LABORATORY TESTS FOR INTERNAL COHESION AND RAVELING OF THIN AND ULTRA-THIN WEARING COURSES

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ABSTRACT

As part of a research project on performance testing of thin and ultra-thin asphalt layers, BRRC is investigating the internal cohesion of the mixtures. Recent field experience with thin and ultra-thin wearing courses in Belgium has revealed a number of raveling cases, showing that internal cohesion is probably one of the most critical performance characteristics for these mixtures.
The water sensitivity test based on the retained Indirect Tensile Strength, which is part of the tender specifications in Belgium, is an appropriate test for evaluating the loss of internal cohesion due to moisture. Therefore, the test is supposed to be indirectly related to raveling, but it does not take into account the impact of traffic, more specifically the shear forces induced by accelerating, braking and turning of heavy vehicles. In recent years, several test devices (RSAT, ARTe, T2R, …) have been developed to simulate the effect of traffic induced shear forces on asphalt pavements. BRRC subjected mixtures designed to have extreme performance characteristics to a number of these tests, with the objective of evaluating their discriminating capacity, precision and correlation to field observations. This work also contributes to the development of a standardized European test method for traffic induced raveling.

Keywords: cohesion, raveling, performance testing, thin and ultra-thin wearing courses

1. INTRODUCTION

Like in many other European countries, the interest in very thin and even ultra-thin layers for asphalt wearing courses is growing in Belgium. This is mainly motivated by improved skid resistance, noise reduction, driving comfort and saving of resources [1, 2]. The need for a pronounced texture, noise reduction and a high resistance to deformation usually results in mixtures with a stony skeleton and a high void content, so the internal cohesion of the mixtures becomes more critical and the risk of loss of aggregates from the road surface increases, particularly in zones which are exposed to high shear forces, e.g. cross-roads, traffic lights, sharp curves and roundabouts. That is why the investigation of the phenomenon and the ways to improve the internal cohesion of thin and ultra-thin asphalt mixtures is a research topic of immediate importance to the road authorities and constructors in Belgium and in the rest of Europe.

Figure 1: Material loss on an ultra-thin wearing course type UTLAC in Belgium (RUMG - Revêtement Ultra Mince Grenu)

The main problem we are facing is that, at this moment, there is no standard European test method yet to measure the resistance of a mixture to this type of damage in the laboratory. A test related to internal cohesion is the so-called water sensitivity test (EN 12697-12). When a mix exhibits a loss of cohesion due to the effect of moisture, the mix will also be more susceptible to aggregate loss on the long term. But this test does not simulate the direct causes of raveling, which are shear forces at the surface induced by heavy vehicles.

Recently task group CEN TC227 WG1 TG2 "Test methods for bituminous mixtures" was charged to develop a standard test method for this important characteristic called "Resistance to scuffing" (prEN12697-50). BRRC has contributed to the selection of the test method by carrying out a study in which several available tests were compared. Available tests that simulate shear forces are:

1. The Wheel Tracking Test with the wheels fixed at an angle with respect to the wheel path;
2. The RSAT-test (Rotating Surface Abrasion Test), developed by the Dutch company Heijmans;
3. The T2R-test (Tribometer for Road Surfacing Material), developed by LCPC (Laboratoire Central des Ponts et Chaussées), now IFSTTAR;
4. The ARTe (Aachener Reibungstester), developed at the German Institut für Strassenwesen Aachen.

The first test can be done on a large size device for wheel tracking (as used for EN 12697-22), provided the angle of the wheel can be off-set from the wheel path. BRRC has the equipment to do this test. The other three tests are all new developments and only prototype test devices exist at the respective laboratories. BRRC decided to fabricate specimens with mixtures for thin and ultra-thin wearing courses and send them to the laboratories for testing. The RSAT test was skipped from the initial planning, because of the complexity of the fabrication of the specimens. The specimens must have a regular octagonal shape and can not be made with the roller compactor of the BRRC laboratory according to EN12697-33. Also due to the complexity of the specimen fabrication, the test is very expensive.

This study was done in the framework of a research project entitled "Development of test methods for thin and ultra-thin wearing courses", supported by the Belgian Government and the Belgian Bureau for Standardization (NBN). The paper will present results from the "scuffing tests", as well as from the water sensitivity test which is indirectly related.

2. MIX DESIGN AND SPECIMEN FABRICATION

As explained in the introduction, this study was carried out in the framework of a project dedicated to the development of performance related test methods for thin and ultra-thin wearing courses. The test mixes were designed with the aim of achieving extreme performance characteristics, but at the same time these mixes had to be representative of today's common practice. An enquiry among the Belgian asphalt producers and road authorities has lead to the following choices:

- For thin layers, SMA 6.3 is the most frequently used mix type, placed at a thickness of 25 to 30 mm. The majority is made with PmB.
- For ultra-thin layers, an UTLAC-type mixture is used, called RUMG "(Revêtement Ultra Mince Grenu"), which is sometimes used in the Walloon Region for courses of 15 mm thickness. The binder is always a pen grade bitumen B50/70 or B70/100, while literature and tender specifications of other European countries recommend the use of PmB's for similar ultra-thin course mixtures.

Table 1 gives an overview of the test mixes and the main parameters of their volumetric composition. The mix design followed the BRRC mix design procedure and used the theoretical mix design software PradoWin.

- The first rows show two mixes of the type SMA 10. This mix type is intended for courses of 40 mm thickness, which are not considered as thin wearing courses. But these mixes are interesting test mixes, because they are expected to have a very different susceptibility to aggregate loss. Also, these mixes have been studied in a previous research project [3] and placed on test sections two years ago, which will provide us with in-field data to contribute to the validation of the laboratory tests in the near future. The first variant was designed for high internal cohesion and the second for poor internal cohesion. Besides the lower binder content and the use of a binder B50/70, this mix is made with gravel (known to be less adhesive to bituminous binders) while all the other mixes in the table are made with porphyry aggregate.
- The following rows are mixes of the type SMA 6.3, intended for thin courses of 25 to 30 mm thickness. The first variant was designed as a mix susceptible to rutting, while the second has a high resistance to rutting. But as this mix contains a PmB, which is often claimed to be more effective against raveling on the road, a third mix variant was added to the list. The third is identical to the second, except for the fact that the binder was replaced by a common pen grade binder B50/70 to obtain a mix with a higher sensitivity to aggregate loss.
- For the UTLAC, intended for wearing courses of 15 mm thickness, mix 1 was designed as a mix with good internal cohesion and mix 2 with less good internal cohesion. Later on, a third variant was tested identical to the first mix, except for a slightly higher binder content and the use of a PmB. These modifications were expected to further improve the internal cohesion.

Table 1: Mixes used for testing

Type	*Mix n°*	*Binder content (%)*	*VMA* PradoWin (%)*	*Binder type*	*Void content (100 gyrations) (%)*
SMA 10	1	6.5	18.8	PmB 50/85-50	5.8
	2	6.0	19.7	B 50/70	11.6
SMA 6.3	1	6.7	18.3	B 70/100	9.5
	2	6.2	18.7	PmB 45/80-50	Not measured
	3	6.2	18.7	B 50/70	Not measured
UTLAC 6.3	1	5.21	22.73	B 70/100	17.4
	2	4.67	24.41	B 50/70	19.9
	3	5.30	22.73	PmB45/80-50	16.3

* VMA: Voids in the mineral aggregate

For the fabrication of test plates, the mixes were all compacted using the roller compactor with pneumatic tires (following EN 12697-33) at their intended layer thickness. In case of the ultra-thin UTLAC, the mix was compacted on top of a base layer (Asphalt Concrete AC 14), with an emulsion tack coat to provide good bonding between the layers. Figure 2 shows the cross section of such a specimen. For ultra-thin mixtures, it was considered important to do the tests on the complex of base course/bonding layer/ultra-thin wearing course, because the quality of the bond (good or weak adhesion, sliding) may have an impact. Also, it is possible that the tack coat partly penetrates into the pores of the mixture placed on top, so there is a gradient in the mix composition over the height of the ultra-thin layer. Therefore, the same emulsion and the same rate of spread were used on all the double layered specimens.

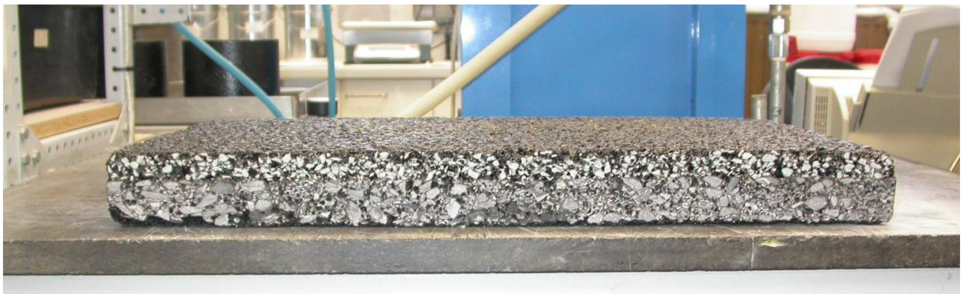


Figure 2: Double layered specimen made of a 35 mm thick base course AC 14 and a 15 mm thick wearing course UTLAC 6.3

3. TEST RESULTS

3.1 Water sensitivity tests

In Belgium, the water sensitivity test is based on the Indirect Tensile Strength (ITS) test, following EN 12697-23. The ratio of the mean ITS of a set of 3 specimens, conditioned in water as described in EN 12697-12, to the mean ITS of a set of 3 unconditioned specimens, expressed in percent, is called the ITS-ratio. A low ITS-ratio means a high sensitivity of the mix to water. The specimens for water sensitivity are made with the gyratory compactor to 25 gyrations. The low compaction level makes the test more discriminating and more representative for roads which are less well compacted.

Table 2 shows the results of the water sensitivity tests.

- The void contents shown are values determined by geometry. These values are high, because of the low level of compaction. Note also that geometrically determined void contents are always higher than hydrostatically determined void contents. The void content of UTLAC is very high, when compared to SMA.
- Most mix variants present high values for the ITS ratio (> 80%) and therefore a low water sensitivity, despite of the high void content. The only exceptions are UTLAC 6.3, mix 3 and SMA 10, mix 2. For this SMA mix, the lower ITS ratio is explained by the aggregate type (gravel, which has a very low binder affinity), the low binder content and the high void content.

Table 2: Water sensitivity tests

Type	*Mix n°*	*ITS unconditioned (MPa)*	*ITS conditioned (MPa)*	*Void content (%)*	*ITS-ratio (%)*
SMA 10	1	1.51±0.01	1.38±0.08	10.6	91±5
	2	1.44±0.07	1.05±0.05	17.0	73±3
SMA 6.3	1	0.92 ± 0.05	0.83±0.04	15.3	90±4
	2	1.08 ± 0.06	1.01±0.03	16.4	93±3
	3	Not measured	Not measured	Not measured	Not measured
UTLAC 6.3	1	0.78 ± 0.03	0.66 ± 0.06	21.8	84 ± 5
	2	0.90 ± 0.08	0.75 ± 0.05	24.8	83 ± 5
	3	1.23 ± 0.03	0.91 ± 0.02	20.6	74 ±1

In addition to the water sensitivity tests, the affinity between porphyry aggregate and the two bitumens of mix 1 and mix 3 of UTLAC 6.3 was measured using the test method as described in EN 12697-11 part C ‘Boiling water stripping method’. The results are summarized in the table 3 below. Referring to previous work with the “Boiling water stripping method” [4], the following conclusions are drawn from these results:

- A stripping percentage of 71% as measured in the case of the bitumen 70/100 can be considered as unexpectedly high. The stripping percentage for porphyry aggregate is normally situated between 32 and 60% (average = 48% ± 8%).
- In the case of the polymer modified bitumen 45/80-50 the observed stripping percentage of 43% is quite close to the expected average value.

Table 3: Boiling water stripping tests

Bitumen aggregate combination	% stripping
B 70/100 – porphyry (8/14)	71
PmB 45/80-50 – porphyry (8/14)	43

The stripping percentages can not be correlated to the results of the water sensitivity tests performed on the UTLAC 6.3 asphalt mixes, shown in table 2. Mix 3, containing the PmB 45/80-50 binder was characterized by a higher water sensitivity (lowest ITS-R value of 74%) but an average to good binder/aggregate affinity. Mix 1, containing the bitumen 70/100 was characterized by a lower water sensitivity (ITS-R value of 84 %), despite of the poor result for the affinity between the aggregate and binder. It is clear that other parameters, such as binder content, aggregate grading or mastic composition (which are not the same for these UTLAC-mixtures) have an influence on the water sensitivity as well. This effect is not considered in a boiling test, in which a fixed binder quantity is used in combination with a given quantity of aggregate.

3.2 Scuffing tests

3.2.1 Wheel tracking tests with wheel fixed at an angle

The wheel tracking test is normally used to measure the resistance to rutting, with the wheel perfectly aligned with the wheel path. When the angle deviates from 0° (see figure 3), the resultant force also has a tangential component. The test more or less simulates the effect of a wheel going through a curve. This test has been used to measure the aggregate loss of surface dressings [4], but test results on hot mix asphalts have never been reported to our knowledge.

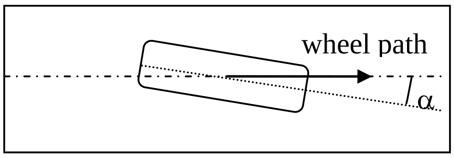


Figure 3: Wheel angle with respect to wheel path (top view)

Table 4 shows the test conditions adopted for the tests, compared to the standard test conditions of the wheel tracking test. As it is not possible to cool the test chamber, a controlled temperature of 25 °C was chosen. The lower tire pressure allows for a better grip of the tire onto the surface. With this combination of lower temperature and wheel load, it was anticipated that rutting would be negligible.

Table 4: Test conditions, as compared to the wheel tracking test

	As scuffing test	As rutting test
Test temperature	25±2 °C	50±2 °C
Tire pressure	300 kPa	600 kPa
Wheel load	2.5 kN	5.0 kN
Angle	5 °	0°

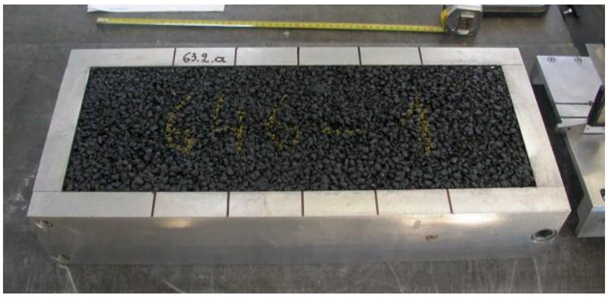
The following test procedure was followed:

1. Measure the mass of the mould and specimen before the test (M_0).
2. Place the mould and specimen in the apparatus and wait until the test temperature is reached.
3. Apply 500 cycles, remove the loss particles with a brush and vacuum cleaner end measure the mass of the mould and specimen (M_5).
4. Repeat the last step after 1000, 2000, 3000 and 5000 and 10000 cycles.

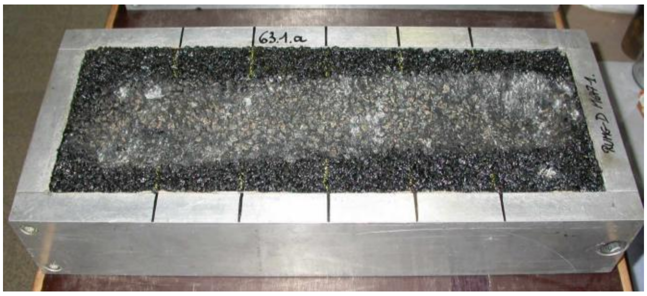
The tests were done on the UTLAC 6.3, mixes 1 and 2. They were compacted to a thickness of 15 mm on a concrete base layer. To ensure a good bonding between both layers, an emulsion C60B1 was applied at a spread rate of 300 g/m² residual binder. Figures 4 to 6 show some pictures taken during, before and after testing.

Figure 4: Wheel tracking test with wheel under angle of 5 °

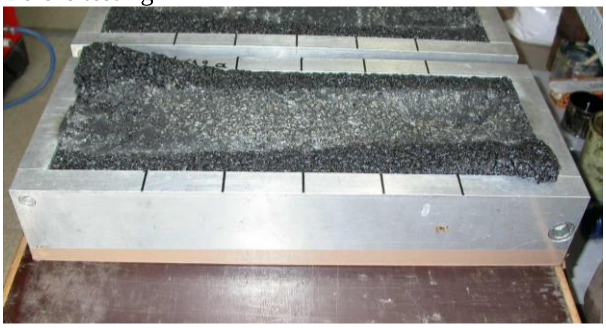
Before testing



Before testing



After testing



After testing

Figure 5: UTLAC 6.3 mix 2 (mix sensitive to raveling)

Figure 6: UTLAC 6.3 mix 1 (mix resistant to raveling)

The material loss as function of the number of cycles for the two mixes (2 plates per mix) is shown in figure 7. The repeatability is acceptable, with a maximum deviation of 15 % with respect to the mean results. The test was feasible from a practical point of view, except for the damage (wearing) caused to the originally smooth tire. After the two tests, the tires had to be replaced. Also a weak point of the test is that the load is concentrated on the same small area and repeatedly acts in the same direction, while in a realistic situation the load position and direction are more random.
The ranking of the results is opposite to the expectations: mix 1 with the higher bitumen content (tests 63.2) shows more loss of material than mix 2. Figure 6 explains what happens: due to the higher binder content and the softer binder, the ultra-thin layer is pushed over the sides of the mould. This results in material loss, not by cohesive failure, but by sliding of the UTLAC wearing course. Leutner shear tests on the same complex of concrete base/emulsion tack coat/UTLAC confirmed that the shear strength at the interface was indeed below the minimum value of 0.85 MPa [5].

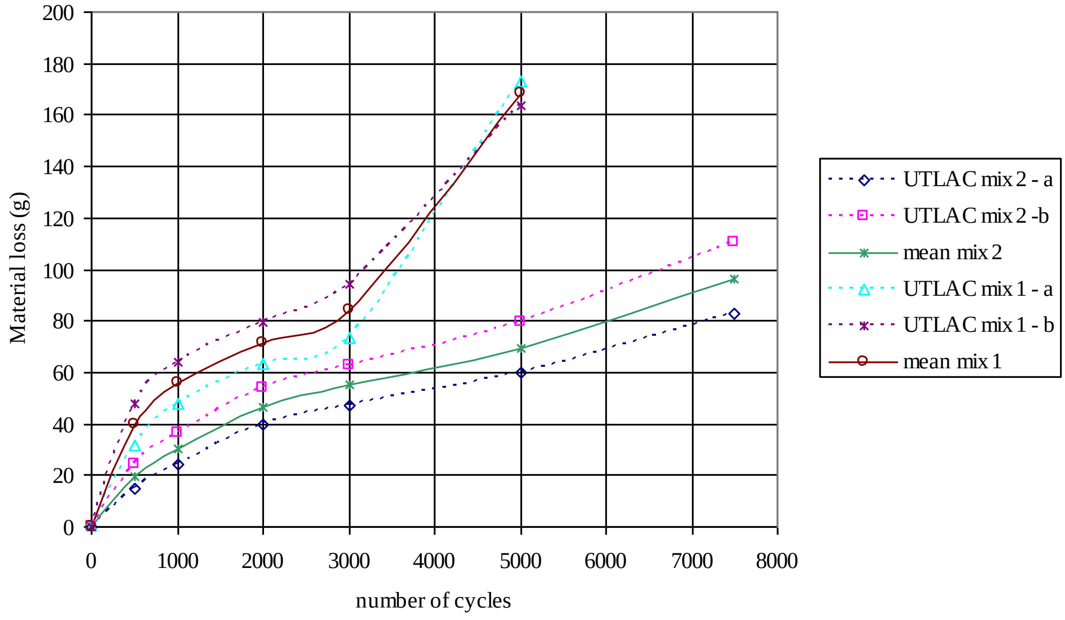


Figure 7: Wheel tracking tests with wheel fixed at an angle for UTLAC 6.3

This experiment has lead to the following conclusions regarding the use of the wheel tracking test as a scuffing test:

- The main disadvantage of the test is that the load is not randomly distributed, but repeatedly acts on the same area and in the same direction. Consequently, other effects like rutting and interface sliding or failure may interfere and influence the results, which may lead to a misinterpretation of the material loss.
- From a practical point of view, an important disadvantage is the wear of the tires, which need to be perfectly smooth for a wheel tracking test.

3.2.2 T2R tribometer tests

The T2R test was developed by the former LCPC (now IFSTTAR) in Nantes. The load is applied by means of a steel block covered by a rubber layer. The steel block has a surface with a logarithmic shape which converts the vertically applied dynamic load in a vertical and horizontal load with a constant ratio [7]. The test has been used to study the effect of the binder type on the internal cohesion of an asphalt mix.

Test plates were made for UTLAC 6.3, mixes 1 and 2, two plates per variant. The base layer was asphalt concrete AC 14 instead of cement concrete, so the shear strength of the interface between both layers was better. The same emulsion C60B1 was applied at 300 g/m² residual binder between the layers. Table 4 shows the material loss, in g/m². The repeatability is quite good, but the results are contradictory to the expectation. The reason is not clear. An assumption is that the texture and the friction between the contacting surfaces also play a role in the test: when the loading block has more grip on the surface the shear forces will be higher, resulting in more material loss than in the case of a smooth and sliding surface. This effect would perhaps not be seen when only the binder type is varied, but in this case, binder type as well as binder content and aggregate grading are varied.

Table 4: T2R test results (after 4000 cycles)

Type	Mix n°	specimen 1 (g/m²)	specimen 2 (g/m²)	mean (g/m²)	Relative deviation from mean value (%)
UTLAC 6.3	1	4870	4162	***4516***	8
	2	2747	2981	***2864***	4

This limited test data on two UTLAC mixes does not allow to draw conclusions about the validity of the test method. Only the following observations are made:

- The repeatability of the results was good, but the ranking of the mixtures was opposite to the expected ranking.

- Our own understanding of the test, especially of the interaction between sliding of the block and the applied shear forces, is not sufficient to explain the results.
- More experimental data, comparing different types of mixtures with various mix parameters and correlations with field data are needed to validate the test as a scuffing test.

3.2.3 ARTe tests

The ARTe test (Aachener Reibungs Tester) developed at the RWTH Aachen is a very realistic laboratory tests. The load is applied by means of two truck tires, rotating around a vertical axis, while the test plate moves horizontally under the tires. A vertical load of 2 kN is applied onto the wheels. Some validation work has already been done by comparing laboratory test results with data from test tracks, for the case of Porous Asphalt [8].

Figure 8: ARTe (test set-up at the RWTH Aachen, Germany)

Test plates were made for UTLAC 6.3, all three mix variants, two plates per variant. The base layer was an asphalt concrete AC 14 and the same emulsion C60B1 at a rate of 300 g/m² residual binder was used as in the previous tests. To compare the behaviour of the UTLAC 6.3 mixes to SMA 6.3, test plates were also prepared for the SMA 6.3, mix 3, which was expected to be the worst case of the three SMA 6.3 mix variants for raveling. These test plates were compacted in one layer at a thickness of 30 mm. In addition, the two mix variants of SMA 10 were compacted at a thickness of 40 mm. The test results are given in table 5, expressed as material loss in g/m².

The following observations are made:

- For the SMA 10 mixes, the mix designed for a good resistance to raveling performs best.
- The SMA 6.3 mix shows slightly more material loss than the SMA 10 mixes, but still far less than all tested UTLAC 6.3 mixes.
- For the UTLAC 6.3 mixes, mix 1 performs better than mix 2, which was also anticipated on the basis of the higher binder content and lower void content.
- The UTLAC 6.3 mix 3 shows more aggregate loss than mix 1, while the higher binder content (only 0.1 % higher) and the use of a PmB were supposed to improve the test results. Note that the water sensitivity of this mix was also lower than expected, but the ITS-value was high.
- Although the number of test results is still limited, the repeatability is sufficiently good to discriminate the mixtures based on two test specimens. Only for the test on SMA 10, mix 1, the relative difference between the two individual test results is high, but this is probably typical for mixes that show little material loss.

Table 5: ARTe results (after 540 cycles)

Type	Mix n°	Spec. 1 (in g/m²)	Spec. 2 (in g/m²)	mean (in g/m²)	Relative deviation from mean value (in %)
SMA 10	1	87	29	***58***	50
	2	162	104	***133***	22
SMA 6.3	3	197	174	***185***	6
UTLAC 6.3	1	1325	1644	***1484***	11
	2	5203	6019	***5611***	7
	3	3090	2112	***2601***	19

From these experiments, we can draw the following conclusions:

- The test results seem to be repeatable and coherent for all the tests done on our mix variants of UTLAC and SMA.
- The ARTe test is a very realistic test, with a randomly distributed load acting on a relatively large area (as compared to the other scuffing tests).

4. CONCLUSIONS AND FUTURE WORK

In this paper, test methods for the measurement of the internal cohesion of asphalt mixtures, in particular mixes for thin and ultra-thin wearing courses, were investigated. The main objective is to find a test, or a combination of tests, capable of predicting the occurrence of raveling on the road.

- The water sensitivity test, based on Indirect Tensile Strength measurements, is not capable of predicting the behavior of the mix when subjected to the forces of traffic on the road. A mixture with a high ITS-ratio is not necessarily a mix with a high resistance to traffic induced forces. One could say that the water sensitivity test is necessary, but not sufficient to predict the durability of the mix on the road.
- The Indirect Tensile Strength test is expected to give some information on internal cohesion, but so far, no correlation was found between ITS and raveling. A possible explanation is that the tensile strength of the asphalt mix depends largely on the cohesive strength of the binder and the adhesion binder-aggregate, while the strength in shear mode depends more on other mix parameters, such as grading and the stability of the aggregate skeleton.
- Tests that simulate the shearing actions of traffic on a compacted mix are being developed. Knowing that theses mechanical actions are the direct causes of damage, such tests are very promising, but the repeatability and reproducibility needs to be evaluated and further validation is required.
  - Simulating the loading in a wheel tracking device is not a good option. The load is concentrated on a small part of the slab and always repeated in the same direction, which means that next to stripping, permanent deformations like rutting or sliding of the wearing course take place. There is also significant damage induced to the tire, which makes it impossible to reuse the tire for a rutting test.
  - The T2R test gives a repeatable result, but the ranking is not as expected. More data are necessary to validate the test.
  - The ARTe test gives repeatable results and most of the tested mixtures behave as expected. The confidence in the test results is good, because it is a realistic, yet relatively simple test.

From this study it can be concluded that at this moment the ARTe-test is the most suitable laboratory test to simulate the effect of shear forces induced by traffic.

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