Investigations for the Development of Simulative Test Methods for the Durability of Thin Surface Course Systems

Sub-Tasks 2, 3 and 4: Develop and Execute the Test Programme, Analyse the Results

Project number: 60580090

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Executive Summary

In June 2018, Arup AECOM Consortium was commissioned by Highways England (HE) to conduct Task 1-614. The title of the project is “Investigations for the Development of Simulative Test Methods for the Durability of Thin Surface Course Systems”. This project included five sub-tasks. This report details the work undertaken under Sub-Tasks 2, 3 and 4. The aims of these sub-tasks were to develop and execute the test programme and analyse the results.

Sub-Task 1, published in a separate report, provided a critical review of the Development of Ravelling Test (DRaT) project. This review identified air voids content as the key factor influencing ravelling of Thin Surface Course Systems (TSCS). Therefore, two TSCS variants were proposed for the next stages, having 6% and 14% air void content to represent good and poor compaction, respectively. The review also led to the selection of the ravelling test devices to be used in the following sub-tasks.

The devices selected from the DRaT project were the Rotating Surface Abrasion Test (RSAT) and the Darmstadt Scuffing Device (DSD). The Modified Scuffing Test was considered as an additional test for evaluation in this project.

To reduce the variability between specimens, all specimens were produced in a single laboratory: AECOM Nottingham laboratory. The material used was a pre-coated gap-graded Stone Mastic Asphalt (SMA) 10 surf 40/60, which satisfied the requirements of Manual Contract Document for Highway Works (MCHW) Clause 942. To ensure that the samples are uniform and within specification, acceptance criteria on the dimensions, density and visual condition of the produced asphalt materials were adopted. The samples which met all the acceptance criteria have been selected for the ravelling tests (DSD, RSAT and Modified Scuffing Test).

Results obtained from the four laboratories have been normalised and expressed as mass loss (g) per surface unit (m^2), to allow for objective comparison and correlation between devices, laboratories, and material variants.

The DSD testing was found to be the most suitable test to assess ravelling of TSCS. Average results showed a marked difference in mass loss between the standard voids TSCS variant (6% - A) and the high voids TSCS variant (14% - B).

The RSAT testing produced very little fretting damage to the cores used for this project. Nevertheless, the results still indicated the samples A (6% air voids) experienced lower mass loss than the samples B (14% air voids), in line with what expected.

The Modified Scuffing Test resulted in considerable damage to the wheel used in the test, leading to the premature stop of testing for samples B. Nonetheless, results for samples A are comparable to those observed for material A after DSD test.

Correlation analysis suggested that a scaling factor of approximately 25 should be used when comparing RSAT with DSD and Modified Scuffing Tests results for TSCS. However, these factors are obtained for one material only and cannot be generalised.

Recommendations for the next steps include:

- proposing DSD as the most suitable test to assess TSCS resistance to fretting;
- collecting more evidence by testing different Clause 942 materials;
- widening the range of air voids content, using typical voids found for each type of surfacing tested;
- gathering enough data evidence to establish mass loss thresholds to assess surfacing suitability and/or durability.

1. Introduction

Material loss at the road surface caused by the scuffing action of tyres - commonly called ‘fretting’ or ‘ravelling’ – is a potential cause of defectiveness in surface course materials. Ravelling is primarily the loss of the coarse aggregate particles whereas fretting has been defined as loss of fine material (mortar). The presence of fretting can develop into ravelling when the support for the aggregate particles is sufficiently reduced to allow the loss of aggregate particles from a road pavement (Nicholls, De Visscher, Hammoum, & Jacobs, 2016). Fretting and ravelling are the most common distress mechanism (responsible for over 60% of all defects) experienced by Thin Surface Course Systems (TSCS) commonly used on the UK strategic road network (SRN) (Ojum, 2016). Approximately 45% of the network is surfaced with TSCS, which are currently the material of choice for any resurfacing work. Therefore, the ability to assess the potential resistance to ravelling of a TSCS prior to any re-surfacing works could be a useful material specification or quality criterion for those designing and specifying highway maintenance schemes. In this respect, a test able to discriminate between good and bad TSCS could be invaluable.

In June 2018, Arup AECOM Consortium was commissioned by Highways England (HE) to conduct Task 1-614. The title of the project is “Investigations for the Development of Simulative Test Methods for Durability of Thin Surface Course Systems”. The key project deliverables are detailed below:

- Sub-Task 1: Critical Review of DRaT Project Outputs
- Sub-Task 2: Devise the Test Programme
- Sub-Task 3: Execute the Test Programme
- Sub-Task 4: Results and Implementation
- Sub-Task 5: Project Management and Dissemination

Sub-Task 1: Critical Review of DRaT Project Outputs

Sub-Task 1 focussed on carrying out a critical review of the outputs and results of the Conference of European Directors of Roads (CEDR) Development of Ravelling Test (DRaT) project. This review included the evaluation of DRaT deliverables and the test methods reported in PD CEN/TS 12697-50. Data gathered from the DRaT report was evaluated and analysed to establish statistical significance of test equipment to discriminate between good and bad quality asphalt mixes and/or variants. Correlations between devices were proposed as well. The analysis and key findings from sub-task 1 provided a ranking matrix for DRaT ravelling devices. Sub-Task 1 also explored alternative tests available in the UK that could be used for assessing ravelling. Sub-task 1 has been published as a separate report for this project.

Sub-Task 2: Devise the Test Programme

Sub-Task 2 focussed on devising a test programme that explored possible ravelling test methods that can simulate failure mechanisms of typical Thin Surface Course Systems (TSCS) used on the SRN. The tests considered were those detailed in PD CEN/TS 12697-50. Alternative test equipment currently available in the UK were also considered. This sub-task identified relevant surfacing materials and information related to their failure mechanism, service life and performance. The key parameters considered in ascertaining variants for material selection for laboratory testing included the influence of TSCS to ravelling, and the impact of air voids content on the TSCS.

Sub-Task 3: Execute the Test Programme

Sub-Task 3 consisted of the programme execution. Highlights from this sub-task include: all samples manufactured at AECOM's specialist laboratory in Nottingham; with robust manufacturing methods and acceptance used. Contacts were made with the relevant laboratories to carry out ravelling tests; testing reports from laboratories have been collated for further analysis of the results.

Sub-Task 4: Results and Implementation

Sub-Task 4 focussed on the review and analysis of the results. Statistical significance of findings was evaluated, and correlations were made between the different sets of test equipment. Based on findings, recommendations were made on how the test might be incorporated into the MCHW and/or approval schemes to be used effectively. As part of this project, the team provided technical support and advice for reviewing Clause 942 and to further support Highways England.

This report details the work undertaken under Sub-Tasks 2, 3 and 4.

2. Sub-Task 1 – Critical Review of DRaT Project Outputs

In the initial phase (Sub-Task 1) of this project, a review and evaluation of the DRaT Project Reports and PD CEN/TS 12697-50 were carried out. The test methods reported in PD CEN/TS 12697-50 were evaluated and ranked with a focus on TSCS.

The critical review carried out led to the following key findings:

- Ravelling occurs in asphalt surfacing when the bond between binder and aggregate reaches a critical point. There are several factors, often interdependent, initiating and/or accelerating this mechanism;
- Air void content plays an essential role in the resistance to ravelling: porous asphalts are more prone to ravelling than dense asphalts. Aged asphalt (with more brittle bitumen) has a lower resistance to ravelling whereas very low correlations were found between ravelling and binder content, binder type and aggregate size;
- The protocol used to manufacture slabs produced very consistent samples. Visual inspection was the most critical acceptance criterion;
- To evaluate which of the PD CEN/TS 12697-50 would be the most suitable to discriminate between good and bad performing TSCS, an independent analysis was carried out using normalised results; overall, RSAT was found to be most suitable test to assess resistance to ravelling, followed by DSD (which has the advantage of being available in two laboratories);
- As an alternative method available in the UK: the Modified Scuffing Test follows similar principles to those stated in last version (2018) of PD CEN/TS 12697-50. Therefore, it was proposed as suitable test to assess the performance of good and bad TSCS in terms of resistance to ravelling.

Further details about the work undertaken for this sub-task are included in a separate report for this project.

3. Sub-Task 2 – Test Programme Development

3.1 Devise Test Plan

Based on findings from Sub-task 1, it was determined that air void content is a key factor influencing ravelling resistance of TSCS. Therefore, two asphalt mixtures were proposed. These mixtures were produced at 6% and 14% air voids content, to represent low and high air void contents, respectively.

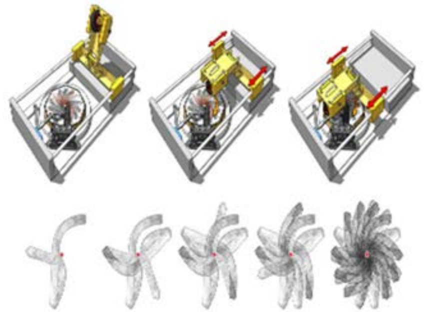
Among the tests reviewed in the DRaT project (Sub-task 1), the recommended for next stage were:

- RSAT
- DSD

The Modified Scuffing Test was also selected as alternative test to assess the performance of typical TSCS used in the UK produced at low and high air void contents.

Table 1 provides a summary of the main features of these devices and lists the laboratories where each device was available.

Table 1. Summary of the Test Devices proposed for Sub-Task 3

Test Devise	Darmstadt Scuffing Device (DSD)	Rotating Surface Abrasion Test (RSAT)	Modified Scuffing Test (ASI procedure)
Description	The asphalt specimen is attached in a fixture oscillating 180°, which is mounted on a horizontal table moving forwards and backwards. During this movement, a vertical load is applied though a tyre.	This test simulates the real condition of a tyre tread continuously deformed when in contact with the pavement. These deformations result in shear stress in the contact area. These stresses cause fatigue in the asphalt surface and lead, eventually, to aggregate loss.	This test consists of a loaded wheel which bears on a specimen held in a moving table with the axle of the wheel held at an angle of (20±1)°C to the vertical plane perpendicular to the direction of travel.
			
Laboratories	BRRC (Belgium) TU Darmstadt (Germany)	Heijmans (Netherland)	NTEC (UK)
Sample dimensions (mm):			
Length	260	500	305
Width	260	500	305
Min. Thickness	25	-	-
Max. Thickness	60	-	-
Core dimensions	Core samples not explicitly covered but can be tested[3]	Diameter[3] of 160±1 mm and height between 30 mm and 60 mm – three cores per test	Core samples not explicitly covered

Test Devise	Darmstadt Scuffing Device (DSD)	Rotating Surface Abrasion Test (RSAT)	Modified Scuffing Test (ASI procedure)
Conditioning	(40±1)°C for 2.5 h	Test temperature for 14 h to 18 h - Preloaded with ≥ 20 kg for ≥ 1 h	(60±1)°C for 4-6 h
Test temperature	(40±1)°C	(-10±1)°C to (25±1)°C with standard (20±1)°C	(60±1)°C
Other initial preparation	None specified	Removal of loose material	None specified
Initial measurements	Mass and photograph	Mass and photograph	Mass, Texture and photograph
Test loading[1]	(1000±10) N with a contact area of 33.3 cm^2 for an average contact pressure of 300 kPa	(35.0±0.1) kg with a contact area of 5.7 cm^2 for an average pressure of 600 kPa	(520±5) N with an average contact pressure of (310 ±10) kPa
Operation during test	Vacuuming of loose grains and wiping off as required	Removal of all loose material by vacuum cleaner	None specified
Test duration	16 cycles[2] (6 minutes)	86,600 passes (24 h)	5,000 passes
Final measurements	Photograph; Residue and loose grains from the asphalt specimen and the tyre	Aggregate loss after removal of rubber lost from tyre	Aggregate Loss, Texture and photograph
Comments	Developed for the measurement of Porous Asphalt (PA). However, it has the capability of testing SMA and very thin surface courses; Binder type has a greater influence if testing is completed at 40°C rather than 20°C	Tests can be prematurely ended by high stone loss	Tests can be prematurely ended by high damage to the tyre and/or sample

[1] The average pressure applied to the asphalt surface by each tyre of a typical tandem 10 tonnes axle load is 800 kPa (Hjort, Mattias, & Jansen, 2008) for an average contact area of 312.5 cm^2.

[2] Configuration used for the tests carried out for the DRaT project.

[3] Diameter requested by Heijmans laboratory.

A summary of the agreed test programme is given in Table 2.

Table 2. Matrix of Proposed Testing Plan for Sub-Task 3

		Test Devise	RSAT	DSD		Modified Scuffing Test
Material	**Variant**	Laboratory	Heijmans	TU Darmstadt	BRRC	NTEC
TSCS	**A) 6% Air Voids**	Samples	3 cores	4 slabs	4 slabs	4 slabs
	B) 14% Air Voids		3 cores	4 slabs	4 slabs	4 slabs

3.2 Asphalt mixture manufacturing method

The manufacturing method included the production of all samples in a single laboratory (AECOM Nottingham laboratory) to reduce the variability between specimens. The method to prepare each batch of samples is described below:

- Use of pre-coated close-graded surface courses Stone Mastic Asphalt (SMA) 10 surf 40/60 satisfying the requirements of MCHW Clause 942.
- Manufacturing of asphalt slabs targeting two different variants on air void content:
  A. SMA with nominal air voids content of 6%;
  B. SMA with nominal air voids content of 14%.
- Pre-heating of the material and mixing with suitable equipment.
- Pouring into moulds of the required size (305 mm x 400 mm x 50 mm).
- Compacting the material according to BS EN 12697-33 (2019). Using two A3 sheets sprayed with silicone lubricant and placed over the top of the mould to prevent the compaction arm from sticking to the asphalt in the mix creating voids in the slab.
- Monitoring the temperature constantly during the production and compaction process.
- Assessing the quality on the dimensions, flatness and density. The acceptance criteria are detailed in Section 3.3.

3.3 Acceptance Criteria

To ensure that the samples are uniform and acceptable, the following criteria were applied:

- The difference in the thickness of the slabs must not exceed one millimetre. This must be measured using a calliper at eight locations for each slab;
- To control the slab manufacturing quality in terms of density, from the initial slabs compacted for each variant cores should be extracted allowing for an accurate determination of the air voids content: Method C of BS EN 12697-6 (2012);
- Visual inspections should look for evidence of fatting, poor coating of the aggregate materials and irregular distribution of the asphalt slab mix at the edges.

4. Sub-Task 3 – Test Programme Execution

4.1 Sample Manufacturing

The sample preparation involved the manufacturing of asphalt slabs, with dimensions of 305 mm x 400 mm x 50 mm – each slab to be cut to the dimensions required from the ravelling tests selected (i.e. DSD, RSAT and Modified Scuffing Test).

The material used was pre-coated close-graded surface courses SMA 10 surf 40/60 provided in bags of 20 kg each. This material satisfies the requirements of MCHW Clause 942.

This SMA was used to manufacture asphalt slabs with 2 different levels (variants) of air voids content (also referred to A and B in the report):

A. SMA with nominal air voids content of 6%;

B. SMA with nominal air voids content of 14%.

For each of these asphalt variants (A and B), one slab was produced to ensure that the volumetric properties were in line with the specifications (6% and 14%).

The asphalt slabs were produced in accordance with BS EN 13108-5 (2016). The pre-coated SMA was pre-heated and placed into the laboratory asphalt mixer (Figure 1). A Josef Freundl GZM-30+ Mixer was used. This mixer is specifically designed to replicate mixing in a typical batch mix asphalt plant.

Figure 1: Laboratory Mixer GZM-30+

The mixed material was then placed in the mould. The quantity was pre-determined to ensure that the required volumetric properties were met. The mould was placed on the bed of the roller compactor, as shown in Figure 2. Compaction was carried out in accordance with BS EN 12697-33 (2019).

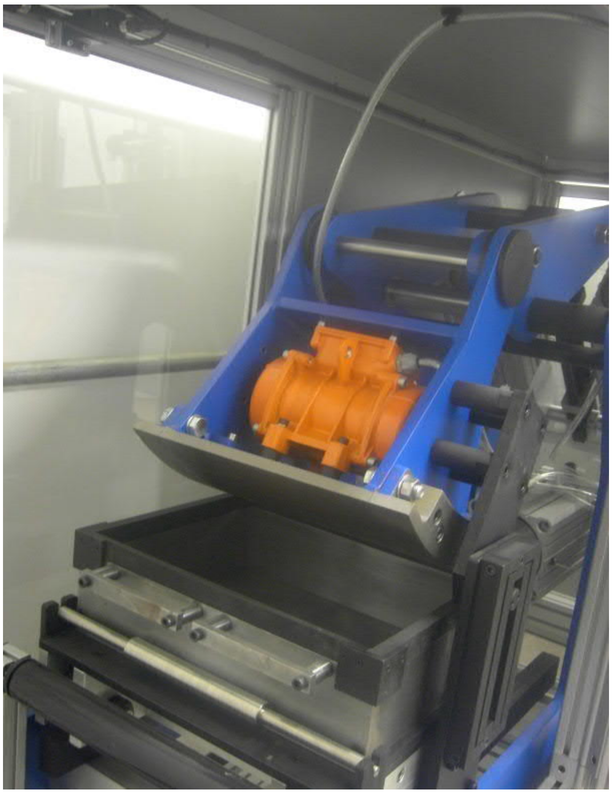


Figure 2: Laboratory Roller Compactor

Figure 3 shows an example of compacted slab inside the mould. A total of 40 asphalt slabs (20 slabs for each asphalt variant) were produced for this project (Figure 4).

Figure 3: Slab Manufacturing: Compacted Slab

Figure 4: Overview of Asphalt Slabs before Acceptance

Following production of the asphalt samples, visual condition inspection was carried out to ascertain if there was evidence of fatting, poor coating of the aggregate materials and irregular distribution of the asphalt slab mix at the edges.

The slabs which passed this visual condition inspection were selected to be cut/cored to the dimensions required for the DSD, the RSAT and Modified Scuffing testing as detailed in (Table 1).

4.2 Volumetric Measurements

To ensure that the volumetric properties were in line with the specifications (6% and 14%), one slab for each asphalt variant (A and B) was produced. From this slab 4 cores of 100 mm diameter were extracted.

For each core the air voids content was determined according to Method C of BS EN 12697-6 (2012). The results, summarised in Figure 5, satisfied the acceptance criteria set in Section 3.3.

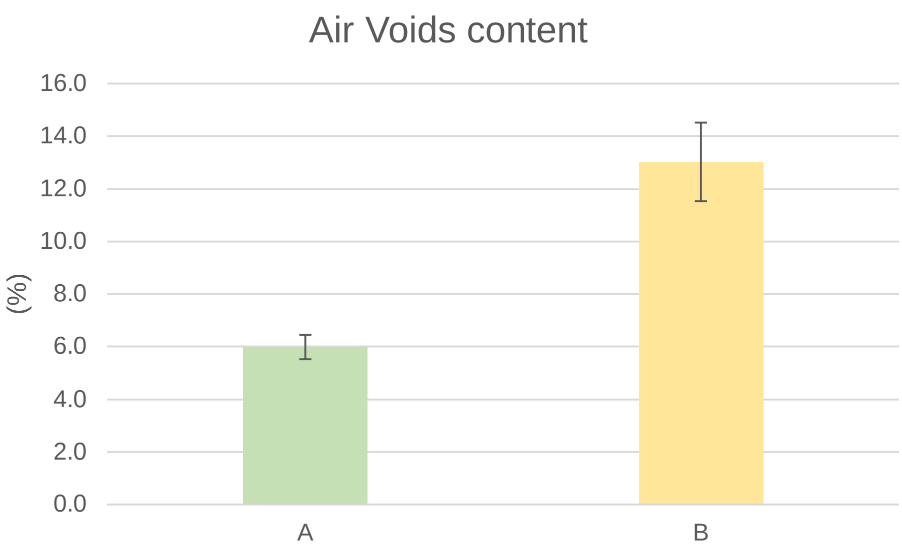


Figure 5: Air Voids Content for Variants A and B determined as Average of 4 Cores Extracted per Each Slab (the Error Bars display the Standard Deviation)

Volumetric measurements have been carried out also on the samples selected after the visual assessment. In this case the Method D of BS EN 12697-6 (2012) had to be used to determine the air voids content. Results are shown in Appendix A.

4.3 Sample Shipping

The samples which met all the acceptance criteria were selected for the ravelling tests in line with the scope for this project. Packing was carried out in AECOM Nottingham Laboratory ensuring adequate protection for each sample was in place (Figure 6). As a precautionary measure, additional samples (1-2 for each variant) were sent to the laboratories. The shipping details are reported in Table 3.

Table 3. Sample Shipping Details

Reference	Address
RSAT	Heijmans Infra Laboratorium Att. Patrick van Osch Graafsebaan 3 5248 JR Rosmalen Netherlands
DSD BRRC	BRRC Fokkersdreef 21 B-1933 Sterrebeek Belgium
DSD Darmstadt	TU Darmstadt, Institut für Strassenwesen, Gruppe Versuche u. Analysen Gebäude L1 02 Jovanka-Bontschits-Strasse 2 64287 Darmstadt Germany
Modified Scuffing Test	Nottingham Transportation Engineering Centre (NTEC) Pavement Research Building University Park Nottingham, NG7 2RD UK

Figure 6: Overview of Boxes containing the Samples prior shipping

4.4 DSD BRRC Testing Report

The report and procedures provided by the testing team at BRRC are detailed below:

- The samples were received by the BRRC laboratory on the 21st March 2019.
- All samples were reported as being in good condition.
- Prior to testing, the length and width of each slab were measured in four positions. Thickness was measured in eight positions evenly spaced around the perimeter, approximately 1 cm from the saw cuts. Mass and density were also determined according to Method D in EN 12697-6.
- The scuffing tests were carried out with the 'Darmstadt Scuffing Device' (DSD, see Figure 7) described in PD CEN/TS 12697-50, Annex B, with the only deviation of carrying out 16 cycles instead of 10, consistent with DRaT project.
- The specimens were heated to the required testing temperature by placing them in an oven for at least three hours. The fixture for the slabs in the DSD was also pre-heated to the testing temperature. The specimens were fixed into the DSD, in the heated fixture. The surface temperature of the specimen was checked in three spots with an infrared thermometer. The average was not allowed to deviate more than 2°C from the required test temperature; if it did, the specimen was placed back in the oven to bring it to temperature.
- The tyre (pressure: 3 bars) was lowered onto the slab and a static load of 1,000 N was applied. As soon as this load level was achieved, the test was started by oscillating and moving back and forth the slab in the horizontal plane, thus generating forces under the tyre that simulated the effect of shearing traffic.
- After four cycles, the movement was stopped and the tyre was raised, to allow vacuuming of the loose grains. The vacuumed material was weighed. The latter three steps were repeated until a total of sixteen cycles had been completed.
- All tests were performed in the period from 25th March through 1st April 2019. No deviations from instructions have been reported/observed.

- Overall, results showed a difference in terms of mass loss between mixture A and mixture B: The mixture with the lowest air voids content exhibited the best results (lower mass loss) in this scuffing test. The full results report provided by BRRC is attached in Appendix B.

Figure 7: BRRC's Ravelling Tester, type 'Darmstadt Scuffing Device'

4.5 DSD TU Darmstadt Testing Report

The report and procedures provided by the testing team at TU Darmstadt are detailed below:

- The samples were received by the Darmstadt laboratory on the 22nd March 2019.
- All samples were reported as being in good condition.
- The scuffing tests were carried out with the 'Darmstadt Scuffing Device' described in PD CEN/TS 12697-50, Annex B. The same procedure followed by BRRC was used by TU Darmstadt laboratory with only 1 difference: 10 cycles instead of 16 have been carried out.
- All tests were performed between the 3rd and 4th of April 2019. Overall, the results of the scuffing test lead to different mass loss depending on the tested asphalt mixture. The cumulative mass loss after ten double shear load cycles varied for asphalt mixture A between 6.0 g and 20.6 g. On average, the cumulative mass loss was 11.3 g. In comparison to the other tested asphalt, mixture A demonstrated very low scuffing. The cumulative mass loss after ten double shear load cycles varied for asphalt mixture B between 43.7 g and 104.1 g. On average, the cumulative mass loss was 63.0 g. In comparison to the other tested asphalt, mixture B produced a high amount of mass loss.
- One example for each asphalt variant of sample appearance before and after testing is given in Figure 8. The full results report provided by TU Darmstadt is attached in Appendix C.

A5

Before Testing **After Testing**

B6

Before Testing **After Testing**

Figure 8: Comparison of the surface of Samples A5 and B6 between before and after performing the Scuffing Test with the DSD

4.6 RSAT Testing Report

The report and procedures provided by the testing team at Heijmans laboratory are detailed below:

- The samples were received by the Heijmans laboratory on the 26th March 2019.
- All samples were reported as being in good condition.
- All tests were performed in the period from 9th April to the 10th April 2019. The scuffing tests were carried out with the RSAT device as described in PD CEN/TS 12697-50, Annex C. In this case, three cores, having 160 mm diameter, were tested per each asphalt variant (A or B). The temperature was constantly monitored over the test duration (24h).
- The visual appearance of the A and B samples after the tests is given in Figure 9. The full results report provided by Heijmans is attached in Appendix D.
- The results showed very little damage to the cores, although samples B exhibited double mass loss (0.6 g) than samples A (0.3 g). This is in line with what expected from the two variants (A performing better than B) and comparable to the mass loss exhibited by the SMA samples in the DRaT project.

- In an attempt to increase the damage to a similar level as that shown in the DSD testing and have a better absolute discrimination between the variants, the tests were repeated with a load increased by 50%. However, no significant difference with the standard load configuration was observed.

Figure 9: Plate 2 (Samples A) and Plate 1 (Samples B) after RSAT Testing

4.7 Modified Scuffing Test Report

The report and procedures provided by the testing team at NTEC laboratory are detailed below:

- The samples have been delivered to the NTEC laboratory on the 11th July 2019.
- All samples were reported as being in good condition.
- All tests were performed in the period from the 12th July to the 13th August 2019. The tests have been carried out according to the TRL Report 176 (Appendix G) procedure and BBA Guidelines (BBA HAPAS SG1 Guidelines, 1997), modified by ASI (ASI Solutions Ltd, 2019).
- The main modifications introduced by ASI are:

  A. Test temperature at 60±1°C

  B. Test duration: 5,000 passes
- The tests carried out under these conditions presented the following issues (as detailed in the full report attached in Appendix E):
  - For all the tests carried out on the A (6% Air Voids) samples, the tyre wore out after 5,000 passes. An overview of the samples post testing is given in Figure 10.
  - For all the tests carried out on the B (14% Air Voids) samples, the tyre burst prematurely (at passes ranging from 422 to 2532).
  - Therefore, a new scuffing wheel was used for each test.

Figure 10: Overview of Samples A after the Modified Scuffing Test

5. Sub-Task 4 – Results Analysis

5.1 Test Results

5.1.1 Normalisation of Results

To allow for objective comparison and correlation between devices, laboratories, and material variants, all results have been normalised and expressed as 'mass loss (g) per unit surface area (m^2)', as follows:

$$Mass\ loss\ per\ unit\ surface\ area(g/m^2) = mass\ loss\ (g)/sample\ area\ (m^2)$$

Table 4 shows an example of normalisation of scuffing test results and the statistics for each variant.

Table 4. Normalisation of DSD Results from TU Darmstadt Laboratory

		Cycles						Cycles					
		0	2	4	6	8	10	0	2	4	6	8	10
Sample	Area (m^2)	Cumulative Mass Loss (g)						Cumulative Mass Loss (g/m^2)					
A05	0.067	0.0	0.5	2.2	2.9	5.1	8.1	**0.0**	**7.5**	**32.9**	**43.4**	**76.4**	**121.3**
A08	0.068	0.0	0.6	2.4	3.4	4.0	6.0	**0.0**	**8.9**	**35.5**	**50.2**	**59.1**	**88.6**
A14	0.068	0.0	2.4	5.9	9.0	14.5	20.6	**0.0**	**35.4**	**86.9**	**132.6**	**213.7**	**303.6**
A15	0.067	0.0	1.1	3.4	6.3	8.2	10.6	**0.0**	**16.3**	**50.5**	**93.5**	**121.7**	**157.3**
A - Average	0.067	0.0	1.2	3.5	5.4	8.0	11.3	**0.0**	**17.0**	**51.4**	**79.9**	**117.7**	**167.7**
A – SD[1]	0.000	0.0	0.9	1.7	2.8	4.7	6.5	**0.0**	**12.8**	**24.9**	**41.5**	**69.2**	**94.8**
B05	0.067	0.0	12.6	27.5	57.7	77.2	104.1	**0.0**	**188.1**	**410.6**	**861.5**	**1152.6**	**1554.3**
B06	0.067	0.0	4.2	13.9	22.3	34.4	45.8	**0.0**	**62.4**	**206.5**	**331.3**	**511.1**	**680.5**
B08	0.067	0.0	5.0	17.6	29.4	44.4	58.2	**0.0**	**74.3**	**261.5**	**436.9**	**659.8**	**864.8**
B14	0.068	0.0	3.2	9.7	14.5	28.9	43.7	**0.0**	**47.3**	**143.4**	**214.4**	**427.3**	**646.1**
B -Average	0.067	0.0	6.3	17.2	31.0	46.2	63.0	**0.0**	**93.0**	**255.5**	**461.0**	**687.7**	**936.4**
B - SD	0.000	0.0	4.3	7.6	18.8	21.6	28.2	**0.0**	**64.3**	**114.1**	**282.0**	**324.5**	**422.9**

[1] SD denotes the Standard Deviation

5.1.2 DSD Results

The normalised DSD results from TU Darmstadt are reported in Figure 11. Results from BRRC DSD are reported in Figure 12.

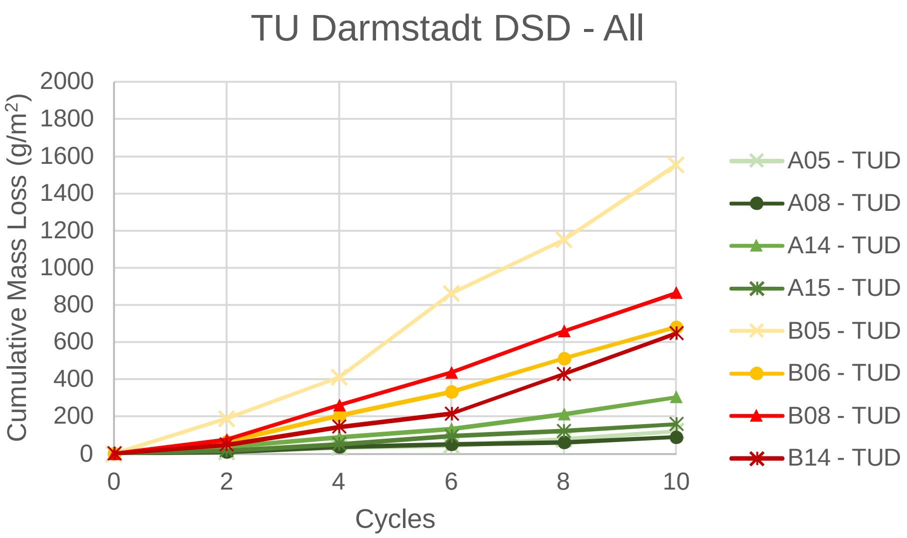


Figure 11: Normalised DSD Results from TU Darmstadt

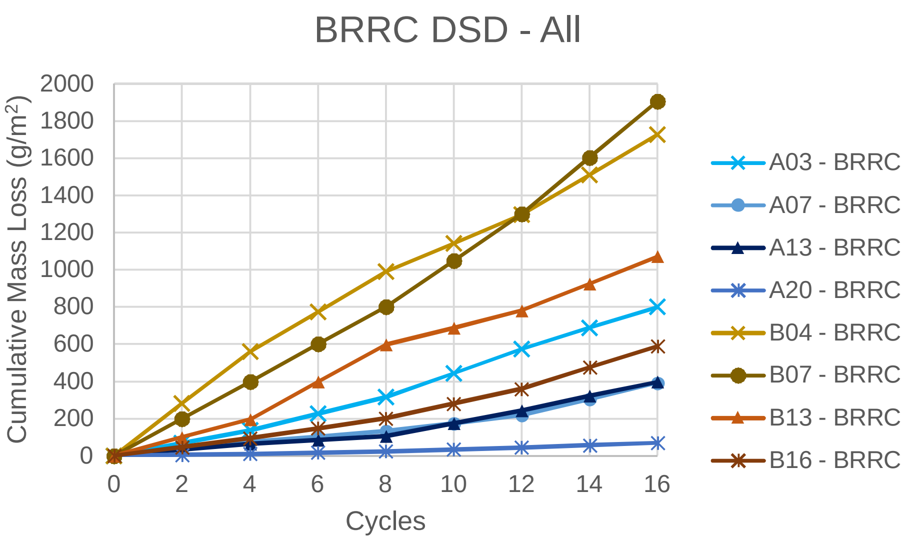


Figure 12: DSD Results from BRRC (Results at Cycles 2, 6, 10 and 14 are linearly interpolated)

Figure 13 and Figure 14 compare DSD results obtained from TU Darmstadt and BRRC laboratories for the asphalt variants A and B, respectively. It can be noted that both DSD equipment provided cumulative mass loss within similar ranges for each asphalt variant. This confirms the good reproducibility observed for this test as reported in Sub-Task 1.

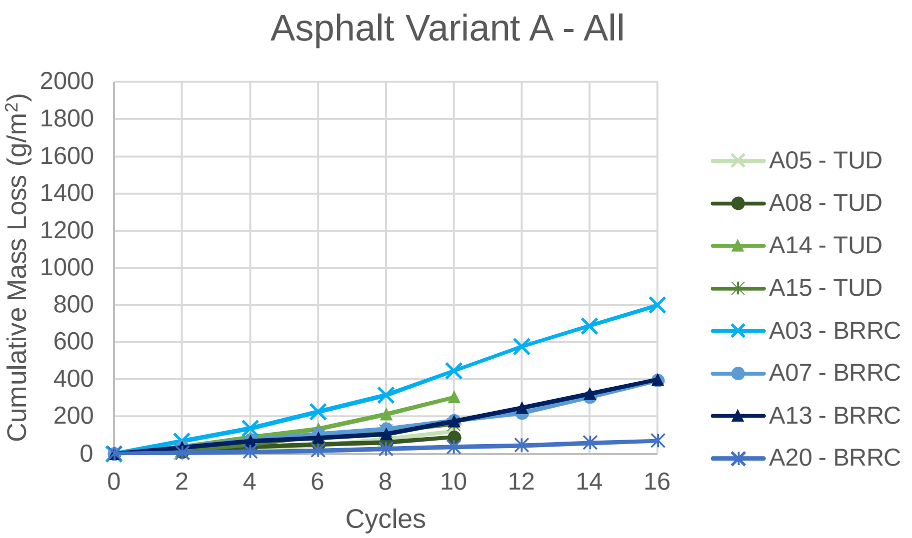


Figure 13: DSD Results from TU Darmstadt and BRRC for Asphalt Variant A only

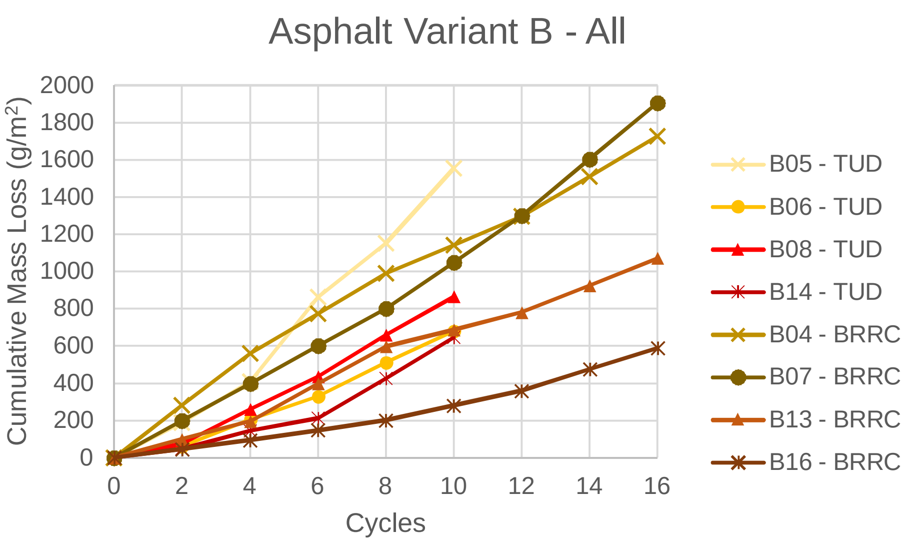


Figure 14: DSD Results from TU Darmstadt and BRRC for Asphalt Variant B only

Results from all DSD tests have been averaged to compare the outcome obtained from each laboratory and each asphalt variant, as reported in Figure 15.

A difference in mass loss can be observed between the standard voids TSCS variant (6% - A) and the high voids TSCS variant (14% - B). This finding was determined by both laboratories, confirming the good reproducibility of the DSD test.

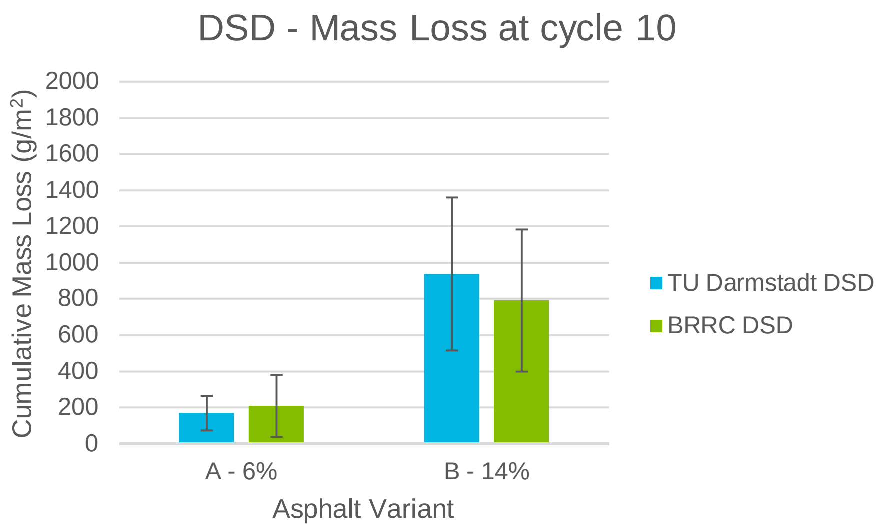


Figure 15: Average Results for Asphalt Variants A and B for DSD Testing carried out in TU Darmstadt and BRRC

5.1.3 RSAT Results

The normalised RSAT results from Heijmans laboratory are reported in Figure 16.

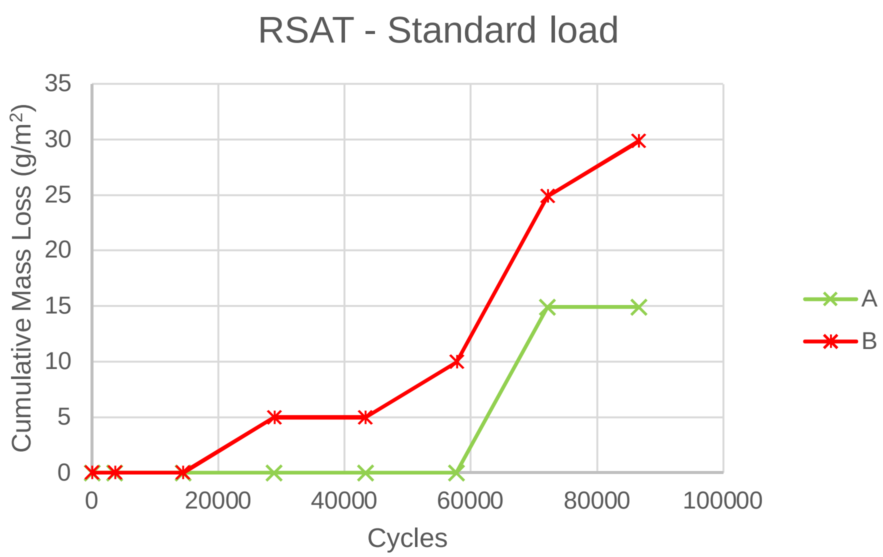


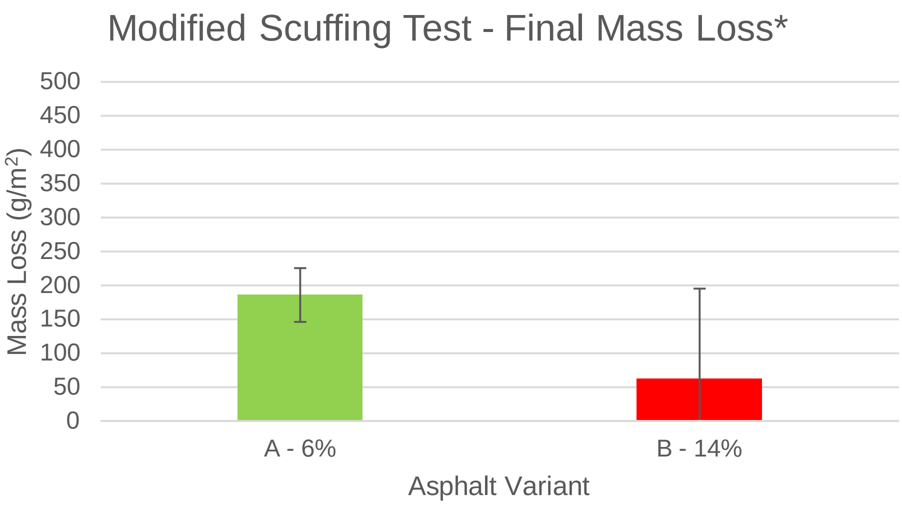
Figure 16: Normalised Results for Asphalt Variants A and B for RSAT Testing

It can be observed that the RSAT results showed lower mass loss in comparison to the DSD test equipment. Nonetheless, the overall trend for the RSAT showed that the lower voided samples (A) had better resistance to ravelling than the higher voided samples (B). This is in line with the findings from the DSD.

Because of the relatively low mass loss, the same tests have been repeated with a 50% increased load, all the other parameters being the same. Nevertheless, the results did not show any significant difference with the standard loading.

5.1.4 Modified Scuffing Test Results

The normalised Modified Scuffing Test results from NTEC laboratory are reported in Figure 17.



*For all the tests carried out on the B (14% Air Voids) samples, the tyre had burst prematurely (at passes ranging from 422 to 2532)

Figure 17: Normalised Results for Asphalt Variants A and B for the Modified Scuffing Test

It can be noted that the mass loss (after 5000 passes) for material A is comparable to that observed for material A after DSD test.

The tests carried out on material B had to be stopped prematurely because the wheel tyre burst. It is worth noting that the longest test ended at cycle 2532 and had a mass loss of 260 g/m^2 (higher than all A samples) whereas all the other tests had a shorter duration.

Based on these outcomes, the following considerations can be drawn:

- The Modified Scuffing Test performed with the current conditions and equipment appears not to be suitable for testing the resistance to ravelling of TSCS.
- If a more resistant wheel is used, this test is deemed to produce results comparable to DSD (based on partial results observed).

5.2 Statistical Analysis

A statistical analysis was carried out to evaluate the following:

- Discrimination – establishing significant differences to discriminate between good and bad mixtures;
- Reproducibility (DSD equipment only);
- Correlation – looking at the rate of ravelling between the test equipment assessing whether conversion factors can be used.

5.3.1 Discrimination

The ability of each device to differentiate between variants of the same material was evaluated on the basis on the normalised results.

A hypothesis test using a two-sample T-test (α = 0.05) was used to determine whether two population means are different (Minitab Inc., 2010):

- The null hypothesis, H_0, was that the sample A (6%) mean is equal to the sample B mean (14%);
- The alternative hypothesis, H_1, was that the sample A (6%) mean is NOT equal to the sample B mean (14%).

The test statistic is $T = \frac{\overline{X_1}-\overline{X_2}}{S_P\sqrt{\left(\frac{1}{n_1}+\frac{1}{n_2}\right)}}$, where S_P^2 is the pooled estimator of the common variance. The null distribution of T is $t(n_1 + n_2 - 2)$. Table 5 below provides a rough guide to interpreting the significance probabilities obtained from this distribution.

This method helped to evaluate whether there is enough evidence to conclude that different TSCS variants had a different resistance to ravelling. This analysis was undertaken for each test method (when applicable).

The discrimination power for each device are summarised in Table 5.

Table 5. Summary of Statistical Analysis carried out on Normalised Results

Test Devise	Darmstadt Scuffing Device (DSD)		Rotating Surface Abrasion Test (RSAT)	Modified Scuffing Test
Laboratories	TU Darmstadt	BRRC	Hejimans	NTEC
n: Observations	4	4	1	4
Sp^2: Pooled estimator of the common variance	939331	228874	N/A	N/A
T: Test Statistic	-3.547	-2.685	N/A	N/A
p: Significance probability	**0.006**	**0.017**	**N/A**	**N/A**

Results interpretation:

Significance probability	Rough Interpretation
$p > 0.10$	Little evidence against H_0
$0.10 \geq p > 0.05$	Weak evidence against H_0
$0.05 \geq p > 0.01$	Moderate evidence against H_0
$p \leq 0.01$	Strong evidence against H_0

This analysis indicates that for both DSD devices there is moderate to strong evidence against the null hypothesis. In other words, the mean of sample A is not equal to the mean of sample B. Therefore, DSD can discriminate between good and bad TSCS.

5.3.2 Reproducibility (DSD equipment only)

A typical reproducibility study in the manufacturing industry requires three operators (laboratories), two repetitions and ten samples. In this case, there are only two laboratories (for DSD device), four repetitions and two samples. The commonly used ANOVA analysis therefore would not be statistically significant.

In this case, it was considered more appropriate to run a hypothesis test using a two-sample T-test ($\alpha = 0.05$) which is more common for comparing results coming from two laboratories. The following hypothesis were used to determine whether two population means are different (Minitab Inc., 2010):

- The null hypothesis, H_0, was that the mean of sample A (or B) from TU Darmstadt is equal to the mean of sample A (or B) from BRRC;
- The alternative hypothesis, H_1, was that the mean of sample A (or B) from TU Darmstadt is NOT equal to the mean of sample A (or B) from BRRC.

The results showed P-values (significance probability) of 0.696 and 0.631 for asphalt variants A and B, respectively. As per the interpretation of Table 5, this means that there is (in both cases A and B) little evidence against the null hypothesis. Therefore, DSD testing on TSCS can be considered having a good reproducibility between laboratories.

5.3.3 Correlation

Results obtained from different devices have been compared to establish whether correlation/scaling factors could be used.

For each asphalt mixture, scaling factors were calculated based on the final mass loss (averaged for each variant) per unit surface area obtained from each device.

Figure 18 shows the correlation between DSD TU Darmstadt and DSD BRRC. In this case, a scaling factor of 0.86~1 can be proposed.

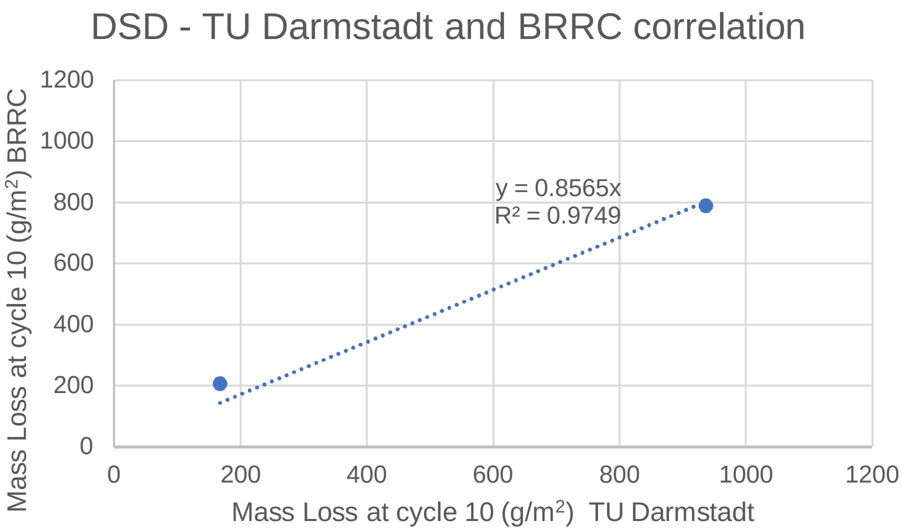
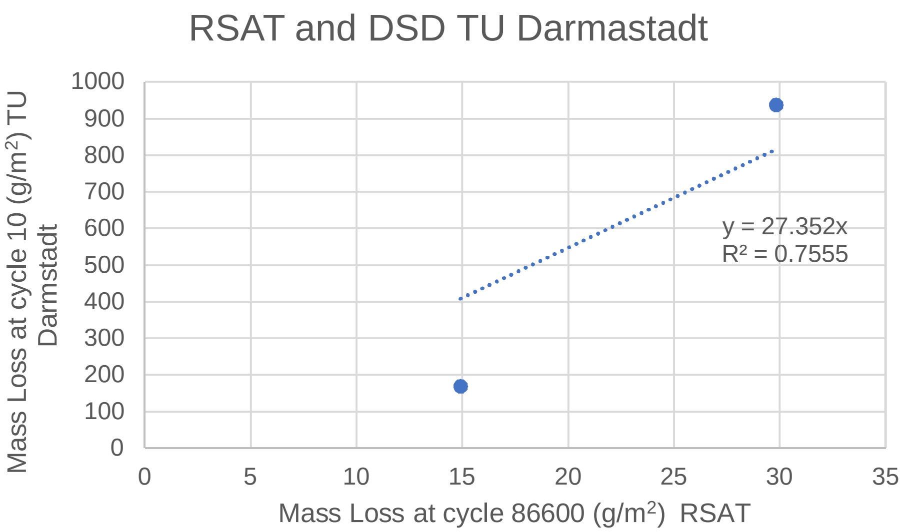


Figure 18: Correlation between DSD TU Darmstadt and DSD BRRC

Figure 19 shows the correlation between DSD devices and RSAT. The scaling factor ranges between 24 and 27, therefore, a scaling factor of ~25.5 can be proposed when comparing results from these two devices.



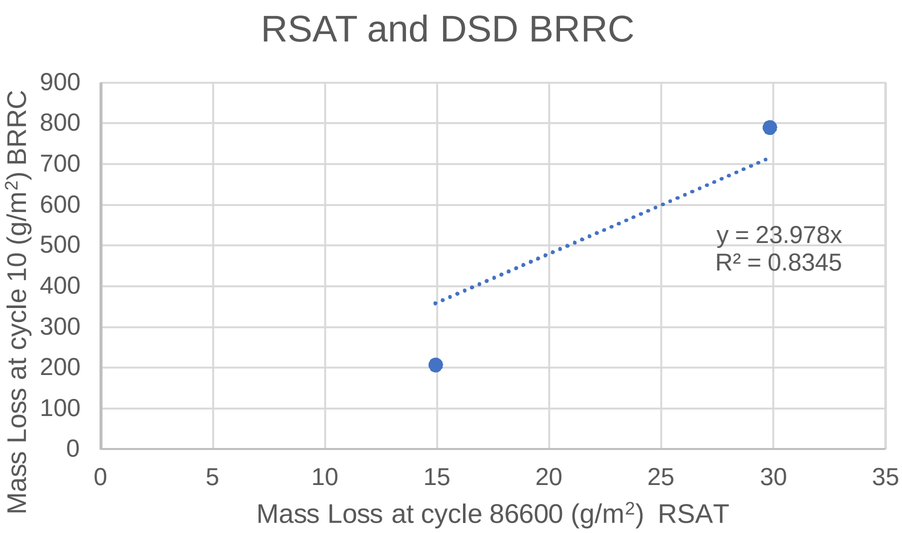


Figure 19: Correlation between DSD Devices and RSAT

The Modified Scuffing Test could be correlated with the other devices only considering results from material A. In this case, a scaling factor ranging from 0.9-1.1 (~ 1.0) could be established with the DSD. Thus, when comparing Modified Scuffing Test results with RSAT, the same scaling factor proposed for DSD (~25.5) can be used,

It is worth stating that these scaling factors could only be evaluated for a single material, i.e. TSCS. However, as found from the analysis carried out in Sub-Task 1, these could change significantly based on the material tested. Therefore, these scaling factors are valid only for tests carried out with similar conditions and materials, and cannot be generalised.

6. Conclusions

This report details the work undertaken under Sub-Tasks 2, 3 and 4. The aim of these sub-tasks was to develop and execute the test programme and analyse the results. These are part of an overarching project commissioned by Highways England (HE): Task 1-614.

The main conclusions from this part of the project can be summarised as follows:

- Based on the findings from the initial phase (Sub-Task 1) of this project, the air void content was determined as the key factor influencing ravelling resistance of Thin Surface Course Systems (TSCS). Therefore, two TSCS variants were proposed for the next stages, having 6% and 14% air void content, to represent good and poor compaction, respectively.
- Among the tests reviewed in the DRaT project, the recommended devices for next stage were RSAT and DSD. In addition, the Modified Scuffing Test was considered the most suitable alternative test available in the UK.
- To reduce the variability between specimens, all specimens were produced in a single laboratory: AECOM Nottingham laboratory. Based on the DRaT project methodology, the in-house protocol used to manufacture and assess the acceptability of slabs produced very consistent samples.
- In order to control the slab manufacturing quality in terms of targeted air voids, the first slab compacted per each variant was used to extract 4 cores (100 mm diameter), allowing for an accurate determination of the air voids content using Method C of BS EN 12697-6. The air void results satisfied the acceptance criteria set.
- The samples were delivered to the relevant laboratories in good condition.
- Results obtained from the four laboratories have been normalised and expressed as mass loss (g) per surface unit (m^2), to allow for objective comparison and correlation between devices, laboratories, and material variants.
- Results originating from two different laboratories using DSD (BRRC and Darmstadt) were comparable in terms of amplitude (mass loss) and outcome (TSCS good vs. bad). Thus, DSD can be considered a highly reproducible test.
- The DSD testing procedure also produced an appreciable outcome in terms of mass loss, ranging from 6 g to 104 g, depending on the TSCS tested. This allowed for confident discrimination between good and bad TSCS in terms of resistance to fretting.
- Therefore, the DSD testing was found to be very suitable to assess ravelling of TSCS.
- The RSAT testing, which was determined as the most suitable for the materials tested in the DRaT project, produced very little damage (0.3 g to 0.6 g) to the cores manufactured for this project. This might be related to the use of the core configuration instead of the slab configuration.
- Nevertheless, the results still indicated the samples A (6% air voids) to perform better than the samples B (14% air voids), in line with what expected.
- The results of Modified Scuffing Test on A samples are comparable to that observed for A samples after DSD test. However, B samples results could not be objectively compared since the wheel tyre burst in the course of the test, and testing was ended prematurely.
- Therefore, the Modified Scuffing Test performed with the current conditions and equipment appears not to be suitable for testing the resistance to ravelling of TSCS. However, if a more resistant wheel is used, this test may produce results comparable to the DSD (based on partial results observed).

- Correlation analysis suggested that a scaling factor of approximately 25.5 should be used when comparing RSAT with DSD and Modified Scuffing Tests results for TSCS – although these factors have been obtained for a single material only and cannot be generalised.

7. Recommendations

The review and testing reported in this paper indicated that ravelling is one of the major mechanisms of distress of TSCS in the UK. The ability to assess the potential resistance to ravelling of a TSCS prior to any re-surfacing works could be a useful material specification or quality criterion for those designing and specifying highway maintenance schemes. The selection of higher quality material, that is less prone to ravelling, could lead to significant lifecycle cost savings – both economic and environmental - as well as resulting in a smoother and safer ride for road users. In this respect, a test able to discriminate between good and bad TSCS would be a useful tool for Highways England to make greater use of.

The next steps for further development and adoption of fretting tests in UK are recommended below:

- This project found the Darmstadt Scuffing Device (DSD) specified in Annex B of PD CEN/TS 12697-50 (2018) to be the most suitable to assess the resistance to fretting of TSCS used in the UK. This test is recommended to be used going forward.
- A quotation for DSD device has been requested and received from the company manufacturing this equipment (Infratest). Four months are needed for the equipment delivery. Purchase of the device is recommended so that resistance to fretting tests can be undertaken more frequently and easily in England.
- The test kit could either be used to test fresh samples of Cl.942 materials in the course of Product Acceptance Schemes. These samples can be either laboratory compacted from loose coated asphalt collected from site or cores with a minimum 370 mm diameter taken from site.
- DSD results would build the evidence base on (a) recently failed surface courses, (b) recently laid surface courses, (c) surface courses which have been in service that have so far demonstrated good resistance to ravelling. The tests could be used together with binder rheology testing to assess the impact of ageing to ravelling potential.
- Novel materials and those that have been subjected to accelerated ageing protocols could also be tested to give an indication of future performance.
- A minimum of four samples per each material type/variant is recommended to be tested to obtain statistical significance in the results.
- As the project explored only one material so far, for the next step it is recommended to widen the scope to include more types of asphalt surfacing used in the UK network, such as Hot Rolled Asphalt (HRA) and Cold Applied Ultra Thin Surfacing (CAUTS).
- For each type of surfacing tested, typical air voids contents of laid materials should be used.
- The data collected should be used to establish mass loss thresholds to assess surfacing suitability and/or durability once a significant number of representative samples have been tested.
- Ultimately use of test method BS EN 12697-50 could be more extensively adopted in England. It could be considered as a further criterion for Product Acceptance Schemes for TSCS in the future, once a sufficient evidence base has been established and suitable thresholds have been set.

8. References

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Appendix A – Volumetric Measurements of the Samples selected for DSD Testing

Sample	Date	Length 1 (mm)	Length 2 (mm)	Length 3 (mm)	Average Length (mm)	Width 1 (mm)	Width 2 (mm)	Width 3 (mm)	Average Width (mm)	Height 1 (mm)	Height 2 (mm)	Height 3 (mm)	Average Height	Volume (cm^3)	Mass (g)	Bulk density (g/cm^3)	Air Voids Content (%)
A03	14/03/2019	259.3	260.2	260.2	**259.9**	261.3	260.9	260.7	**261.0**	48.9	48.2	48.8	**48.6**	3298.6	7868.9	2.386	**2.91**
A05	14/03/2019	258.9	258.4	258.1	**258.5**	258.3	258.7	258.3	**258.4**	48.7	48.5	48.1	**48.4**	3235.2	7794.4	2.409	**1.94**
A07	14/03/2019	259.8	260.2	260.5	**260.2**	259.8	259.6	259.2	**259.5**	48.3	48.9	48.8	**48.7**	3286.1	7786.4	2.370	**3.56**
A08	14/03/2019	261.2	260.5	260.2	**260.6**	259.9	259.8	259.5	**259.7**	48.9	48.2	48.3	**48.5**	3281.0	7801.6	2.378	**3.22**
A13	14/03/2019	260.1	260.8	260.5	**260.5**	260.3	260.3	260.6	**260.4**	49.4	49.4	48.8	**49.2**	3337.0	7788.4	2.334	**5.01**
A14	14/03/2019	259.7	259.4	260.0	**259.7**	261.4	261.2	261.3	**261.3**	49.0	49.3	49.6	**49.3**	3345.5	7874.6	2.354	**4.20**
A15	14/03/2019	260.1	259.9	259.6	**259.9**	259.0	259.1	259.8	**259.3**	50.0	49.1	49.4	**49.5**	3335.5	7731.9	2.318	**5.65**
A20	14/03/2019	260.1	261.0	260.8	**260.6**	260.3	260.4	260.2	**260.3**	47.8	48.6	47.9	**48.1**	3263.2	7842.5	2.403	**2.19**
B04	14/03/2019	261.9	261.0	261.1	**261.3**	258.7	259.0	259.1	**258.9**	48.4	48.0	48.0	**48.1**	3257.1	7222.8	2.218	**9.74**
B05	14/03/2019	258.5	258.5	259.2	**258.7**	259.2	258.7	258.7	**258.9**	48.3	48.5	48.9	**48.6**	3252.9	7029.9	2.161	**12.04**
B06	14/03/2019	259.6	259.1	260.4	**259.7**	259.1	259.9	258.5	**259.2**	48.0	47.5	47.9	**47.8**	3217.2	7235.7	2.249	**8.46**
B07	14/03/2019	260.2	260.1	260.5	**260.3**	259.5	259.0	259.6	**259.4**	48.2	48.5	48.9	**48.5**	3276.2	7163.3	2.186	**11.01**
B08	14/03/2019	259.6	258.9	259.0	**259.2**	259.8	259.8	259.4	**259.7**	47.4	47.7	47.7	**47.6**	3203.3	7109.7	2.219	**9.67**
B13	14/03/2019	260.6	260.4	260.5	**260.5**	260.5	259.8	260.4	**260.2**	48.0	47.4	47.9	**47.8**	3238.1	7172.6	2.215	**9.85**
B14	14/03/2019	259.7	260.0	260.2	**260.0**	260.3	260.3	259.9	**260.2**	46.6	47.2	47.5	**47.1**	3185.6	7297.5	2.291	**6.77**
B16	14/03/2019	260.8	260.5	260.6	**260.6**	259.9	260.0	260.0	**260.0**	47.9	48.0	47.9	**47.9**	3247.8	7331.8	2.257	**8.12**

It can be noted that the maximum difference in the thickness of the slabs was lower than one millimetre, therefore the acceptance criterion was met.

The air void contents measured according to BS EN 12697-6 Method D slightly differ from those measured from the cores, as expected from the lower accuracy of this method.

Appendix B – Belgian Road Research Centre (BRRC), DSD Results Report

Belgian Road Research Centre
Your partner for sustainable roads

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Our ref.: RE-EP-012060-1/3232

STERREBEEK, April 2, 2019

TEST REPORT RE-EP-012060-1

Scuffing tests on two mixtures

TESTING ORGANIZATION

Belgian Road Research Centre
Boulevard de la Woluwe 42
B-1200 BRUSSELS

DOCUMENT

RE-EP-012060-1/3232 of 2nd April 2019, comprising 6 pages (+ 1 annex).

WARNING

Our test reports are only valid in their unabridged versions and only relate to the products tested. Any reproduction – even partial – of this report shall be subject to a written authorization of the head of the division in charge of the testing laboratory.

CLIENT

Dr Giacomo D'ANGELO
AECOM
12 Regan Way
Chetwynd Business Park, Chilwell
Nottingham NG9 6RZ, UNITED KINGDOM

REFERENCES

Our quotation of 11th December 2018 (reference: EP-012060-1/3735).

Your order by e-mail dated 19th December 2018 (BRRC reference: 3317) for scuffing tests on two mixtures.

TESTS PERFORMED

This report discusses the scuffing tests performed on two mixtures. The test specimens were manufactured and sawn by you. They were delivered to BRRC in the appropriate size for the scuffing tests.

DATES OF TESTS

All tests were performed in the period from 25th March through 1st April 2019.

TEST SPECIMENS

The test specimens were registered at BRRC under the following numbers:

Table 1 – Survey of test specimens

Test specimens	BRRC registration number	Date of receipt
Asphalt slab for scuffing B16 T1531	OCW-19-0190	2019-03-21
Asphalt slab for scuffing B13 T1531	OCW-19-0189	2019-03-21
Asphalt slab for scuffing B9 T1531	OCW-19-0188	2019-03-21
Asphalt slab for scuffing B7 T1531	OCW-19-0187	2019-03-21
Asphalt slab for scuffing B4 T1531	OCW-19-0186	2019-03-21
Asphalt slab for scuffing A20 T1531	OCW-19-0185	2019-03-21
Asphalt slab for scuffing A19 T1531	OCW-19-0184	2019-03-21
Asphalt slab for scuffing A13 T1531	OCW-19-0183	2019-03-21
Asphalt slab for scuffing A7 T1531	OCW-19-0182	2019-03-21
Asphalt slab for scuffing A3 T1531	OCW-19-0181	2019-03-21

The numbers already marked on the test specimens (see table 1) are also used in this report. There are five specimens per mixture, four of which were tested and one was kept in reserve.

Dimensions and density of the test slabs

The length and width of each slab were measured in four positions. Thickness was measured in eight positions evenly spaced around the perimeter, approximately 1 cm from the saw cuts.

Table 2 shows the results for dimensions, mass and density as determined according to procedure D in EN 12697-6.

Table 2 – Dimensions, mass and bulk density of the test specimens

	Length-Width (cm)		Thickness (cm)		Volume (cm^3)	Mass (g)	Bulk density (g/cm^3)
Slab No.	Average	Standard deviation	Average	Standard deviation			
Mixture A (6 % AV content)							
A3	26.08	0.07	4.97	0.02	3,381	7,868.9	2.328
A7	26.04	0.04	4.93	0.03	3,343	7,786.4	2.329
A13	26.10	0.03	4.91	0.01	3,348	7,788.4	2.326
*A19**	*26.05*	*0.04*	*4.92*	*0.02*	*3,338*	*7,876.8*	*2.360*
A20	26.11	0.06	4.91	0.02	3,345	7,842.5	2.345
Mixture B (14 % AV content)							
B4	26.03	0.12	4.84	0.01	3,278	7,222.8	2.203
B7	26.05	0.04	4.89	0.01	3,317	7,163.3	2.160
*B9**	*25.99*	*0.05*	*4.83*	*0.01*	*3,263*	*7,358.3*	*2.255*
B13	26.06	0.02	4.86	0.03	3,302	7,172.6	2.172
B16	26.10	0.02	4.81	0.01	3,278	7,331.8	2.237

*: these specimens were kept in reserve. Their bulk densities deviated the most from the average values of the five specimens per mixture.

TEST METHODS

The scuffing tests were carried out according to prTS 12697-50: Bituminous mixtures – Test methods for hot-mix asphalt – Part 50: Resistance to Scuffing, annex B (version of May 2014), with the deviation described below. As requested in your e-mail of 28th November 2018, the tests were made under a load of 1,000 N, at 40 °C. Sixteen cycles were performed and mass loss was measured every four cycles.

PROCEDURE

1. The scuffing tests were carried out with the 'Darmstadt Scuffing Device' (DSD, see figure 1) described in pr TS 12697-50, annex B.
2. Before testing, the density of the asphalt slabs was determined according to procedure D ('Bulk density by dimensions') in EN 12697-6.
3. The specimens were heated to the required testing temperature by placing them in an oven for at least three hours. The fixture for the slabs in the DSD was also pre-heated to the testing temperature.
4. The specimens were fixed into the DSD, in the heated fixture.
5. The surface temperature of the specimen was checked in three spots with an infrared thermometer. The average was not allowed to deviate more than 2 °C from the required test temperature; if it did, the specimen was replaced in the oven to bring it to temperature.
6. The tyre (pressure: 3 bars) was lowered onto the slab and a static load of 1,000 N was applied. As soon as this load level was achieved, the test was started by oscillating and moving back and forth the slab in the horizontal plane, thus generating forces under the tyre that simulated the effect of shearing traffic.
7. After four cycles, the movement was stopped and the tyre was raised, to allow vacuuming of the loose grains. The vacuumed material was weighed.
8. The latter three steps were repeated until a total of sixteen cycles had been completed.

Figure 1 – BRRC's ravelling tester, type 'Darmstadt Scuffing Device'

TEST RESULTS

Scuffing

A few pictures of specimens before and after testing are presented in appendix 1.

Table 3 lists the results of the scuffing test at 40 (± 2°C) for each test slab, as well as the average values and standard deviations for the two mixtures.

Table 3 – Material loss after sixteen cycles at 40 °C, for all test specimens

Test slab	BRRC registration number	Average temperature	Material loss	Material loss per unit area	Average material loss / mixture	Standard deviation / mixture
		°C	(g)	(g/m²)	(g/m²)	(g/m²)
A3 - T1531	OCW19-0181	38.9	31.8	800	415	299
A7 - T1531	OCW19-0182	40.3	15.6	393		
A13 - T1531	OCW19-0183	40.6	15.8	398		
A20 - T1531	OCW19-0185	40.2	2.8	70		
B4 - T1531	OCW19-0186	40.3	68.6	1,726	1,324	607
B7 - T1531	OCW19-0187	40.5	75.8	1,907		
B13 - T1531	OCW19-0189	40.6	42.6	1,072		
B16 - T1531	OCW19-0190	40.6	23.4	589		

Figure 2 shows the trend of material loss for each individual test specimen with the number of loading cycles at 40 °C, and of the average value - for mixture A.

Figure 3 shows the trend of material loss for each individual test specimen with the number of loading cycles at 40 °C, and of the average value - for mixture B.

Figure 4 shows the trend of material loss with the number of loading cycles at 40 °C, per mixture (average of four test specimens).

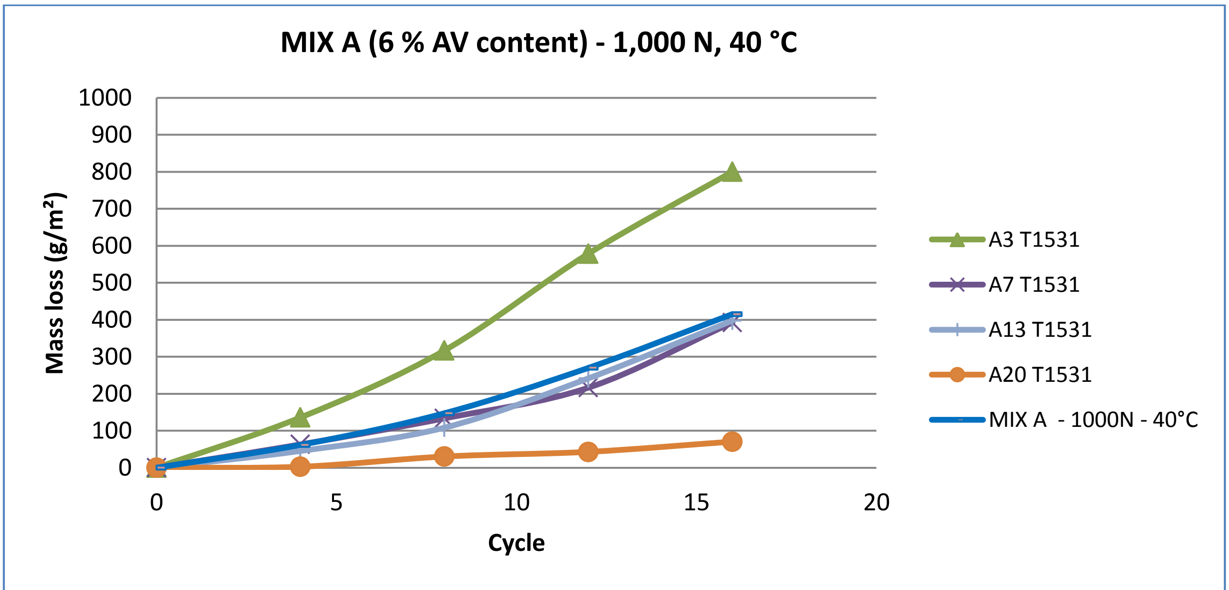


Figure 2 - Material loss from each test specimen, and average value – for mixture A

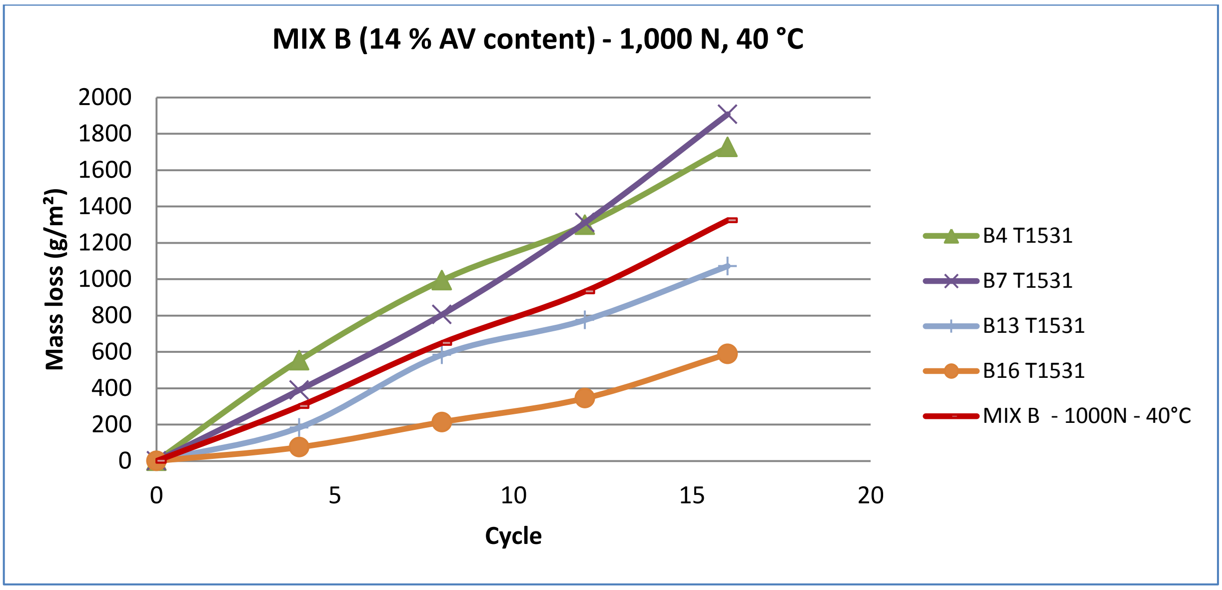


Figure 3 - Material loss from each test specimen, and average value - for mixture B

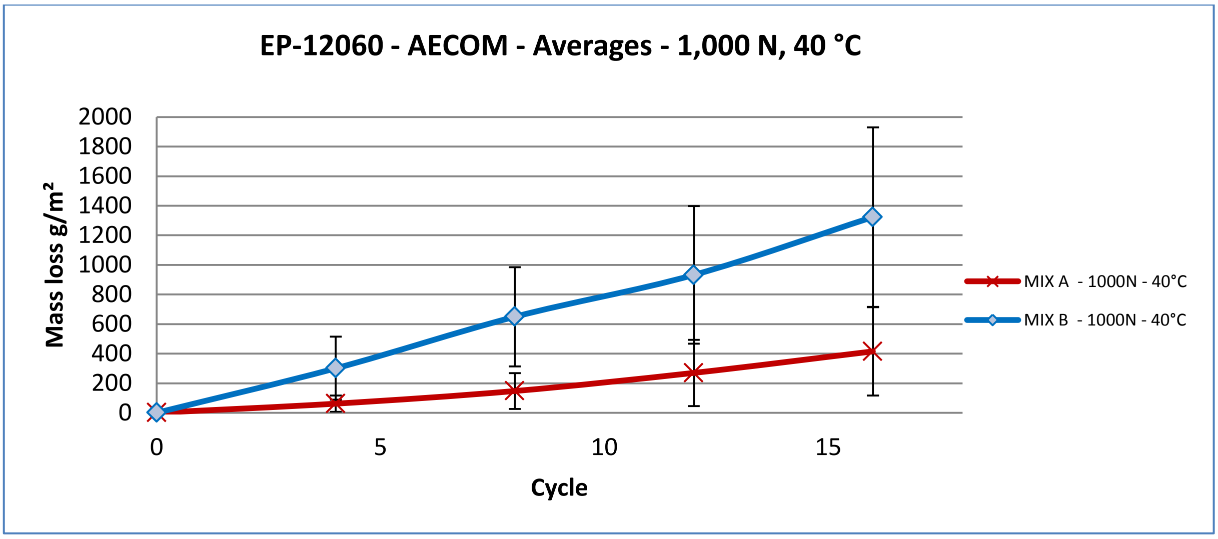


Figure 4 - Material loss per mixture

CONCLUSION

A difference can be observed between mixture A and mixture B. The mixture with the lowest air voids content exhibited the best results in this scuffing test.

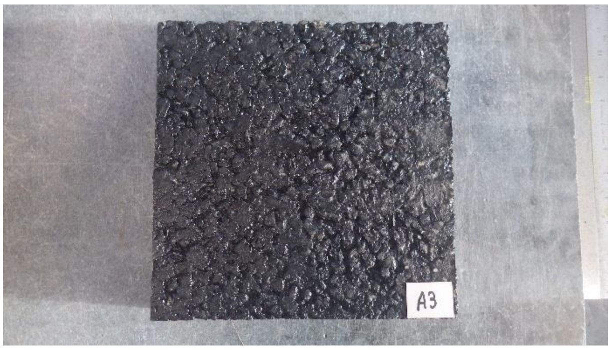
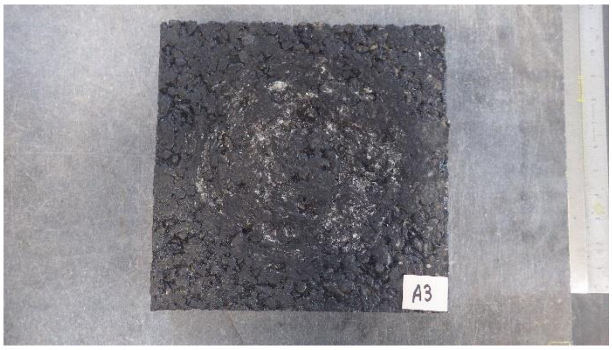
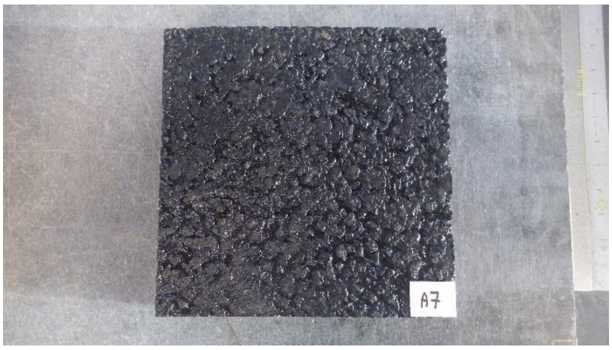
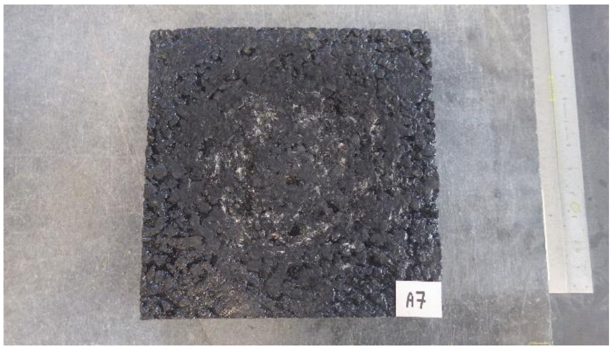
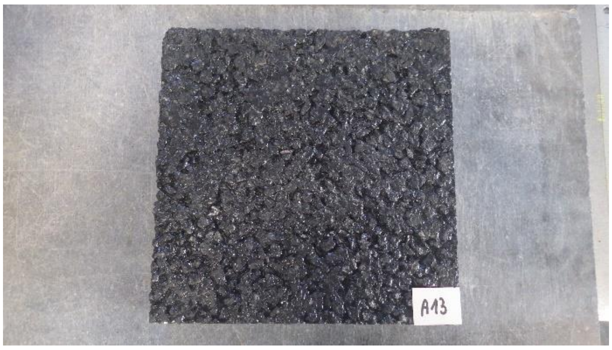
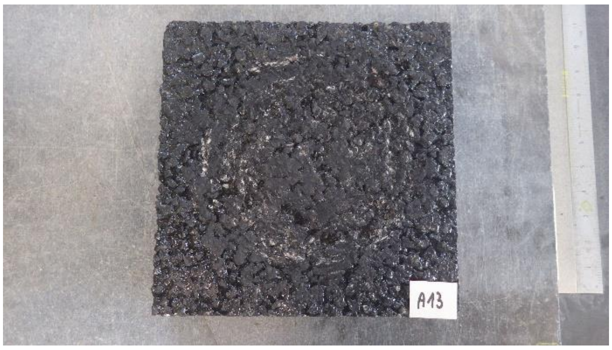
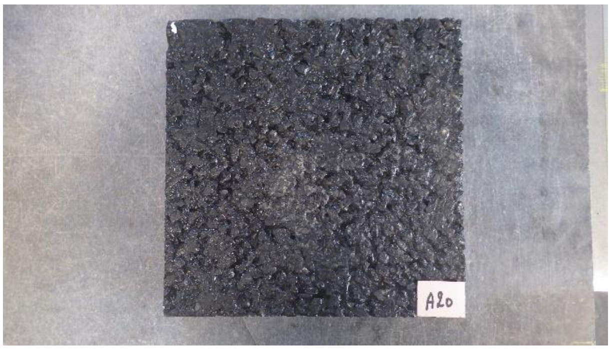
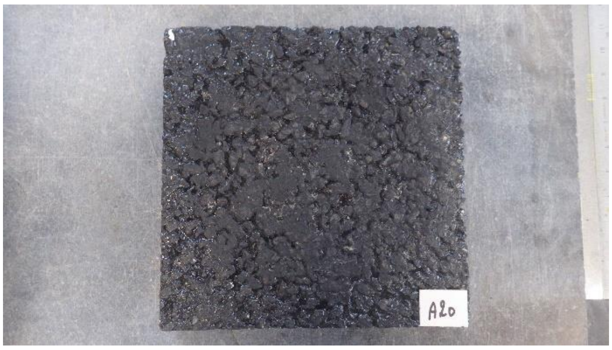
Tine TANGHE, M.Eng.
Manager of the Mechanical Performance Testing (MPT) lab.

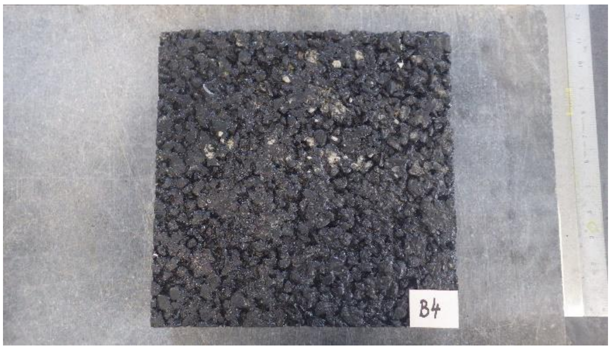
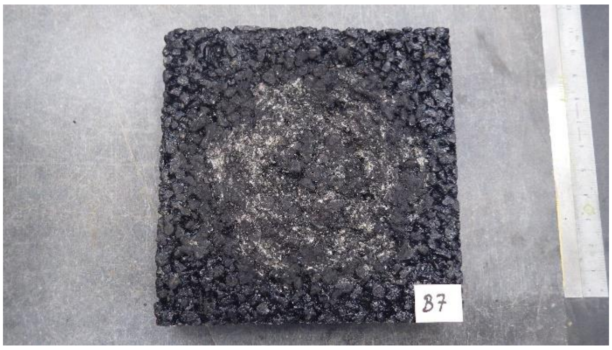
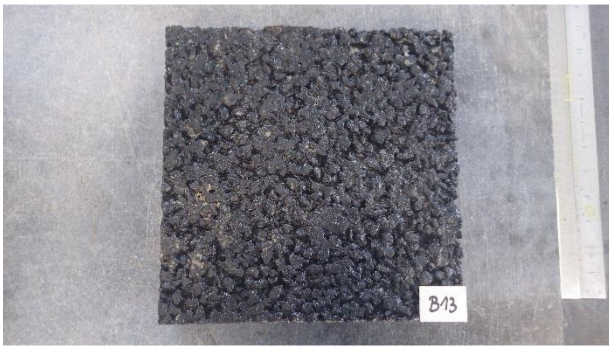
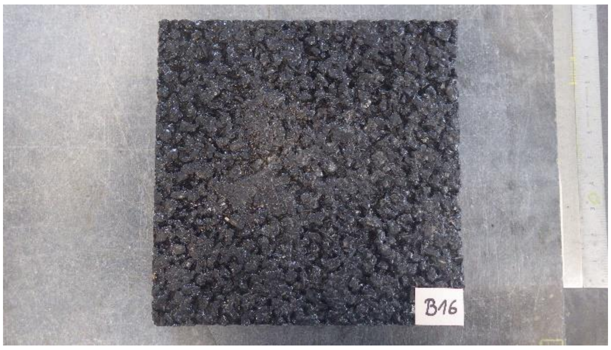
Appendix: - A few pictures of asphalt test specimens before and after testing

cc: Giacomo.Dangelo@aecom.com

TETE/FT

Appendix 1 - A few pictures of asphalt specimens before and after testing

Before testing	End of test after sixteen cycles
	
	
	
	

Before testing	**End of test after sixteen cycles**
	
	
	
	

Appendix C – Technische Universität Darmstadt, DSD Results Report

Technische Universität Darmstadt | Institut für Straßenwesen | Otto-Berndt-Str. 2 | 64287 Darmstadt

AECOM
12 Regan Way
Chetwynd Business Park, Chilwell
Nottingham NG9 6RZ
United Kingdom

Fachbereich 13
Bau- und
Umweltingenieurwissenschaften
Institute für Verkehr
Institut für Straßenwesen
Gruppe Versuche und Analysen
Amtliche Prüfstelle für das
Straßenwesen in Hessen

Amtliches Prüfzeugnis

Testing the Resistance Against Raveling with Darmstadt Scuffing Device (DSD) DIN/TS 12697-50

AP 029/19

Customer:	AECOM
Date of order:	December 2018
Test order:	Testing the Resistance Against Raveling with Darmstadt Scuffing Device (DSD) DIN/TS 12697-50
Project:	Research project for Highways England

Gruppe Versuche & Analysen (VA)

Otto-Berndt-Straße 2
64287 Darmstadt
Telefon (+49 6151) 16-23810
Telefax (+49 6151) 16-23811
e-mail: va@sw.tu-darmstadt.de

Sachgebiet : 3

Sachbearbeiter:

Tim Blumenfeld, M.Sc.

Contents

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List of Tables

1 Study size

The Institute for Road and Pavement Engineering of Technische Universität Darmstadt was asked in December of 2018 to perform tests with the Damrstadt Scuffing Device (DSD) on asphalt samples. Therefore, eleven asphalt slabs had been delivered by AECOM on 26.03.2019 to Darmstadt. The sample size was ca. 260 mm x 260 mm. The following table 1 gives an overview to the eight of eleven slabs that were tested with the DSD.

Tabelle 1: Overview to the tested asphalt samples

Sample Type	Material	Name	Date of testing
Asphalt slab	A	5	03.04.2019
		4	–
		6	–
		8	03.04.2019
		14	03.04.2019
		15	03.04.2019
	B	5	04.04.2019
		6	04.04.2019
		8	04.04.2019
		14	04.04.2019
		15	–

2 Results

The results of the scuffing test are shown in table 2 as well as in the following figures.

Tabelle 2: Measured Massloss of all tested asphalt slabs

	Massloss [g]							
	A				B			
Sample	A5	A8	A14	A15	B5	B6	B8	B14
Initial Weight [g]	7794,4	7801,6	7874,6	7731,9	7029,9	7235,7	7109,7	7297,5
0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
2	0,5	0,6	2,4	1,1	12,6	4,2	5,0	3,2
4	1,7	1,8	3,5	2,3	14,9	9,7	12,6	6,5
6	0,7	1,0	3,1	2,9	30,2	8,4	11,8	4,8
8	2,2	0,6	5,5	1,9	19,5	12,1	15,0	14,4
10	3,0	2,0	6,1	2,4	26,9	11,4	13,8	14,8
Final Weight [g]	7.783,0	7.794,2	7.852,5	7.719,5	6.919,5	7.187,3	7.049,3	7.252,0
DSLC	Cumulative Massloss [g]							
0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
2	0,5	0,6	2,4	1,1	12,6	4,2	5,0	3,2
4	2,2	2,4	5,9	3,4	27,5	13,9	17,6	9,7
6	2,9	3,4	9,0	6,3	57,7	22,3	29,4	14,5
8	5,1	4,0	14,5	8,2	77,2	34,4	44,4	28,9
10	8,1	6,0	20,6	10,6	104,1	45,8	58,2	43,7
DSLC	Average Cumulative Massloss [g]							
0	0,0				0,0			
2	1,2				6,3			
4	3,5				17,2			
6	5,4				31,0			
8	8,0				46,2			
10	11,3				63,0			

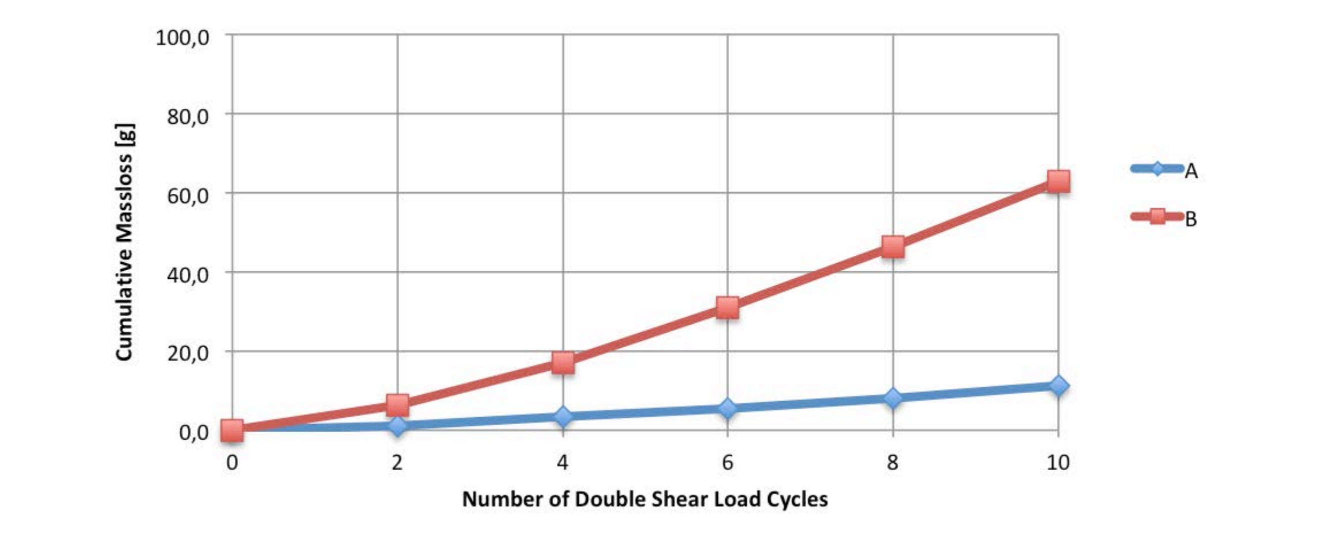


Abbildung 1: Average cumulative massloss of Material A and B in dependence on the number of Double Shear Load Cycles (DSLC)

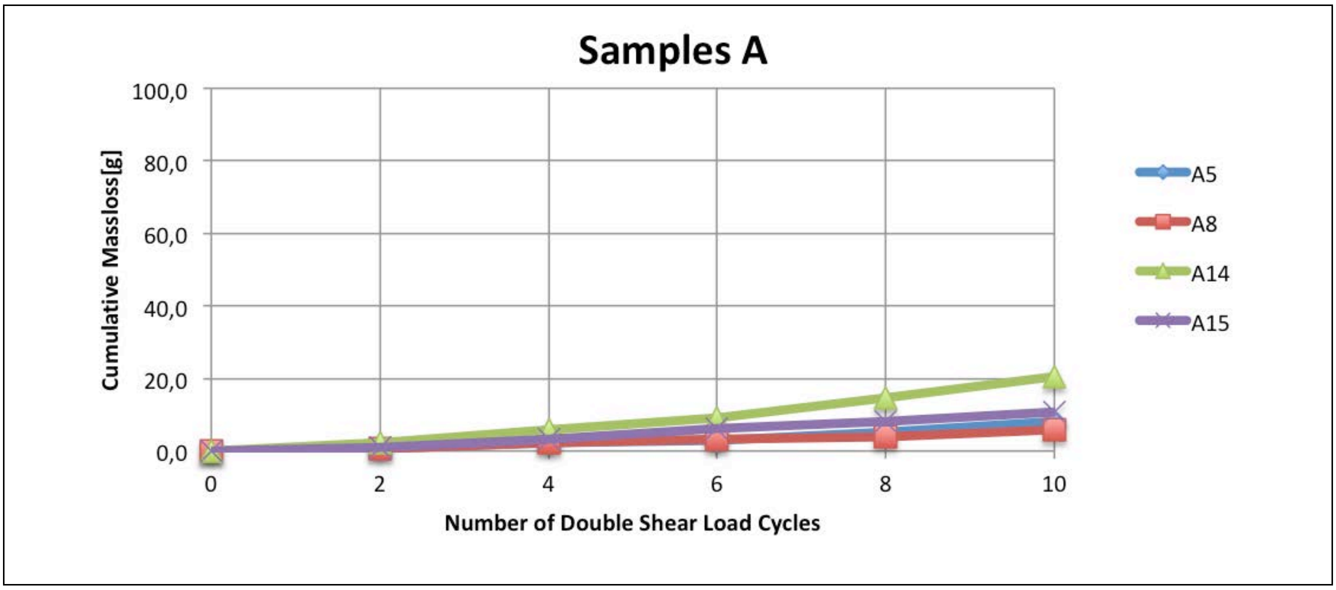


Abbildung 2: Cumulative massloss of Material A in dependence on the number of Double Shear Load Cycles (DSLC)

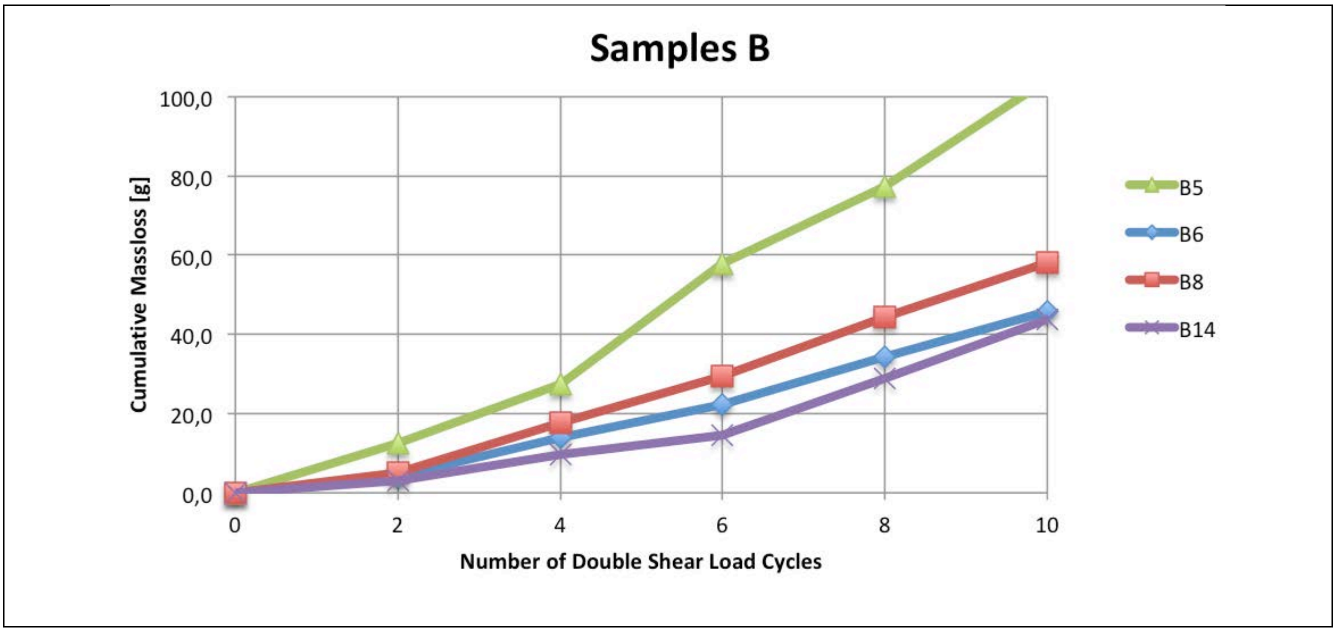


Abbildung 3: Cumulative massloss of Material B in dependence on the number of Double Shear Load Cycles (DSLC)

3 Evaluation of Results

The results of the the scuffing test lead to different mass loss in dependence on the tested asphalt mixture.

The cumulative mass loss after ten double shear load cycles varied for asphalt mixture A between 6,0 g and 20,6 g. On average, the cumulative mass loss was 11,3 g. In comparison to the other tested asphalt sort, mixture A shows very low scuffing.

The cumulative mass loss after ten double shear load cycles varied for asphalt mixture B between 43,7 g and 104,1 g. On average, the cumulative mass loss was 63,0 g. In comparison to the other tested asphalt sort, mixture B shows a high amount of mass loss.

Darmstadt, den 09.04.2019

Tim Blumenfeld, M.Sc.

Sachbearbeiter

Dr.-Ing. Stefan Böhm

Prüfstellenleiter

Appendix

The following figures show the comparison of the surface of the slabs between before and after performing the tests.

Tabelle 3: Comparison of the surface of slab A5 between before and after performing the Scuffing test with the DSD

Name: A5	
before testing	after testing
	
Comments:	

Tabelle 4: Comparison of the surface of slab A8 between before and after performing the Scuffing test with the DSD

Name: A8	
before testing	after testing
	
Comments:	

Tabelle 5: Comparison of the surface of slab A14 between before and after performing the Scuffing test with the DSD

Name: A14	
before testing	after testing
	
Comments:	

Tabelle 6: Comparison of the surface of slab A15 between before and after performing the Scuffing test with the DSD

Name: A15	
before testing	after testing
	
Comments:	

Tabelle 7: Comparison of the surface of slab B5 between before and after performing the Scuffing test with the DSD

Name: B5	
before testing	after testing
	
Comments:	

Tabelle 8: Comparison of the surface of slab B6 between before and after performing the Scuffing test with the DSD

Name: B6	
before testing	after testing
	
Comments:	

Tabelle 9: Comparison of the surface of slab B8 between before and after performing the Scuffing test with the DSD

Name: B8	
before testing	after testing
	
Comments:	

Tabelle 10: Comparison of the surface of slab B14 between before and after performing the Scuffing test with the DSD

Name: B14	
before testing	after testing
	
Comments:	

Appendix D – Heijmans, Rotating Surface Abrasion Test (RSAT) Results Report

Wegbouwkunde	Projectnummer: G01117524255626200	Rapport Nr: L19.80016
	Project: Enquiry Test	
	Start Proef:	10-4-2019
	Platen aangeboden:	27-3-2019
	Platen gemaakt:	N.V.T
Plaat Nr: Plaat 2	Dichtheid proefstuk: XXXXXXXX	kg. / m³

Vervorming DAL voor	Vervorming DAL na
Gat	Gat
Gat	Gat
Gat	Gat
Gat	Gat
Gat	Gat
Gat	Gat
Gat	Gat
Gat	Gat
Gat	Gat

Regressie in g/uur	0,02
Belastingtijd in uren	24,00
Schade in grammen	0,3
Vervorming in mm	0,00

{Dal is t.o.v. oorspronkelijk niveau}

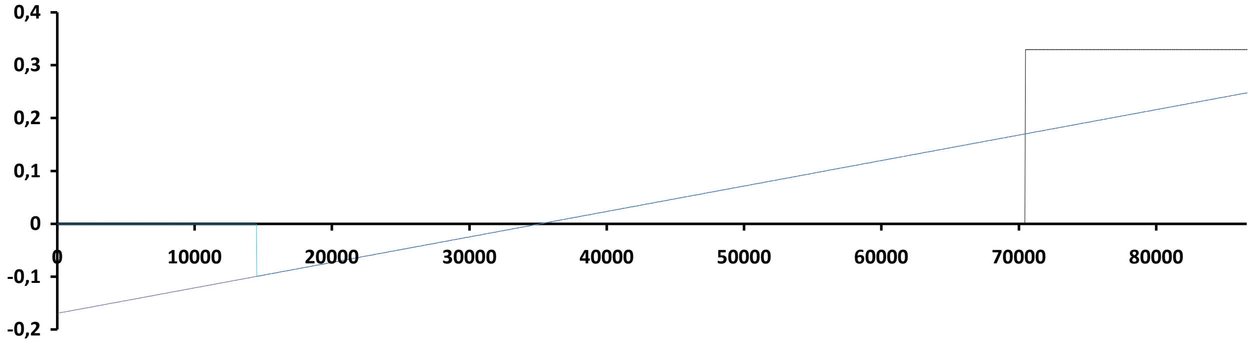
Parameters

Het Proefstuk	Plaat 1 Kernen A12-1; A12-2; A16-1
Contactdruk van het wiel	0,6 N/mm²
Shore A van de band	68
Druk van het asfalt opsluitplaatje	0,6N/m
Afzuiging van het proefstuk	Aan
Temperatuur koelcel	20°C
Opmerking proefstuk	XXXXXXXX
Wiel overgangen	86600
Proefstuk belasting	
Afstrooien voor het inlopen	5 gram Talk

Rafelingsproef

Start/Stop tijden	Temp asfalt °C	Belastingtijd uren	Aantal bewegingen	Schade visueel	Steenverlies grammen
10-4-2019 15:44	20,0	0	0	zie appendix	0,0
10-4-2019 16:45	20,0	1	3608	zie appendix	0,0
10-4-2019 19:46	20,0	4	14433	zie appendix	0,0
10-4-2019 23:47	20,0	8	28867	zie appendix	0,0
11-4-2019 3:48	20,0	12	43300	zie appendix	0,0
11-4-2019 7:49	21,0	16	57733	zie appendix	0,0
11-4-2019 12:14	21,0	20	72167	zie appendix	0,3
11-4-2019 16:15	20,0	24	86600	zie appendix	0,3

Stop na 24,00 uur



Start regressie (u)	4,0	Schade proefplaat	0,3	Vervorming	0,00

	Wegbouwkunde	Projectnummer: G01117524255626200	Rapport Nr: L19.80015
		Project: Enquiry Test	
		Start Proef:	9-4-2019
		Platen aangeboden:	27-3-2019
		Platen gemaakt:	N.V.T
	Plaat Nr: Plaat 1	Dichtheid proefstuk: XXXXXXXX	kg. / m³

Vervorming DAL voor	Vervorming DAL na
Gat	Gat
Gat	Gat
Gat	Gat
Gat	Gat
Gat	Gat
Gat	Gat
Gat	Gat
Gat	Gat
Gat	Gat

Regressie in g/uur	0,03
Belastingtijd in uren	24,00
Schade in grammen	0,6
Vervorming in mm	0,00

{Dal is t.o.v. oorspronkelijk niveau}

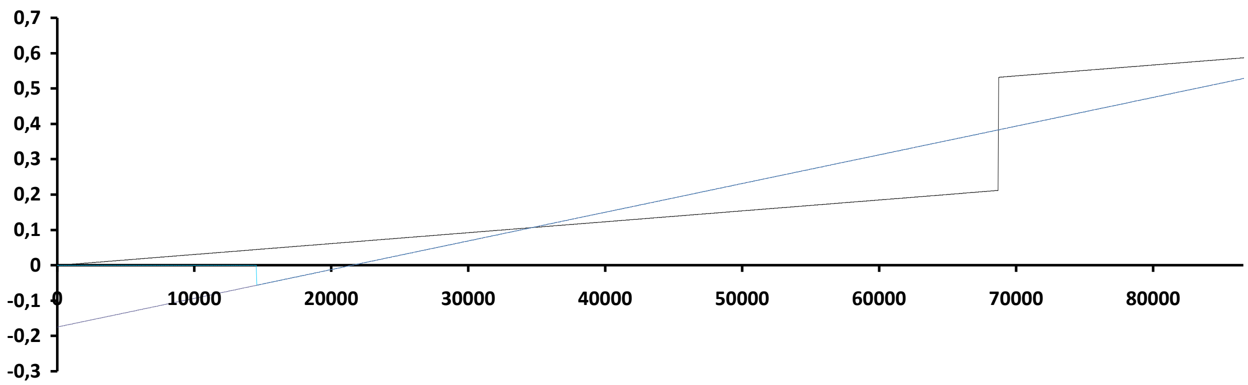
Parameters

Het Proefstuk	Plaat 1 Kernen B10-1; B10-2; B11-1
Contactdruk van het wiel	0,6 N/mm²
Shore A van de band	65
Druk van het asfalt opsluitplaatje	0,6N/m
Afzuiging van het proefstuk	Aan
Temperatuur koelcel	20°C
Opmerking proefstuk	XXXXXXXX
Wiel overgangen	86600
Proefstuk belasting	
Afstrooien voor het inlopen	5 gram Talk

Rafelingsproef

Start/Stop tijden	Temp asfalt ºC	Belastingtijd uren	Aantal bewegingen	Schade visueel	Steenverlies grammen
9-4-2019 10:52	20,0	0	0	zie appendix	0,0
9-4-2019 11:53	20,0	1	3608	zie appendix	0,0
9-4-2019 14:55	21,0	4	14433	zie appendix	0,0
9-4-2019 18:57	21,0	8	28867	zie appendix	0,1
9-4-2019 23:00	21,0	12	43300	zie appendix	0,1
10-4-2019 3:03	21,0	16	57733	zie appendix	0,2
10-4-2019 7:05	20,0	20	72167	zie appendix	0,5
10-4-2019 11:08	20,0	24	86600	zie appendix	0,6

Stop na 24,00 uur



Start regressie (u)	4,0	Schade proefplaat	0,6	Vervorming	0,00

Appendix E – Modified Scuffing Test Report

NTEC
Nottingham Transportation
Engineering Centre

Pavement Research Building
University Park
Nottingham
NG7 2RD
Tel: +44 115 846 8453

LABORATORY TEST REPORT: 1128

Client: Dr Giacomo D'Angelo - Pavement Engineer
Company: Aecom
Phone +44 (0) 1159077040
Email Giacomo.dangelo@aecom.com

CLIENT ORDER REFERENCE: PO NML810 60580090

NTEC REFERENCE: 19-9287-14859

Test Methods Used

Modified TRL Report 176 Appendix G **TEST PROCEDURE FOR SCUFFING**

Test Results

1. **Modified TRL Report 176 Appendix G – Resistance to wear by scuffing and BS 598-105:2000 Methods of test for the determination of texture depth (Clause 5 Sand Patch)**

NTEC Sample ID	19-1417	19-1418	19-1419	19-1420
Client Reference	A6%	B6%	C6%	D6%
Initial Texture Depth (mm)	1.3	1.7	2.1	1.8
Test Temperature During Test	60±1°C	60±1°C	60±1°C	60±1°C
Initial Tyre Pressure (PSI)	45.0	45.0	45.0	4.5
Initial Tread Depth (mm)	1.5	1.5	1.5	1.5
Time/ Date Tested	19/07/19	22/07/19	22/07/19	23/07/19
Angle of Wheel	19.7	19.7	19.7	19.7
Final Tyre Pressure (PSI)	44.0	45.0	45.0	45.0
Final tread Depth (mm)	0.0*	0.0*	0.0*	0.0*
Initial Mass of sample (g)	9995.9	10037.1	10050.1	10166.7
Mass of sample post-test (g)	9976.5	10016.3	10036.8	10152.1
Loss in Mass (%)	0.19	0.21	0.13	0.14
Final Texture Depth	9.9	6.2	3.3	3.5
Loss of texture Depth (%)	-661	-264	-57	-94

Pavement Research Building
University Park
Nottingham
NG7 2RD
Tel: +44 115 846 8453

LABORATORY TEST REPORT: 1128

Notes

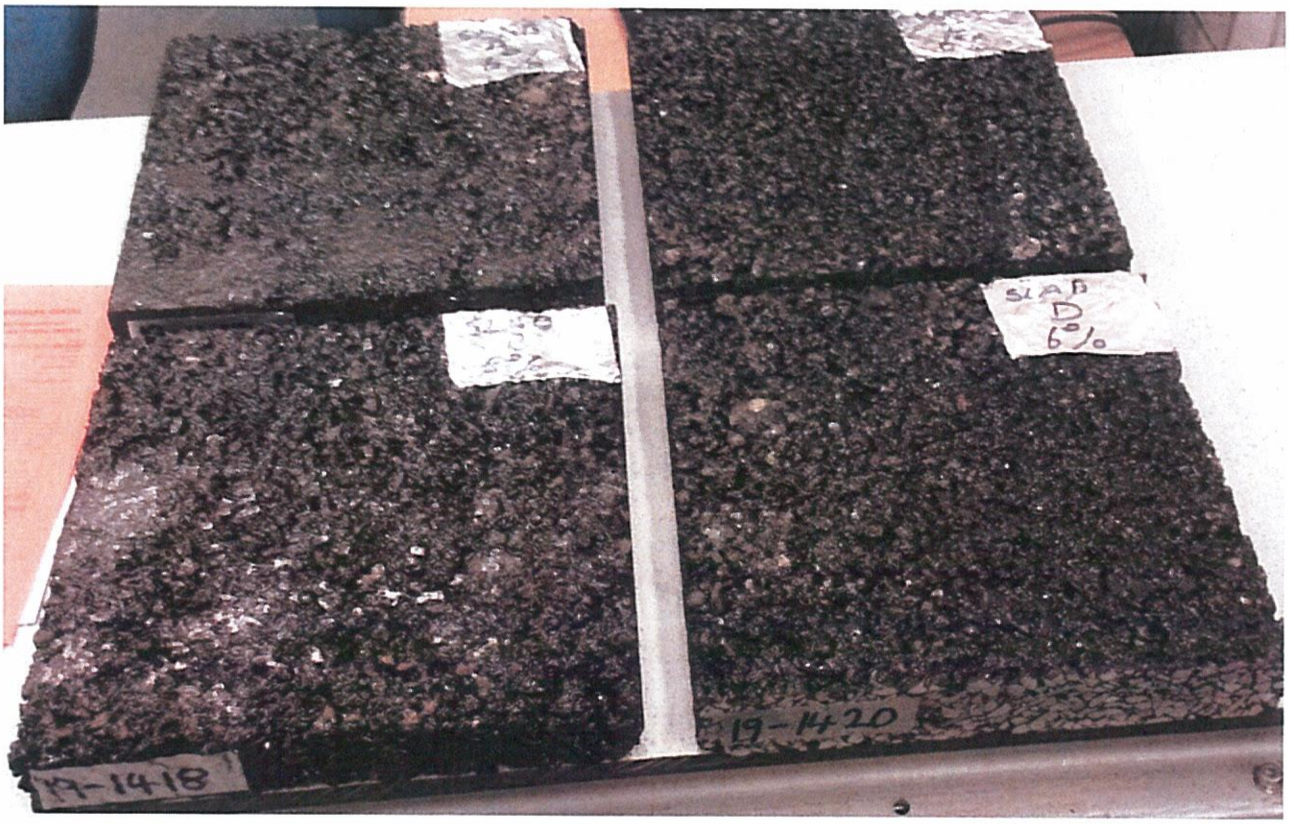
1. Samples will be disposed of four weeks after the test date, unless the laboratory is informed otherwise.
2. We do not hold UKAS Accreditation in this test method.
3. *Tyre worn bald by end of the test
4. There has been no deviation by agreement or otherwise from the procedure specified unless stated below.
5. See Appendix A for photographs of slabs pre and post scuffing

Signed: **Authorised Signatory**

J D Watson
(Laboratory Manager)

Issue Date: 25/07/2019

Appendix A



6% Samples pre testing

NTEC

Nottingham Transportation Engineering Centre

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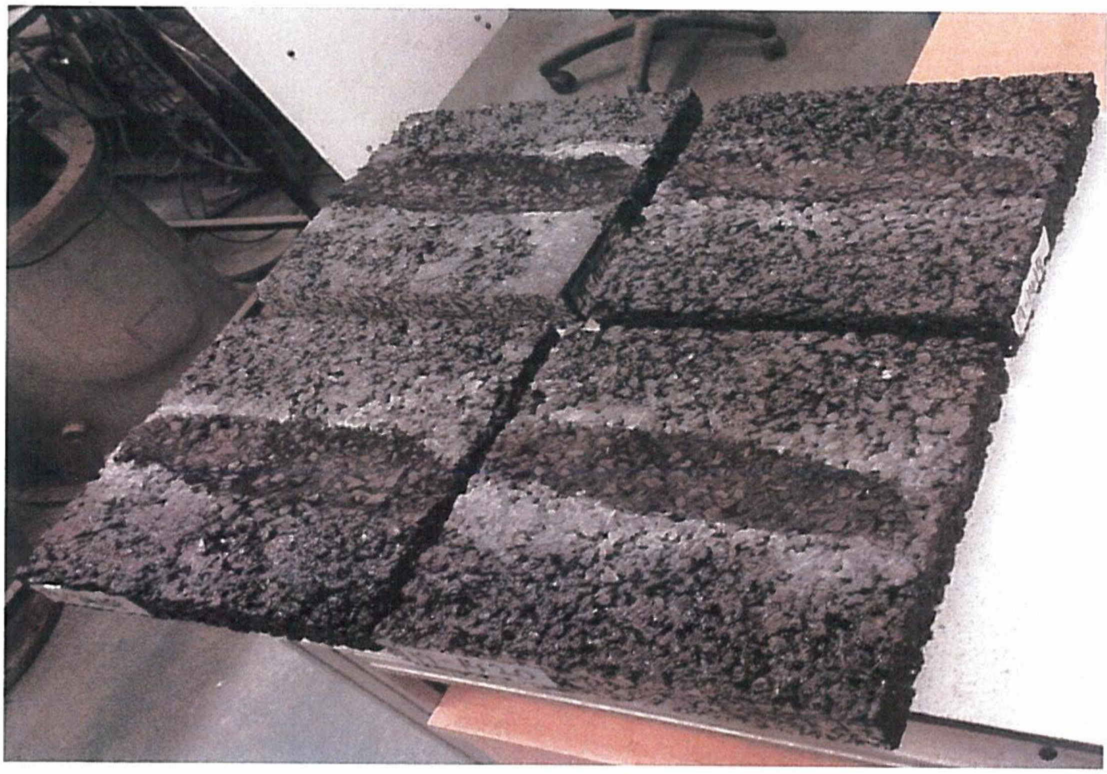
University Park
Nottingham
NG7 2RD
Tel: +44 115 846 8453

LABORATORY TEST REPORT: 1128



6% samples post testing

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LABORATORY TEST REPORT: 1128

19-1417 post test

19-1418 post test

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Nottingham
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Tel: +44 115 846 8453

LABORATORY TEST REPORT: 1128

19-1419 post test

19-1420 post test

NTEC

Nottingham Transportation Engineering Centre

Pavement Research Building
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Nottingham
NG7 2RD
Tel: +44 115 846 8453

LABORATORY TEST REPORT: 1129v2

Client: Dr Giacomo D'Angelo - Pavement Engineer
Company: Aecom
Phone +44 (0) 1159077040
Email Giacomo.dangelo@aecom.com

CLIENT ORDER REFERENCE: PO NML810 60580090

NTEC REFERENCE: 19-9287-14859

Test Methods Used

Modified TRL Report 176 Appendix G **TEST PROCEDURE FOR SCUFFING**

Test Results

1. **Modified TRL Report 176 Appendix G – Resistance to wear by scuffing and BS 598-105:2000 Methods of test for the determination of texture depth (Clause 5 Sand Patch)**

NTEC Sample ID	19-1421	19-1422	19-1423	19-1424
Client Reference	A14%	B14%	C14%	D14%
Initial Texture Depth (mm)	3.0	3.7	4.1	3.5
Test Temperature During Test	60±1°C	60±1°C	60±1°C	60±1°C
Initial Tyre Pressure (PSI)	45.0	45.0	45.0	4.5
Initial Tread Depth (mm)	1.5	1.5	1.5	1.5
Time/ Date Tested	23/07/19	31/07/19	31/07/19	01/08/19
Angle of Wheel	19.7	19.7	19.7	19.7
Final Tyre Pressure (PSI)	44.0	45.0	45.0	45.0
Final tread Depth (mm)	0.0*	0.0*	0.0*	0.0*
Number of Passes	2532**	1779**	422**	1690**
Initial Mass of sample (g)	8883.4	9040.9	9064.9	8970.1
Mass of sample post-test (g)	8859.6	9043.0	9064.2	8969.7
Loss in Mass (%)	0.27	-0.02	0.01	0.00
Final Texture Depth	6.5	5.7	4.2	3.7
Loss of texture Depth (%)	-116.0	-54.0	-2.4	-5.7

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Notes

1. Samples will be disposed of four weeks after the test date, unless the laboratory is informed otherwise.
2. We do not hold UKAS Accreditation in this test method.
3. *Tyre worn bald by end of the test
4. ** Test stopped as tyre had burst
5. There has been no deviation by agreement or otherwise from the procedure specified unless stated below.
6. See Appendix A for photographs of slabs pre and post scuffing

Signed: **Authorised Signatory**

J D Watson
(Laboratory Manager)

Issue Date: 13/08/2019

Appendix A

14% Samples pre testing

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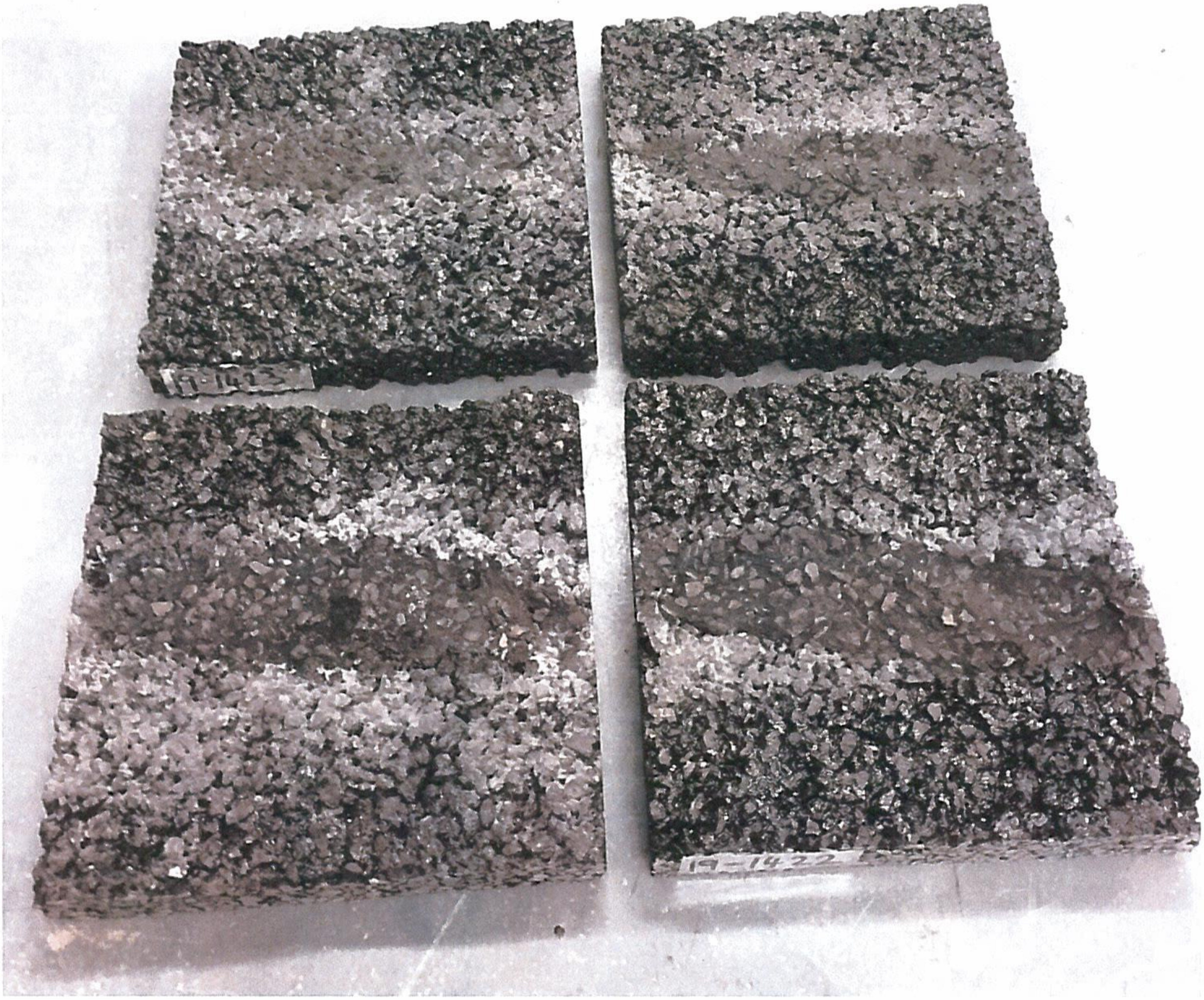

14% samples post testing

The University and its employees accept no responsibility for the results of this test(s) nor warrant that the material(s) or the material of the sample(s) tested is or is not suitable for any particular purpose.

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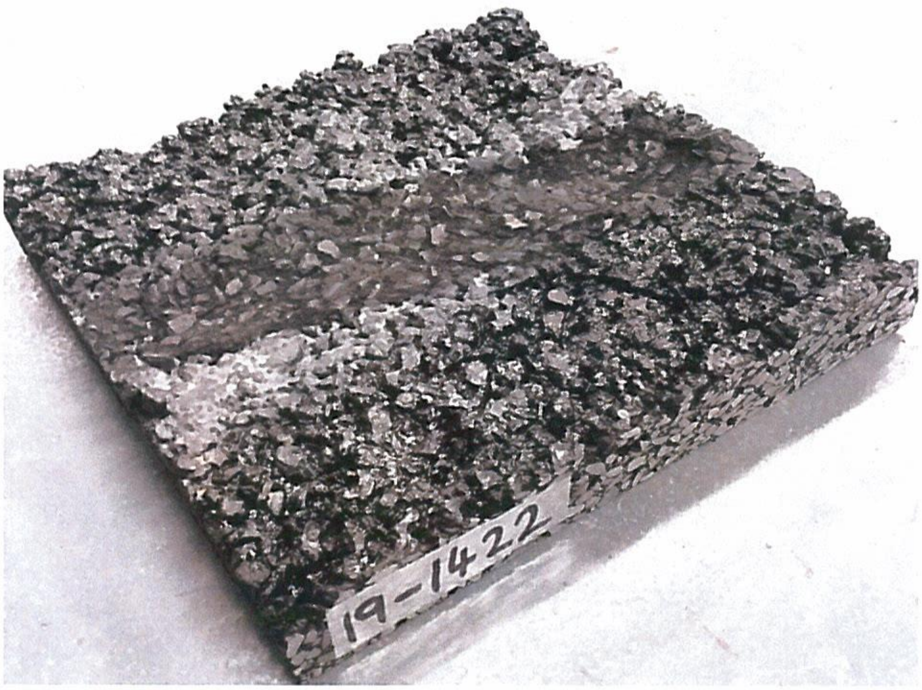
19-1421 post test



19-1422 post test

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19-1423 post test

19-1424 post test