CEDR Transnational Road Research Programme
Call 2012: Recycling: Road construction in a post-fossil fuel society

funded by Denmark, Finland, Germany, Ireland, Netherlands and Norway

CEDR
Conférence Européenne des Directeurs des Routes
Conference of European Directors of Roads

EARN

Report on the results of the laboratory tests for the RA mixtures without considering the effect of ageing

Deliverable Nr. 2

February 2014

TRL Limited, UK

University of Kassel

University College Dublin

Technische Universiteit Delft

Lagan Asphalt

Shell Bitumen, UK / Germany Shell

EARN
Effects on Availability of Road Network

Deliverable Nr. 2 – Report on the results of the laboratory tests for the RA mixtures without considering the effect of ageing

Due date of deliverable: 28.02.2014

Actual submission date: 28.02.2014

Start date of project: 01.01.2013 End date of project: 31.12.2014

Author(s) this deliverable:

Aikaterini Varveri, Technische Universiteit Delft, Netherlands

Stavros Avgerinopoulos, Technische Universiteit Delft, Netherlands

Tom Scarpas, Technische Universiteit Delft, Netherlands

Cliff Nicholls, TRL, UK

Konrad Mollenhauer, University of Kassel, Germany

Ciaran McNally, University College Dublin

Amanda Gibney, University College Dublin

Amir Tabaković, University College Dublin

Table of contents

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 specimens 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 will be taken 12 months later and the same testing programme will be undertaken. In this manner, apart from the moisture damage susceptibility, the effect of 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 first phase of testing in WP3 and aims to investigate the effect of RA on the moisture damage susceptibility of asphalt mixtures. In the following sections, the conditioning protocol applied and the test procedure utilized for the evaluation of the mixtures are described and the analysis of the results is presented.

1 Introduction

The use of reclaimed asphalt (RA) and secondary materials has grown extensively due to the associated environmental benefits, i.e. reduction of the use of virgin materials and of the amount of waste send to landfills, which contribute to the development of sustainable asphalt pavements. The challenge for engineers is to achieve pavement materials with similar mechanical performance to those of the equivalent material made of virgin components, and at the same time to consider ways to increase further the RA content in pavement mixture design. Similarly, traditional technologies for asphalt mixture production are gradually being replaced by warm mix asphalt (WMA) technologies, which allow the production and laying of the material at lower temperatures, with significant benefits in terms of lowering fuel consumption and decreasing the production of greenhouse gases. Obviously, the benefits arise from the use of RA and WMA can be compromised if performance of the mixture in the long-term is poor.

The durability of the asphalt materials is an important factor that influences the service life of asphalt pavements. From the production phase of the asphalt until long after the construction of the pavement, the performance of asphalt is greatly affected by different environmental factors such as moisture, oxygen, temperature, pressure and ultraviolet light. For this work, moisture damage and ageing due to oxygen diffusion were assumed to be the most 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.

A serious cause for diminishing the long-term performance of an asphalt pavement is the presence of water in the pavement structure and the detrimental effect that water has on the mechanical properties of the mixture. Moisture-induced damage is an extremely complicated mode of distress that leads to the loss of stiffness and structural strength of the asphalt and eventually to the premature failure of the pavement structure.

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. within the binder-aggregate bond) failure pattern. Even though not necessarily initiated by the presence of water, most pavement distress mechanisms (cracking, permanent deformation, raveling, etc.) will be increased in extent and severity with the presence of water or other forms of moisture [1]. An improved understanding of moisture-induced damage in asphalt and more moisture-resistant materials will have a significant impact on pavement maintenance expenditure, particularly because rainfall is predicted to increase due to global warming.

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. Moisture diffusion in asphalt mixtures is a long-term process driven by the diffusion coefficient D, which depends on the characteristics of each type of binder. The moisture diffuses through the binder layers surrounding the aggregates and eventually reaches the interface area between them. Depending on the chemical characteristics of both the binder and the aggregates, the water can cause an adhesive failure of the binder-aggregate interface. In addition, the cohesive strength of the binder particles weakens as the moisture concentration increases within the binder film. A fast flow of water through an asphalt mixture can cause desorption of the weakened binder, referred to as “erosion”. Once the outer layer of a binder film is eroded, the next layer of binder, now exposed to the water flow, can be damaged.

Pumping action can act accumulatively on the above damage mechanisms. In asphalt mixtures, the pores are interconnected and allow the water to move through the pavement. When some macro-pores in an asphalt pavement are saturated, the dynamic traffic load can cause excess pressure in these pores. Once the pore pressure increases to a high level, the binder film on the aggregate will break under the pressure and create a crack in the film, allowing water easy access to the surface of the aggregate. Additionally, the intense pore pressures can cause a local fast flow of water which contributes to the washing away, i.e. erosion of the binder.

Another important process that can cause slow alteration of the mechanical properties is ageing due to oxygen diffusion. Age hardening 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 asphalt binder due to elevation of the complex modulus and reduction of the viscoelastic phase angle, making the asphalt more prone to damage under the same loads and strains.

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 EARN project tasks 3.1 and 3.2.1. It aims to quantify the degradation of mechanical properties due to moisture damage and investigate the effect of RA on moisture susceptibility of asphalt mixtures.

In section 2, a description of the mixture design employed in this study is given. Also, information on the applied moisture conditioning protocol and test procedure used for the evaluation is given in detail.

In section 3, the results of the tests for the first phase of the laboratory programme (without the effect of aging) 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 from site trials. A typical surface course, SMA 10 mm with a target of 4 % to 6 % air voids, was produced according to the Irish and European standards. Four variants of the SMA mixture were determined and laid in the test sections, as shown in Figure 1.

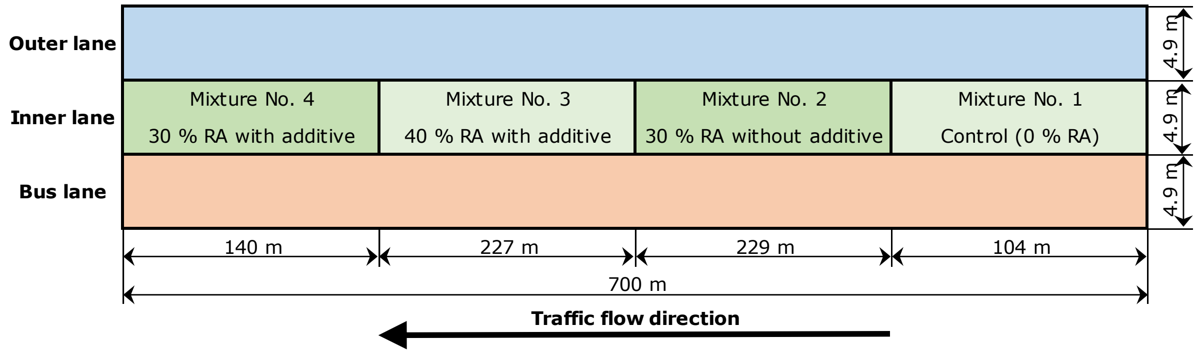

Figure 1. Schematic representation of the trail section

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. The grading curves for these mixtures are presented in Figure 2, illustrating the good agreement between the control mixture grading and those of the mixtures containing RA. Using the control mixture grading as the guideline allowed the best particle distribution for the mixtures, and consequently the best mixture design as illustrated in Table 1.

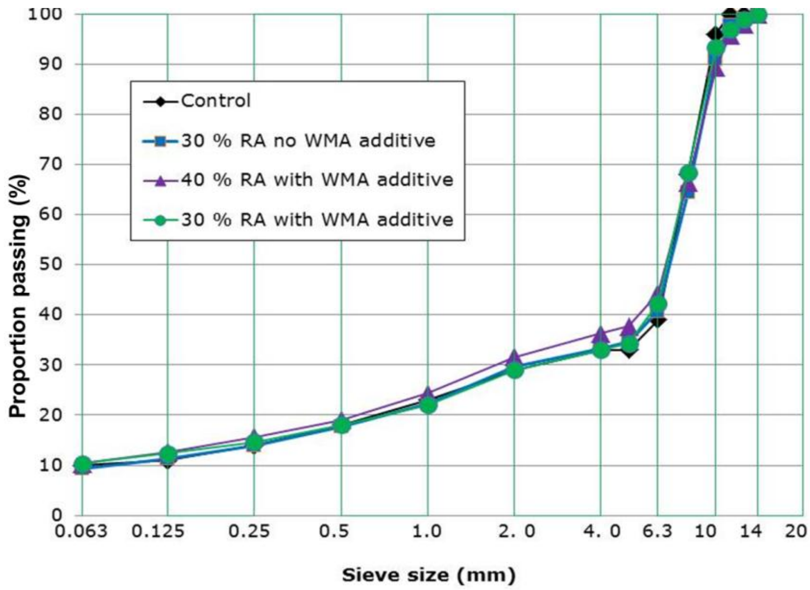

Figure 2. Particle size distribution

Table 1. Mixture design

Mix No.	Proportional content (%)					
	RA	10 mm	CRF*	Filler	Fresh Binder	Warm Mix Additive**
A	0	65.9	22.8	5.7	5.6	0
B	28.6	43.8	17.0	5.7	4.9	0
C	38.1	34.4	17.1	5.7	4.7	0.3
D	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

A total of 108 cores (27 from each trial section) were collected 24 hours after the construction of the test sections was completed. The coring procedure is shown in Figure 3. The cores were used for subsequent testing for their sensitivity to moisture damage in the laboratory. The laboratory testing procedures are further described in the paragraph 2.3 of this report.

a) Material sampling b) Coring c) A core sample

Figure 3. Collection of samples from site

The asphalt cores, collected from the field, were 100 mm in diameter and 60 mm in height. As shown in Figure 4, the cores consisted of two different layers, i.e. SMA surface course and binder course. Therefore, prior to testing, the asphalt cores had to be trimmed by sawing in order to remove the regulating material. The height and the bulk density of the samples were determined in accordance with the European standards EN 12697-29 and EN 12697-6, Method B (SSD), respectively. The results are summarized in Table 2.

Figure 4. Asphalt cores collected from site trials

Table 2. Bulk density and height of the specimens

Specimen Code	Height (mm)	Bulk Density (kg/m^{3})	Specimen Code	Height (mm)	Bulk Density (kg/m^{3})
A1	34.0	2360	**D1**	35.0	2326
A2	38.5	2354	**D2**	35.0	2302
A3	32.5	2319	**D3**	36.0	2370
A4	34.0	2309	**D4**	36.0	2334
A5	36.5	2302	**D5**	40.5	2357
A6	30.5	2368	**D6**	36.5	2348
A7	32.5	2364	**D7**	40.0	2372
A8	31.0	2360	**D8**	37.5	2390
A9	35.0	2347	**D9**	32.5	2388
A10	36.0	2348	**D10**	34.5	2396
A11	32.5	2348	**D11**	39.5	2400
A12	34.5	2392	**D12**	36.5	2378
A13	33.5	2380	**D13**	38.5	2364
A14	34.5	2018	**D14**	35.5	2381
A15	35.5	2347	**D15**	36.5	2385
A16	35.0	2376	**D16**	39.5	2362
A17	35.0	2354	**D17**	38.5	2377
A18	34.5	2367	**D18**	36.0	2388
A19	35.0	2350	**D19**	37.5	2361
A20	40.5	2336	**D20**	40.5	2365
A21	33.5	2336	**D21**	40.0	2396
A22	32.5	2347	**D22**	36.5	2368
A23	34.5	2370	**D23**	39.5	2384
A24	30.5	2342	**D24**	40.5	2387
A25	36.5	2307	**D25**	34.5	2362
A26	34.5	2344	**D26**	33.5	2390
A27	32.5	2362	**D27**	33.5	2354
B1	35.5	2368	**C1**	34.5	2371
B2	34.5	2357	**C2**	34.5	2392
B3	36.0	2371	**C3**	35.5	2384
B4	35.5	2378	**C4**	35.5	2390
B5	34.5	2375	**C5**	34.5	2378
B6	37.5	2357	**C6**	35.5	2383
B7	38.0	2329	**C7**	35.5	2378
B8	36.5	2338	**C8**	37.5	2375
B9	36.5	2357	**C9**	32.5	2387
B10	34.5	2360	**C10**	36.5	2340
B11	36.0	2336	**C11**	36.5	2334
B12	35.5	2331	**C12**	34.5	2335
B13	34.5	2381	**C13**	35.5	2339
B14	36.5	2314	**C14**	36.5	2346
B15	36.0	2344	**C15**	34.5	2344
B16	35.0	2354	**C16**	37.0	2377
B17	35.0	2356	**C17**	38.5	2365
B18	40.0	2302	**C18**	35.5	2389
B19	35.5	2322	**C19**	37.5	2411
B20	36.0	2397	**C20**	39.0	2398
B21	34.0	2380	**C21**	35.5	2378
B22	34.5	2370	**C22**	37.0	2394
B23	34.5	2348	**C23**	39.5	2370
B24	37.0	2341	**C24**	37.5	2372

Specimen Code	Height (mm)	Bulk Density (kg/m^3)	Specimen Code	Height (mm)	Bulk Density (kg/m^3)
B25	32.5	2342	**C25**	35.0	2388
B26	37.5	2370	**C26**	35.0	2382
B27	37.0	2371	**C27**	36.0	2394

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 concrete 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) [2]. In Europe, the water sensitivity of asphalt mixtures is determined according to the European standard EN 12697-12 [3]. 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 [4]. In addition, field observations have shown that stripping of open asphalt mixtures is a rather localized phenomenon in trafficked areas of a pavement which are oversaturated with water [5]. 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 [6] is utilized, 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).

2.3.2 Test protocol description

A total of 27 cores were drilled from each trial section. For each mixture, the specimens were divided into two subsets. The first subset was subjected to moisture conditioning, while the other subset was stored in a climate chamber at dry conditions at 20°C. In order to address the individual damage mechanisms associated with the two types of damage inducing processes, 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). The MIST was designed as an accelerated conditioning device for the evaluation of the resistance of an asphalt mixture to stripping by simulating the high pressure fields which develop within an asphalt layer due to traffic loading [7].

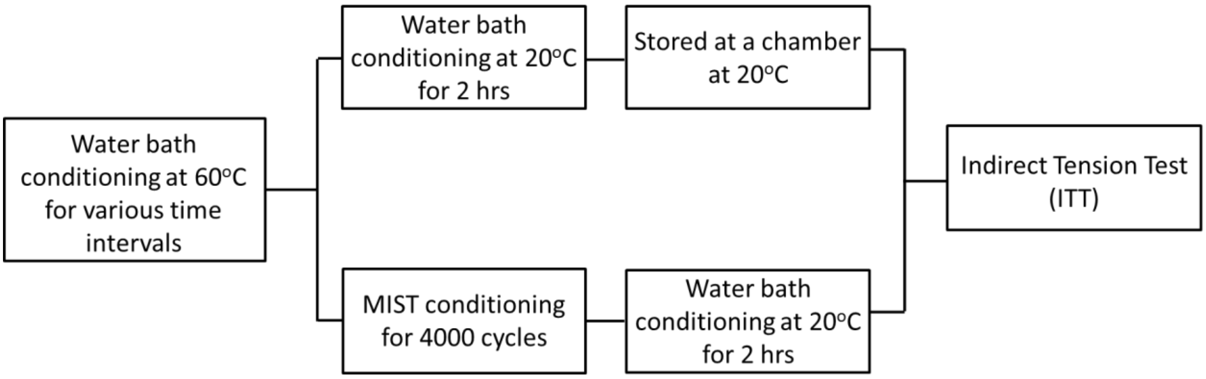

Figure 5. Schematic of the applied moisture conditioning protocols.

MIST is a self-contained unit, Figure 6(a), which includes a hydraulic pump and a piston mechanism that is designed to cyclically apply pressure inside a sample chamber. The test involves placing a 100 mm or 150 mm diameter sample of 25 to 150 mm height inside the sample chamber, filling the chamber with water, closing the sample chamber lid, choosing the preferred conditioning settings and starting the test, Figure 6(b-d). The machine then automatically heats the sample to the desired temperature and starts cycling between zero and the selected pressure. Tests can be performed at different pressures and temperatures to replicate different traffic and environmental conditions. Furthermore, the user can specify the desired number of conditioning cycles.

Figure 6. Moisture induced sensitivity tester.

In the applied protocol, the specimens 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. At fixed time intervals of 3 and 6 weeks, three specimens per mixture were removed from the bath, placed in a bath at 20°C for 2 hours 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 are placed in a water bath, at 20°C for 2 hours. After conditioning, the indirect tensile strength of each of the two subsets is determined in accordance with EN 12697-23 [8]. In Table 3, the number of specimens utilized 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	A	6	3	3
	B	6	3	3
	C	6	3	3
	D	6	3	3
Water bath	A	-	3	3
	B	-	3	3
	C	-	3	3
	D	-	3	3
Water bath & MIST	A	3*	3	3
	B	3*	3	3
	C	3*	3	3
	D	3*	3	3

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

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

2.4 Standard asphalt tests

In addition to the moisture susceptibility tests, additional tests were conducted on asphalt mixtures sampled during construction of the test pavements. Following tests were conducted for the mixtures B (30 % RA, without additive), C (40 % Ra with additive) and D (30 % RA with additive):

- Binder tests on bitumen, recovered from asphalt mixtures and the RA as well as on fresh bitumen sample
  - Ring and ball temperature (EN 1427)
  - Complex shear modulus according to EN 14770 in time-frequency domain (-20 °C to +90°C; 0,01 Hz to 10 Hz)
  - Force ductility tests (T = +25 °C)
- Compactability tests according to EN 12697-10B for compaction temperature 150 °C and 130 °C.
- Water sensitivity tests according to EN 12697-12/23.

3 Test results

3.1 Results of moisture sensitivity tests

In order to investigate the effect of RA on the moisture damage susceptibility characteristics of the mixtures the Indirect Tensile Strength Ratio (ITSR) was utilized. The mean ITSR values (from 3 replicas) for the combined protocol (bath and MIST conditioning) at each time interval are shown in Figure 7. 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 and Irish standards [9]. The ITSR values decrease with conditioning time for all mixtures, which is in accordance with expectations. Moreover, it is found that all mixtures have an acceptable ITSR value apart from mixture B, which showed the worst performance for moisture damage.

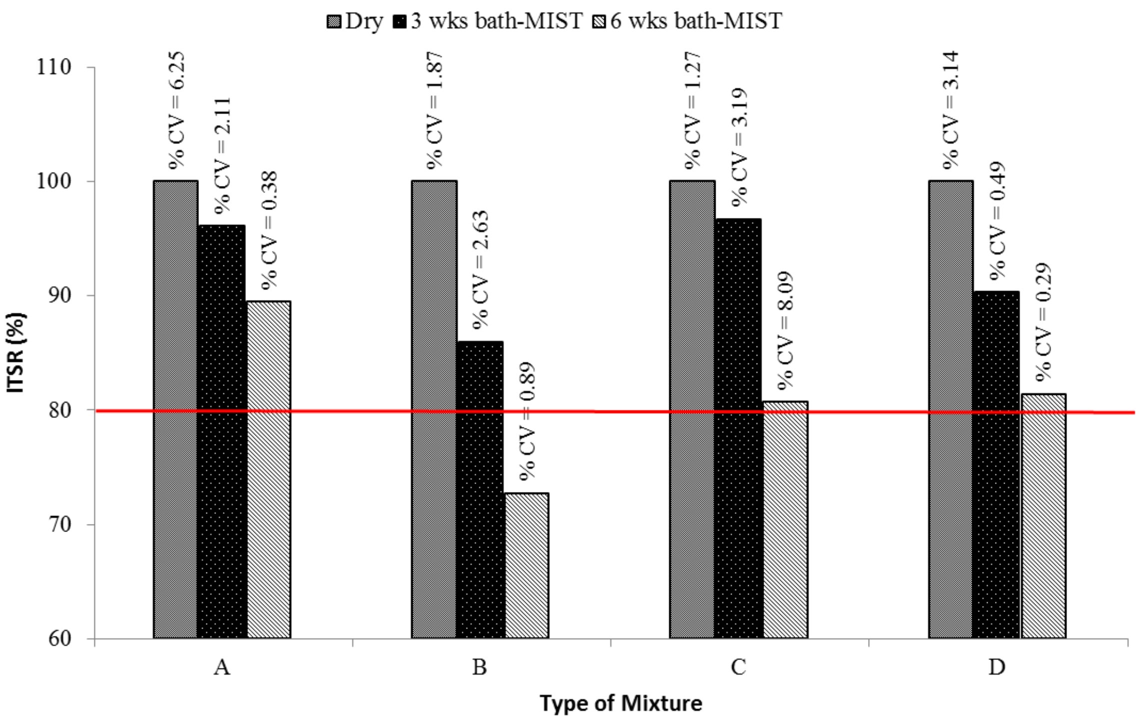

Figure 7. Mean ITSR values

In Figures 8-11, the results of the indirect tensile tests are plotted for all mixtures. Three different curves are specified for each mixture; the blue curve which shows the effect of ageing on the ITS over time, the red curve which demonstrates the effect of moisture diffusion due to bath conditioning alone on the ITS and the green curve shows the influence of the combined conditioning protocol (bath and MIST) on the specimens. The difference between the red and the green curve corresponds to the contribution of the cyclic pore pressures to the total damage of the specimens. From the results, the contributions of the short- and long-term moisture damage on the strength of the specimens can be quantified.

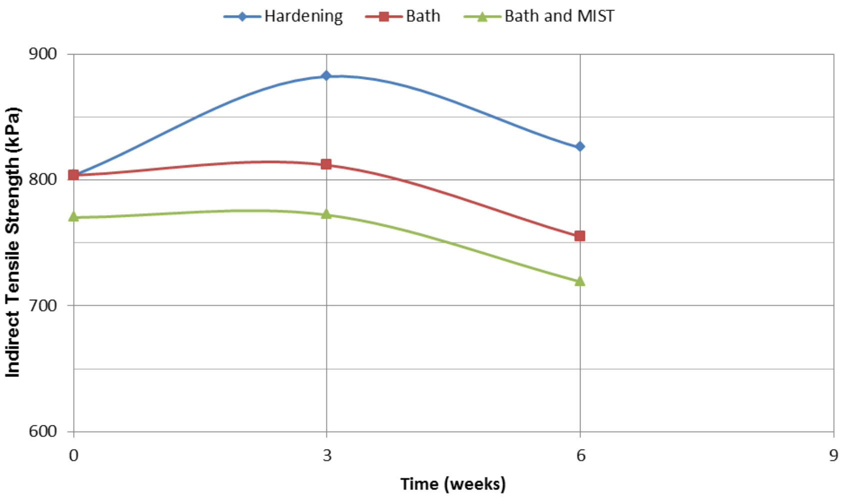

Figure 8. Indirect tensile strength of mixture A (Control: 0% RA).

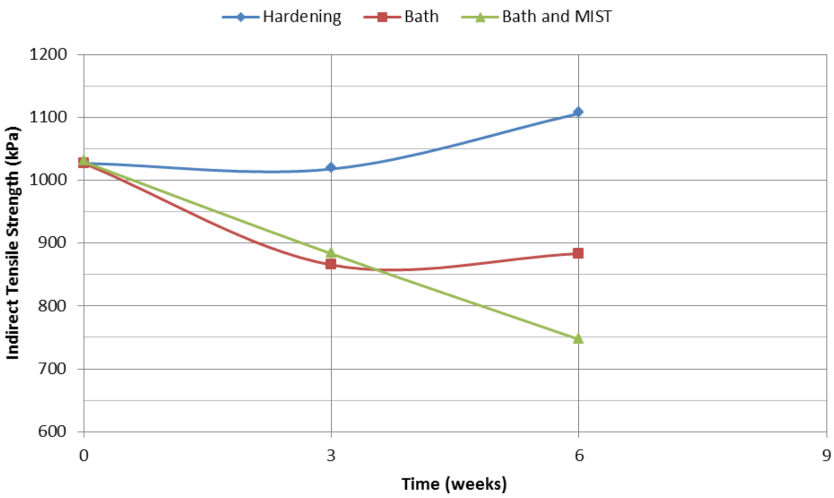

Figure 9. Indirect tensile strength of mixture B (30% RA without warm mix additive).

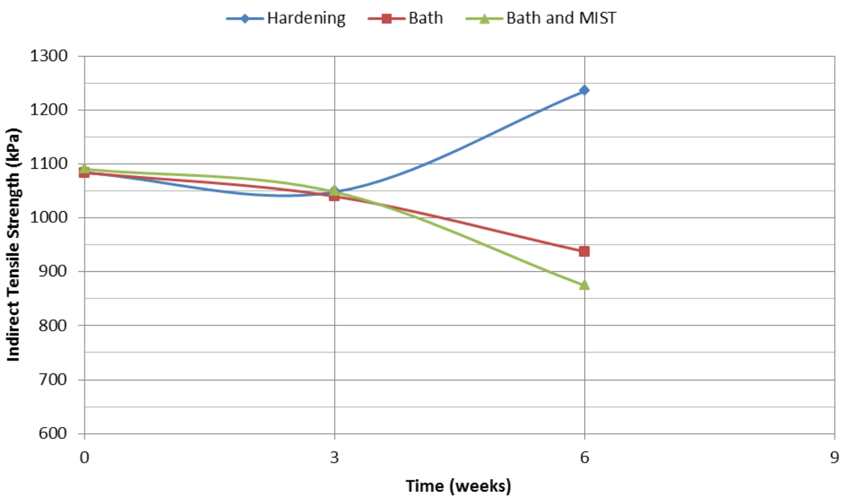

Figure 10. Indirect tensile strength of mixture C (40% RA with warm mix additive).

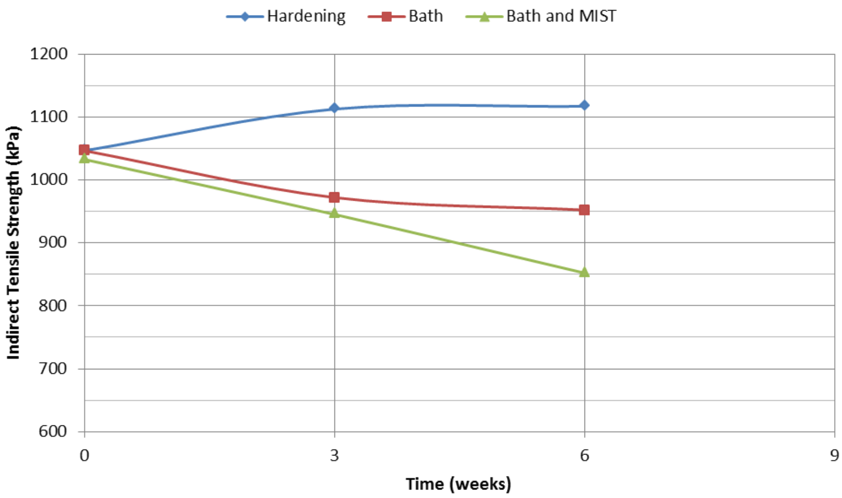

Figure 11. Indirect tensile strength of mixture D (30% RA with warm mix additive).

The results show that the strength of the specimens increased with time due to age hardening for all mixtures. Further investigation on the ageing characteristics of the mixtures will be achieved in the second stage of WP3, in which cores will be taken from the site trials after one year of service and tested.

After the application of both protocols, the indirect tensile strength for all mixtures decreased with conditioning time. Overall, the mixtures containing RA had a higher reduction in strength compared to the control mixture, after the application of the different moisture conditioning protocols, even though at dry conditions their indirect tensile strength is higher. Specifically, after 6 weeks of bath conditioning, the indirect tensile strength (compared to the ITS of the dry unconditioned specimens) was reduced by 6.1 %, 13.9 %, 13.5 % and 9.1 % for mixtures A, B, C and D, respectively. If the short–term effects of moisture are taken into account, the reduction in strength appears to be greater; 10.5 %, 27.3 %, 19.3 % and 18.6 % for mixtures A, B, C and D respectively. In Table 4, the mean indirect strength values after bath and combined bath-MIST conditioning are summarized.

Table 4. Mean ITS Values for the Various Mixtures*

Duration of conditioning protocol (weeks)	**Mean Indirect Tensile Strength (kPa) – Type of mixture**							
	A		B		C		D	
	Bath	Bath & MIST	Bath	Bath & MIST	Bath	Bath & MIST	Bath	Bath & MIST
0	803.73	770.21**	1027.20	1029.37**	1084.13	1090.466**	1046.676	1032.823**
3	811.86	772.24	865.45	883.08	1040.23	1048.29	972.1654	945.34
6	754.86	719.04	883.43	746.85	937.69	874.72	952.3207	852.16

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

The contribution of the cyclic pore pressures to the total damage of the specimens 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. At first glance, pore pressure development does not seem to have a significant effect on the ITS of the mixtures containing RA. In dry conditions and after 3 weeks of bath conditioning, the ITS strength roughly decreases before and after the application of MIST conditioning. However, it can be observed that after 6 weeks of bath conditioning the influence is significant. This change can be explained by the fact that, as the duration of the long-term moisture conditioning phase increases, the properties of the RA mixtures degrade further, 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 C and D, which contain an additive, show a better behaviour compared to mixture B. In particular, because the only variance between mixtures B and D 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.

3.2 Results of binder tests

The binder properties obtained for the fresh binder sample and of binders recovered from the asphalt mixtures B, C and D as well as from the RA using EN 12697-1/3 hot extraction procedure with toluene are listed in Table 5.

The softening points ring and ball obtained from the fresh binder and from the binder extracted from the RA and asphalt mixtures vary considerably. the highest $T_{R\&B}$ can be observed for the fresh binder - followed by the RA binder. The $T_{R\&B}$ results for the bitumen extracted from the three mixtures tested indicate very similar values. Unusually, the $T_{R\&B}$ obtained for the fresh binder reached the highest value. This can be explained by the effect of modifier rather than binder viscosity. The lower softening points in the binders which were extracted from the mixtures as well as the RA indicate that the modifier might not be completely recovered from the mixture.

Table 5: Bitumen properties

Bitumen property	Fresh binder	Binder recovered from asphalt mixture			
		RA	B	C	D
$T_{R\&B}$ [°C]	72	65	55	56	54
G*(60 °C; 1,59 Hz) [Pa]	3560	10035	3080	3867	3563
δ(60 °C; 1,59 Hz) [°]	60,8	73,2	72,6	72,9	73,2
Force ductility:					
F_{Max} (25 °C) [N]	0,178	0,690	0,969	1,182	1,288
$W_{0,2\text{-}0,4}$ (25 °C) [J/cm²]	0,021	0,055	0,107	0,110	0,121

The complex shear modulus and phase angle as well as the black curves derived in DSR tests for a frequency of 1.59Hz are shown in Figures 12 to 14. Especially the phase angles obtained above a test temperature of 30°C indicates the effect of a polymer modification in all binder samples tested. Also for the bitumen recovered from the RA the same type of modification effect can be observed. The higher viscosity of the RA binder results in an increased shear modulus as well as a decreased phase angle compared to the fresh binder sample for temperatures <35°C whereas for higher temperatures, the fresh binder inhibits the lower phase angle. This may indicate, that not only the bitumen viscosity is influenced by aging, but also the polymer effect decreases due to aging and/or binder extraction and recovery.

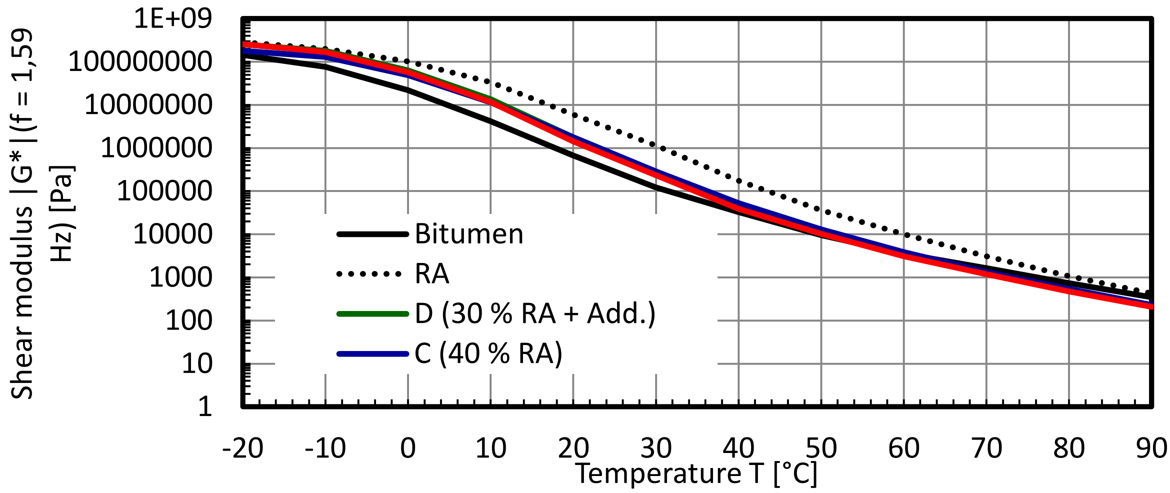

Figure 12. Complex Shear modulus derived for a frequency f = 1.59 Hz

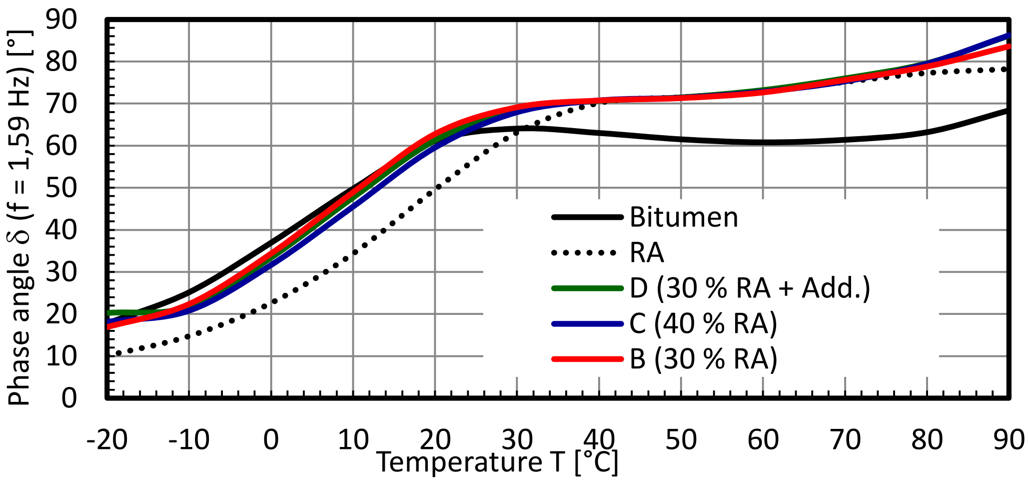

Figure 13. Phase angle derived for a frequency f = 1.59 Hz

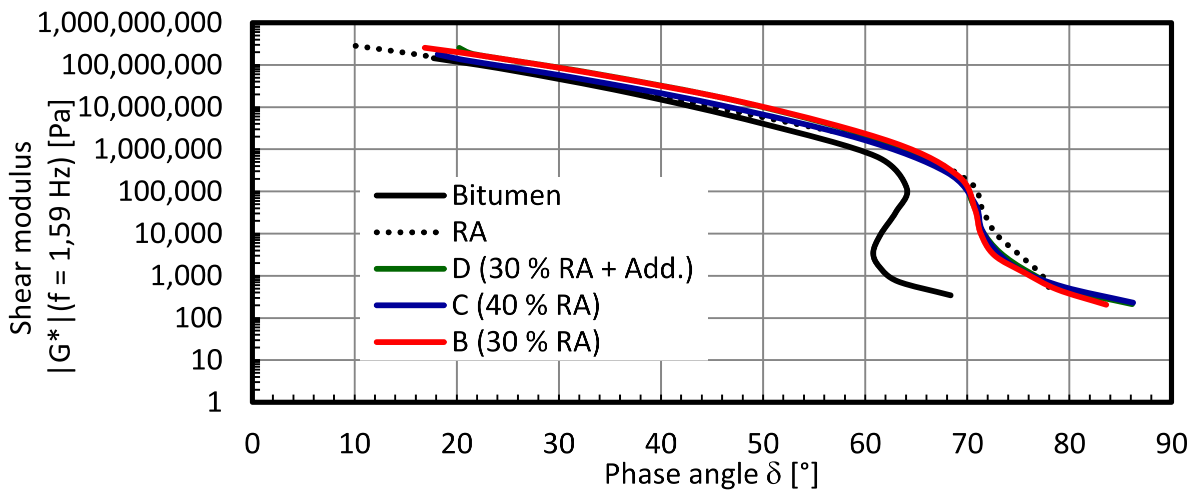

Figure 14. Black curve derived in a temperature sweep between -30 ° and 90 °C for a frequency of 1.59 Hz

In Figure 15, the force development during force-ductility tests is plotted. The modified character of the virgin bitumen is obvious as indicated by the large polymer peak at high ductility (>200mm). From the graph it is observed, that the maximum force can be dedicated to the polymer peak and not to the bitumen peak usually observed for a ductility of approx. 10mm. Again, the specific polymer indicating peaks at high ductility as found for the asphalt mixtures analysed as also for the RA indicate active polymer modified binder in all tested samples.

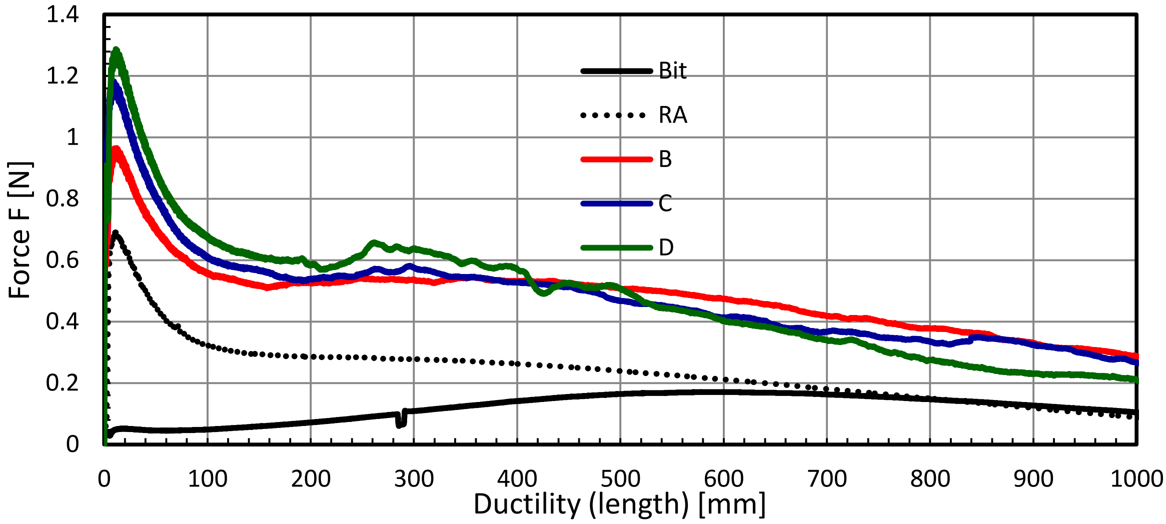

Figure 15. Force versus specimen length in force-ductility tests

3.3 Results of compactability tests

Two asphalt mixture samples were produced with a low-temperature additive in order to reduce the mixing temperature and the temperature of (overheated) aggregates which allows for higher contents of cold-added reclaimed asphalt. In order to evaluate the effect of the warm-mix additive, the compactability of the mixture samples was evaluated for two compaction temperatures (130°C and 150°C).

In Table 6, the bulk densities obtained for the specimens which were compacted with 2x35 impacts for the water sensitivity test are summarised as well as the regression parameters obtained from the compactability tests. The bulk density results as well as the calculated compaction resistance values T are plotted in Figure 16.

For all mixtures tested, the bulk density of water sensitivity test specimens obtained after 2x35 compaction blows is higher for the compaction temperature 150°C compared to 130°C. the increase in compaction temperature also decreases the compaction resistance value T for mixtures C and D, though the difference is not significant.

The use of low-temperature additive results in slightly higher bulk densities for mixture D compared to mixture B, whereas the compaction resistance is not influenced. The addition of a higher content of RA results in better compactability as indicated in higher bulk density and lower compaction resistance T.

Table 6: Bulk densities of specimens compacted for water sensitivity tests and regression parameters of compaction resistance tests

Asphalt mixture	B 30% RA		C 40% RA + Add.		D 30% RA + Add.	
Compaction temperature	**130°C**	**150°C**	**130°C**	**150°C**	**130°C**	**150°C**
Bulk density of specimen for water sensitivity tests						
Bulk density $\rho_{b,SSD}$ [kg/m³]	2295±20	2314±11	2360±17	2390±14	2304±16	2332±11
Maximum density ρ_m [kg/m³]	2493		2497		2523	
Regression parameters of compactability tests acc. EN 12697-10 (Mean ± stand. dev.)						
Compaction resistance T [1/21 Nm]	43,3±2,7	45,3±1,2	46,9±1,35	44,7±1,98	36,8±2,31	34,5±4,44
Initial height h_0 [mm]	84,3±0,95	82,9±0,96	86,2±0,06	84,2±0,85	85,1±0,85	83,6±1,18
Minimum height h_∞ [mm]	63,9±0,35	63,5±0,44	64,4±0,40	63,2±0,06	63,7±0,35	63,6±0,68

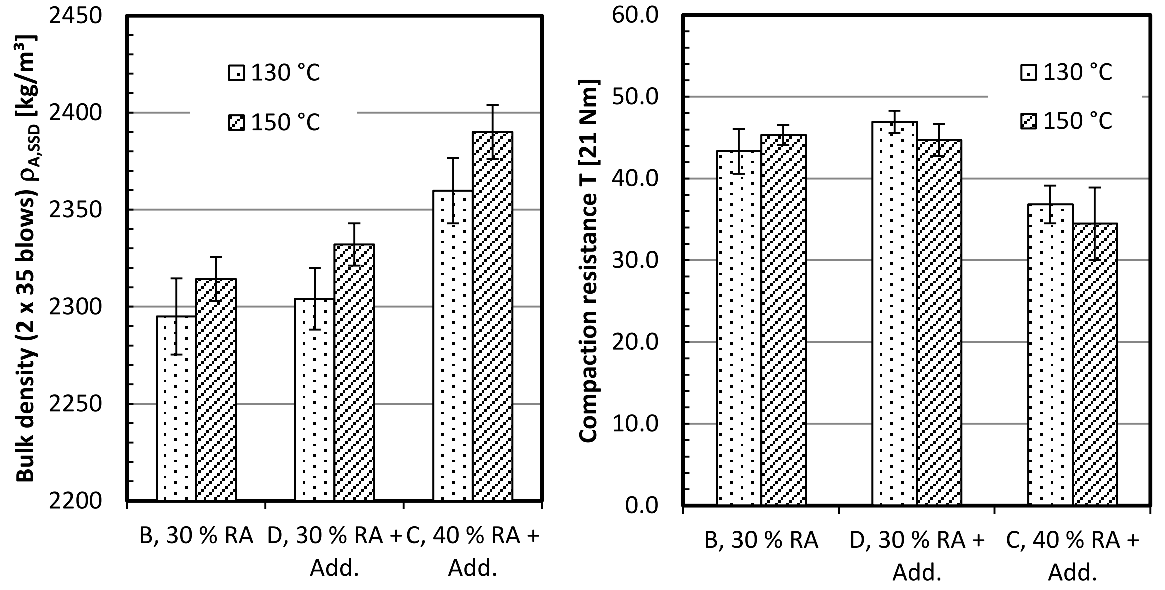

Figure 16. bulk density of water sensitivity test specimen (left) and compaction resistance (right)

3.4 Results of water sensitivity tests

For the asphalt mixtures B, C and D containing reclaimed asphalt, water sensitivity tests according to EN 12697-12/23 were conducted. Therefore, four specimens were prepared for each asphalt mixture and compaction temperature applied by impact compaction according to EN 12697-30 with 2x35 blows. After demoulding, two specimen were stored at room condition, whereas 2 specimen were water saturated in a vacuum (67hPa) for 30 minutes and afterwards stored in water at temperature of 40°C for 3 days. Both sets for specimens were temperature conditioned to 15°C and tested by indirect tensile strength (ITS) test at a test temperature of 15°C. The ITS results as well as the calculated indirect tensile strength ratio ITSR are summarised in Table 7.

When evaluating the test results for the effect of compaction temperature it can be observed, that the strength values obtained for the specimens compacted at 150°C are higher compared to the values obtained after 130°C compaction. The higher strength values (both for dry and wet specimens) correlate well with the void content of the specimens, which is lower for the specimens compacted at 150°C. The difference in void content shows no effect for the ITSR-values on mixtures C and D, where similar values are obtained.

When comparing the results obtained on mixture A and D, it can be observed that ITSR is reduced for the mixture D by application of low-temperature additive. This observation is based on very high wet strength values obtained in mixture B, which were higher compared to the dry strength. The increased rate of reclaimed asphalt results in a decrease of ITSR (mixture C compared to mixture D). Still, all measured ITSR results are comparably high.

Table 7: Results of water sensitivity tests

Asphalt mixture	B		C		D	
	30% RA		40% RA + Add.		30% RA + Add.	
Compaction temperature	130°C	150°C	130°C	150°C	130°C	150°C
Void content V_m [%]	7,8	7,2	5,5	4,8	8,7	7,6
ITS (dry) [MPa]	1,671	1,822	2,266	2,274	1,798	2,216
ITS (wet) [MPa]	1,798	2,060	2,136	2,516	1,761	2,162
ITSR [%]	107,9	113,1	94,2	92,4	97,9	97,5

4 Conclusions

In this study, an experimental programme was undertaken in order to investigate the effect of RA on the moisture damage susceptibility of asphalt mixtures. Cylindrical specimens were cored from site trials and used for testing. 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 can affect the strength of the mixtures. ITS values were found to increase with increasing RA content in dry conditions, which can be explained by lower void content due to reduced compaction resistance. Still, the rate of strength degradation due to moisture damage was found to be higher for the RA mixtures and increased RA content. The use of warm mix additive was shown to increase the resistance to moisture damage as shown by the MIST results, whereas the conventional test procedure according to EN 12697-12 results in the contrary result. This first observation indicates the importance of the need for better understanding of moisture damage and its consideration in test procedures for durability assessment.

In the second stage of WP3, asphalt cores will be collected from the field and tested for their indirect tensile strength under the same conditions. A comparison with the results obtained in phase one will allow a better understanding of the influence of ageing and moisture on the durability of mixtures containing RA. Furthermore, the laboratory findings will be evaluated and linked to the degree of ravelling and other distresses observed in the trial sections.

5 Acknowledgement

The research presented in this report/paper/deliverable was carried out as part of the CEDR Transnational Road research Programme Call 2012. The funding for the research was provided by the national road administrations of Denmark, Finland, Germany, Ireland, Netherlands and Norway.

6 References

[1] Miller J.S. and Bellinger, W.Y. (2003). *Distress identification manual for the long-term pavement performance program (Fourth Revised Edition)*. Federal Highway Administration Report: FHWA-RD-03-031.

[2] Lottman R. (1974). *Laboratory Test System for Prediction of Asphalt Concrete Moisture Damage*. Transportation Research Record: Journal of the Transportation Research Board, No. 515.

[3] CEN, EN 12697-12 (2008). *Bituminous mixtures-Test methods for hot mix asphalt: Determination of water sensitivity of bituminous specimens.* European Committee For Standardization, Brussels.

[4] Kringos N., H. Azari and A. Scarpas (2009). *Identification of Parameters Related to Moisture Conditioning That Cause Variability in Modified Lottman Test.* Transportation Research Record: Journal of the Transportation Research Board, No. 2127, pp.1–11.

[5] Kandhal P.S., C.W. Lubold and F.L. Roberts. *Water Damage to Asphalt Overlays: Case Histories.* Proceedings of the Association of Asphalt Paving Technologists, St Paul, Minnesota, Vol. 58, 1989, pp. 40-67.

[6] Varveri A., S. Avgerinopoulos, A. Scarpas, A. Collop and S. Erkens (2014). *On the Combined Effect of Moisture Diffusion and Cyclic Pore Pressure Generation in Asphalt Concrete.* Proceedings of the 93rd Annual Meeting of the Transportation Research Board, Washington, D.C.

[7] InstroTek, Inc. (2009). *Moisture Induced Sensitivity Test Operators Guide,* Raleigh, NC.

[8] CEN, EN 12697-23 (2003). *Bituminous mixtures-Test methods for hot mix asphalt: Determination of the indirect tensile strength of bituminous specimens.* European Committee for Standardization, Brussels.

[9] CROW (2010). *Standaard RAW Bepalingen*. Publicatie 470, The Netherlands.