

The Influence of Recycled Asphalt Pavement on 20mm Binder Course Mix Performance

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ABSTRACT: This paper presents the results of ongoing research on the mechanical performance of a 20mm binder course asphalt pavement mix incorporating recycled asphalt pavement (RAP). A series of binder course mixes were designed containing varying percentages of RAP. A mix made only from virgin material was selected as the control mix for the investigation. The effect of introducing RAP into the binder course mix was evaluated through a series of laboratory tests including the Marshall Test, Indirect Tensile Stiffness Modulus Test, Indirect Tensile Fatigue Test and Water Sensitivity Test. A Circular Wheel Track (CWT) was developed in order to study the dynamic effects of a rolling wheel travelling over an asphalt pavement. The CWT was commissioned within a temperature controlled room along with a customised Data Acquisition (DAQ) system. The system involves the testing of rectangular slabs and allows for the investigation of the dynamic tensile strain. The dynamic tensile strain is digitally recorded and the loading effect assessed. The laboratory tests have shown that the introduction of RAP to the binder course mix resulted in an improvement in all mechanical properties. This was also observed in the dynamic tensile strain test.

KEY WORDS: Recycled asphalt pavement, stiffness, fatigue.

1 INTRODUCTION

Ireland's Environmental Protection Agency (EPA, 2002) recently reported that 3.65 million tonnes of construction and demolition (C&D) waste is produced annually by the Irish construction industry and that most of this waste ends up in landfill. There is an urgent need for Ireland to adopt sustainable technologies and practices. It is also important that suitable end uses be identified for significant waste streams in Ireland. The benefits associated with the diversion of selected waste from landfill are clear, both environmentally and economically. Significant end uses have been found internationally for C&D waste (Public Roads, 2005; Khalaf et al. 2004; Khalaf, 2004; Woodward, 2004; Perez Jimenez et al. 2004; Hossain et al. 1993; Emery, 1993; Gerardu & Hendriks, 1985). In this study RAP was investigated as an alternative material for use in the road pavement industry. The road construction industry is one of the biggest users of rock aggregates in Ireland and worldwide: as such, it represents the best example of where alternative aggregate replacement materials could be used. RAP represents only 1% of the total construction

and demolition waste produced in Ireland, but it can be recycled 100%. Even though this is well known, the reuse of RAP in road construction has not been fully embraced in the Irish context. There are many reasons for this, not least of which is RAP variability. It causes concern because it is removed from an old road and may therefore contain original pavement materials as well as patches, chip seals and other maintenance treatments. The current project is centred around an investigation into the influence of RAP on the physical and mechanical properties of a 20mm binder course mix utilising a single source of RAP.

2 MATERIAL MIX

The bituminous mixture investigated in this study was a 20mm binder course mix typical of that used in Irish practice. In order to investigate the influence of RAP on the fatigue performance of the 20mm binder course mix, varying percentages of RAP were incorporated into the mix design. RAP was introduced to the bituminous mixtures at the levels of 10%, 20% and 30%. Control samples free from RAP were also manufactured. The primary concern in using RAP in the mix is that RAP contains a variety of materials such as crushed rock aggregates and binder, as well as possibly containing some contaminants. Base and surface courses from old roads could be mixed together in a single stockpile, along with RAP from several projects. If the RAP varies widely in properties such as gradation or binder content, the resulting binder course may also be variable. Good stockpile management should be followed to keep material variability under control. For this project the RAP material was provided by Roadstone Dublin Ltd.

Four representative samples of RAP were used to determine the apparent relative density of the RAP, which was calculated to be 2626 kg/m³. Another set of four samples was taken to determine the aggregate gradation, according to the British standard BS 812: Part 103.1: 1985. The grading results for the RAP and virgin aggregates are presented in Table 1. It can be observed that RAP is a continuously graded material and as such can be used to replace a proportion of each constituent in the mix.

Table 1: Percentage by weight passing.

Sieve size (mm)	20mm	14mm	10mm	CRF ¹	Sand	RAP
28	100	100	100	100	100	100
20	92.46	100	100	100	100	95.80
14	23.10	94.65	100	100	100	85.85
10	2.80	32.01	98.73	100	100	75.41
6.3	0.87	2.23	33.41	99.37	100	58.38
3.35	0.75	1.00	1.65	90.83	100	43.73
0.300	0.74	0.70	0.85	23.46	58.32	25.64
0.075	0.66	0.62	0.77	13.62	6.53	17.34

Following BS 4987: Part 1: 1993; four mixes containing 0%, 10%, 20% and 30% RAP were designed. The grading results are presented in Figure 1, illustrating how the mix designs fit within the standard grading envelope region. The standard design control envelope to region allowed us to create a best particle distribution for the mix designs, and consequently to design the best mix as illustrated in Table 2.

¹ CRF-Crushed Rock Fines

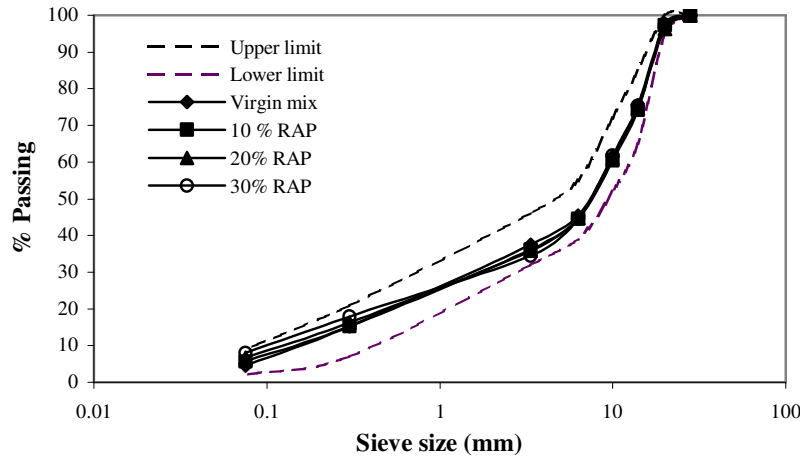


Figure 1: Particle size distribution percentage passing.

Table 2. Mix designs.

Mix No.	Percentage content of constituent in the mix					
	RAP	20mm	14mm	10mm	CRF	Sand
1	0	31	12	18	27	12
2	10	31	10	16	20	13
3	20	28	10	14	16	12
4	30	26	8	14	12	10

3 LABORATORY TESTING

3.1 Marshall Test

In accordance with British standard BS 598: Part 107: 1990, the Marshall test was employed in an attempt to determine the optimum binder content for the mix. A 70/100 pen bitumen was used in the mix. A series of test specimens were prepared for a range of different binder contents so that the test data curves show well-defined relationships. The test method was modified, where the specimens were compacted in the gyratory compactor in accordance with EN 12697-31:1998 test standard. Initially a Marshall compaction hammer was used to compact the specimens, but preliminary results showed variation in stability and flow. Subsequently samples were compacted using the gyratory compactor: these samples demonstrated consistent stability and flow test results. Recent research also indicated less variation in sample void content and stiffness results where the gyratory compactor was used, (Fitzsimons and Gibney, 2004; Hartman et al. 2001). The dimensions of the test specimens were 100mm in diameter and 63.5mm in height with a void content of 6%. At first the specimens were placed in a water bath at 60°C for 45 minutes. Once the specimens reached the test temperature, they were placed into the test frame and a load was applied to the specimens at a constant rate of deformation of 50mm/min. During the tests, the maximum applied load and the vertical deformation of the specimen were recorded. The test was repeated for each mix and the results are presented below in Table 3.

Table 3: Optimum binder content for binder course mixes.

RAP content	Optimum Binder Content in the Mix (%)
0%	4.70
10%	4.20
20%	4.16
30%	4.00

These results illustrate that the optimum binder content for the mix decreases with an increase in the percentage of RAP in the mix. However discussions were held with industry and it was suggested that a binder content of below 4.5% would not be acceptable to industry in light of doubts over the long term durability of the resulting mix. While this research has suggested that it is feasible to reduce the added binder content when using RAP, it was decided to heed the comments from industry and use a minimum binder content of 4.5% with all the mixes tested. Nevertheless, with some detailed knowledge of the binder content in the RAP, this research shows that it would be feasible to reduce the binder content below 4.5% (EN 12697-39: 2004 or CP-L 5120). Additional durability tests at reduced binder content would be advisable to confirm this finding.

3.2 Stiffness Modulus Test (ITSM)

Prior to the Marshall load test, a non-destructive ITSM test was conducted which complied with British standard BS DD 213: 1993. 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. The specimens were conditioned at 20°C, for four hours prior to testing. The stiffness value was recorded on two diameters orientated at 90° to each other, and an average of these two values was reported as the specimen stiffness. The results are presented in Figure 2.

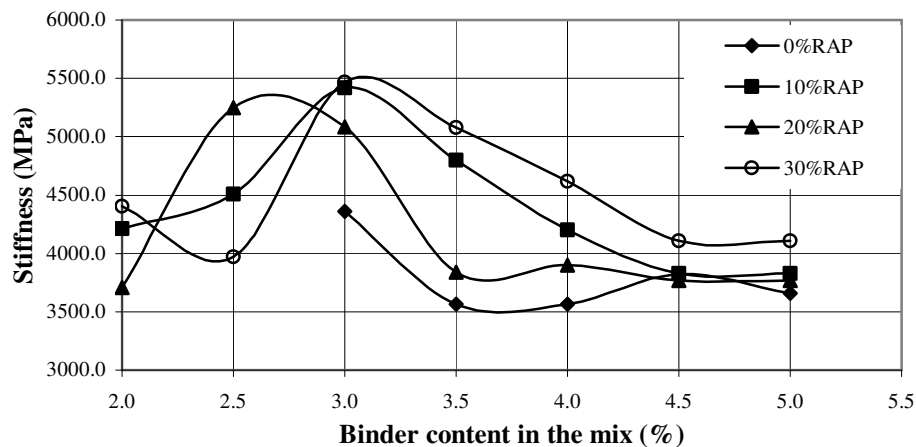


Figure 2: Effect of RAP content on stiffness modulus measured against varying binder content.

From the results we can see that the stiffness value increased with increasing content of RAP in the mix and peaked at a mix binder content of between 2.5 and 3.0%. The stiffness value of all

the mixes are very close at the chosen mix binder content of 4.5%. The stiffness values at this binder content range from 3768 to 4109MPa, as illustrated in Figure 2.

3.3 Water Sensitivity Test (WST)

The water sensitivity test was performed in accordance with European standard EN 12697-12: 2003. For each mix, six specimens, 100mm diameter and 70mm in height with a void content of 6% were prepared using the gyratory compactor. The specimens were then divided into two subsets of three. The first set was stored in the laboratory at room temperature (approximately 20°C). The second set was placed under distilled water and subjected to a vacuum of 6.7kPa for 30minutes. After conditioning in vacuum, the wet set was placed into a water bath at 40°C for 72hours. Both sets of test specimens were then conditioned at a test temperature of 25°C for two hours 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. An Instron servo-hydraulic system was employed to complete the Indirect Tensile Strength Test (ITST) in accordance with EN 12697-23: 1998; the results are presented in Table 4.

Table 4: Water sensitivity test results.

RAP content	ITST for wet Specimen (kPa)	ITST for dry Specimen (kPa)	Indirect Tensile Strength Ratio (%)
0%	0.920	0.965	93.40
10%	0.920	0.899	102.36
20%	0.873	0.931	93.82
30%	0.813	0.934	87.89

Guidance values given for water sensitivity test suggest that values of indirect tensile strength ratio of less than 80% indicate moisture damage, (Solaimanian, 2002). The results from Table 4 illustrate the detailed indirect tensile strength ratio test results for all four mixtures tested. It is evident from the results that moisture damage is not an issue for the mixes containing 0%, 10% and 20% RAP. With inclusion of 30% of RAP in the mix indirect tensile strength ratio decreases significantly, which indicates that further increase of RAP content in the mix could initiate moisture damage.

3.4 Fatigue Strength Test (ITFT)

The Indirect Tensile Fatigue Test (ITFT) was carried out according to the procedure described by British standard BS DD AFB: 1997. The same Cooper testing apparatus was used to determine the resistance of the mixtures to failure under repeated loading. Nine specimens were manufactured for each mix, each specimen being 100mm in diameter and 70mm in height with a void content of 6%. These were prepared using the gyratory compactor in accordance with the method described in EN 12697-31. The specimens were subjected to a repeated constant load with $124\text{ms} \pm 4\text{ms}$ loading time and pulse repetition time of $1.5 \pm 0.1\text{second}$ at a temperature of 20°C. Prior to the ITFT test, the indirect tensile stiffness modulus parameter was obtained for the specimens at the fatigue test stress level. Readings were taken for two diameters at 90° to each other and the average value was calculated. The pulse repetition in the ITFT test simulates traffic passing over the pavement, which results in repeated applications of tensile stress and strain within the test sample. The fatigue life is defined as the total number of load pulses that cause

complete structural failure of a test specimen. Strain is calculated from the direct computation of maximum tensile stress at the centre of the specimen, using the indirect tensile stiffness at the maximum tensile stress.

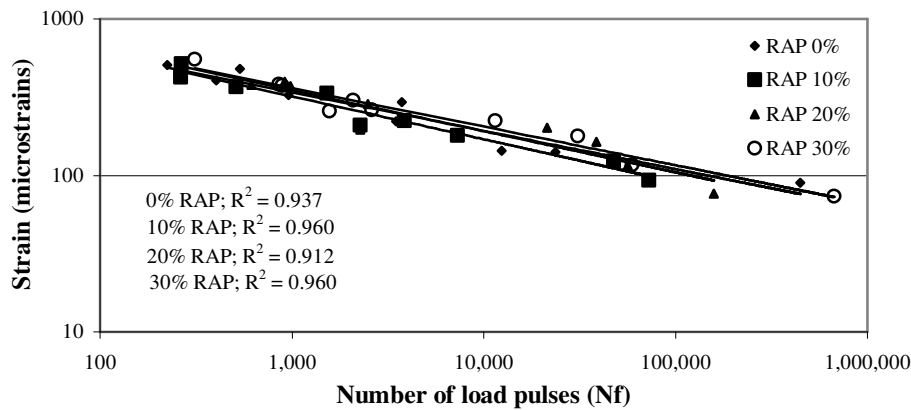


Figure 3: Effect of RAP content on the tensile strain response under repetitive pulse loads.

The results of the ITFT testing are presented in Figure 3. From the results it is apparent that the mix with a lower amount of RAP (10%) demonstrated lowest resistance to fatigue. An increase in the amount of the RAP in the mix improved the fatigue life of the mix. Of the mixes tested, the binder course mix containing 30% RAP demonstrated the best resistance to repeated tensile stress loading. It is unknown why the performance of the mix deteriorates with the addition of 10% RAP into the mix but then improves with an increase of RAP content to 20% and 30% of the mix. The suspected cause of this behaviour is that mixes with a higher RAP content also contain a higher binder content as a result of the binder content present in the RAP, which makes them more resilient to deformation.

4 CIRCULAR WHEEL TRACK

In order to study the dynamic effects of a rolling wheel travelling over an asphalt pavement and to better understand the initiation and growth of fatigue cracks, a Circular Wheel Track (CWT) was developed (Hartman et al. 2001). A schematic diagram of the CWT is shown in Figure 4.

The testing facility permitted large slab specimens (305x305x50mm) to be tested using dynamic wheel loading. Specimens were compacted using the standard Cooper Research Technology roller compactor. The slab specimens were supported on a soft elastomeric foundation, selected to represent a weak foundation and also to prevent any gravitational bending of the slabs. Using this system, all four mixtures were evaluated under identical loading conditions, i.e., at a temperature of 20°C and with a vertical constant loading of 80kg per wheel, resulting in a pressure on the specimen of approximately 695kPa per wheel. The diameter of the working circle is 3m, the centrifugal forces are minimised by the relatively slow operational speed of the CWT, of approximately 3km/h or 7rpm. The CWT operates on a dead load system with the rotating arms linked through the hinged joints to the wheel fixtures, as illustrated in Figure 4. This ensures that the load follows the deformation of the test sample. As a safety measure, adjustable stopper plates are attached to the hinged joints, thus preventing the wheel

from dropping into the foundation and causing damage, (Hartman et al. 2001). The maximum permanent deflection depth in the test was 5mm.

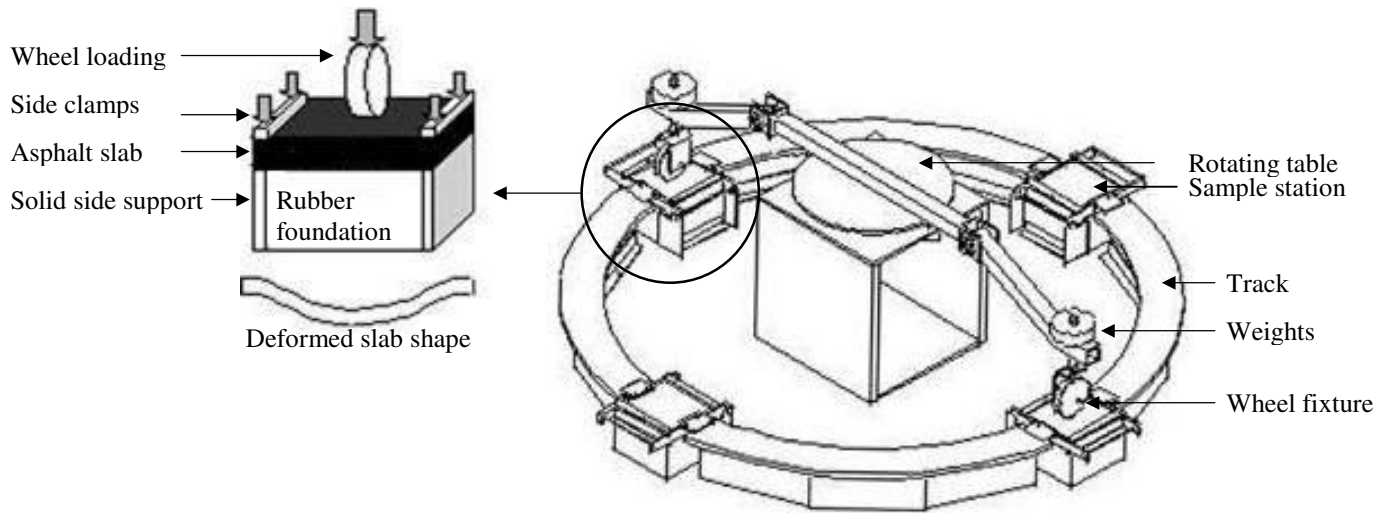


Figure 4: Schematic diagram of the Circular Wheel Track with slab clamping mechanism (Hartman et al. 2001).

4.1 Dynamic strain test

A purpose designed data acquisition (DAQ) system was developed to measure the dynamic strain at the bottom of the test slabs. National Instruments LabView 7.0 software was used to collect data from the strain gauges, placed on the underside of the slab specimens, as shown in Figure 5.

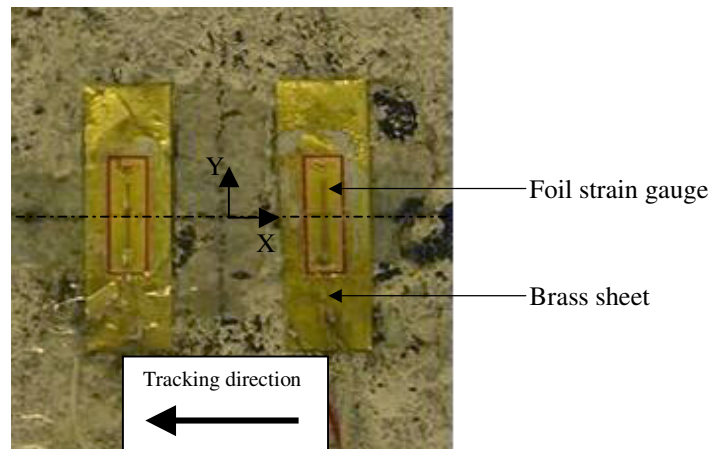


Figure 5: Position of strain gauges on test specimen.

The horizontal tensile strain was monitored using a 120Ω strain gauge with 10mm gauge length. In order to eliminate the influence of aggregates, the strain gauges were glued to a thin (0.3mm) brass foil strip (12.5x40mm), this procedure was also used by Hartman et al. 2001. Two gauges were fixed to each slab, 50mm apart and 25mm from the centre of the test specimen. They

were positioned perpendicular to the direction of the wheel travel, and as a result the strain gauges measure strain transverse to the direction of tracking.

During the test, the dynamic tensile strain was monitored and the total strain calculated. When the test sample reached a permanent deflection limit of 5mm, it was removed from the test rig.

Figure 6 illustrates the typical manner in which dynamic strain varied during loading intervals for all binder course mixes. The dynamic strain results initially show sharp strain increases until the slab settles (for some 1000 passes). Following this stage, the strain remains relatively constant until small cracks begins to form at the bottom surface of the test specimen. After about 3000 passes, the dynamic strain begins to increase sharply, which indicates that the cracks are propagating underneath the strain gauges.

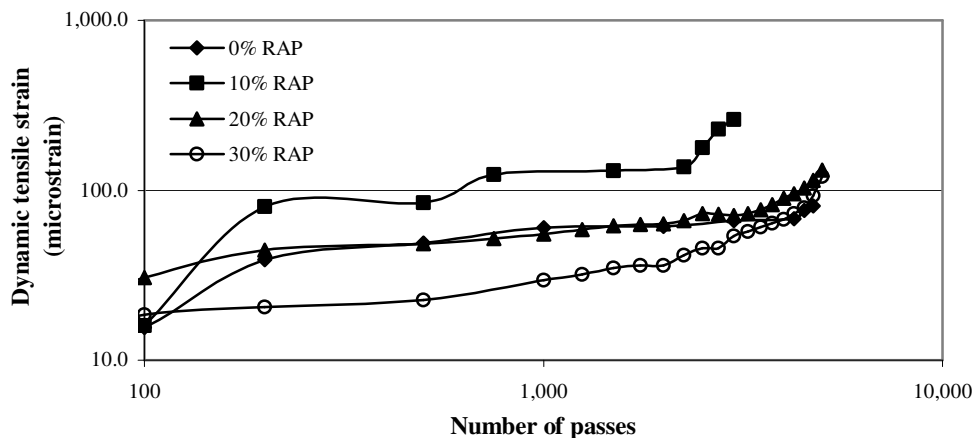


Figure 6: Development of dynamic tensile strain under fatigue loading.

The dynamic strains shown in Figure 6 indicate a similar trend to that observed in the ITFT test, see Figure 3. It also is apparent from the results that the mix containing the RAP improves the resistance to failure with an increase of RAP content in the mix beyond approximately 20%.

5 DISCUSSION

The binder course mixtures that were tested demonstrated good response in both the physical and mechanical properties of the mix with the inclusion of RAP, when compared with the control mix of 0% RAP. The water sensitivity test showed that the ITSR values for all four mixtures are above the standard limit of 80%. The fatigue test showed a slight improvement in mix performance with the inclusion of 30% RAP into the mix. The CWT dynamic tensile strain test demonstrated material ranking similar to that previously observed in the ITFT test. The results from the fatigue tests, as presented in Figure 3 and 6, indicate the similar response of all four mixtures. Using a binder content of 4.5%, it was expected that an increase in the fatigue life with subsequent increase of RAP in the mix would be obtained. A variability of RAP may be a reason for the results obtained. Further investigation of mixtures is necessary in order to ascertain the reason for the mix behaviour.

6 CONCLUSIONS

The laboratory tests demonstrated that the 20mm binder course mixtures, which contained up to 30% of the RAP, performed as well as the mix containing virgin material when subjected to fatigue loading. It would appear that RAP can be used as a viable aggregate alternative material for a 20mm binder course mixture. The maximum value of 30% used in the study was due to the limitation of the grading envelope for the mix type under investigation. Previous work has shown that up to 100% of RAP can be successfully included in the mix, (Public Roads, 2005; Khalaf et al. 2004; Perez Jimenez et al. 2004; Hossain et al. 1993; Emery, 1993; Gerardu and Hendriks 1985); this can improve the fatigue properties of the asphalt pavement mix. The findings of this study indicate that caution should be exercised with the addition of more than 30% of RAP into the binder course mix because the ITSR test results demonstrate that higher quantities of RAP in the mix enhance the moisture susceptibility of the mix. With 30% RAP in the mix, the ITSR value had dropped to approximately 88%; concerns exist that the further inclusion of RAP in the mix would reduce the ITSR value below the critical 80% threshold.

A full-scale site test will be undertaken in the near future using instrumented road sections, constructed using recycled materials. The site test is expected to confirm the trends observed in the laboratory tests. This will be reported on in a future publication.

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