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EARN

Report of laboratory and site testing for site trials

Deliverable Nr. 8

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EARN
Effects on Availability of Road Network

Deliverable Nr. 8 – Report of laboratory and site testing for site trials

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1 Introduction

The durability of road materials plays an important role in influencing the service lifetime of the road structure. Because of its effects on the frequency and extent of maintenance road works, durability issues play an important role on the environmental life-cycle performance of the road structure, as well as on its life-cycle costs. The EARN project (**E**ffects on **A**vailability of **R**oad **N**etwork), on which this report is based, was designed to assess the effect of such durability changes. The project had a particular focus on the inclusion of reclaimed and secondary materials in the manufacture of new pavement materials, and the effect of these on the cost of the construction, both financially and with regard to the environment.

This report focuses on *in situ* pavement performance evaluation. A stretch of 700 m of a National road (N3) on the outskirts of Dublin city was selected as a test site. Four test mixtures were selected for the site testing containing varying proportions of reclaimed asphalt (RA), including a mixture containing 0 % RA as a control mixture. Ride quality and laboratory testing were selected for evaluation of the material performance. For ride quality, the international roughness index (IRI), mean profile depth (MPD) and skid resistance have been investigated at 6th and 12th month after the surface has been laid. For the laboratory investigation, the indirect tensile stiffness modulus (ITSM) and water sensitivity tests were selected for the material evaluation. The results illustrated good performance of the mixtures containing RA and warm additive. They have also shown that using warm mix additives, mixing temperatures could be reduced, which can play significant role in reduction of the road construction carbon footprint.

2 Full-scale testing

2.1 Reason for site trial

There are particular advantages that are uniquely associated with full-scale testing over simulated laboratory test programmes (Hartman *et al*., 2001). The effects of size, manufacturing, environment, sub-structure and loading all represent uncertainties which are not easily simulated directly in the laboratory, and to do so would require a significant amount of testing. These effects inevitably lead to inconsistencies between laboratory and site produced test results. However, it must be borne in mind that the ultimate test of the various pavement materials employed will be their performance when they are used in service, and as such the use of full-scale tests (in outdoor ambient conditions, with no temperature and moisture controls) is preferred.

Various pavement monitoring procedures are available for use on site (Hartman *et al*., 2001) and the level of complexity can vary considerably. These procedures include physically measuring permanent deformation on the pavement surface; evaluation of structural integrity though monitoring of crack initiation and propagation; monitoring the transverse and longitudinal strains in the surface and subgrade layers and associated wheel loads and contact pressures. In situ material properties can be evaluated by obtaining material cores from the road trial and testing in the laboratory for stiffness, water sensitivity ageing and fatigue. The falling weight deflectometer (FWD) can be used to measure in situ surface quality, and the application of appropriate back calculation methods can be used to determine stiffness of the pavement layers. The road surface profiler (RSP) and the sideway-force coefficient routine investigation machine (SCRIM) can be used to assess the ride quality of the pavement surface (Feighan and Mulry, 2012).

2.2 Mixture design

The asphalt mixtures investigated in this study was a 10 mm SMA typical of that used in Irish and European practice. The variations of the 10 mm SMA mixture were:

- Control mixture (0 % Reclaimed Asphalt, RA);
- 30 % RA and no additive;
- 40 % RA and Cecabase RT 945 warm mix additive;
- 30 % RA and Cecabase RT 945 warm mix additive.

The grading curves for these mixtures are presented in Figure 1, 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 mix designs, and consequently the mixture design as illustrated in Table 1.

Table 1. Mixture designs

Mixture No.	Proportional content (%)					
	RA	10 mm	CRF *	Filler	Fresh Binder	Warm Mix Additive
1	0	65.9	21.8	6.7	5.6	0
2	28.6	43.8	17.0	5.7	4.9	0
3	38.1	34.4	17.1	5.7	4.7	0.5 **
4	28.6	43.8	17.0	5.7	4.9	0.5 **

* Crushed Rock Fines

** Warm mix additive added to Mixtures 3 & 4 at 0.5 % of the total binder content in the mixture.

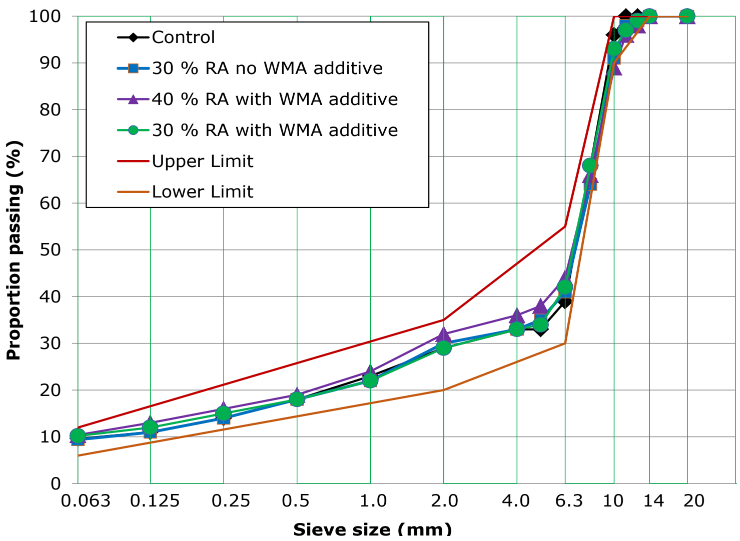


Figure 1. Particle size distribution

2.3 Reclaimed asphalt feedstock

The RA feedstock was supplied from a site on the M1 motorway in North County Dublin and was 14 mm porous asphalt derived from a single source. The material was milled and stored in a depot until required on this project. The total amount of reclaimed asphalt material supplied was 170 tonnes. The quantity of the processed RA material by size is given in Table 2. A visual inspection revealed that the >16 mm material contained binder course material aggregate. Therefore, the >16 mm and <6 mm reclaimed asphalt aggregate was screened out and not used for the trial asphalt mixtures.

Table 2. The quantity of the processed RA material by size

Size (mm)	>16	16 to 12.5	12.5 to 6	<6
Quantity (T)	40	45	35	50
Proportion of total (%)	24	26	21	29

The binder content in the RA was determined according to procedures described in EN 12697-39 (CEN, 2012a). Five samples of RA were taken and weighed. The samples were placed in the oven at 530 °C for 30 min. Once the samples had cooled, they were weighed again and the proportion of binder in the mixture calculated. The binder contents were found to be 5.2 %, 5.4 %, 4.8 %, 5.7 % and 5.4 %; the average was 5.3 %. Following the binder burn-off procedure, the material particle size distribution determined following EN 12697-2 (CEN, 2002) and the results are shown in Figure 2.

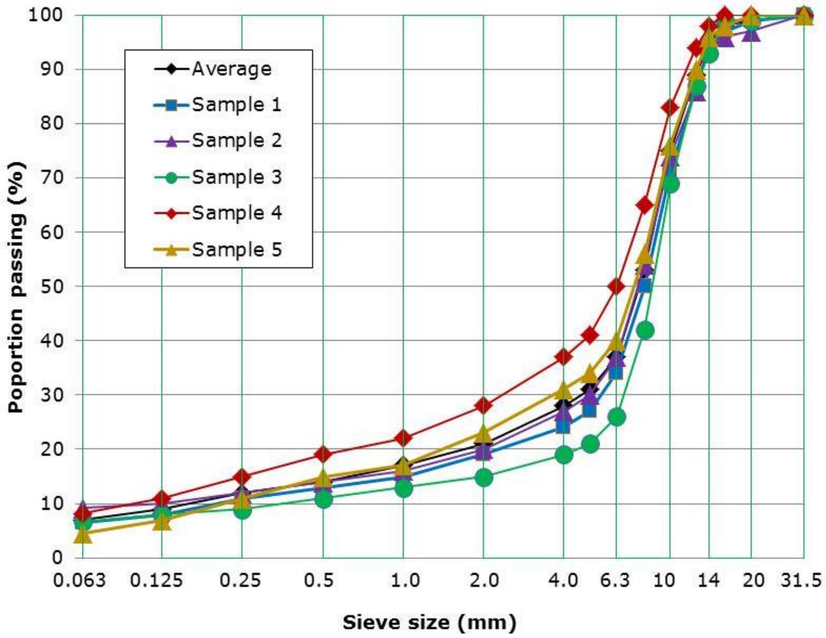


Figure 2. RA material grading after the binder removal

2.4 Selection and construction of the test section

In collaboration with the Irish National Roads Authority, a section of the N3 national road was identified as a suitable road section for the site trial experiment. The site is located between Blanchardstown and Clonee Village, at the outskirts of Dublin city. The GPS coordinates of the trial site are:

Start:	Latitude 53° 24’ 19.35”	Longitude 6° 24’ 30.55’’
End:	Latitude 53° 24’ 6.43’’	Longitude 6° 23’ 59.21’’

The section was chosen for a number of reasons, including the fact that is was scheduled for resurfacing, its proximity to an appropriate asphalt plant (c.60 km) and its location on a main commuter route into Dublin city with an average daily vehicle traffic count (one direction only) of 15,480 vehicles (including heavy goods vehicles).

Figure 3 illustrates a satellite image of the trial section and surrounding area. The road is a dual carriageway with three traffic lanes on each side (bus lane and two traffic lanes). The middle lane was chosen as the test lane because it will be subjected to the most trafficking, particularly from heavy goods vehicles. The traffic direction is towards Dublin city. Figure 4 shows a schematic layout of the trial section. The site was split into four sections of varying lengths for the different mixtures.

Figure 3. Satellite image of the trial road section

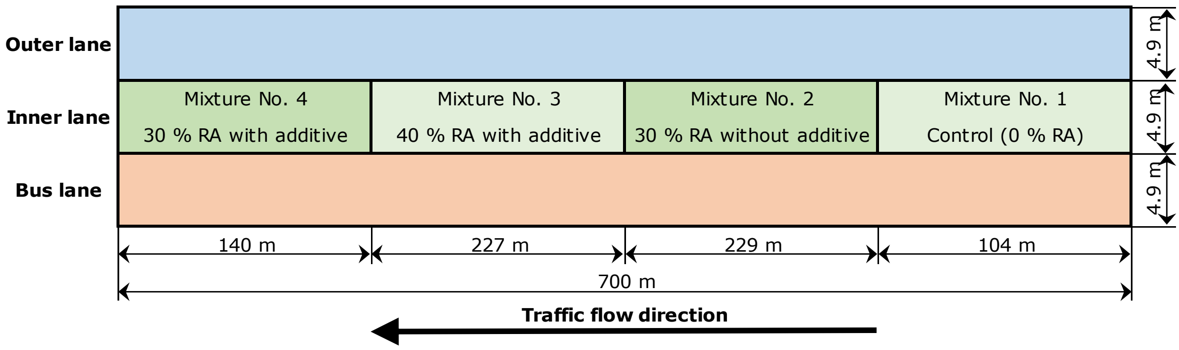


Figure 4. Schematic representation of the trail section

It was estimated that just over 230 tonnes of asphalt material was required in order to cover the trial section area. The work started with removal of the existing surface course which was milled to a depth of 40 mm. An initial regulating course was then laid to a depth of 20 mm. The outer lane and bus lane (Figure 4) were resurfaced with a standard SMA, containing no RA or warm mix additive, to a depth of 40 mm. The test lane was resurfaced with the materials described above.

The paving process started with laying Section 1 (control mixture). The asphalt material was hauled from the plant to the site by truck and unloaded to the material transfer vehicle before it was sent to the paver. The purpose of the material transfer vehicle was to remix the material before paving. The paving process is shown in Figure 5.

For the first section, the paving process passed as expected without any difficulties. However, Section 2 proved to be more difficult because the mixture was cooling down rapidly with the consequential reduction in workability of the mixture. The paving of Sections 3 and 4 passed without much difficulty, highlighting the improved workability of the mixtures incorporating the warm mix additive, with up to 40 % RA. The site work records are summarised in Table 3, giving section lengths, temperature and weight of each mixture.

Figure 5. Paving process of the trial section

Table 3 On-site work record of asphalt material

Section No.	RA Content	Warm Mix Additive?	Load No.	Start Chainage	End Chainage	Discharge Temp. (°C)	Rolling Temp. (°C)	Weight (Tonnes)
1	0 %	No	1	0	104	150	134	30.00
2	30 %	No	2	104	155	115	105	17.20
			3	155	220	130	115	17.20
			4	220	333	150	130	28.90
3	40 %	Yes	5	333	385	137	125	30.10
			6	385	458	135	125	17.00
			7	458	560	134	128	28.80
4	30 %	Yes	8	560	618	125	118	17.00
			9	618	672	132	124	17.20
			10	672	700	136	128	28.65

2.5 Ride quality evaluation

2.5.1 International roughness index and mean profile depth

The IRI and MPD test are conducted in accordance with ASTM E950 / E950M (ASTM, 2009) and EN ISO 13473-1 (ISO, 2004), respectively. Continuous measurements of IRI and MPD were acquired using the road surface profiler (RSP). The data was collected at speeds of 70-80 km/h in order to ensure that there was no delay or disruption for other road users. The entire data collection process was non-contact, using high-frequency lasers and accelerometers in conjunction with a very accurate distance measurement system. The IRI measurements were continuously measured in both inner and outer wheel paths and the values were recorded at 10 m intervals. Where the MPD was measured in the inner wheel-path only, the values were recorded at 1 m intervals.

Table 4 shows the average IRI and MPD values for the test sections for a period of 12 months. The average IRI value for each section is < 2 m/km which shows good ride quality of the pavement surface. The average MPD values are below 0.9 mm and above 0.4 mm, which indicates that the surfaces have suitable macro-texture depth for the type of the road (a National road) where the maximum speed limit is 100 km/h (Aavik *et al*., 2013), indicating good friction level and also low level noise because the test site is located near to a residential area. However, these values are lower than average MPD values on the Irish road network (Feighan and Mulry, 2012), which are typically around 1.4 mm. As such, further monitored is required to ensure that the trial sections remain safe.

Table 4. Average IRI & MPD values of the test site

Section No.	Test period (month)	IRI (m/km)			MPD (mm)
		Left	Right	Average	
1	0	1.25	1.23	1.24	0.86
2		0.96	0.99	0.98	0.76
3		1.04	1.10	1.07	0.68
4		1.33	1.43	1.38	0.77
1	6	1.06	1.36	1.21	0.62
2		1.17	1.06	1.11	0.61
3		1.17	1.13	1.15	0.55
4		1.70	1.45	1.58	0.73
1	12	1.24	1.33	1.29	0.77
2		1.18	1.03	1.11	0.64
3		1.21	1.12	1.16	0.53
4		1.51	1.37	1.44	0.70

2.5.2 Skid Resistance

The SCRIM test was conducted in accordance with the HD28/11 (NRA, 2011), Transport Research Laboratory (TRL) standard procedures, BS 7941 (BSI, 2006) CEN/TS 15901-6 (CEN, 2009a).

The SCRIM machine operates by applying a freely rotating wheel, at an angle of 20 ° to the direction of travel, on to the wetted road surface under a known load. The standard test speed for the SCRIM machine is 50 km/h, and the skid resistance is typically measured in the left hand wheel-path with the average for each 10 m section being recorded. The vertical load and the sideway force generated by the frictional resistance to skidding of the test wheel is measured. The ratio of the sideway-force and normal load gives the sideway-force coefficient (SFC) value. The SCRIM results are used to identify stretches of road with unacceptably low wet skidding resistance and check surface for compliance with friction standards.

Table 5 shows average SFC and SC values for the test sections for months 6 and 12. The average SFC and SC value for each section is > 0.3 which shows good friction quality of the pavement surface. These values reassure that MPD values are in safe levels and all sections have a good ride quality and are safe for road users.

Table 5. Average SFC and SC values of the test site

Section No.	Test period (month)	SFC	SC
1	6	0.72	0.50
2		0.68	0.47
3		0.64	0.44
4		0.68	0.46
1	12	0.54	0.49
2		0.52	0.48
3		0.49	0.45
4		0.50	0.46

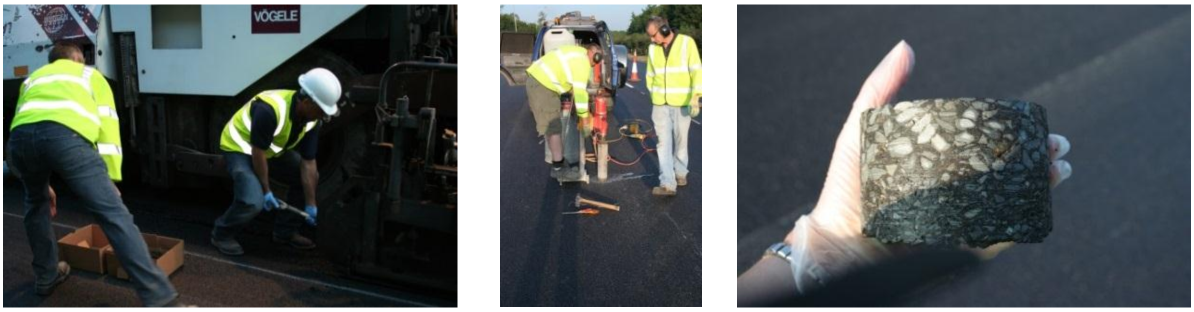
3 Laboratory testing

3.1 Test programme

During their service life, the performance of asphalt pavements is greatly affected by different environmental factors such as moisture, oxygen, heat, pressure and UV light. Primarily in 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 RA, secondary aggregates and lower temperatures will affect the various factors in different ways, further complicating an already complex situation. The laboratory investigation, focused on the stiffness and moisture damage on the performance of the asphalt mixtures on the site trial.

In order to evaluate the material used on-site, a series of laboratory tests were conducted, including the ITSM test to EN 12697-26 (CEN, 2012b) and a water sensitivity test to EN 12697-12 (CEN, 2008). The ITSM and water sensitivity tests were carried out at four stages starting with when the trial was constructed and then after 3 months, 6 months and 12 months in service.

At site construction/paving stage, the asphalt mixture material was sampled from the paver as shown in Figure 6a. These mixtures were later compacted in the laboratory using the gyratory compaction procedure given by the EN 12697-31 (CEN, 2007). For subsequent material evaluation periods (months 3, 6 and 12), the coring process was used in order to obtain test samples. The coring procedure is shown in Figure 6b & 6c. After obtaining cores from the site, they usually contained material from the lower bituminous layer. This material was removed using a circular cutting saw.



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

Figure 6. Collection of samples from site

3.2 Indirect tensile stiffness modulus test

The non-destructive ITSM test was conducted which complied with EN 12697-26 (CEN, 2012b). The Cooper Research Technology NU-10 testing apparatus with a pneumatic close loop control system was used. Two linear variable differential transformers (LVDT) were used to measure the horizontal deformation. After the conditioning period of 14 days at 20 °C, the test specimens dimensions and weights were recorded and the specimens were placed in a temperature controlled chamber for ITSM test temperature conditioning at 20 °C for 3 h prior to testing. The stiffness value was recorded on two diameters orientated at 90 ° to each other and the average of these two values was reported as the specimen stiffness.

3.3 Water sensitivity test

The water sensitivity test was performed in accordance with EN 12697-12 (CEN, 2008b). After the 14 day conditioning period at 20 °C, the set of six specimens were then divided into two subsets of three specimens. The first set was stored in a temperature control chamber at 20 °C. The second set was placed under distilled water and subjected to a vacuum of 6.7 kPa for 30 min, and then left submerged in water for another 30 min at atmospheric pressure. After this conditioning, the wet conditioned set of specimens was placed into a water bath at 40 °C for 72 h. Both sets of test specimens were then conditioned at a test temperature of 25 °C for 3 h prior to testing. The dry set was conditioned in a temperature controlled air chamber, and the wet set conditioned in a temperature controlled water bath. A Controls testing system was employed to complete the indirect tensile strength test (ITS) in accordance with EN 12697-23 (CEN, 2003a). The ITS test is conducted by applying a vertical compressive strip load to a cylindrical specimen. The load is distributed over the thickness of the specimen through two loading strips at the top and bottom of the test specimen. The critical stresses and strains within the indirect tensile specimen are computed using following analytical formulation based on linear elastic theory:

$$\sigma_{xy(\max)} = \frac{2P}{\pi d t} \qquad (1)$$

where: P = Load (N);
d = Diameter (mm);
t = Thickness/height (mm).

Using equation 1, the maximum tensile strengths of both wet and dry conditioned test specimens were calculated and an indirect tensile strength ratio was calculated for each.

3.4 Test results

Table 6 summarises the ITSM test results for samples taken over the first 12 months of the trial. The maximum and bulk densities test were conducted on the laboratory compacted specimens in accordance with EN 12697-5 (CEN, 2009b) and EN 12697-6 (CEN, 2012c). In addition, the maximum density and for each material was calculated, which allowed the air voids content of each mixture to be calculated in accordance with EN 12697-8 (CEN, 2003b); these values are presented in Table 7 alongside the target air void content. From the results is clear that the specimens were compacted to a higher level than originally expected. 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 %. Nevertheless, the results allow comparison of the asphalt mixtures, and it can be seen that the mixture containing 40 % RA and warm mix additive (Section 3) consistently outperformed the other test mixtures; the lowest stiffness was associated with the control mixture.

Table 6. ITSM test results

Section No.	RA content	Warm mix additive?	Stiffness (MPa) at test month		
			3	6	12
1	0 %	No	1692.5	1703.2	1620.1
2	30 %	No	2295.3	2237.8	1789.6
3	40 %	Yes	2407.0	2322.5	2005.6
4	30 %	Yes	1898.4	2181.5	1629.9

The results further show reduction in mixture stiffness values between test months 3 and 12, with the control mixture having lowest reduction of 4.3 % where the mixture containing 30 % RA and no warm mix additive (Mixture 2) had the highest reduction of 22 %. Mixtures 3 and 4 had stiffness reduction of 16.7% and 14.1% respectively.

Table 7. Max density, bulk density and air voids content of test specimens

Section No.	Max density (kg/m^3)	Bulk density (kg/m^3)	Air voids content (%)	Target air voids content (%)
1	2402.7	2238.4	6.8	10
2	2415.5	2235.7	7.4	
3	2415.6	2235.7	7.4	
4	2413.6	2233.6	7.5	

The wet and dry ITS results arising from the water sensitivity testing are shown in Figures 7 and 8 and the associated ITSR values are provided in Table 8. The results show good resistance to the moisture damage, where all mixes achieve ITSR value about required 80 %. An exception is control mixture (Mixture 1) whose ITSR value dropped just below 80 % (to 79.3%) at 12th month. Results further show improvement in ITSR values in the 12th month for Mixtures 2 and 4. This change is due to the improvement in material wet strength (ITS_w) for both materials.

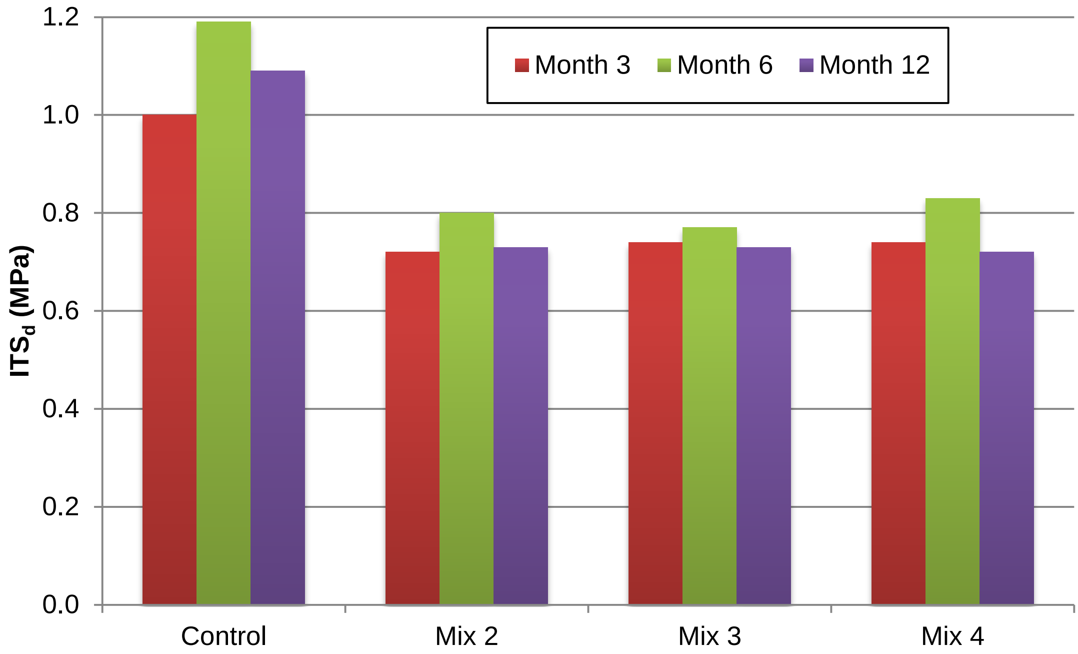


Figure 7. ITS results after dry conditioning

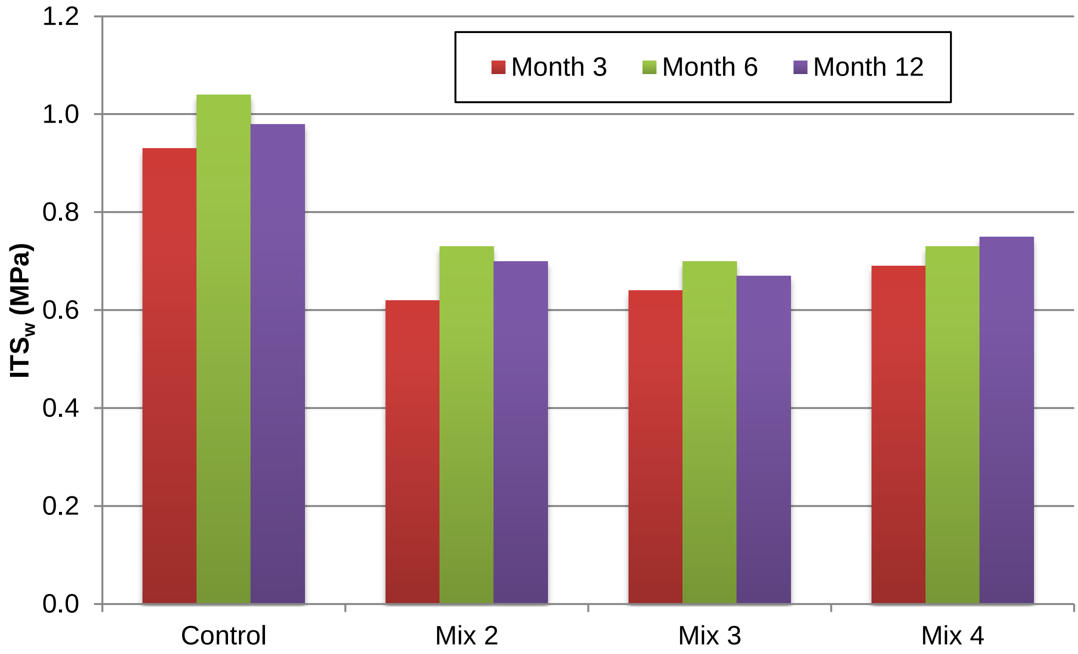


Figure 8. ITS results after wet conditioning

Table 8. Change in ITSR values with time

Section No.	RA content	Warm mix additive?	ITSR values (%) at test month		
			3	6	12
1	0 %	No	89.5	88.5	79.3
2	30 %	No	85.6	87.4	92.9
3	40 %	Yes	61.0	91.8	87.6
4	30 %	Yes	95.4	91.5	104.3

4 Conclusions

This study focused on the investigation of the warm mix additive influence on a stone mastic asphalt mixture, containing varying proportion of RA over a period of 12 months. A 700 m stretch of Irish National (N3) road was used as the trial section.

- Four different mixtures containing varying proportions of RA and warm mix additive were used, and these were assessed using a combination of laboratory and *in situ* testing.
- Site Quality testing (IRI, MPD and SC) showed good asphalt material performance, with MPD values being slightly lower than usual national values of 1.4 mm. The most likely reason for lower MPD values is excess of the residual binder in the mixture. This finding suggests that, in the material mix designs, it should be assumed that a significant portion of the binder in RA will be activated (Fallon *et al*., 2014; Coffey *et al*., 2013; McDaniel, 2000). This approach will lead to associated reductions in the amount of fresh binder required.
- Laboratory tests showed good material performance throughout a 12 month test period. However, it was noted that the stiffness of the mixtures containing RA did decrease over the monitoring period, which may represent a cause for concern in the long term.
- Water sensitivity tests showed good material resistance to water damage, with ITSR values above the required 80 % threshold. The mixture containing 30 % RA and warm mix additive (Mixture 4) at the 12th month period saw an improvement in its wet ITS value, thus obtaining ITSR value above 100 %. The ITSR value for the mixture containing 40 % RA and warm mix additive (Mixture 3) decreased slightly (4.6 %) between months 6 and 12.

5 Acknowledgement

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