2-23	38.0	2326	**4-23**	37.9	2353
2-24	37.8	2338	**4-24**	38.1	2374
2-25	37.5	2377	**4-25**	36.0	2387
2-26	37.9	2353	**4-26**	37.4	2385
2-27	36.9	2169	**4-27**	38.1	2368

2.3 MIST test protocol

2.3.1 Introduction

Over the years, several test procedures have been proposed for the evaluation of moisture susceptibility of asphalt mixtures including the Boiling Water Test (ASTM D3625), Static Immersion Test (AASHTO T-182), Tunnicliff and Root Conditioning (NCHRP 274) and the modified Lottman (AASHTO T283) (Lottman, 1974). In Europe, the water sensitivity of asphalt mixtures is determined according to the European standard EN 12697-12 (CEN, 2008). However, the moisture conditioning protocols described in the aforementioned tests fail to capture the time frame over which moisture infiltration occurs and furthermore disregard the short term moisture processes related to pumping action (Kringos et al., 2009). In addition, field observations have shown that stripping of open asphalt mixtures is a rather localised phenomenon in trafficked areas of a pavement which are oversaturated with water (Kandhal *et al*., 1989). These findings strengthen the claim that pumping action can be an important damage mechanism which acts concurrently with the long term damage processes and contributes to premature failure in asphalt pavements.

In the EARN project, a new moisture conditioning protocol (Varveri *et al*., 2014b) is utilised, which can distinguish the individual contributions of short- and long-term moisture damage to mixture degradation. The evaluation of the asphalt mixtures for their sensitivity to moisture is performed on the basis of their Indirect Tensile Strength (ITS) and the Indirect Tensile Strength Ratio (ITSR). At the same time, moisture sensitivity tests (according to the EN 12697-12 standard) were performed in University College Dublin as part of task 2.4. A comparison between the results obtained from the combined test and the EN 12697-12 test will be made in the final report (Nicholls *et al*., 2014).

2.3.2 Test protocol description

The moisture conditioning protocol applied to the field aged cores is the same as the one used in the first phase of the WP3. In order to address the individual damage mechanisms associated with the two types of damage inducing processes, i.e. moisture diffusion and pumping action, the moisture conditioning protocol applied is a combination of two different conditioning methods: (a) bath conditioning and (b) cyclic water pore pressure application. Cyclic pore pressure generation in the asphalt mixture is achieved by means of the Moisture Induced Sensitivity Tester (MIST).

In the applied protocol (Figure 1), the samples were first subjected to moisture infiltration by placing them in a bath, filled with distilled water at an elevated conditioning temperature of 60°C, in order to facilitate the infiltration of water into the asphalt mixture and, consequently, accelerate the long-term degradation of the material properties.

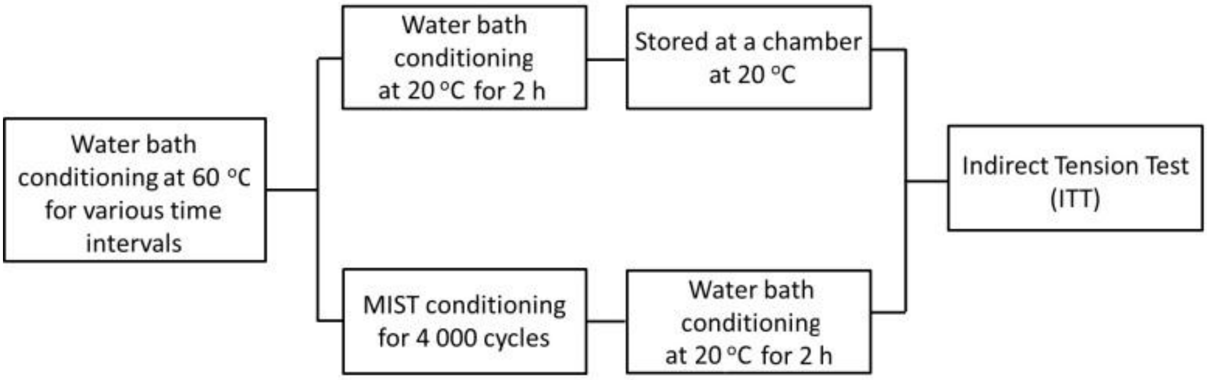

Figure 1. Schematic of the applied moisture conditioning protocols

At fixed time intervals of 3 and 6 weeks, three samples per mixture were removed from the bath, placed in a bath at 20 °C for 2 h and then maintained in a climatic chamber at 20 °C until tested for their strength using the ITT. An additional three samples per mixture were removed from the bath and further conditioned in the MIST device by applying 3500 cycles of pressure application at a temperature of 60 °C and a pressure of 70 psi (0.48 MPa). After MIST application, the samples were placed in a water bath, at 20 °C for 2 h. After conditioning, the indirect tensile strength of each of the two subsets was determined in accordance with EN 12697-23 (CEN, 2003). In Table 3, the number of samples utilised for each type of conditioning level is shown.

Table 3. Testing matrix

Type of conditioning	Mixture type	Week 0	Week 3	Week 6
Dry conditions	1	6	3	3
	2	6	3	3
	3	6	3	3
	4	6	3	3
Water bath	1	-	3	3
	2	-	3	3
	3	-	3	3
	4	-	3	3
Water bath & MIST	1	3*	3	3
	2	3*	3	3
	3	3*	3	3
	4	3*	3	3

**Only MIST conditioning was applied on the dry subset at week 0.*

A total of six additional samples per mixture were stored in a climate chamber at 20 °C after delivery. These dry samples were kept in the chamber during the time of conditioning and were tested together with the conditioned samples at each defined time interval. In this way, any differences in their strength due to age hardening, while in storage, were taken into account.

3 Test results

The evaluation of the asphalt cores for their moisture damage and ageing susceptibility was performed on the basis of the indirect tensile strength (ITS) and the indirect tensile strength ratio (ITSR).

Figure 2 shows the effect of physical hardening on strength with the samples being kept in storage at dry conditions. The dry tensile strength increases with increasing RA content for all mixtures. In addition, the mixture strength further increases with time, due to physical hardening of the asphalt binder, while the samples were kept in storage. As shown in Figure 3, the hardening rates vary for the different mixtures. Physical hardening appears to have more of an influence on the mixtures with higher RA content. However, in general, smaller differences in the ITS values are expected for RA mixtures, due to the fact that asphalt binders used in RA mixtures have already undergone oxidation, so the rate of hardening of the RA mixture is slower. A comparison of the hardening rates of the fresh and aged asphalt cores (while in storage) is given in Varveri *et al*. (2014c).

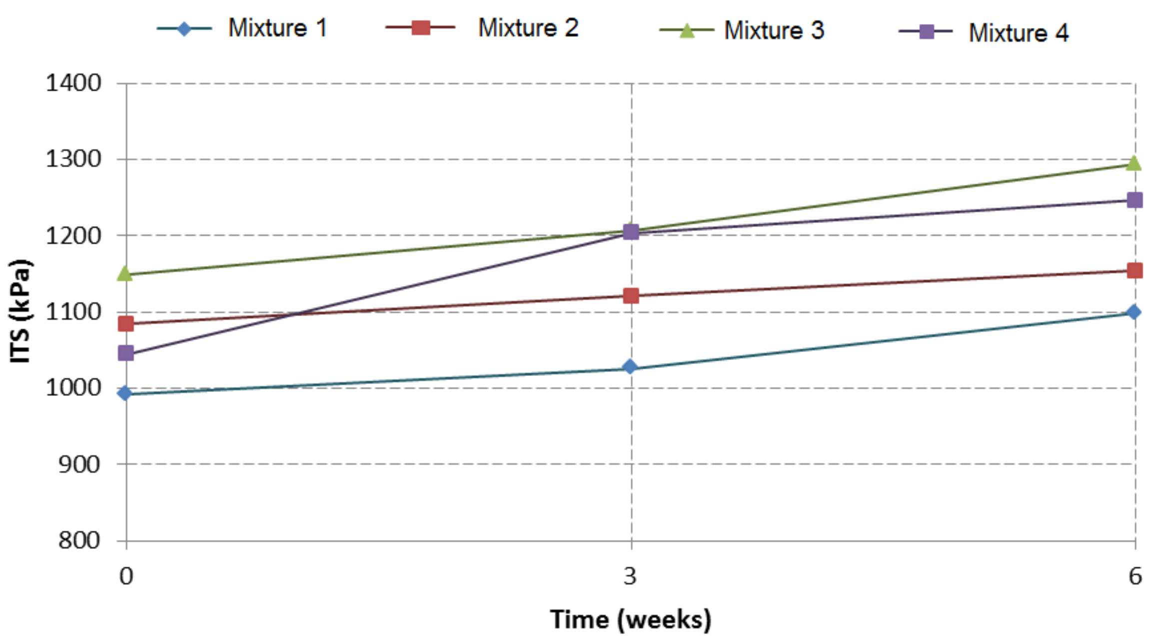

Figure 2. Effect of age hardening on indirect tensile strength

The mean ITSR values (from 3 replicas) for both the bath conditioned and the bath-MIST conditioned samples are shown in Figure 3. Also, the coefficient of variation for each mixture was calculated and is presented on the top of the bars. The solid red line represents the threshold value below which an asphalt mixture is considered to be more susceptible to moisture damage, according to the Dutch (CROW, 2010) and Irish standards. The results indicate that mixtures with high RA content and WMA additives perform better against moisture damage. Mixtures 1 (0 % RA) and 2 (30 % RA; no WMA additive) were found to be susceptible to moisture damage. Quite the opposite trend was observed for Mixture 4 (30 % RA plus WMA additive), which showed slight variations in ITS for the several moisture conditioning scenarios. An unexpected increase in strength was observed for Mixture 3 (30 % RA plus WMA additive) after 6 weeks bath and MIST conditioning compared to the ITS after 6 weeks of bath conditioning alone.

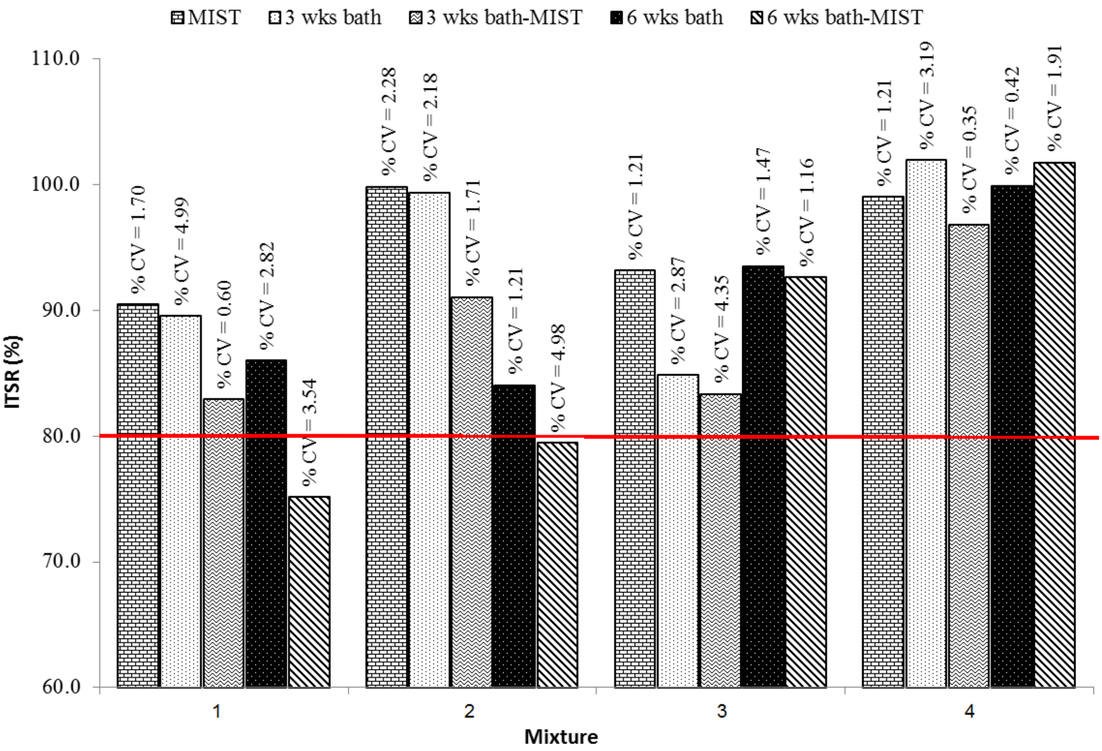

Figure 3. Mean ITSR values

Overall, the mixtures containing RA had a lower reduction in strength compared to the control mixture, after the application of the different moisture conditioning protocols, as shown in Table 3. From the results, the contributions of the short- and long-term moisture damage on the strength of the samples can be quantified. Specifically, Mixture 1 (0 % RA) had the highest reduction in strength for all conditioning protocols. Mixture 2 (30 % RA; no WMA additive) was found to perform better against moisture damage after only bath conditioning. However, after the application of the combined protocol the reduction in strength was significantly high. The results indicate that, for Mixture 2, the weakening effect of moisture diffusion (through bath conditioning) results to high levels of damage when cyclic pore pressures are applied.

Table 3. Average reduction* in strength

Conditioning method	Time (weeks)	Mixture			
		1	2	3	4
Bath	0	-	-	-	-
	3	-10.5	-0.7	-15.2	+1.9
	6	-14.0	-16.0	-6.5	-0.1
Bath-MIST	0	-9.6	-0.2	-6.8	-1.0
	3	-17.1	-9.0	-16.7	-3.2
	6	-24.9	-20.6	-7.4	+1.7

The results demonstrate that the use of WMA additives improves the moisture susceptibility characteristics of the mixtures. Mixture 3 (30 % RA plus WMA additive) shows a decreasing strength with increasing bath conditioning time; however, it appears to be insensitive to the application of cyclic pressure, indicating that Mixture 3 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 seems to improve the adhesion properties of the aggregate-binder systems. Mixture 4 (30 % RA plus WMA additive) exhibited the best performance against moisture damage. The rate of strength degradation was extremely low; comparable strength levels were measured after the various conditioning scenarios. In Table 4, the mean indirect strength values after bath and combined bath-MIST conditioning are summarised.

Table 4. Mean ITS values*

Duration of conditioning protocol (weeks)	Mean indirect tensile strength (kPa) Mixture							
	1		2		3		4	
	Bath	Bath-MIST	Bath	Bath-MIST	Bath	Bath-MIST	Bath	Bath-MIST
0	992.0	897.2**	1084.1	1081.9**	1148.8	1070.1**	1044.7	1034.0**
3	887.8	822.5	1076.7	986.8	974.4	957.2	1064.7	1011.0
6	853.0	745.1	910.9	861.1	1073.7	1063.4	1043.3	1062.7

**Mean values based on results of three samples; **MIST was applied on samples without any prior conditioning*

The aforementioned observations are depicted in Figures 4 to 7. The red curve demonstrates the effect of moisture diffusion on tensile strength due to bath conditioning alone, while the green curve shows the influence of the combined conditioning protocol (bath and MIST) on strength. The difference between the red and the green curve corresponds to the contribution of the cyclic pore pressures to the total strength degradation of the samples.

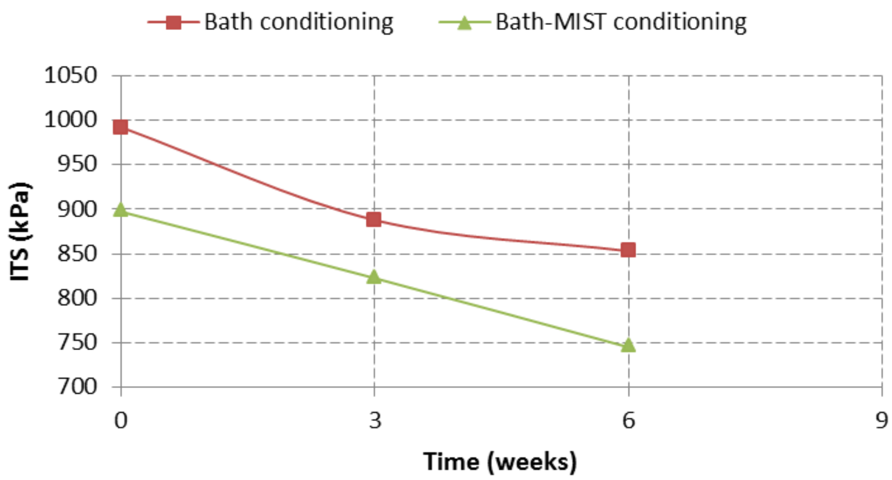

Figure 4. Indirect tensile strength of Mixture 1 (Control; 0 % RA)

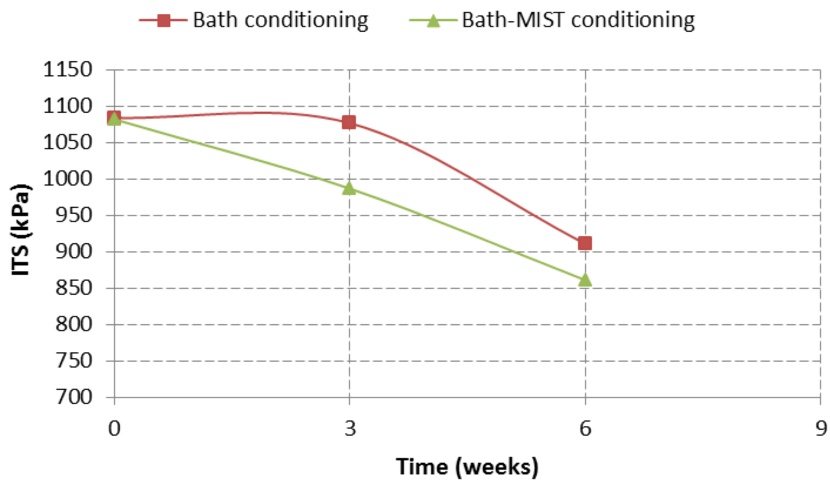

Figure 5. Indirect tensile strength of Mixture 2 (30 % RA; no WMA additive)

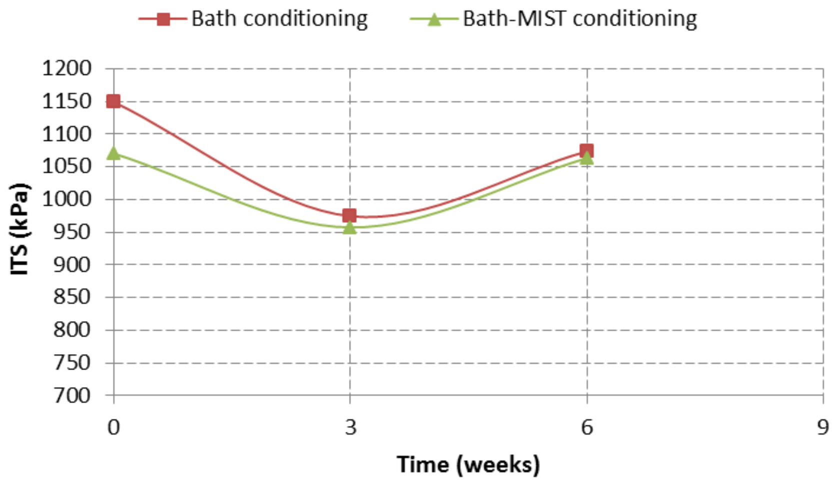

Figure 6. Indirect tensile strength of Mixture 3 (40 % RA; WMA additive)

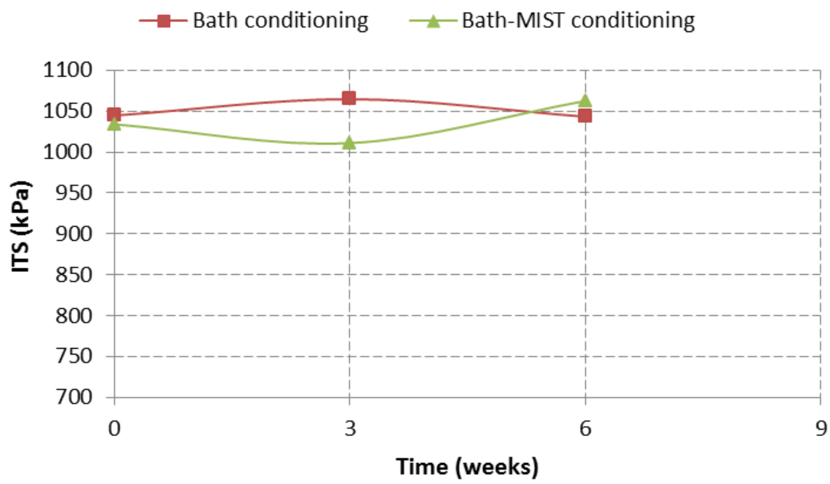

Figure 7. Indirect tensile strength of Mixture 4 (30 % RA; WMA additive)

The contribution of the cyclic pore pressures to the total damage of the samples is given as the gap between the two curves corresponding to the different conditioning protocols. Two different damage mechanisms (i.e. moisture diffusion and high pore pressure development) are present in the combined protocol. The results show that pore pressure development does not seem to have a significant effect on the ITS of the mixtures containing reclaimed asphalt and WMA additive. On the other hand, for the control mixture and the mixture without WMA additive, it can be observed that the gap, and therefore the influence of pore pressure, increases with bath conditioning time. This change can be explained by the fact that long moisture diffusion conditioning further degrades the properties of the mixtures, resulting in a greater reduction in strength for the same amount of MIST conditioning.

The results indicate that the performance of the mixtures against moisture damage is improved by the use of warm mix additives. In general, both Mixtures 3 and 4, which contain an additive, show a better behaviour compared to Mixture 2. In particular, because the only variance between Mixtures 2 and 4 is the use of the additive, it is clear that the positive effect additives can have on the ITS. Furthermore, it can be observed that a change in the amount of RA content, from 30 % to 40 %, does not result in major differences in the ITS and ITSR values.

4 Conclusions

In this study, an experimental programme was undertaken in order to investigate the effect of RA on the moisture damage and ageing susceptibility of asphalt mixtures. This report summarises the findings of tests performed on cylindrical samples, which were collected from the field a year after laying the site trials. Four variants of a typical SMA 10 mixture were prepared. The variations were 0 % RA as control; 30 % RA and no additive; 40 % RA and warm mix additive; and 30 % RA and warm mix additive. The Indirect Tensile Strength (ITS) and the Indirect Tensile Strength Ratio (ITSR) were used for the evaluation of moisture damage resistance of the mixtures.

The results show that the inclusion of RA has an effect on mixture tensile strength. The ITS values were found to increase with increasing RA content. Also, the rate of strength degradation due to moisture damage was found to be lower for the RA mixtures compared to control mixtures. The use of warm mix additive was shown to increase the resistance to moisture damage induced both by bath conditioning alone and by combined bath-MIST conditioning.

In the final deliverable report from WP3 (Varveri et al., 204c), a comparison of the results obtain in phase one (fresh mixtures) and phase two (aged mixtures) will allow a better understanding of the influence of ageing and moisture on the durability of mixtures containing RA and WMA additives to be gained.

5 Acknowledgement

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