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DRaT – Development of the Ravelling Test

Proposals for revision of standard prCEN/TS 12697-50

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CEDR Call 2014: Asset Management and Maintenance
DRaT
Development of the Ravelling Test

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Executive summary

The test methods for four scuffing devices have been written up as a draft technical specification by Comité Européen de Normalisation (CEN) as prCEN/TS 12697-50, Resistance to scuffing. The CEDR-DRaT project has evaluated the test methods and the results produced for the four scuffing devices to determine whether the methods can lead to a harmonised test method of which the technical specification can be converted into a test standard.

The main part of the work of the DRaT project was a round robin testing programme of four replicate samples of three variations each of three mixture types together with a review of existing knowledge on scuffing. The results of the round robin were statistically analysed to identify the similarities and difference between the designs of scuffing apparatus as well to look at correlations and precision of the results.

However, the round robin testing did not demonstrate that:

- The various designs of scuffing equipment could be correlated, either for specific asphalt mixture types or overall; or
- Specific designs of scuffing equipment could be identified as being best for identifying the scuffing-resistance of asphalt mixtures, either for specific types or overall.

The lack of correlation is partly due to variation in the results and partly because the devices do not provide constant ratios between the outcomes of their results for different materials. However, estimated factors for normalising the results between the different devices have been proposed, although they will need to be reviewed when further data becomes available.

Nevertheless, this report examines what enhancements to the current draft of prCEN/TS 2697-50 that the project has identified can be made to make a better and more unified document without rejecting any of the designs of scuffing apparatus. The revised version of the standard with the proposed improvements recommended are given in an Appendix.

1 Introduction

The trans-national research programme "**Call 2014: Asset Management and Maintenance**" was launched by the Conference of European Directors of Roads (CEDR). CEDR is an organisation which brings together the road directors of 25 European countries. The aim of CEDR is to contribute to the development of road engineering as part of an integrated transport system under the social, economic and environmental aspects of sustainability and to promote co-operation between the National Road Administrations (NRA).

The participating NRAs in this Call are Belgium-Flanders, Finland, Germany, Ireland, Norway, the Netherlands, Sweden, United Kingdom and Austria. As in previous collaborative research programmes, the participating members have established a Programme Executive Board (PEB) made up of experts in the topics to be covered. The research budget is jointly provided by the NRAs who provide participants to the PEB as listed above.

Ravelling is a common mode of early failure for many types of asphalt pavement. Recently several simulative laboratory tests have been developed to give an indication of the ravelling potential of an asphalt mixture. These tests use scuffing machines that repeatedly apply a scuffing action to specimen samples to replicate in service loading. The test methods for four such scuffing machines have been written up as a draft technical specification by Comité Européen de Normalisation (CEN) as prCEN/TS 12697-50, Resistance to scuffing (CEN, 2014). Ideally these methods need to be culled or combined so that there is only one (harmonised) test method for this one property before the technical specification can be converted into a test standard. However, the results obtained from the experimental programme conducted in this project have suggested this not to be to be feasible. Consequently, a method based on normalisation factors has been developed to facilitate some level of comparability between the results obtained from different test apparatus.

The CEDR-DRaT project looks at the methods of testing and the results produced for the four scuffing machines in order to identify:

- The extent to which sample preparation needs to be standardised, such as compaction level, evenness, storage conditions and age when tested.
- The most effective method of measurement in terms of extent of differentiation, validity as a measure of ravelling and practicality.
- Whether the results from one or more scuffing machines can be validated from experience on site.
- Whether the results from different scuffing machines can be converted to a common measure.
- Estimates of the precision of the results with each scuffing machine or, if the results can be converted to a common measure, of the common measure.
- Whether the results from either pair of similar machines are comparable and their results are reproducible.
- A procedure to identify if other scuffing machines can be used for the standard test.

It was not known at the start of the project whether these findings would be the same for all asphalt mixture types or different for different types.

The evaluations were made based on three variants of three asphalt mixture designs that were tested using six scuffing machines (two of two of the options and one each for the other two options) with four replicates of each combination of mixture, variant and test machine.

All testing was undertaken on laboratory prepared samples. The validation of the test methods was sought by identifying how mixtures with each tested mix design have performed on site or in trials.

The CEDR-DRaT project is organized in 5 Work Packages (see Figure 1). The test specimens were prepared by one single laboratory in WP2 'Sample preparation' and sent to the different laboratories for testing in WP3 'Test programme'. The results of the testing were analysed both statistically and for the practical application to the development of prCEN/TS 12697-50.

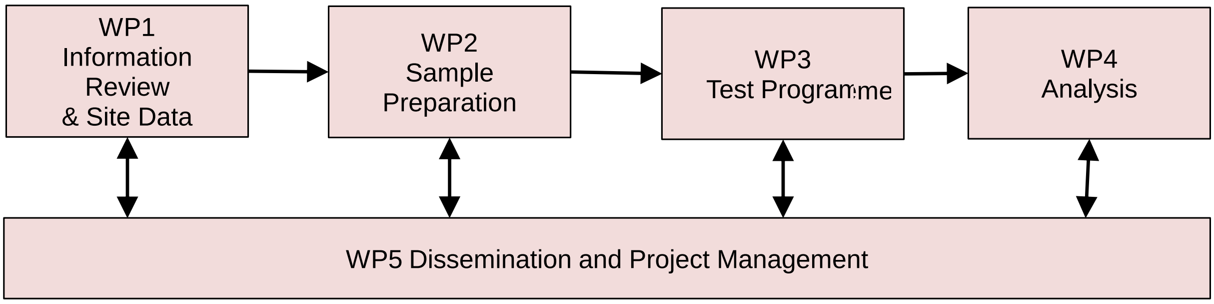

Figure 1: Project organisation

The overall objective is to provide advice on how to refine prCEN/TS 12697-50 to be an acceptable standard with a draft incorporating that advice. The test programme involved round robin testing of four samples each of three mixtures and three options, as shown in Table 1, by each laboratory.

Table 1: Testing options for the round robin programme

Mixture type	Porous asphalt	Very thin layer asphalt concrete	Stone mastic asphalt
Standard	PA	BBTM	SMA
Low mixing temperature	PA/lt	BBTM/lt	SMA/lt
Low binder contents	PA/lb	BBTM/lb	SMA/lb

The low mixing temperatures (lt) were:

- 105 ˚C (compared to 150 ˚C for the Standard option) for PA;
- 110 ˚C (compared to 160 ˚C for the Standard option) for BBTM; and
- 105 ˚C (compared to 155 ˚C for the Standard option) for SMA.

However, the differences were partly negated by compacting the specimens to the same density/air voids contents as for the Standard option.

The low binder (lb) contents were:

- 4,2 % (compared to 5,2 % for the Standard option) for PA;
- 4,6 % (compared to 5,2 % for the Standard option) for BBTM; and
- 5,5 % (compared to 6,8 % for the Standard option) for SMA.

The samples were tested by three scuffing devices by different laboratories as listed in Table 2.

Table 2: Scuffing devices and operators in DRaT project

Scuffing test device	Acronym	Operator(s)
Aachener Ravelling Tester	ARTe	ISAC and BAM
Darmstadt Scuffing Device	DSD	TUD and BRRC
Rotating Surface Abrasion Test	RSAT	Heijmans
TriboRoute device	TRD	IFSTTAR

This report reviews the findings of the sample preparation, testing and statistical analysis in terms of their practical implication for prCEN/TS 12697-50. A revised draft of the standard has been produced as Milestone M.6 and is attached as Appendix A. The changes are generally highlighted in red for major additions, in mauve for minor changes in terminology, in blue for moved sections, green for a compilation of ideas from the Annexes into the main text and grey across gaps from which text has been removed. However, because these changes are so extensive, the highlighting can only be indicative.

2 Draft standard

2.1 Definitions

Several terms (particularly 'scuffing', 'fretting' and 'ravelling') have been used in association with this test without clear definition of the different meaning. Therefore, the definitions in the standard need to extended from just 'material loss' to a series as follows:

- scuffing: the action of tyres, particularly when the wheels are rotating about an axis not perpendicular to the direction of travel of the vehicle (or relative motion of the tyres and asphalt surface simulating the vehicle movement) which causes material loss from the surface of the asphalt
- material loss; amount of material that has been lost from the surface of the asphalt due to scuffing divided by the area being scuffed
- ravelling: loss of coarse particles from the surface of the asphalt due to scuffing divided by the area being scuffed
- fretting: loss of fine material from the surface of the asphalt due to scuffing divided by the area being scuffed

These definitions are deliberately worded in order to apply to the scuffing of a road surface by passing vehicle tyres or to the simulated scuffing of a test sample by the tyres on scuffing apparatus during a test. These definitions would require two supplementary definitions of:

- coarse particles: material retained on a 2-mm sieve
- fine material: a combination of the binder, filler and fine aggregate that passes a 2-mm sieve

Material loss can be initiated by either ravelling or fretting, but in time each tends to exacerbate the potential for the other because loss of aggregate particles will expose the mortar to more direct scuffing whilst the loss of mortar will weaken the bond of aggregate particles to the surface. As such, the principal aim of the test is to measure the overall damage to the surface of the asphalt. However, it is sometimes important to identify ravelling from fretting and, therefore, two results of material loss from scuffing tests are proposed as follows:

- primary test result: the total mass of material lost from the test piece during the test period divided by the tracked area of the test sample
- secondary test result: mass of the collected coarse particles lost from the surface of a test plate during the test period divided by the tracked area of the test sample

Based on these definitions, it can be seen that the material loss from scuffing is the sum of ravelling and fretting. By sieving the loose material on a 2-mm sieve, the extent of ravelling relative to fretting can be determined.

It should be noted that any rubber from the test tyre that is worn away and falls into the open pores of, for example, a PA sample will have an opposite effect in that it will increase the weight of the test piece, masking the true loss of asphalt material and/or aggregate particles. Such apparent mass increase has to be allowed for in measuring either the primary or secondary test result, which can be done by checking for any mass loss from the tyre..

2.2 Use of Appendices

The approach taken in the official draft of prCEN/TS 12697-50 (CEN, 2014) sets out most of the technical details in separate Appendices of each of the different pieces of equipment. As such, it is not immediately obvious as to the similarities and difference between the requirements for the test as operated with the different designs of scuffing apparatus. Therefore, it is proposed to move as much of the technical details into the main text as is practicable in order to promote harmonisation. Where necessary, some parameters that cannot be harmonised will be set out in tabular form with different values for each design of scuffing apparatus.

2.3 Current differences

The common features identified from the main text are given in Table 3 while the aspects covered separately in the annexes are summarised in Table 4 (Nicholls, 2015).

Table 3: Common features across the apparatus in the initial draft standard

Attribute	Requirements common to all methods
No. of samples	2 slabs or 2 (sets of) cores
Slab dimensions	(500 ± 20) mm by (500 ± 20) mm or (500 ± 20) mm by (320 ± 20) mm
Core dimensions	Diameter of (150 ± 2) mm
Sample thickness	Between 30 mm and 80 mm
Storage	20 ºC for between 14 days and 42 days from time of manufacture
Test results	Visual inspection and/or pictures before and after the test (Material loss or increase in texture) per covered area

The initial proposals for harmonisation (Nicholls, 2015) are given in Table 5 but will be discussed further in Chapters 3, 4 and 5.

Table 4: Aspects varying with apparatus in the initial draft standard

Attribute	Annex A – ARTe	Annex B – DSD	Annex C – RSAT	Annex D – TRD
Slab dimensions	Area of 500 mm x 500 mm, 500 mm x 320 mm or 320 mm x 260 mm; thickness 30 mm to 80 mm	(260 ± 5) mm by (260 ± 5) mm	Octagonal with length and width c. 500 mm x 500 mm and thickness between 30 mm and 60 mm	Parallelepiped specimen 185 mm by 247 mm from 400 mm x 600 mm slab
Core dimensions	Core samples not explicitly covered but can be tested	Core samples not explicitly covered	Diameter of (150 ± 1) mm and height between 30 mm and 60 mm – Three cores per test	300 mm in diameter
Condition-ing	(20 ± 2) ºC for at least 4 h	(40 ± 1) °C for 2,5 h	Test temperature for 14 h to 18 h Preloaded with ≥ 20 kg for ≥ 1 h	(20 ± 2) °C for 2 h to 3 h
Other initial preparation	None specified	None specified	Removal of loose material	Removal of loose material
Initial measure-ments	Dimensions and mass Photograph or 3-dimensional texture	Mass and photograph	No additional measurements to those in the main text required	Surface flatness Macro-texture Photograph Dimensions and mass
Test load	(250 ± 5) kg	(1000 ± 10) N for pressure of 0,25 N/mm²	(35,0 ± 0,1) kg for pressure shall be (0,60 ± 0,01) N/mm²	Average 2.500 N with an amplitude of 833 N or Variable until reach 2 500 N
Test temper-ature	18 ºC to 25 ºC	(40 ± 1) °C †	(-10 ± 1) °C to (25 ± 1) °C with standard (20 ± 1) °C	(20 ± 2) ºC
Operations during test	Slab rotated 180 ° halfway through test	Vacuuming of loose grains and wiping off as required	Removal of all loose material by vacuum cleaner	Removal of all loose material by vacuum cleaner
Length of test run	600 cycles	Specified (number of) double shear cycles	86 600 passes in 24 h	10 000 cycles
Final measure-ments	Visual, photograph and 3-dimensional texture (if available)	Photograph Residue and loose grains from the asphalt specimen and the tyre	Aggregate loss after removal of rubber lost from tyre	Aggregate loss Number of cycles to reach specified degree of degradation

† In the DRaT round robin, BRRC also tested with the DSD at (20 ± 1) °C.

Table 5: Harmonisation of aspects currently varying with apparatus

Attribute	Proposed additional harmonisation
Slab dimensions	Dependent on apparatus; harmonisation not considered appropriate
Core dimensions	Dependent on apparatus; harmonisation not considered appropriate
Conditioning	(20 ± 1) ºC for at least 4 h
Other initial preparation	Removal of all loose material
Initial measurements	Visual inspection At least one photograph Sample dimensions Sample mass Macro-texture by patch method (possible with smaller volume) Dimensional texture by laser measurement (if equipment available)
Test load	Dependent on apparatus; harmonisation not considered appropriate
Test temperature	(20 ± 1) ºC other than DSD at (40 ± 1) ºC
Operations during test	No additional requirement
Length of test run	Dependent on apparatus; harmonisation not considered appropriate
Final measurements	As for initial measurement plus mass of loose material collected

3 Test equipment

3.1 Equipment design

The main aim of the project was to compare the results from the four designs of scuffing apparatus. The statistical analysis of the results from the project (Schoen *et al*., 2017) showed:

- ARTe device (ISAC and BAM) – The results obtained strongly differ among the two laboratories with ISAC only establishing a statistically significant increase in weight loss for PA/lb with respect to standard PA whilst BAM establishing increased weight losses for PA/lt, PA/lb, BBTM/lb and SMA/lt.
- DSD device (TUD and BRRC) – The BRRC results at 40 ^{0} C were smaller on average than those from TUD by a factor of 1,2. The PA/lb results were statistically significant higher than the PA standard for both laboratories but no other increased weight loss with respect to the standard could be established for this device within the round robin investigation.
- RSAT device (Heijmans) – A statistically significant increase in weight loss with respect to the standard was established for PA/lt, PA/lb, SMA/lt and SMA/lb. However, the statistically significant increases in weight loss for PA/lt and SMA/lt was only observed for one of the two weight loss measures (primary and/or secondary), and a different one in each of these cases.
- TRD device (IFSTTAR) – There was a statistically significant increase in weight loss found with respect to the standard for BBTM/lb after 6,000 cycles, SMA/lt after 6,000 cycles and 12,000 cycles and SMA/lb after 6,000 cycles. Any differences observed appear to be greater earlier in the test procedure than those later on.

The statistically significant differences found in the round robin tests are shown in Table 6.

Table 6: Statistically significant differences in the round robin tests
(Schoen *et al*., 2017)

Laboratory	Device	Asphalt type					
		PA		BBTM		SMA	
		Low temp.	Low binder	Low temp.	Low binder	Low temp.	Low binder
TUD	DSD	0	1	0	0	0	0
BRRC	DSD	0	1	0	0	0	0
IFSTTAR	TRD	0	0	0	1	1	1‡
Heijmans	RSAT	1‡	1	0	0	1†	1
ISAC	ARTe	0	1	0	0	0	0
BAM	ARTe	1	1	0	1	1	0

† Only for primary weight loss ‡ Only for secondary weight loss

Additionally, because the three mixture types are represented by a single mixture with two variants, it is uncertain whether the differences found are because of the mixture type or the precise grading chosen from within the envelope for that mixture type.

Therefore, the scuffing devices cannot be used interchangeably because the devices' discrimination potential for standard and poor-quality materials of the same type are not comparable (Schoen *et al*., 2017). Furthermore, no single device is capable to detect all the designed differences between the standard and poor-quality materials according to the current test methods.

Although, specific devices did appear to be capable of detecting the designed differences in asphalt type (e.g. between AUTL [asphalt for ultra-thin layers], PA, BBTM and/or SMA), it would be very awkward and, indeed, costly to have different designs of scuffing apparatus for different types of asphalt. Furthermore, whilst a limited review of site results (Nicholls, 2016) found that:

- there can be a significant scatter in the extent of ravelling with the same asphalt mixture;
- twin-layer porous asphalt is more susceptible to ravelling than more dense asphalts;
- the ranking for resistance to ravelling of three mixture types was SMA as best, then BBTM and then AUTL;
- higher binder contents do reduce the tendency to ravel;
- the use of polymer-modified bitumen does not reduce the tendency to ravel;
- higher binder contents tend to reduce scuffing;
- larger aggregate sizes tend to reduce scuffing;
- slag aggregate makes asphalt more susceptible to ravelling; and
- ravelling increases with age, as would be expected,

the difference between different material types is relative arbitrary. It has been shown that there is a tight 10 mm aggregate grading that can be classified as being an asphalt concrete (AC10), a very thin layer asphalt concrete (BBTM10), a stone mastic asphalt (SMA10) or a porous asphalt (PA10) (Nicholls, 2017). As such, proposing different designs of scuffing apparatus for different asphalt types is unsound and, furthermore, would require further testing of asphalt types currently untested.

Therefore, it is proposed that all four designs of scuffing apparatus are retained in the standard with no recommendations as to which design or designs are suitable for which type of asphalt. In addition, a new appendix should be added to allow alternative designs of scuffing apparatus not included in this project to be used after due calibration. If this investigation has not been able to determine the 'right' design, it should not exclude any future, possibly improved, design.

3.2 Normalisation factors

A statistical comparison between the results from the different devices for the three materials demonstrated that there are clear differences between results produced with different devices and with the parameters used (Schoen *et al*., 2017). Furthermore, it was found:

- any scaling strongly depends on the material tested; and
- many of the devices show a different damage development with time (although the implications of non-linear material loss has not been analysed in this project).

Hence, based on the test results obtained in the DRaT investigation, it was concluded that there was no uniform correlation between the devices nor could the results be culled or unified for a particular performance level and loading history that would convert to a common measure (Schoen *et al*., 2017).

However, if multiple designs of scuffing apparatus are to be included, some rough estimates for each device will be needed even if it is not realistic to propose scaling between them. In particular, it is not theoretically robust to extend the ratios found from the different compositions and processes of fabrication to other combinations. Nevertheless, the various normalising factors found (Schoen *et al*., 2017) can be combined as shown in Table 7 to make such estimates. The values are normalised about the lowest factor, which is for the RSAT.

Table 7: Normalising factors between devices

Device	**ARTe**			**DSD**			**RSAT**	**TRD**
Laboratory	**ISAC**	**BAM**	**Mean**	**TUD**	**BRRC**	**Mean**	**Heijmans**	**IFSTTAR**
PA	5,0	2,4	3,0	0,2	0,2	0,2	1,6	(91,7) †
BBTM	15,2	5,3	10,3	0,7	0,7	0,7	1,9	10,1
SMA	6,9	4,6	5,8	13,3	21,1	17,2	3,5	37,9
Mean	6,6			6,0			2,3	24,0
Normalised	2,81			2,59			1,00	10,3

† A problem occurred during the testing of porous asphalt with the TRD (permanent deformation being observed) so this value is not included in the calculation of the mean for that device.

Given the variability in the values used to produce these values, it is proposed to round them off to 2,8 for the ARTe, 2,6 for the DSD, 1,0 for the RSAT and 10 for the TRD. Using these factors, a result from the TRD will be multiplied by 10 to be equivalent to the result measured with the RSAT and by 10/2,8 to be equivalent to the result measured with the ARTe. These normalising factors will need to be reviewed once more extensive comparative data with the various designs of scuffing apparatus become available. Such revised factors may not be independent of the type of mixture with separate factors for different mixture types or groups of mixture types.

An alternative to normalising factors would be to adjust the number of load repetitions to achieve the same average loss from all the designs of scuffing apparatus. However, the devices show a different damage development with time so that the number of repetitions cannot just by changed using the calculated normalising factors. Also, it would extend the test with the TRD excessively. Therefore, this alternative normalising factor is not currently considered to be a practical option.

4 Sample production

4.1 Sample preparation

The sample preparation of laboratory-prepared specimens for the round robin (Jacobs, 2017) was intended to involve:

- Rotating the specimen by 90 ^{0} halfway through the compaction to improve the homogeneity.
- Checking the density at four points with a nuclear measuring device to ensure the maximum difference is not greater than 15 kg/m³, although the measurements were not sufficiently accurate. The mean density of each slab could only be determined by dividing the mass in the mould by the volume of the mould.
- Checking the thickness of the samples at eight positions with a calliper to ensure the maximum difference between the average thickness of the slabs is not great than 1 mm.
- Checking the overall dimensions, flatness (±1,0 mm), surface texture (using a laser scanner for PA and the patch method for the denser mixtures) and compaction of each sample. The MTD measurements showed that there were no significant variations for slabs of the same mixture, which implies that the texture was quite uniform.
- Checking the visual condition is acceptable and does not include:
  - Binder-rich spots > 20 mm diameter;
  - Binder-lean areas > 5000 mm²;
  - Stone loss due to aggregate particles sticking to roller drum; or
  - Irregular distribution near the specimen edges.

With regard to the density of samples, the present version of prCEN/TS 12697-50 requires that the bulk density is measured but without any requirement on the maximum difference permitted. The degree of compaction has a significant impact on the resistance to ravelling, so it is proposed to specify a limit on the difference in density between samples of 0,050 Mg/m³ (De Visscher, 2017). The compaction of a set of laboratory samples to a tight target density could mask what might prove to be a poor asphalt in the field. Therefore, the compaction of laboratory samples should be representative of the intended site practice (i.e. a certain number of passes with a roller rather than compaction to a specific density as in the DRaT project).

This testing schedule is considered too extensive for regular scuffing tests. Furthermore, rotating the specimen by 90 ^{0} halfway through the compaction to improve the homogeneity is not practical for most types of laboratory slab compactors and is not representative of the practice of compaction on site. Therefore, it is proposed to limit the sample preparation requirements to:

- Checking the bulk density of the slab or core by the dimensions procedure (as already included by the test method) with a maximum allowable difference of 0,050 Mg/m³.
- Checking the thickness of the samples at nine positions with a calliper to ensure a maximum allowable difference of 2,5 mm.
- Checking the overall dimensions and flatness (±1,0 mm) of each sample.
- Checking the visual condition is acceptable.

4.2 Sample dimensions

No harmonisation is possible on the sample dimensions because the type (slabs/cores) and dimensions of samples depend on the test device being used. However, it is proposed that the dimensions for each design of scuffing apparatus will be given in a table in the main text of the standard.

4.3 Conditioning

It was initially proposed to harmonise the condition of samples prior to testing to (20 ± 1) ºC for at least 4 h (Nicholls, 2015). However, because the test temperature has not been fully harmonised (Section 5.2), this proposal has been modified as follows:

- All devices except DSD: (20 ± 2) °C for at least 4 h
- DSD: (40 ± 2) °C or (20 ± 2) °C (depending on the test temperature) for at least 4 h

4.4 Storage / age of the samples

In the DRaT test programme, all the test specimens were prepared by one single laboratory and subsequently shipped to all other laboratories. Therefore, it was logistically impossible to adhere to the prCEN/TS 12697-50 requirement of testing the samples within 42 days (7 weeks) of manufacture. However, it is proposed not to change this aspect of the test standard because, presumably in practice, samples will be manufactured and tested at the same laboratory in smaller numbers than in the DRaT programme and so not require the extra time.

5 Testing

5.1 Test load

No harmonisation is possible on the test load because the means of applying that load depends on the test device being used. However, it is proposed that the test load for each design of scuffing apparatus will be given in a table in the main text of the standard.

5.2 Test temperature

As with the sample conditioning (Section 4.3), it was initially proposed to harmonise the condition of samples prior to testing to (20 ± 1) ºC for at least 4 h (Nicholls, 2015). However, the DSD device has been designed for testing at 40 °C whereas the other designs of scuffing apparatus were designed for testing at around 20 °C. Therefore, it is proposed that the test temperature should be as follows:

- DSD (standard): (40 ± 2) °C for at least 4 h
- DSD (alternative): (20 ± 2) °C for at least 4 h
- All other devices: (20 ± 2) °C for at least 4 h

5.3 Sample cleaning

In the current draft of prCEN/TS 2697-50, the different annexes for each of the designs of scuffing apparatus had different requirements for cleaning the samples before and during testing. It is proposed that the samples should be required to have all loose material removed with a vacuum cleaner initially and before each set of measurements. The material vacuumed off will need to be retained for determining the material lost.

5.4 Measurements

It is proposed that the following initial measurements (some of which are also needed for the checks of the sample preparation, Section 4.1) should be required:

- Dimensions of the sample.
- Mass of the sample.
- Photographs of the top surface of the sample from above and at a 45 ° angle.

It is further proposed that the location relative to the sample from which the pictures are taken together with the lighting and camera settings will be required to be recorded so that they can be replicated for subsequent photographs (De Visscher, 2017).

It is proposed that the measurements of mass from which the material can be determined should be repeated at each measurement interval. Optionally, the mass of coarse particles lost can also be measured. It is further proposed that the measurement shall be made at the end of the test and not less than three equally spaced intervals during the test.

At the end of the test, the following measurements shall be made:

- Mass of the sample.
- Mass of lost coarse particles (optional).
- Photographs of the top surface of the sample from above and at a 45 ° angle.

5.5 Length of test

No harmonisation is possible on the length of the test because the extent and duration of load cycles is dependent on the design of the scuffing equipment, particularly with the extended loading pattern for the RSAT device. However, it is appreciated that there are situations where the resistance to scuffing is more critical and that there are some mixture types that are more prone to ravelling and fretting. Therefore, it is proposed to have two test durations, the standard number of cycles and an extended number of about double the standard. However, no investigations have been made as to whether the same normalisation factors should be applied for the extended loading cycle because of the different development in damage over time and loading.

5.6 Number of samples

In the current draft of prCEN/TS 12697-50, a minimum of two replicate tests are required to be averaged for a test result whereas, in the round robin exercise, four replicates of each mixture option were tested to allow for statistical analysis. A large variation in the outcomes of the test was found in the round robin testing (Schoen *et al*., 2017), so it is proposed for the revised standard that a test result should be the average of not less than three replicate measurements.

5.7 Precision

It was found that that the test methods have relatively large geometric standard deviations, often more than 30 % (Schoen *et al*., 2017), as summarised in Table 8.

Table 8: Standard deviations found

Device	ARTe			DSD			RSAT	TRD
Laboratory	ISAC	BAM	Mean	TUD	BRRC	Mean	Heijmans	IFSTTAR
PA	49 %	24 %	37 %	17 %	18 %	17 %	38 %	53 %
BBTM	42 %	38 %	40 %	15 %	22 %	18 %	28 %	34 %
SMA	18 %	25 %	22 %	37 %	30 %	34 %	12 %	35 %
Mean	33 %			23 %			26 %	41 %
	31 %							

These values are for single measurements, so can be reduced by dividing by the square root of three for test results which are the mean of tests on three samples. However, it is proposed that these values will only be given as guidance for repeatability rather than to make estimates of repeatability and reproducibility because of the limited number of devices involved.

6 Conclusions

The round robin testing carried out as part of the DRaT project did not demonstrate that:

- The various designs of scuffing equipment could be correlated, either for specific asphalt mixture types or overall; or
- Specific designs of scuffing equipment could be identified as being best for identifying the scuffing-resistance of asphalt mixture, either for specific types or overall.

The lack of correlation is partly due to variation in the results and partly because it was found the devices do not provide constant ratios between the outcomes of their results for different materials.

Nevertheless, the project has identified certain aspects of the current draft of prCEN/TS 12697-50 to make a better and more unified document without rejecting any of the designs of scuffing apparatus. The revised version of the standard with the proposed improvements recommended are given in Appendix A. The changes are generally highlighted in red for major additions, in mauve for minor changes in terminology, in blue for moved sections, green for a compilation of ideas from the Annexes into the main text and grey across gaps from which text has been removed. However, because these changes are so extensive, the highlighting can only be indicative.

7 References

CEN TC227/WG1/TG2 (2014). Bituminous mixtures – Test methods – Part 50: Resistance to scuffing. *prCEN/TS 12697-50*. Unpublished draft.

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Appendix A – Proposed update of prCEN/TS 12697-50

DRaT draft revision

CEN/TC 227

prCEN/TS 12697-50:2017
CEN/TC 227
Secretariat: DIN

Bituminous mixtures — Test methods — Part 50: Resistance to scuffing
Asphalt — Prüfverfahren — Teil 50: Wiederstand gegen kornausbruch
Mélanges bitumineux — Méthodes d'essai — Partie 50: Résistance aux éraflures
ICS: 98.080.20
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Document type: European Technical Specification
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Document stage: DRaT proposed revision
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Contents

Foreword

This document (CEN/TS 12697-50:2017) has been prepared by the DRaT Consortium that undertook a research project for the Conferences of European Directors of Roads as part of the 2014 Call under the Asset Management and Maintenance topic for the use of standard ravelling tests to predict pavement durability. It is a development, based on the results of the consortium's testing programme, of document CEN/TS 12697-50:2014 that was prepared by Technical Committee CEN/TC 227 'Road materials', the secretariat of which is held by DIN.

This document is being offered to Technical Committee CEN/TC 227 for consideration by Working Group 1 'Asphalt Mixtures' and WG1/Task Group 2 'Test Methods'.

1 Scope

This draft European Technical Specification specifies a test method for determining the resistance to scuffing of bituminous mixtures which are used in surface layers and are loaded with high shear stresses in road or airfield pavements. These shear stresses occur in the contact area between tyre and pavement surface and can be caused by cornering of the vehicle. Due to these shear stresses, material loss will occur at the surface of these layers. The test is normally performed on asphalt layers with a high amount of air voids (e.g. porous asphalt), but can also be applied on other bituminous mixture types. Test specimens are either produced in a laboratory or cut from the pavement.

NOTE: The test has been developed to determine the resistance to scuffing for noise reducing surface layers where ravelling is the normative damage criterion. The test can also be performed on other surface mixtures with a high resistance to permanent deformation. In case a mixture has a low resistance to permanent deformation, rutting will probably precede scuffing both on site and in the test. The presence of ruts is likely to influence the test results significantly.

2 Normative references

The following referenced documents are indispensable for the application of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

EN 12697-6, Bituminous mixtures — Test methods for hot mix asphalt — Part 6: Determination of bulk density of bituminous specimens.

EN 12697-12, Bituminous mixtures — Test methods for hot mix asphalt — Part 12: Determination of the water sensitivity of bituminous specimens.

EN 12697-27:2001, Bituminous mixtures — Test methods for hot mix asphalt — Part 27: Sampling.

EN 12697-29, Bituminous mixtures — Test method for hot mix asphalt — Part 29: Determination of the dimensions of a bituminous specimen.

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EN 12697-33, Bituminous mixtures — Test methods for hot mix asphalt — Part 33: Specimen prepared by roller compactor.

EN 12697-35, Bituminous mixtures — Test methods for hot mix asphalt — Part 35: Laboratory mixing.

EN 13036-1, Road and airfield surface characteristics – Test methods – Part 1: Measurement of pavement macro-texture depth using a volumetric patch technique.

…….

EN 13036-7:2003, Road and airfield surface characteristics – Test methods – Part 7: Irregularity measurement of pavement courses – The straightedge test.

ISO 48, Rubber, vulcanized or thermoplastic — Determination of hardness (hardness between 10 IRHD and 100 IRHD).

ISO 4649, Rubber, vulcanized or thermoplastic – Determination of abrasion resistance using a rotating cylindrical drum device.

3 Principle

Laboratory compacted asphalt specimens or asphalt specimens cut from a pavement are fixed in a test facility. In this facility, the asphalt material is loaded simultaneously with both normal and shear stresses. Due to these stresses, material loss will occur from the surface of the sample. This material loss depends on the resistance to scuffing of the tested bituminous mixture: the higher the resistance, the less material will disappear.

To determine the resistance to scuffing, three slabs or three sets of cores shall be tested using one of the designs of scuffing apparatus for either a standard or extended duration. The average of the replicate determinations is reported as the test result for the resistance to scuffing.

…….

4 Terms, definitions, symbols and abbreviations

For the purposes of this document, the following terms and definitions, symbols and abbreviations apply.

4.1 *Terms and definitions*

4.1.1 *scuffing*

the action of tyres, particularly when the wheels are rotating about an axis not perpendicular to the direction of travel of the vehicle (or relative motion of the tyres and asphalt surface simulating the vehicle movement) which causes material loss from the surface of the asphalt

4.1.2 *material loss*

amount of material that has been lost from the surface of the asphalt due to scuffing divided by the area being scuffed

NOTE 1: The amount of material loss is determined by weighing the mass of the specimen before and after the test or by weighing the collected material lost from the surface. The difference in mass per area is a measure for the resistance to scuffing of the tested bituminous mixture.

NOTE 2: Scanning the surface of the specimen before and after the test provide 3D pictures from the surface of the specimen. After mathematically subtracting the 3D picture after the test from the one before the test, an accurate 3D overview of the material loss can be generated. If permanent deformation occurs during the test, the results of the surface scan have to be compensated for this phenomenon. The calculated volume of this 3D overview of the material loss is an accurate value for the resistance to scuffing of the tested bituminous mixture. However, this alternative method of determining the amount of material loss, including the method for compensating for any deformation, needs to be calibrated against the direct measurement by weighing.

NOTE 3: Visual observation of the surface, either direct observation or of photographs, can provide an estimate of the degree of material loss and may provide additional information on the type of failure (cohesive or adhesive).

NOTE 4: If possible, measurements of the material loss should be made after different numbers of loading sequences so that the evolution of the material loss can be determined.

4.1.3 *ravelling*

loss of coarse particles from the surface of the asphalt due to scuffing divided by the area being scuffed

4.1.4 *fretting*

loss of the mastic from the surface of the asphalt due to scuffing divided by the area being scuffed

4.1.5 *coarse particles*

material retained on a standard 2 mm sieve

NOTE: This definition is specific to this test method.

4.1.6 *fine material*

a combination of the binder, filler and fine aggregate that passes a 2-mm sieve

NOTE: This definition is specific to this test method.

4.1.7 *primary test result*

the mass of material lost from the test piece during the test period divided by the tracked area of the test sample

NOTE: Any rubber from the test tyre that is worn away and falls into the open pores of, for example, a PA sample will have an opposite effect in that it will increase the weight of the test piece, masking the true loss of aggregate particles.

4.1.8 *secondary test result*

mass of the collected coarse particles lost from the surface of a test plate during the test period divided by the tracked area of the test sample (defined as "ravelling")

4.2 *Symbols and abbreviations*

A = surface area of each specimen that is scuffed, in 0,01 mm².

d = diameter of cores when a specimen is a set of cores, in 0,1 mm.

D = diameter of a specimen that is scuffed when the scuffed area is circular, in 0,1 mm.

k = number of measurements made during the test.

L = length of a specimen when the specimen is a slab, in 0,1 mm.

L_S = length of the area of the specimen that is scuffed when the scuffed area is rectangular, in 0,1 mm.

$M_{i,0}$ = mass of specimen i before performing the test, in 1 gram.

$M_{i,j}$ = mass of specimen i after scuffing at measurement j, in 1 gram.

$\Delta M_{i,j}$ = loss of mass of specimen i after scuffing at measurement j, in 1 gram.

Mai_m = mass loss per surface area scuffed of specimen i after scuffing at measurement j, in 0,1 kg/m².

MA = mean corrected mass loss per surface area scuffed at end of test, in 0,1 kg/m².

n = number of specimen replicates in the test.

n_c = number of cores in a set when a specimen is a set of cores.

N_f = Normalisation factor (specific to scuffing device used)

$P_{i,j}$ = mass of coarse aggregate particles recovered from specimen *i* after scuffing at measurement *j*, in 1 gram.

$Pa_{i,j}$ = mass of coarse aggregate particles recovered per surface area scuffed of specimen *i* after scuffing at measurement *j*, in 0,1 kg/m².

Pa = mean corrected mass of coarse aggregate particles recovered per surface area scuffed at end of test, in 0,1 kg/m².

R_M = range of mass loss per surface area scuffed at end of test as a proportion of the mean value, in 1 %.

R_P = range of mass of coarse aggregate particle loss per surface area scuffed at end of test as a proportion of the mean value, in 1 %.

R_V = range of increase in texture depth volume per surface area scuffed at end of test as a proportion of the mean value, in 1 %.

T = thickness of the specimen before testing, in 0,1 mm.

$V_{i,0}$ = texture depth volume on the surface of specimen *i* before performing the test, in 0,1 mm³.

$V_{i,j}$ = texture depth volume on the surface of specimen *i* after scuffing at measurement *j*, in 0,1 mm³.

$\Delta V_{i,j}$ = increase in texture depth volume on the surface of specimen *i* after scuffing at measurement *j*, in 0,1 mm³.

$\Delta Va_{i,j}$ = texture depth volume increase per surface area of specimen *i* after scuffing at measurement *j*, in 10 mm³/mm².

ΔVa = mean corrected texture depth volume increase per surface area scuffed at end of test, in 10 mm³/mm².

W = width of a specimen when the specimen is a slab, in 0,1 mm.

W_S = width of the area of a specimen that is scuffed when the scuffed area is rectangular, in 0,1 mm.

5 Apparatus

5.1 *Scuffing equipment*

Either:

- An Aachener Ravelling Tester (ARTe) in accordance with Clause A.1 of Annex A; or
- A Darmstadt Scuffing Device (DSD) in accordance with Clause B.1 of Annex B; or
- A Rotating Surface Abrasion Test (RSAT) in accordance with Clause **Error! Reference source not found.** of Annex C; or
- A TriboRoute Device (TRD) in accordance with Clause D.1 of Annex D; or
- Another design of scuffing apparatus that has been validated in accordance with Annex E.

5.2 *Temperature-controlled space (optional)*

A room or cabinet in which the specimens held in the scuffing device are housed that is temperature controlled to ± 2 °C of the test temperature and ventilated.

NOTE: When the testing period for the intended scuffing device is sufficiently short that the surface temperature can be maintained at the test temperature ±2 °C without temperature-controlled space, it can be omitted.

5.3 *Oven*

An oven capable of raising the asphalt specimens to the test temperature ± 1 °C.

NOTE. The temperature controlled space can also be used as the oven.

5.4 *Temperature measuring devices*

A surface temperature measuring device with an accuracy of 1 °C at the test temperature.

NOTE: Infra-red measuring devices can be used.

5.5 *Balance*

Balance capable of weighing the specimens with an accuracy of ± 0,5 gram.

5.6 *Vacuum cleaner*

An industrial vacuum cleaner with 1.800 to 4.500 Watts of power (Figure 1).

NOTE 1 The purpose of the vacuum cleaner is to collect the loose aggregates lost by the test specimen. It is extremely important to keep the specimen surface free from material (tyre rubber and minerals). This cleaning will influence the results.

Figure 1: Vacuum cleaner on one of two different RSAT plates, each with three cores

The air flow containing the extracted material (mineral aggregates and rubber powder) shall be led by a centrifugal separator.

NOTE 2 Stone loss development over the duration of the test period gives information about the type of damage in terms of whether ravelling or fretting predominates. However, the loss of coarse particles will expose the fine material to abrasion and the loss of fine material will weaken the bond of coarse particles to the pavement, so that the presence ravelling will encourage fretting and vice versa.

5.7 *Laser texture meter (optional)*

Laser texture meter capable of measuring the texture of the surface of a specimen with an accuracy of ± 0,1 mm.

5.8 *Electric fan (optional)*

An electric fan can be used during the test to cool the specimen and the tyre(s).

6 Specimen preparation

6.1 *General*

Three slabs or three (sets of) cores of that material shall be tested to determine the resistance to scuffing of an asphalt mixture. The average of the three test determinations shall be considered the resistance to scuffing result.

6.2 *Manufacture of specimens*

6.2.1 Bituminous mixture shall either be prepared in a laboratory in accordance with EN 12697-35 or sampled from an asphalt plant in accordance with EN 12697-27. The bituminous mixture for laboratory-prepared samples shall be compacted into slabs in accordance with EN 12697-33. Samples shall be compacted following the same compaction level plan which reflects the expected compaction that will be achieved on site.

6.2.2 Slab specimens can be cut down from larger laboratory-prepared slabs but cutting shall not be undertaken only from one side.

6.2.3 Alternatively, specimens can be cored from an asphalt pavement in accordance with Clause 4.7 of EN 126797-27:2001 for testing with a device that can test cylinders. The under face of cores shall be cut or polished to a smooth surface that is parallel to the upper face as far as practicable.

6.3 *Dimensions of specimens*

6.3.1 The test can be performed on specimens with various dimensions, depending on the type of test device.

NOTE: Slab specimens generally have the dimensions relevant to the scuffing device used as listed in Table 1.

Table 1: Test parameters for different scuffing devices

Scuffing device	Width (mm)	Length (mm)	Test temp. (°C)	Duration of tests (cycles) Standard	Duration of tests (cycles) Extended †	Normalisation factor N_f
ARTe	520 ± 5	520 ± 5	20	600	1200	2,8
DSD	260 ± 5	260 ± 5	40 or 20	10	20	2,6
RSAT	500 ± 20 *	500 ± 20 *	20	86.600	173.200	1,0
TRD	400	600	20	6.000	12.000	10
Other scuffing device validated to Annex E	Relevant section of validation report					

* Specimens for the RSAT shall be of a regular octagonal shape formed in accordance with 0 of Annex C.

† The standard duration was developed for porous bituminous mixtures, which is a bituminous mixture type with a relative short expected service life. The extended duration tests are available for checking the resistance for scuffing of longer-lasting mixtures and mixture types.

NOTE: The normalisation factors have been calculated from the results of the DRaT test programme. These values only give a very rough estimate of the order of magnitude and may be refined with further experience of these scuffing devices.

6.3.2 A set of three cylinders or cores with a diameter of (150 ± 2) mm shall form a single specimen for the RSAT (Figure 1). A single cylinder or core with a diameter of (300 ± 2) mm shall form a single specimen for the DSD or TRD.

6.3.3 The thickness of specimens shall be between 30 mm and 80 mm.

6.4 *Specimen compliance*

6.4.1 The length (= *L*) and width (= *W*) of the sample shall be measured in accordance with EN 12697-29.

6.4.2 The thickness (= *T*) of the specimen shall be measured in accordance with EN 12697-29 at eight points. Each point shall be taken 10 mm from the edge of the specimen using a vernier calliper. All eight points shall be equally divided over the surface of the specimen. The accuracy of each measurement shall be 0,1 mm. The maximum difference between the eight individual measurements shall be 2,5 mm. If not, the specimen shall not be tested. The average of the eight measurements shall be the thickness *T* of the specimen.

6.4.3 If cores are tested, the diameter (= *D*) and thickness (= *T*) of each core shall be determined in accordance with EN 12697-29.

6.4.4 The bulk density of the specimen shall be determined in accordance with EN 12697-6 using the bulk density by dimensions procedure. Before measuring the mass $M_{0,i}$ of the specimen, the specimen shall be dried to constant mass in air at a relative air humidity of less than 80 % at a temperature not more than 20 °C. A test specimen shall be considered to be dry when two weighings, performed not less than 12 h apart, differ by less than 0,1 %. The maximum difference between the bulk density of replicate specimens shall be 0,050 Mg/m³.

6.4.5 The surface irregularity of specimens shall be measured in accordance with EN 13036-7 and any specimens with irregularities of more than 2 mm shall not be tested.

6.4.6 The visual condition of specimen shall be inspected and any specimens with: areas of excessive mortar greater than 10 mm diameter; binder-lean areas > 5000 mm²; or aggregate particles not fully coated shall not be tested.

6.5 *Storage conditions*

As a general rule, the specimens shall be stored on a flat surface at a temperature of not more than 20 ºC for a period between 14 days and 42 days from the time of their compaction to the start of testing. When deviating from this general rule, the time of compaction and the storage conditions between compaction and testing shall be reported. In the case of laboratory-prepared specimens requiring cutting, the cutting shall be performed no more than 8 days after compaction of the asphalt, with the time of manufacture for these specimens being the time when they are cut. In the case of specimens cut or cored from a road, report the time between compaction and cutting or coring.

NOTE: Not only fresh bituminous mixtures can be tested, also aged specimens can be examined in the scuffing test. In literature, several aging procedures can be found. The choice of a proper ageing procedure depends on the characteristics of the tested material.

7 Procedure for carrying out a single measurement

7.1 *Initial measurements*

7.1.1 The surface of the specimen shall be photographed from above and at a 45 ° angle. The location relative to the sample from which the pictures are taken together with the lighting and camera settings shall be recorded so that they can be replicated for subsequent photographs.

7.1.2 The mass of specimen *i*, whether slab or multiple cores, prior to scuffing, $M_{i,0}$, shall be measured on the balance. The mass shall include the mass of any mould or other item that is used to protect the specimen when removed from the test device when removed for future measurements.

NOTE: The use of a mould or other item to protect the specimen during measuring should minimise damage to the edges of the specimen that could significantly affect the results of the test.

7.1.3 If required, the texture depth volume on the surface of specimen *i*, whether slab or multiple cores, prior to scuffing, $V_{i,0}$, shall be measured with the laser texture meter.

7.2 *Scuffing*

7.2.1 Small rubber tyres and blocks used on some of the scuffing devices shall be replaced before the test is started. The vehicle tyres on other scuffing devices shall be inspected for any wear or damage and, if present, replaced before the test is started.

7.2.2 The specimen shall be brought up to the test temperature in the temperature controlled space or oven for at least 4 hours, where the test temperature shall be taken from Table 1. The specimen shall then be installed in the scuffing device if not already there.

7.2.3 The vacuum cleaner shall be used remove any detritus from the surfaces of the specimen, the tyre and adjacent equipment so that all loose grains are removed. While vacuuming, shear stresses shall not be applied to loose grains still adhering to the specimen as far as practicable.

7.2.4 The scuffing device shall be started and the specimen trafficked. Additional requirements that are given in either shall be implemented as appropriate:

- The Aachener Ravelling Tester (ARTe) in accordance with Clause 0 of Annex A; or
- The Darmstadt Scuffing Device (DSD) in accordance with Clause 0 of Annex B; or
- The Rotating Surface Abrasion Test (RSAT) in accordance with Clause C.3 of Annex C; or
- The TriboRoute Device (TRD) in accordance with Clause 0 of Annex D; or

- The relevant section of the report on another design of scuffing equipment that has been validated in accordance with Annex E.

7.2.5 During the test, the surface temperature of the specimen shall be measured with an accuracy of ±1 °C. The average of the temperatures measured in at least three points (left corner, middle and right corner) shall remain within the range of test temperature -2 °C to test temperature +5 °C.

NOTE: The temperature of the specimen surface can be raised by the high shear stresses on the contact area. The temperature can be controlled by using an electric fan.

7.2.6 The test shall be continued for the number of cycles set in Table 1 for the scuffing device being used. At the end and at not less than three equally spaced intervals, the scuffing shall be stopped and the detritus generated vacuumed off the surfaces of the specimen, the tyre and adjacent equipment. If required, the coarse particles (≥ 2 mm) shall be separated from the fine material. A set of measurements in accordance to Clause 7.3 shall be taken.

7.3 *Measurement*

7.3.1 The mass of specimen *i* at measurement *j*, $M_{i,j}$, shall be measured on the balance. Alternatively, the cumulated mass of the material loss can be measured, avoiding the necessity to remove the sample at each interval.

7.3.2 If required, the mass of coarse aggregate particles recovered from specimen *i* at measurement *j*, $P_{i,j}$, shall be measured on the balance.

7.3.3 If practical, the surface of the specimen shall be photographed from the same location and with the same lighting and camera settings as for the initial photographs.

7.3.4 If required, the texture depth volume on the surface of specimen *i* at measurement *j*, $V_{i,j}$, shall be measured with the laser texture meter.

8 Procedure for carrying out a single test

The procedure for carrying out a single measurement in Clause 7 shall be carried out on not less than three replicates for one test.

9 Calculation and expression of results

NOTE: The results of the tests shall be reported using the results of the visual inspection and/or pictures before and after the test and the material loss per scuffed area (= *MLpA*). Alternatively, the increase in texture per scuffed area (= *ΔV*) can be used.

9.1 *Visual damage*

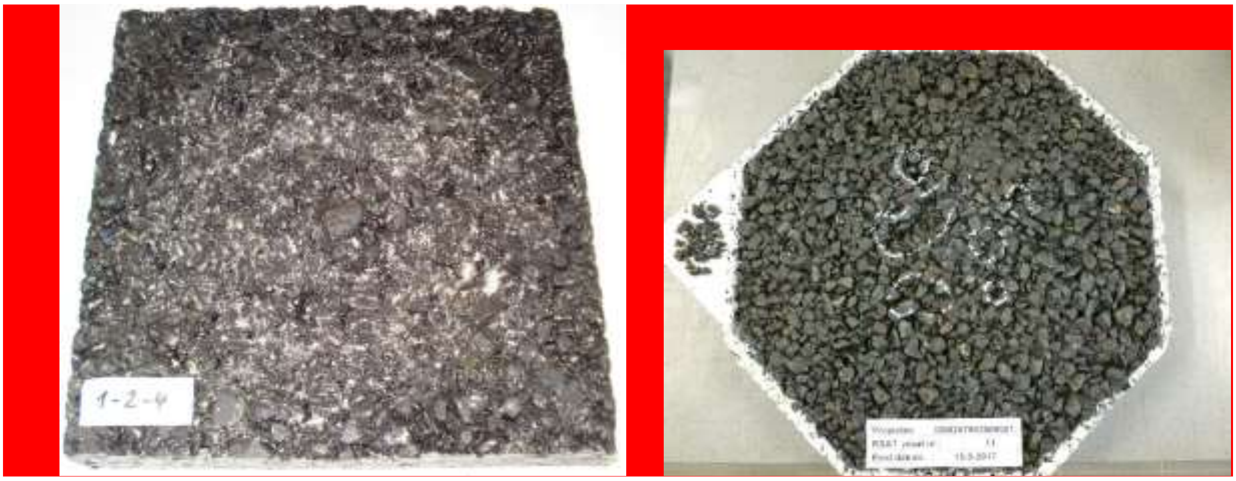
The visual damage for porous asphalt shall be assessed as '*negligible*', '*limited*', '*moderate*' or '*extensive*' by comparing the photographs taken after the test with those in Figures 2, 3, 4 and 5. For other mixture types, different levels of scuffing may apply.

From DSD From RSAT

Figure 2: Examples of '*negligible*' scuffing

From DSD From RSAT

Figure 3: Examples of '*limited*' scuffing



From DSD From RSAT

Figure 4: Examples of '*moderate*' scuffing

From DSD From RSAT

Figure 5: Examples of '*extensive*' scuffing

9.2 *Scuffed area*

9.2.1 Where scuffing is not applied to the complete surface of the asphalt sample, the width and diameter or the diameter of the area that is scuffed shall be measured in accordance with EN 12697-29.

NOTE: The dimensions of the scuffed area should remain constant for a specific scuffing device so that these dimensions need not be repeated for each test.

9.2.2 The surface area scuffed for a specimen where the scuffing is undertaken over a rectangular within the area of the specimen shall be calculated as follows:

$$A = W_s \times L_s \quad (1)$$

where:

A = surface area of each specimen that is scuffed, in 0,01 mm².

W_s = width of the area of the specimen that is scuffed in 0,1 mm.

L_s = length of the area of the specimen that is scuffed in 0,1 mm.

NOTE The width and length of the area of the specimen that is scuffed will be the same as the width and length of the slab if the entire area of the slab specimen is scuffed.

9.2.3 The surface area scuffed for a specimen where the scuffing is undertaken over a circle within the area of the specimen shall be calculated as follows:

$$A = \frac{1}{4}\pi \times D^2 \quad (2)$$

where:

A = surface area of each specimen that is scuffed, in 0,01 mm².

D = diameter of the area of the specimen that is scuffed in 0,1 mm.

9.2.4 The surface area scuffed for a set of cores that are treated as a single specimen shall be calculated as follows:

$$A = \frac{n}{4}\pi \times d^2 \quad (3)$$

where:

A = surface area of each specimen that is scuffed, in 0,01 mm².

d = diameter of each core that is scuffed in 0,1 mm.

n_c = number of cores in a specimen.

9.2.5 The surface area that is scuffed for specimens that are scuffed over an area that is not rectangular, circular or a set of cores shall be calculated in accord with basic geometric principles for the relevant shape.

NOTE: Sometimes a substantial part of the scuffing occurs close to the edges of the specimen. This phenomenon especially occurs when course graded porous asphalt specimens are tested. In this situation, the increase in volume can be determined for a smaller area of the slab or core. If, for example, a slab of 500 mm by 500 mm shows excessive scuffing close to the edges, ΔV can be determined over an area of 400 mm by 400 mm, skipping the material loss which occurs in the outer strip with a width of 50 mm of the slab. The considered area should be noted in the test report.

9.3 *Primary test result*

9.3.1 The loss of mass and the loss of mass per surface area scuffed of specimen i after scuffing at measurement j shall be calculated as follows:

$$\Delta M_{i,j} = M_{i,j} - M_{i,0} \tag{4}$$

$$\Delta Ma_{i,j} = N_f \times {}^{\Delta M_{i,j}}\!/_{A} \times 10^3 \tag{5}$$

9.3.2 The mean and range loss of mass per surface area scuffed at end of test shall be calculated as follows:

$$\Delta Ma = {}^{\left(\sum_{i=1}^{n} \Delta Ma_{i,k}\right)}\!/_{n} \tag{6}$$

$$R_M = 100 \times {}^{\left\{Max_{i=1}^{n}\left(\Delta Ma_i\right) - Min_{i=1}^{n}\left(\Delta Ma_i\right)\right\}}\!/_{\Delta Ma} \tag{7}$$

where:

- A = surface area of the specimen that is scuffed, in 0,01 mm².
- k = number of measurements made during the test.
- $M_{i,0}$ = mass of specimen *i* before performing the test, in 1 gram.
- $M_{i,j}$ = mass of specimen *i* after scuffing at measurement *j*, in 1 gram.
- $\Delta M_{i,j}$ = loss of mass of specimen *i* after scuffing at measurement *j*, in 1 gram.
- $\Delta Ma_{i,j}$ = mass loss per surface area scuffed of specimen *i* after scuffing at measurement *j*, in 0,1 kg/m².
- ME = mean mass loss per surface area scuffed at end of test, in 0,1 kg/m².
- n = number of specimen replicates in the test.
- N_f = normalisation factor for the scuffing device used, as listed in Table 1.

NOTE: Normalisation factor N_f has been calculated from the average values measured using the four different scuffing devices in the research project that the DRaT Consortium undertook for the Conferences of European Directors of Roads under 2014 Call under the Asset Management and Maintenance topic for the use of standard ravelling tests to predict pavement durability. The means were used because no direct correlations were found between the devices in that project. As such, these factors may need to be revised with further experience of the test.

- R_M = range of mass loss per surface area scuffed at end of test as a proportion of the mean value, in 1 %.

9.4 *Secondary test result (optional)*

9.4.1 The loss of mass of coarse aggregate particles and the loss of mass of coarse aggregate particles per surface area scuffed of specimen i after scuffing at measurement j shall be calculated as follows:

$$P_{i,j} = P_{i,j} - P_{i,0} \quad (8)$$

$$Pa_{i,j} = N_f \times {}^{P_{i,j}}\!/_{A} \times 10^3 \quad (9)$$

9.4.2 The mean and range loss of mass of coarse aggregate particles per surface area scuffed at end of test shall be calculated as follows:

$$PA = {}^{\left(\sum_{i=1}^{n} Pa_{i,k}\right)}\!/_{n} \quad (10)$$

$$R_P = 100 \times {}^{\left\{Max_{i=1}^{n}(Pa_i) - Min_{i=1}^{n}(Pa_i)\right\}}\!/_{Pa} \quad (11)$$

where:

A = surface area of the specimen that is scuffed, in 0,01 mm².

k = number of measurements made during the test.

n = number of specimen replicates in the test.

N_f = normalisation factor for the scuffing device used, as listed in Table 1.

NOTE: The same normalisation factors, N_f, are used for each of the calculated measures.

$P_{i,j}$ = mass of coarse aggregate particles recovered from specimen *i* after scuffing at measurement *j*, in 1 gram.

$Pa_{i,j}$ = mass of coarse aggregate particles recovered per surface area scuffed of specimen *i* after scuffing at measurement *j*, in 0,1 kg/m².

Pa = mean mass of coarse aggregate particles recovered per surface area scuffed at end of test, in 0,01 kg/m².

R_P = range of coarse aggregate particle loss per surface area scuffed at end of test as a proportion of the mean value, in 1 %.

9.5 *Texture depth volume increase (optional)*

NOTE: This measure is not a replacement for the primary test result because, depending on the initial texture and on whether the material loss is primarily ravelling or fretting, a loss of material may result in either more or less texture.

9.5.1 The increase in texture depth volume and the increase in texture depth volume per surface area scuffed of specimen i after scuffing at measurement j shall be calculated as follows:

$$\Delta V_{i,j} = V_{i,j} - V_{i,0} \quad (12)$$

$$\Delta Va_{i,j} = {}^{\Delta V_{i,j}}\!/_{A} \quad (13)$$

9.5.2 The mean and range increase in texture depth volume per surface area scuffed at end of test shall be calculated as follows:

$$\Delta VA = N_f \times {}^{\left(\sum_{i=1}^{n} \Delta a_{i,k}\right)}\!/_{n} \quad (14)$$

$$R_M = 100 \times {}^{\left\{Max_{i=1}^{n}(\Delta Va_i) - Min_{i=1}^{n}(\Delta Va_i)\right\}}\!/_{\Delta Va} \quad (15)$$

where:

A = surface area of the specimen that is scuffed, in 0,01 mm².

k = number of measurements made during the test.

n = number of specimen replicates in the test.

N_f = normalisation factor for the scuffing device used, as listed in Table 1.

NOTE: The same normalisation factors, N_f, are used for each of the calculated measures.

R_V = range of texture depth volume increase per surface area scuffed at end of test as a proportion of the mean value, in 1 %.

$V_{i,0}$ = texture depth volume on the surface of specimen *i* before performing the test, in 0,1 mm³.

$V_{i,j}$ = texture depth volume on the surface of specimen i after scuffing at measurement j, in 0,1 mm³.

$\Delta V_{i,j}$ = increase in texture depth volume on the surface of specimen *i* after scuffing at measurement j, in 0,1 mm³.

$\Delta Va_{i,j}$ = texture depth volume increase per surface area scuffed of specimen *i* after scuffing at measurement j, in 10 mm³/mm².

ΔVa = mean texture depth volume increase per surface area scuffed at end of test, in 10 mm³/mm².

10 Test report

The test report for the resistance to scuffing test shall contain not less than the following information:

a) Name of organisation carrying out the test.

b) Date of the test.

c) A reference to this test method and test conditions.

d) A characterisation and the origin (laboratory compacted slabs or cylinders or cores cut from a pavement) of the tested material.

e) If known, the age and history of the specimens

f) A short description of the test facility.

g) For each specimen tested, report.

g.1) Length, width (or number and diameter if cores) and thickness of the specimen, expressed to the nearest 0,1 mm.

g.2) The results of the visual inspection of the surface of the specimen initially and for each measurement.

g.3) The mass of the specimen initially (= $M_{0,i}$) and at each measurement (= $M_{i,j}$), expressed to the nearest 1 gram.

g.4) The material loss per scuffed area (= ΔMa_i), expressed to the nearest 0,1 kg/m².

g.5) If measured, the mass of coarse aggregate recovered at each measurement (= $P_{i,j}$), expressed to the nearest 1 gram.

g.6) If measured, the mass of coarse aggregate recovered per scuffed area (= Pa_i), expressed to the nearest 0,1 kg/m².

g.7) If measured, the texture depth volume on the surface of the specimen initially (= $V_{0,i}$) and at each measurement (= $V_{i,j}$), expressed to the nearest 0,1 mm³.

g.8) If measured, the increase in texture depth volume on the surface per scuffed area (= ΔVa_i), expressed to the nearest 10 mm³/mm².

h) The number of specimens tested.

i) If the specimens are laboratory-compacted slabs, the method and level of compaction.

j) The primary test result (average material loss per scuffed area, *ΔMa*), expressed to the nearest 1 g/mm².

k) The range of material loss per scuffed area (= R_M), expressed to the nearest 1 %.

l) If measured, the secondary test result (average mass of coarse aggregate particles recovered per scuffed area, *ΔMa*), expressed to the nearest 1 g/mm².

m) If measured, the range of mass of coarse aggregate particles recovered per scuffed area (= R_P), expressed to the nearest 1 %.

n) If measured, the average increase in texture depth volume on the surface per scuffed area (= *ΔVa*), expressed to the nearest 10 mm³/mm².

o) If measured, the range of increase in texture depth volume on the surface per scuffed area (= R_V), expressed to the nearest 1 %.

p) A general conclusion about material loss, based on the results of the visual inspection of all specimens.

11 Precision

Currently, insufficient precision data are currently available to provide reliable values of repeatability and reproducibility. However, estimates of the standard deviation of three replicate determinations are available from the test programme that the DRaT Consortium undertook for the Conferences of European Directors of Roads as part of the 2014 Call under the Asset Management and Maintenance topic for the use of standard ravelling tests to predict pavement durability. The estimates were calculated from the standard deviations of single determination determined from sets of four determinations. These estimates are given in Table 2.

Table 2: Estimates of standard deviation for the mean of three determinations

Device	**ARTe**			**DSD**			**RSAT**	**TRD**
Laboratory	**1**	**2**	**Mean**	**3**	**4**	**Mean**	**5**	**6**
PA	28 %	14 %	21 %	10 %	10 %	10 %	22 %	31 %
BBTM	24 %	22 %	23 %	9 %	12 %	11 %	16 %	19 %
SMA	11 %	15 %	13 %	21 %	17 %	19 %	7 %	20 %
Mean	19 %			13 %			15 % %	23 %
	18 %							

In addition, Project SOst [6] produced estimates for the precision with the Darmstadt Scuffing Device (DSD) of:

- Repeatability $r = 0{,}625 \times \Delta M - 3{,}392$
- Reproducibility $R = 1{,}069 \times \Delta M - 0{,}879$

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Annex A Aachener Ravelling Tester (ARTe)
(Normative)

A.1 Scuffing device

A.1.1 General

The specimen is fixed in a specimen fixation box and is moving forwards and backwards. This movement shall be created by mounting the specimen and the specimen fixation box on a lateral moving table, which is travelling for- and back-wards. During this movement, a set of two wheel with pneumatic tyres shall rotate over the loading table and the asphalt specimen, creating large shear stresses due to the combination of the lateral movement of the table and the rotation of the wheel set.

NOTE: An example of the test facility is given in Figure A.1 and an overview is shown in Figure A.2.

Figure A.1: An example of the scuffing device

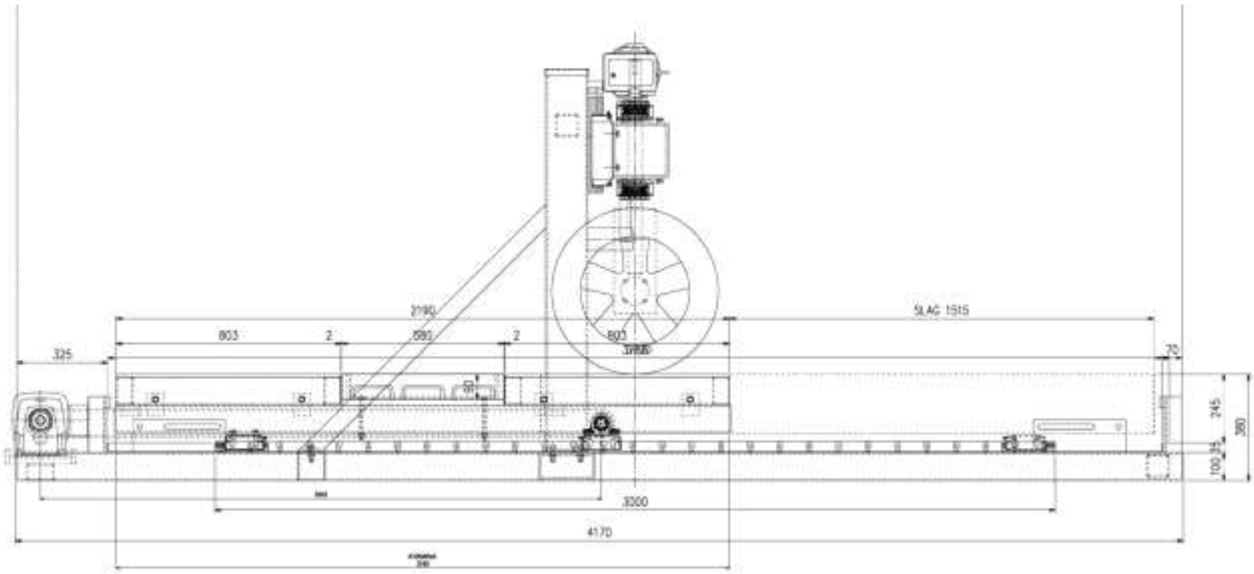


Figure A.2: An example of a longitudinal view of the scuffing device with the lateral moving table in the left position in which the specimen fixation box is in the middle of the lateral moving table

A.1.2 Lateral moving table

The lateral moving table shall consist of a loading frame on wheels which travels over a fixed distance using rails. By using rails, the table shall move back and forth along a straight line.

On the loading frame, on both sides of the specimen, a horizontal surface shall be created. Together with the specimen fixation box and the surface of the specimen, a horizontal surface shall be created where the set of rotating wheels can move around without creating extra vertical dynamic forces due to jumping of the set of wheels.

The lateral movement of the table shall be realised by using, for example, a belt which is driven by an electro motor. The speed of the moving table does not need to be constant during the test, so acceleration and deceleration is possible. However, during the time the set of wheels is travelling over the specimen, the speed of the loading table shall be (0,30 ± 0,03) m/s.

A.1.3 Set of rotating wheels

To create a set of rotating wheels, an electro motor with a vertical axis shall be mounted about mid-length of the rails on a loading frame. This frame shall consist of two vertical bars which are connected by a horizontal bar. The connection between the horizontal bar and the two vertical bars shall not be completely fixed.

NOTE 1: Vertical movement of the horizontal bar is allowed and even necessary to be sure that during the test the set of wheels are always in contact with the asphalt specimen, also when material loss occurs from the specimen.

The vertical axis from the electro motor on the horizontal bar shall have a rotation speed of (47 ± 1) rpm. In this test, two smooth profiled 165/75 R14C radial 97/95 tyres are used.

The tyre pressure shall be (230 ± 10) kPa during the test. Both tyres shall rotate freely when the set of loading wheels does not touch the lateral moving table. The distance between the centre of both tyres shall be (460 ± 5) mm, which implies that the total area of the specimen that will be loaded during the test.

The total mass of the horizontal bar, electro motor and set of rotating wheels shall be (250 ± 5) kg. To prevent any loss of vertical forces during the test, the vertical movement of the horizontal bar shall be as free as possible.

NOTE 2: An example of a cross section of the scuffing device with a set of rotating wheels is given in Figure A.3.

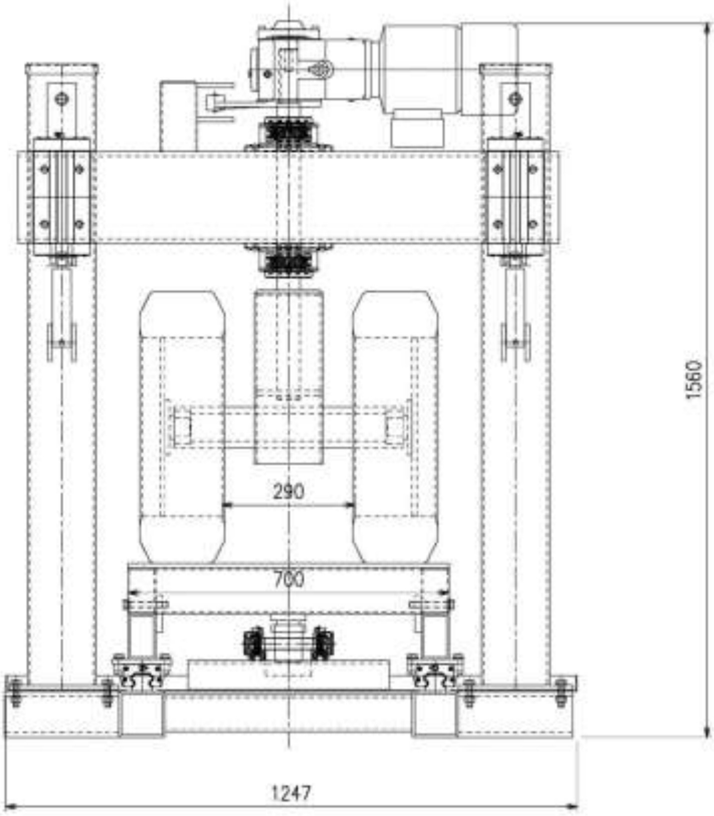


Figure A.3: An example of the set of rotating wheels of the scuffing device

A.1.4 Specimen fixation box

The specimen shall be built in the lateral moving table in such a way that the surface of the specimen and of the lateral moving table are in one horizontal plane.

NOTE 1: In this way, the variation of the vertical force due to jumping of the set of rotating wheels can be limited to acceptable values.

To accomplish the correct setting of the asphalt specimen in the lateral moving table, the specimen shall be fixed in a specimen fixation box.

NOTE 2: To ease the fixation of the specimen in the scuffing device, the specimen fixation box can be taken from the lateral moving table. This box consists of a large squared bottom plate and four vertical plates. These plates are fixed together is such a way that an un-deformable box arises.

NOTE 3: An example of a specimen fixation box is given in Figure A.4.

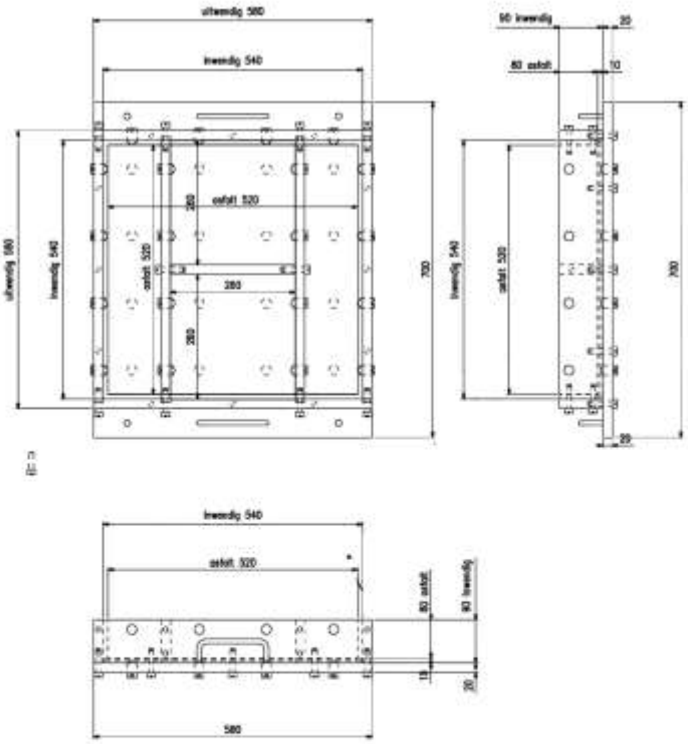


Figure A.4: An example of the specimen fixation box of the scuffing device

The inner dimensions of the box shall be chosen in such a way that the asphalt specimen fits easily in the inner volume of the box. The height of the box shall be chosen so that the surface of the specimen fixation box and the lateral moving table are in one horizontal plane when the specimen fixation box is built in in the lateral moving table.

To be able to test asphalt specimens with various thicknesses, the surface of the asphalt specimen shall be in one horizontal plane with the surface of the lateral moving table. This positioning shall be accomplished by applying various metal and/or wooden plates with the same surface as the asphalt specimen between the bottom of the specimen fixation box and the specimen.

At several points in the vertical walls of the specimen fixation box, horizontal holes shall be drilled. These holes shall be provided with screw-threads and bolts. Between the inner walls of the specimen fixation box and the asphalt specimen, metal or wooden inlays shall be applied. By regularly tightening all screws, the asphalt specimen shall be complete fixed in the specimen fixation box. Attention shall be paid to the fact that the surface of the inlays between specimen and specimen fixation box is in one horizontal plane with the lateral moving table. All vertical planes of the asphalt specimen shall be completely supported by the inlays. There shall be no gap between the asphalt specimen and the inlays.

NOTE 4: For tests on dense graded bituminous mixtures, gypsum can be used to fix the specimen in the specimen fixation box.

…….

A.2 Addition requirements for test procedure

…….

After mounting the specimen in the specimen fixation box, the specimen fixation box shall be mounted in the lateral moving table, making sure that the surface of the lateral moving table, the specimen fixation box and the surface of the specimen are in one plane. In this way, extra vertical forces due to bouncing of the set of rotating wheels shall be limited.

……. During the test, the wheels shall rotate at (47 ± 1) rpm. After half the number of load repetitions, the specimen fixation box shall be rotated 180 º and the bolts in the specimen fixation box shall be re-tightened.

NOTE: The rotation of the specimen is necessary to be sure that the surface of the specimen is equally loaded over the whole surface. If, for example, there is some misalignment in the set of rotating wheels or a small difference in tyre pressure, this influence on the ravelling process is eliminated.

After rotation of the specimen halfway through the test, the test can be continued until the end.

…….

Annex B Darmstadt Scuffing Device (DSD)
(Normative)

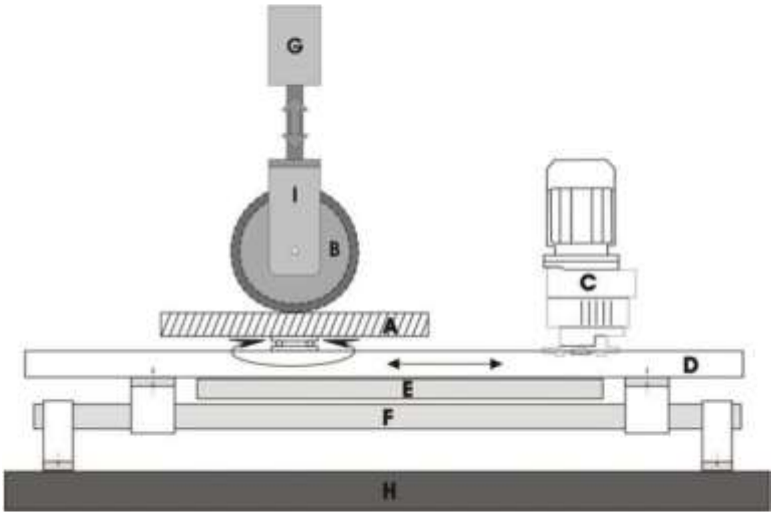
B.1 Scuffing device

B.1.1 General

……. The asphalt specimen shall be attached in a fixture oscillating 180 °, which shall be mounted on a horizontal table moving back and forth. During this movement, a test tyre under load shall be lowered onto the specimen.

NOTE: Figure B.1 shows an example of such a machine. Figure B.2 shows a system drawing.

Figure B.1: An example of the Darmstadt Scuffing Device



Key: A Specimen clamping device B Test wheel C Rotary motor with head gear
D Baseplate E Drive construction F Guide slide
G Pneumatic pressure cylinder H Bearing construction

Figure B.2: A system drawing of the Darmstadt Scuffing Device

B.1.2 Lateral moving table

The horizontal table shall be guided by a rail through which the table is movable. Powered with an electric motor linked with the table via scotch yoke, the feed speed shall be held constant at 0,04 m/s during the test. The rail shall be fixed on a foundation via framework.

On top of the table there shall be a fixture for the specimen that is turning around the axis with an oscillating amplitude of 180 °. Rotational angular velocity shall be kept at 5 turns per minute and can be applied through the same electric motor that powers the table.

B.1.3 Test tyre

The test tyre shall be a pneumatic tyre without tread (10*4.5-5, slick) mounted onto an axis held by a fork carriage and freely turntable.

NOTE: The fork carriage can be held vertically by a pneumatic cylinder. This provides the possibility to apply load to the asphalt specimen through the test tyre.

Vertical load shall be chosen to apply a pressure of 0,25 N/mm². With the aforementioned tyre size, a vertical load of (1000 ± 10) N is necessary.

Tyre pressure shall be (300 ± 10) kPa.

The test tyre shall be fixed in place horizontally. Rolling movement and shear stress shall be exclusively from the back and forth movement of the table and the oscillating fixture under the surface tension of the test tyre.

B.1.4 Asphalt specimen fixture

The lateral moving table, clause B.1.2, shall have a fixture that can hold an asphalt specimen of 260 mm by 260 mm that is secured with adjustable screw. To avoid tension within the specimen, the screws shall be tightened by hand.

…….

B.2 Addition requirements for test procedure

NOTE 1: The usual thickness of the specimens is 40 mm.

…….

The specimen shall be fixed in the scuffing device. Screws shall be tightened by hand so that the material of the asphalt specimen is not compressed. ……. The asphalt specimen shall be put under load by lowering the test tyre and applying a force of (1,000 ± 10) N through the pneumatic pressure cylinder. When the targeted force is reached, the test shall be started.

NOTE 2: It is important to start testing directly when the force is reached to prevent unwanted deformation of the asphalt specimen.

Vacuuming of loose grains takes place shall be undertaken between loading cycles. Wiping off shall be done as required.

NOTE 3: It is extremely important to remove all loose grains from the surface of the asphalt specimen as this could lead to additional mechanical stress to the surface, whereby measurements could be obscured.

After finishing the specified double shear load cycles, ……. the tyre shall then be unloaded and raised.

…….

Annex C The Rotating Surface Abrasion Test (RSAT)

NOTE The RSAT method was developed to reproduce the scuffing damage as it occurs on real life pavement roads. The basis was not only the damage as it occurs in cornering due to friction forces, but specifically the normal damage on straight road sections.

When a tyre load rolls over a road, the tyre tread is continuously deformed. This is the 'flat-band' effect: the tread is normally curved and only the contact area of the tread with the road surface is flat. These deformations result in shear stress (transverse and lateral) in the contact area. Therefore, the load pattern on the road surface of a rolling tyre is a combination of shear and normal stresses in the contact area. These stresses cause fatigue effects in the asphalt surface and lead, in time, to aggregate loss from the pavement surface.

These stress components were modelled in the RSAT method. The relationship between these components in the development of the test was optimised by varying the vertical angle of the wheel, the wheel load and the rotating motion. At the end of the test of 24 hours, the visual damage should resemble the damage of the pavement surface at the end of its real service life.

C.1 Scuffing device

C.1.1 Motion mechanism

The motion mechanism shall have a standard wheel tracking device with sliding bearings, linear ball bearing such as SKF 102.0090.500 or equivalent. The motion of the wheel in relation to the test specimen shall be as shown in Figure C.1. The motion of the arm shall be constant, with the guiding arms playing a part in ensuring constancy. The rotation of the test specimen shall be caused by the turning forces of the tyre-road action. In order to stimulate the shear stresses, the specimen shall be blocked in one direction by a brake.

C.1.2 Test tyre

The wheel shall have a solid cast iron rim into which the rubber tyre is pressed. The tyre shall be made of solid rubber and have the following properties:

- Width: (50 ± 2) mm
- Thickness: (32 ± 2) mm
- Inner diameter: 140 mm
- Outer diameter: 200 mm
- Hardness: 80 IRHD or 65 – 70 Shore A

The hardness shall be measured with ISO 7619 and checked by ISO 48 for Shore hardness.

C.1.3 Wheel load and contact pressure

The mass on the wheel shall consist of the weight of the wheel and the wheel arm, plus an extra load on the wheel in the shape of two metal blocks. The total weight shall be (35,0 ± 0,1) kg.

The contact surface shall be checked by placing a loaded wheel on millimetre paper. The tyre shall be equipped with a medium that leaves an impression on the paper, which shall be repeatable several times. The contact surface area of the tyre shall be determined as the area that has been impressed, measured in square millimetres.

The contact pressure on the specimen shall be the total mass divided by the contact area (loaded) of the tyre. The measured contact pressure shall be (0,60 ± 0,05) N/mm². The contact pressure shall be in the same range as that of truck tyres. The contact area shall be chosen to keep the surface temperature by friction in control during the test. A temperature increase of the tyre shall be limited to 2 °C.

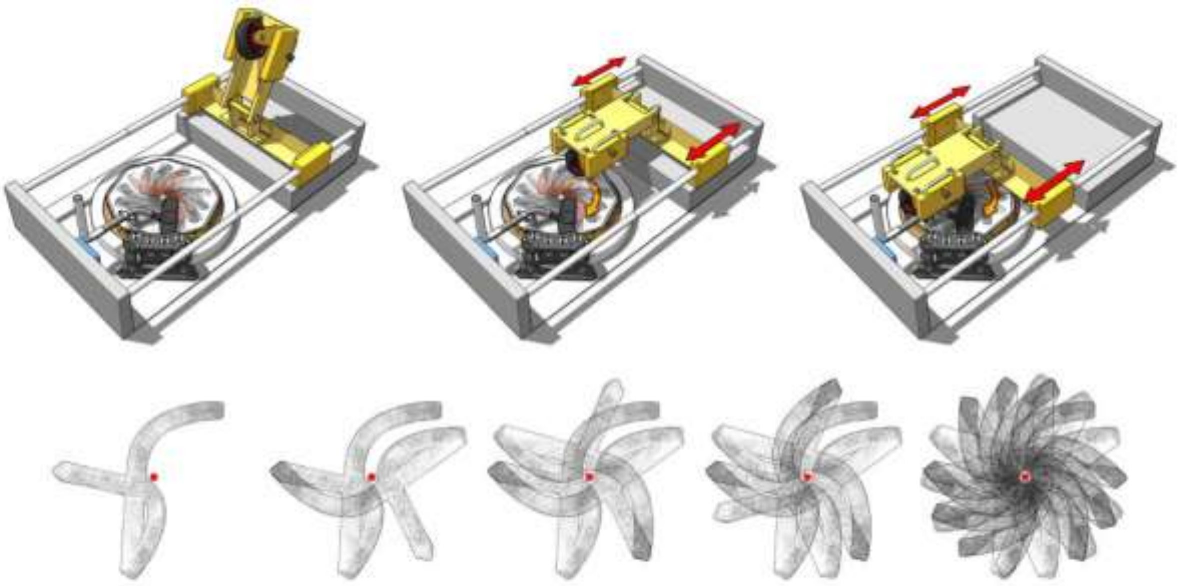


Figure C.1: The Rotating Surface Abrasion Test device

C.1.4 Wheel arm guide

The wheel arm guide shall keep the wheel in the desired angle with the path of (33,7 ± 0.1) degrees. It shall also serve as a carrier to carry the extra load over onto the wheel (Figure C.2). It shall be attached to the main frame by means of a maintenance-free rotation bearing.

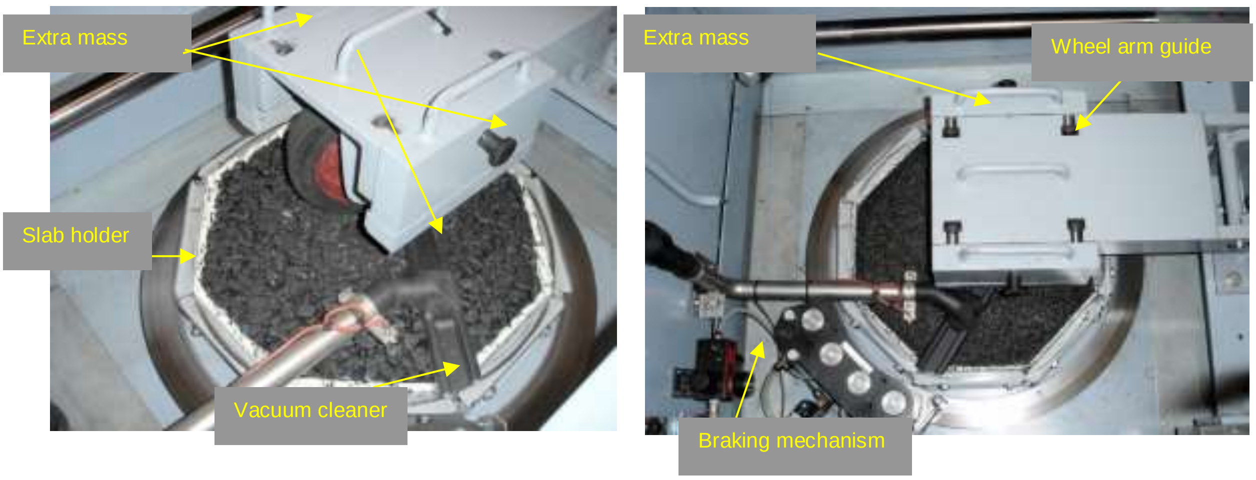


Figure C.2: Wheel arm guide, wheel, weight and specimen holder of RSAT equipment

C.1.5 Attachment of the wheel to the wheel arm

The attachment of the wheel shall be very precise so that the wheel is able to spin around without resistance. The attachment shall be by means of a maintenance-free bearing to the axle. The wheel shall be able to spin around without resistance and shall not have any slack horizontally or vertically.

C.1.6 Rotation hinge (wheel arm guide)

The rotation hinge shall secure the wheel horizontally relative to the specimen holder. Vertically, the rotation hinge shall enable the wheel to follow the surface of test specimen freely when unloaded. The bearings in the rotation hinge shall be maintenance free.

C.1.7 Specimen holder test specimen

The specimen holder for the test specimen shall keep the test specimen in its place during the testing with the use of clamps and bolts.

NOTE This control is needed in order to prevent the test specimen to move inside the specimen holder while performing the test.

During testing, the force shall be controlled with a torque wrench. All bolts shall initially be tightened at 20 degrees, then tightened further with a specific torque with a moment of 6 Nm.

The test specimen shall be placed on a rubber sheet with a thickness of 3 mm.

C.1.8 Bearing and rotary axle, consisting of a ring bearer

A ring bearing directly below the specimen holder shall keep the specimen constantly supported, free to rotate, and stable.

C.1.9 Braking mechanism

The braking mechanism to stop the return motion shall be a pneumatic brake, which is directly attached to the specimen holder (Figure C.3). Two sensors attached to the guide arm activate the pneumatic break.

Figure C.3: The RSAT pneumatic brake

…….

C.2 Specimen preparation

For the fabrication of the RSAT test specimen, a wooden mould shall be made according to the following sizes and specifications. The sizes of the mould are given in Figure C.4.

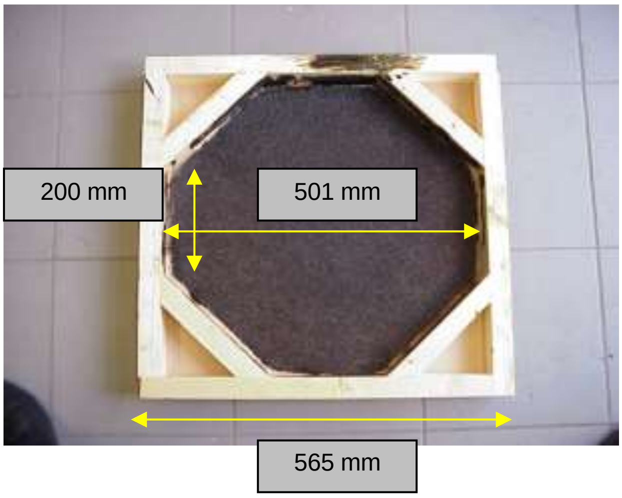


Figure C.4: Picture and schematically representation of the mould

The nominal thickness of the specimen shall be 30 mm when a bituminous mixture with a maximum nominal aggregate size of 11 mm is tested; for mixtures with a maximum nominal aggregate size larger than 11 mm the specimen nominal thickness shall be 50 mm.

The sides of the test specimen shall be parallel. After sawing, the test specimen shall be cleaned with compressed air to remove water and sand caused by the sawing.

The bottom of the mould shall be fabricated from plywood. In order to prevent sliding between the test specimen and the mould:

- Apply a coat of glue(epoxy) in the bottom of the mould;
- Scatter a handful of uniform grained sand on the epoxy;
- Remove excess (loose) sand;
- Spray an adhesive bituminous layer to cover the sand.

After compaction, the test specimen shall cure for at least 14 days before testing.

Before starting the test, the specimen shall be taped off at 5 mm from the edges. The edge exposed shall then be sprayed with road paint.

NOTE This prevents possible damage not caused by the test, from being measured.

C.3 Addition requirements for test procedure

The test specimen shall be mounted into the specimen holder ……. at the right height. Where appropriate, the excess height can be filled out using plywood sheets. On top of the fill out sheets, a rubber mat of (3 ± 1) mm shall be attached. The test specimen shall then be placed on top of this sheet and, between the test specimen and the edge of the specimen holder, steel plates shall be placed to keep the specimen in position (the centre of the test specimen shall correspond to the centre of the specimen holder).

The steel plates shall be pushed against the test specimen by adjusting bolts, to thoroughly enclose and secure the entire test specimen. All bolts shall be tightened at 20 degrees with a torque wrench. After that, the bolts shall be tightened again with a torque of 6 Nm.

After the warming up procedure, all bolts shall be checked with a torque wrench to ensure that the test specimen is still enclosed by the steel plates.

…….

Before starting the test, the specimen shall be preloaded with the new wheel for a period of at least 1 hour applying a minimum load of 20 kg. After this warming-up period, the specimen shall be completely cleaned by removing all loose aggregate parts and rubber powder. The removed material (stones and rubber from the wheel) caused by the warming up period shall not be included in the measurement of the scuffing damage.

…….

The movement of the wheel over the specimen is presented in Figure C.1. One run shall be defined as a full rotation of the flywheel. During this full rotation, the wheel shall move forward and backward and forward again (up and down).

The total wheel load shall be (35,0 ± 0,5) kg. A total 86.600 wheel runs in 24 hours shall be applied on the specimen, equally divided over the length of the test. The test shall be stopped when too much damage occurs on the specimen.

During the test, the particle loss > 2 mm shall be collected from the out coming material flow by the vacuum cleaner. This collection is undertaken with a cyclone separator (Figure C.5) and a sieve of 2 mm. Via an air slot, the particle loss > 2 mm is weighed by a balance every 5 min. The balance shall be connected to a computer so that the mineral loss of the test plate shall be recorded automatically during the test period of 24 h (Figure C.6).

Figure C.5: Cyclone separator and vacuum cleaner

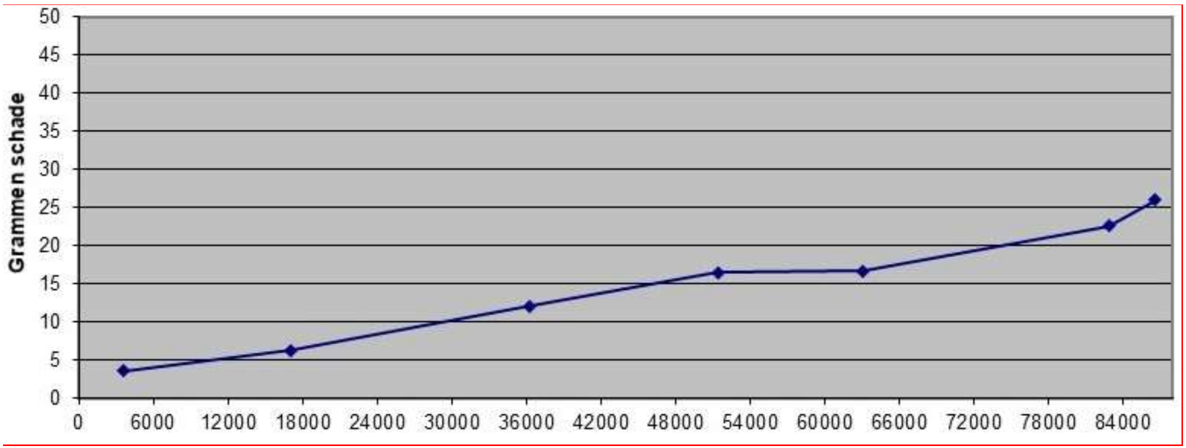


Figure C.6: Continuous registration of particle loss > 2 mm

Annex D TriboRoute Device (TRD)
(Normative)

D.1 Scuffing device

D.1.1 General

NOTE The device called a tribometer for road surfacing material named TriboRoute Device (acronym TRD) is a test bench with one perpendicular axe positioned on a stiff and heavy base.

The TRD shall be composed of a braced vertical column supporting the load applicator and mounted on a classical hydraulic press and a roller-mounted horizontal table. This table shall be able to accommodate a parallelepiped specimen (185 mm by 247 mm) or an in-situ core sample up to 300 mm in diameter. The test of resistance to tangential forces shall consist of applying an average load that represents the loading of a truck tyre on the surfacing material. The sliding of tread rubber shall be obtained through the vertical displacement rate.

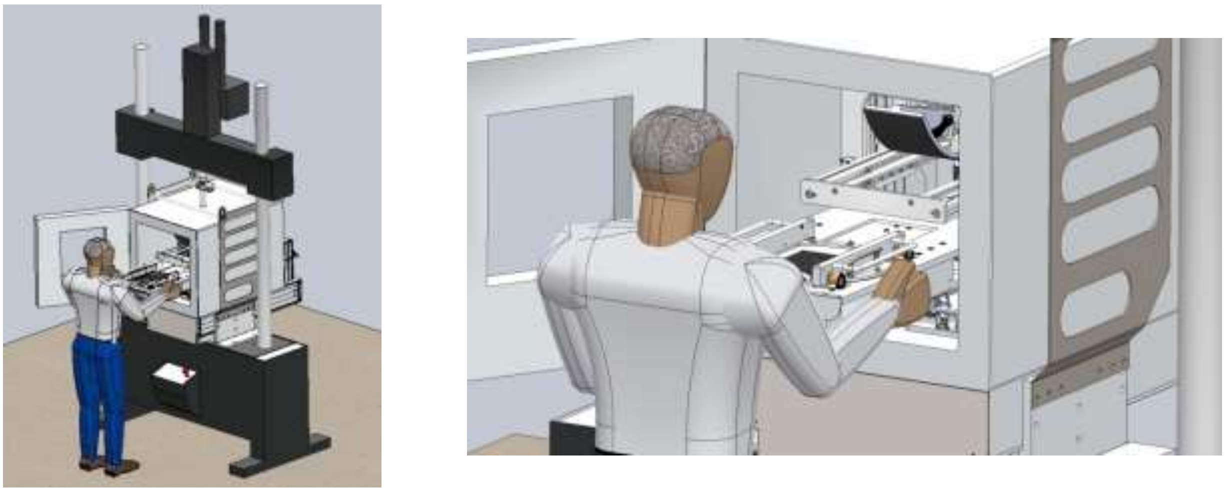


Figure D.1: An example of the TRD mounted on a classical hydraulic press

D.1.2 Load applicator

The load applicator representing the tyre shall be a logarithmic shaped block (LSB) (Patent No. FR 06 50 054) with a width of 140 mm covered by an 8-mm thick rubber layer with rheological characteristics close to those of tyre treads. This rubber shall display diamond-shaped sculptures and its hardness at room temperature shall be approximately 68 Shore degrees. The abrasion resistance for the tyre shall not exceed 90 mm³, expressed as relative volume loss, in accordance with Method A of ISO 4649 where the standard reference compound Nr.1 is used.

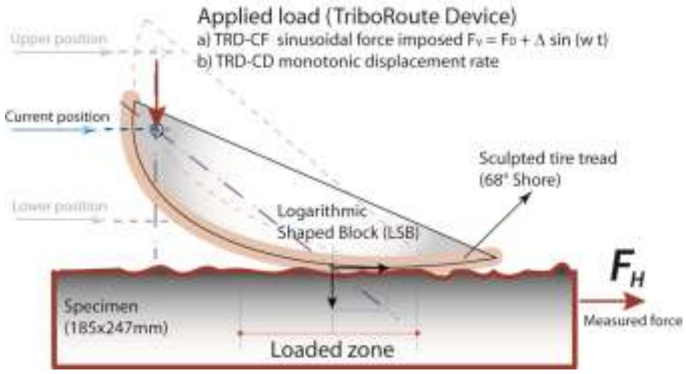


Figure D.2: Principle of test using a logarithmic shaped block (LSB) as load applicator representing the tyre

D.1.3 Lateral moving table

The horizontal table shall be guided by a rail through which the table is movable. The table shall be equipped with an automatic system to monitor the mass loss of the specimen during the test. The table shall also be equipped with a force sensor placed at the end position of the rail. The horizontal force acting on the specimen shall also be recorded throughout the test, providing information on the mechanical contact between the LSB and the surfacing material.

…….

D.2 Additional requirements for test procedure

D.2.1 General

Test specimens shall originate either from the laboratory production of a 400 mm x 600 mm specimen using a one- or two-pneumatic wheel compactor (EN 12697-33) or from a borehole core extracted onsite with a 300-mm diameter. Specimen thickness *T* shall not exceed 150 mm.

NOTE 1 A thickness between 50 mm and 100 mm is the advised dimension for these ravelling tests.

NOTE 2 All types of aggregates are capable of satisfying the needs specific to ravelling tests. Nonetheless, a few recommendations merit consideration at this point:

- The hardness of aggregates introduced should be ensured; and
- As for requirements inherent in the scale effect specific to the loading surface, aggregate size *D* will be limited in the grading curve to 10 mm.

……. For a very thin asphalt concrete (BBTM), a high level of compaction shall be applied to the smooth cylinder in order to ensure surface flatness.

…….

The specimen shall be inserted into the clamping device, firmly fastened to the test bench table and a thermocouple placed near the specimen surface.

The texture depth in accordance with EN 13036-1 shall be measured. The TRD shall be used:

- in controlled force mode (TRD-NF) for specimen whose average texture depth is more than 0,5 mm; and
- in displacement mode (TRD-CD) for specimens whose average texture depth is less than or equal to 0,5 mm.

NOTE The controlled displacement rate offers another possibility to apply a tangential force to the specimen surface.

D.2.2 Test performed with controlled force (TRD-NF)

The test protocol shall comprise the following three phases, one of which concerns removing debris potentially produced during the loading steps [Reference 5]:

- Pre-loading phase – The pad shall be placed into contact with the material surface by applying an imposed displacement and then driving the force higher in order to continue loading on the specimen, until reaching the required average vertical force. On average, the necessary attachment time shall be 40 s. Attachment conditions shall be correlated with the state of the material surface, as well as with contact material stiffness and test temperature.

- Cyclic loading phase – Once the recommended limit has been reached, a sinusoidal loading shall be imposed with an amplitude set at 1/3 of the average force, so as to ensure that the pad is well attached (i.e. at a stable sliding speed and with as much friction as possible). The average vertical load shall then be set at 2.500 N with an amplitude of 833 N to reproduce an apparent contact pressure equivalent to that generated by a truck with a loading frequency equal to 1 Hz. The LSB loads a surface of the specimen denoted A.

- LSB rising phase – The LSB shall be returned to the upper position, which serves to free space roughly 15 mm underneath the LSB for the purpose of removing any stripped aggregates eventually present, using a vacuum cleaner. This phase shall last approximately 10 s. Once the surface has been cleaned, the test shall be repeated with the same cyclic contact force. This procedure, described with all three phases, shall then be repeated for the number of times necessary to obtain a specified degree of degradation. The cumulated number of cycles shall be limited to a maximum of 10.000 cycles. This test shall be carried out on at least two specimens.

D.2.3 Test performed with controlled displacement rate (TRD-CD)

This test protocol shall be for a simple monotonic test which the displacement rate is fixed to 0,035 m/s. The test protocol shall comprise two phases, one of which concerns removing debris potentially produced during the following loading steps:

- Monotonic loading phase – The LSB into contact with the material surface shall be moved by applying an imposed displacement rate. The resulting force shall be variable, adjusted until reaching the required average vertical force (2.500 N). The vertical displacement rate shall be imposed until the lower position of the LSB.

- LSB rising phase – The LSB shall be returned to the upper position, which serves to free space roughly 15 mm underneath the LSB for the purpose of removing any stripped aggregates eventually present, using the vacuum cleaner. Once the surface has been cleaned, the test shall be repeated with the same movement. This procedure, described here, shall then be repeated for the number of times necessary to obtain a specified degree of degradation. The cumulated number of cycles shall be limited to a maximum of 10000 cycles. This test shall be carried out on at least two specimens.

NOTE Experiments on specimens showed that the duration of testing is strongly dependent on the type of bitumen used [Reference 5]. On asphalt with relatively soft bitumen, grain loss appears very fast on the surface of the asphalt specimens. Experiments with soft bitumen had to be quit after 1500 cycles with a lot of mass loss. To determine a link between number of applied load cycles and mass loss, it is recommended to monitor mass loss after every 500 load cycle.

Annex E Validation of other scuffing devices

(Normative)

E.1 Test programme

When validating an alternative scuffing device for use in this test, a test programme shall be undertaken using both the candidate scuffing device and one of the established scuffing devices (ARTe, DSD, RSAT or TRD). The testing shall be conducted on four bituminous mixtures, two of which shall be standard mixtures (one of which shall be a porous asphalt) that have a reasonable history of durability but have not been designed for heavy-duty use and two of which shall be the standard mixtures with their binder content reduced by 0,5 %.

The scuffing test in accordance to this standard for the standard duration of test shall be carried out on each bituminous mixture using both scuffing devices (i.e. 4 x 2 = 8 tests) using four replicates for each test. In the case of the candidate device, the test parameters and any additional requirements the test procedure shall be recorded and followed consistently.

E.2 Analysis of results

The normalisation factor for the candidate scuffing device shall be calculated as follows:

$$N_f = \frac{\sum_{x=1}^{4} \Delta Ma_{e,x}}{\sum_{x=1}^{4} \Delta Ma_{c,x}}$$

where:

N_f = normalisation factor for the candidate scuffing device, as listed in Table 1.

$\Delta Ma_{c,x}$ = mean mass loss per surface area scuffed at end of test with the candidate scuffing device on mixture *x* using a normalisation factor of unity, in 0,1 kg/m².

$\Delta Ma_{e,x}$ = mean mass loss per surface area scuffed at end of test with the established scuffing device on mixture *x*, in 0,1 kg/m².

The validation shall be discarded if the normalisation factor for the candidate scuffing device is greater than 12.

NOTE: A normalisation factor greater than 12 indicates that the test has done less than the damage of the typical established device and that the test duration in the test parameters need to be extended.

The validation shall also be discarded if effect of reducing the binder content by 0,5% does not increase $\Delta Ma_{c,x}$ for both basic mixtures.

E.3 Validation report

A validation report shall be prepared that incorporates in separate, clearly marked sections:

- The details and results of the test programme.
- A description of the scuffing device similar to that given to the established scuffing device in Clauses A.1, B.1, **Error! Reference source not found.** and D.1 of this standard.
- The test parameters for the scuffing device similar to those in Table 1 of this standard.
- The additional requirements the test procedure for the scuffing device similar to those in Clauses 0, 0, C.3 and 0 of this standard.

The validation report shall be provided with each test report using the scuffing device, either in hard copy or by reference to a website from which it can be freely downloaded.