Research to the applicability of the ITS-R test as a ravelling indicator for SMA mixtures

D. Seghers, J. Stoop, W. Van den bergh
Artesis University College of Antwerp, Road Engineering Research Section, Antwerp, Belgium

S. Vansteenkiste & J. De Visscher
Belgian Road Research Centre, Brussels, Belgium

F. Hammoum
Laboratoire Central des Ponts et Chaussées, Route de Bouaye, France

R. Reynaert
Flemish Administration – Department of Mobility and Public Works (MOW), Brussels, Belgium

ABSTRACT: Ravelling of Stone Mastic Asphalt (SMA) is a frequently encountered damage phenomenon which shortens significantly its service lifetime. However, within the framework of European test methods, a validated procedure for the determination of the ravelling potential of a SMA mixture is lacking. During the last 2 years, the Road Engineering Research Section of Artesis University, jointed by BRRC and the Flemish administration, has evaluated the potential of a series of test methods to investigate the resistance to ravelling of SMA, such as the Brush test, the determination of the indirect tensile strength ratio (ITSR) used for the determination of the water sensitivity, the Rotating Surface Abrasion Test (RSAT) and the LCPC tribometer (T2R). This comparative study was conducted using two SMA mixtures especially designed to expect extreme characteristics with respect to resistance to ravelling.
This study is situated in a 2-year research project (2008-2009) which consists of 6 work packages: 1) a literature review, 2) the usability of the ITS-R test as a ravelling indicator, 3) a study of three mix design programmes (the Belgian Pradowin, the Dutch volumetric design method and the American Bailey method), 4) the influence of the mixture components on ravelling, 5) test tracks and finally 6) report. . In August 2009 test tracks with both mixtures were constructed and will be evaluated. At last, the paper will discuss the results of work packages 1 and 2.

KEY WORDS: Ravelling, water sensitivity, SMA, indirect tensile strength, ravelling tests.

1 INTRODUCTION

SMA mixtures are asphalt mixtures that are often used in top layers in Belgium. It is known that these SMA mixtures have a shorter lifetime than dense asphalt concrete. In recent years, SMA top layers suffered inexplicably from ravelling. Ravelling is the loss of aggregates. These ravelling problems may cause a fast degradation of the road.

At the moment, there isn't a validated test method in Belgium to predict the resistance to ravelling nor is there an European standard available. The goal of this project is to investigate the applicability of the ITS (Indirect Tensile Strength) test and its water conditioning method (ITS Ratio) as a ravelling predictor. The ITSR is now used to predict the water sensitivity of asphalt mixtures but it is known that water has a negative impact on the resistance to ravelling. To achieve this new ravelling prediction test protocol, it is necessary to find a possible correlation between the ITSR and one of the potential existing ravelling tests through an experimental test programme.

2 OBJECTIVES

This paper will present the results of work package one and two (literature review and the usability of the ITS-R test as a ravelling indicator). In a first step a literature review was carried out. The literature research has led to an overview of:

- parameters which can have an influence on the ravelling of SMA,
- research about possible or candidate (not standardised) ravelling tests

In a following step the goal was to validate the ITSR-method to check the resistance to ravelling of SMA.

3 LITERATURE OVERVIEW: SELECTED TESTS

Three different tests were selected to check the resistance to ravelling. For a detailed description and more technical information of the different tests we would like to advise to consult the mentioned references.

The RSAT (Hartjes et al, 2008) is a test developed by the Dutch company Heijmans and is used to predict the resistance to ravelling and lateral forces applied to top layers. This test is not an European standard.

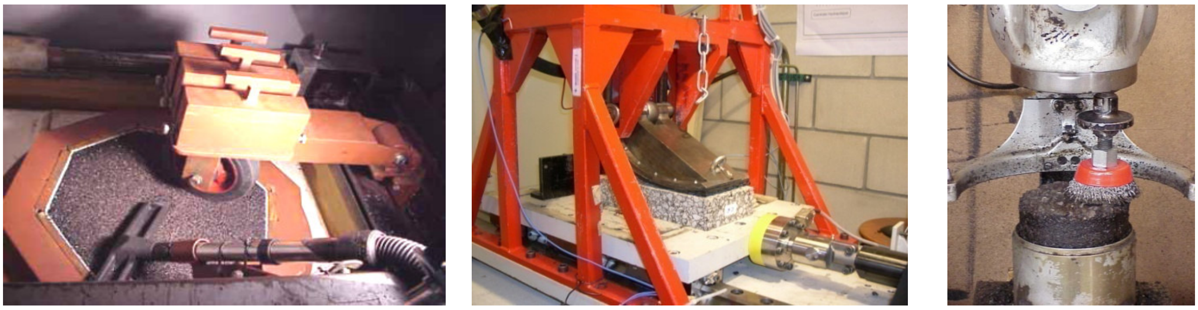

Figure 1: Overview of the three selected ravelling tests, from left to right: RSAT, Tribometer T2R and Brush test. Photos were taken from the references (brush test: van Buël et al, 2001).

An octagonal specimen (figure1) is loaded by a solid rubber wheel (0,6 N/mm²) during 24h in a climate chamber at 20°C. The wheel moves back and forth with an angle of 33,7° relative to the direction of movement of the wheel. The loading causes material loss out of the specimen. This material loss will be gathered with a vacuum cleaner followed by a sieving on the 2mm sieve. Finally a graph is made with the material loss in function of time (loading cycles). Also the rutting depth is measured after the test has been finished. These results are compared to the results of a reference mixture.

The Tribometer test (T2R) (Hammoum et al, 2008) has been developed by LCPC France (figure1). At the moment, the test is used to determine the effect of the binder type on the resistance to tangential forces. This test developed recently is not standardised in Europe.

The surface of a rectangular specimen is loaded by a loading block (0,6N/mm²) with a rubber layer which makes cyclic movements. These cyclic movements cause loss of aggregates. Due to the logarithmic shape of loading block, the angle of the loading force with the specimen remains nearly constant throughout the test. The test can be finished after a certain degree of degradation has been reached or after a certain number of loading cycles (test time of ±5 hours). The test temperature is 20°C. This test categorizes surfacing materials both by type (surface dressing, cement concrete, bituminous mixtures) and by composition (conventional binder, modified binder, synthetic resin, etc.).

The brush test (figure1) is an European standardised test (EN 12697-43:2005) which is used to determine the resistance to fuel of bituminous mixtures. A cylindrical specimen with known mass is immersed for a certain time in fuel. After the immersion the specimen is cleaned and dried (24h at 25°C). The mass loss is determined (Ai) and the specimen is visual inspected. Next the surface of the specimen is brushed following an established procedure with a standardised brush, brush speed and pressure. After 30, 60 and 120 seconds the mass of the specimen is determined. The mass after 120sec is used for the calculation of the mass loss (Bi). The average of A en B is a measure of resistance to the used test liquid. Depending on this values the specimen can be ranked in 3 possible categories (good, mediocre or bad resistance to the used test liquid).

4 METHODOLOGY AND EXPERIMENTAL PROGRAM

The main goal is to validate the ITSR method (EN12697-23 and EN12697-12) to check the resistance to ravelling of SMA-mixtures. The experimental program consists out of 5 different phases.

The aim of phase 1 is to design two different mixtures: a “water sensitive” and a “water resistant” mixture. The water sensitive mixture will be a mixture where all the parameters are chosen in a certain direction so that we expect the mixture will have the highest potential risk on ravelling. The water resistant mixture will be a mixture where all the parameters are chosen in a way that we expect the mixture will have the lowest potential risk on ravelling. The different parameters are chosen based on experience and the literature review. The mix designs are made with the PradoWin software (volumetric design method developed by BRRC).

In the second phase, ITS and ITSR tests are carried out on the two extreme mixtures. The influence of two different conditioning methods (water and freeze/thaw) on the ITS and ITSR values was examined. Based on the results the conditioning method characterized by the highest distinctive capacity was used throughout the next phases of the research project.

Phase 3 depends on the results of phase 2: if there is no significant difference in ITS-R between the two mixtures, it could be that none of the two conditioning methods is severe enough. In that case the conditioning methods must be adapted so that there is a distinctive capacity between the mixtures. Between phase 3 and 4 an evaluation of the 2 mixtures and their ITS and ITSR results will be made.

Because the ITS(R) test isn’t applied as a ravelling test, a comparison with other test that simulates ravelling must be made. This is done in phase 4. These tests are selected from the literature review(§3): Tribometer test (LCPC), the brush test and the RSAT (Heijmans). These three tests were chosen because the loading cycles are carried out at the surface of the specimens.

A final evaluation is made in phase 5: all test results will be compared and a ranking of the ravelling indicators is determined.

5 RESULTS

5.1 Phase 1, 2 and 3

There will be two different SMA-C mixtures to test. One mixture (A) was designed so that we expect it will be water sensitive and the other (mixture B) was designed so that we expect it to have a high resistance to water. This was done by varying parameters with a high risk or the opposite, a low risk to ravelling. In table 1 and 2 the mix design corresponding to these two extreme mixtures are shown. These mix design have been made with respect to the limitation described in the documents: SB250v2.1 and RW99. In these documents the obligatory standards for road construction in Belgium are described.

Table 1: Design criteria mixture compositions.

	Mixture A: water sensitive	**Mixture B: water resistant**
Type aggregate ≥2mm	Gravel	Porphyry
Type filler	Composite, Rigden voids: V38/45	composite filler, Rigden voids V38/45 + 20m-% Ca(OH)2
Type binder	Paving grade 50/70 with cellulose fibres	PmB E50/85-50
%Binder	Minimum binder content = **5,9% 'IN' mixture** (min. minus allowed deviation)	Higher binder content = **6,5% 'IN' mixture**
%voids	As high as possible = 7% (Marshall compaction)	As low as possible = 3,5% (Marshall compaction)

Table 2: Mixture compositions of the two extreme mixtures.

Water sensitive mixture: SMA-C (mixture A)		**Water resistant mixture: SMA-C (mixture B)**	
Raw material	**m/m% (in mixture)**	**Raw material**	**m/m% (in mixture)**
Gravel 6,3/10	56,37	Porphyry 6,3/10	54,12
Gravel 4/6,3	11,43	Porphyry 4/6,3	12,11
Crushed sand	15,78	Crushed sand	19,23
Composite Filler	10,19	Composite Filler + Ca(OH)2	8,04
Cellulose fibre	0,23	Binder: E50/85-50	6,5
Binder: B50/70	5,98		
Design voids (v/v%) = 6,4%		Design voids (v/v%) = 3,6%	

In phase 2, the ITS and ITSR test program was conducted on the two extreme mixtures. The influence of two different conditioning methods (water and freeze/thaw) on the ITS and ITSR values was investigated. The conditioning with the greatest distinctive capacity will be chosen for the rest of the experimental program. Two different compaction degrees were used:

- High compaction: 2x50 blows with the Marshall hamer and 100 gyrations with the gyratory compactor
- Low compaction: 2x25 blows with the Marshall hamer and 25 gyrations with the gyratory compactor

The two types of conditioning used in this research are the following:

- Water conditioning according the standard EN12697-12

By this conditioning the test specimens are placed in a water bath at 40°C for a period of 68 to 72hours. Before the start of the conditioning the specimens undergo a vacuum (6,7kPa) during 30 minutes in a water bath at 20°C. After this vacuum the specimens rest another half hour in the water bath at 20°C. The standard also mentions that an extra additional water conditioning or freeze/thaw cycle can be added to this procedure.

- Freeze/thaw conditioning according an adapted version of the AASHTO T 283 (Modified Lottman)

In an extensive study conducted by Kiggundu et al (1988) where different stripping tests were compared it was shown that the modified Lottman test is the most suitable to predict stripping. The tests results were compared with in situ results. In the standard procedure the specimens are first saturated with water by applying a vacuum of 13-67 kPa during 5 to 10 minutes. After this vacuum the test specimens remain another 5 to 10 minutes in the water. After the vacuum there must be a saturation degree of 70 to 80%. Then the specimens are placed for 16h in a freezer at -18°C (freeze conditioning). At last the specimens are conditioned during 24h in a waterbath at 60°C (thaw conditioning).

The procedure used in this project (adjusted modified Lottman) is a variant of the procedure described above. The saturation is done by a pressure of 6,7kPa during 30 minutes. After this vacuum the specimens rest another half hour in the water bath. The saturation degree is not taken into account. The freeze conditioning is the same as with the normal procedures (-18°C during 16h). The thaw conditioning of the AASHTO T 283 is replaced by the water conditioning NBN EN 12697-12 (40°C during 72h).

All the ITS results are determined according the standard EN12697-23. The test temperature is 15°C. The table below presents an overview of all the average ITS values en %voids in function of type and amount of compaction.

Table 3: ITS results of the two extreme mixtures A and B for three conditions

			not conditioned		**water conditioning**		**adjusted mod.-Lottman**	
			% Voids	ITS (MPa)	% Voids	ITS (MPa)	%Voids	ITS (MPa)
low compaction	Marshall 2 x 25 blows	**A**	10,6 ± 0,5	1,33 ± 0,10	10,9 ± 0,7	0,73 ± 0,04	--	--
		B	7,6 ± 1,0	1,41 ± 0,10	7,5 ± 0,5	1,39 ± 0,04	--	--
	Gyrator 25 gyrations	**A**	8,6 ± 0,7	1,62 ± 0,11	8,4 ± 0,4	1,23 ± 0,08	8,4 ± 0,3	1,37 ± 0,10
		B	5,5 ± 0,3	1,51 ± 0,01	5,3 ± 0,5	1,39 ± 0,14	5,6 ± 0,8	1,38 ± 0,08
high compaction	Marshall 2 x 50 blows	**A**	8,2 ± 0,5	1,73 ± 0,07	9,3 ± 0,4	0,99 ± 0,11	9,5 ± 0,1	0,97 ± 0,08
		B	5,5 ± 0,9	1,70 ± 0,07	5,7 ± 0,5	1,65 ± 0,13	5,7 ± 1,0	1,48 ± 0,14
	Gyrator 100 gyrations	**A**	5,0 ± 0,8	2,45 ± 0,14	4,2 ± 1,0	1,98 ± 0,04	4,3 ± 0,2	2,09 ± 0,13
		B	1,7 ± 0,2	1,88 ± 0,08	1,5 ± 0,2	1,84 ± 0,14	1,5 ± 0,4	1,82 ± 0,05

If one looks at the ITS results of mixture A (water sensitive) there is a clear difference between the unconditioned ITS values and the values obtained after conditioning (both at high and low compaction). There is high decrease in ITS value after applying the water conditioning or the adjusted modified Lottman. This applies for both the Marshall and gyratory compaction. It may be noted that this difference is smaller with the gyratory compaction then with the Marshall compaction. The ITS values obtained with the gyrator are higher than the ones obtained with Marshall (within the same compaction degree).

The ITS values of mixture B (water resistant) show another tendency than mixture A. The decrease in ITS values after conditioning is very small. The ITS values obtained by applying a freeze-thaw conditioning are slightly lower than the values of the water conditioning. This trend is observed for both the Marshall and gyratory compaction. Also with mixture B the gyratory compaction gives higher ITS values compared to the Marshall compaction (within the same compaction degree).

When the unconditioned ITS values of mixture A are compared to those of mixture B it is not possible to distinguish mixture A from mixture B. The difference between the two mixtures is too small. The unconditioned ITS values of mixture A are in the most cases higher than the ones achieved with mixture B.

After conditioning however, there is a significant difference between the two mixtures. This can be better visualized if we compare with the ITSR values (table 4).

Table 4: ITSR results of the two extreme mixtures A and B.

			water conditioning	**adjusted mod.-Lottman**
			ITSR (%)	ITSR (%)
Low compaction	Marshall 2 x 25 blows	**A**	55,0 ± 2,7	--
		B	98,8 ± 3,0	--
	Gyrator 25 gyrations	**A**	75,9 ± 4,0	84,6 ± 5,0
		B	92,1 ± 5,0	91,4 ± 3,0
high compaction	Marshall 2 x 50 blows	**A**	57,2 ± 6,5	55,9 ± 4,4
		B	97,5 ± 7,8	87,5 ± 8,3
	Gyrator 100 gyrations	**A**	80,8 ± 3,0	85,3 ± 4,0
		B	97,9 ± 5,0	96,8 ± 3,0

The highest distinctive ability between mixture A en B is situated by the water conditioning (for both Marshall as gyrator specimens) and not by the adjusted modified Lottman conditioning. For example with 2x50 Marshall blows there is difference between mixture A en B of 40,3% with the water conditioning and a difference of 31,6% with the adjusted modified Lottman conditioning. The distinctive ability is more present with the Marshall compaction than with de gyratory compaction.

Since the water conditioning (EN12697-12) has a sufficient distinctive ability there is no need to make the conditioning more severe and therefore is phase 3 redundant. The adjusted modified Lottman conditioning (based on AASHTO T283) will be not further used in this research.

5.2 Phase 4 and 5

In these phases, the other selected tests (§3) are conducted on the two extreme mixtures. Phase 2 has shown that the resistance to water of the 2 mixtures only becomes clear after the (water) conditioning (EN12697-12) has been applied. For this reason the mixtures A en B will be tested before and after the water conditioning in each different test.

a) Evaluation of the ravelling resistance with the Brush test

For this project the specimens are not immersed in fuel. The mass loss is determined after 120 seconds of brushing (Bi).

Table 5: Brush test results of the two extreme mixtures.

	voids(%)	conditioning	Bi.(%)
Mixture A Marshall 2x25 blows	11,3±0,2	none	0
	11,4±0,2	water	0
Mixture B Marshall 2x25 blows	6,4±0,5	none	0
	6,6±0,7	water	0

Both mixtures have no mass loss after brushing, even after the conditioning is applied there is no mass loss by mixture A and B. We can conclude that the brush test in this setting is incapable to give an indication about the ravelling sensitivity of the extreme mixtures. Possible reasons for the lack of distinctive ability is that the brushing time is very short (for mixtures that are not immersed into fuel) and the movement and loading of the steel brush on the specimen is not comparable with the real loading of a tyre on the road.

b) Evaluation of the ravelling resistance with the Tribometer T2R

The objective of this test is to evaluate the resistance to tangential forces of a material used for road wearing courses. A cyclic contact force is imposed at a predetermined inclination to cause surface degradation by loss of aggregates.

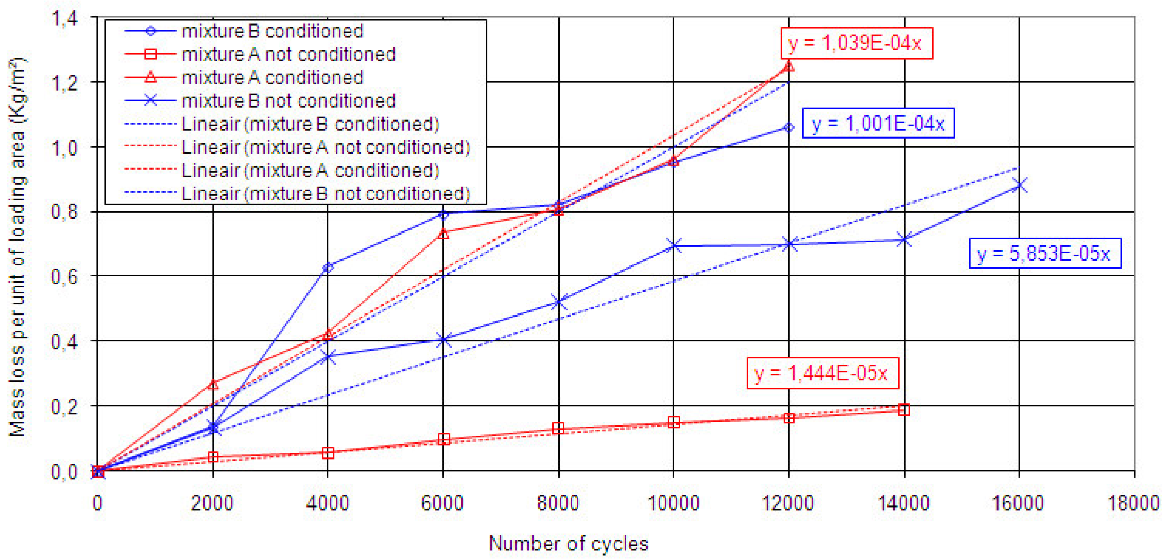

Figure 2: Tribometer results

The graph in the figure 3 show the ravelling progression using mass loss per unit of loaded area (in kg/m²) plotted on the y-axis versus the number of cumulative cycles on the x-axis.
On the figure 3 one can observe that before conditioning the mixture A (water sensitive) has a less steep slope and as a consequence less mass loss than the mixture B. It should be mentioned that the frictional resistance between the sample and the rubber layer has a influence on the test result. The greater the frictional resistance at the surface the greater the horizontal force will act on the surface. Since the test specimen of mixture B has a significant larger surface roughness than that of mixture A , the horizontal force is bigger and as a consequence the material loss could be larger. After conditioning both mixtures show a similar slope of the curves.

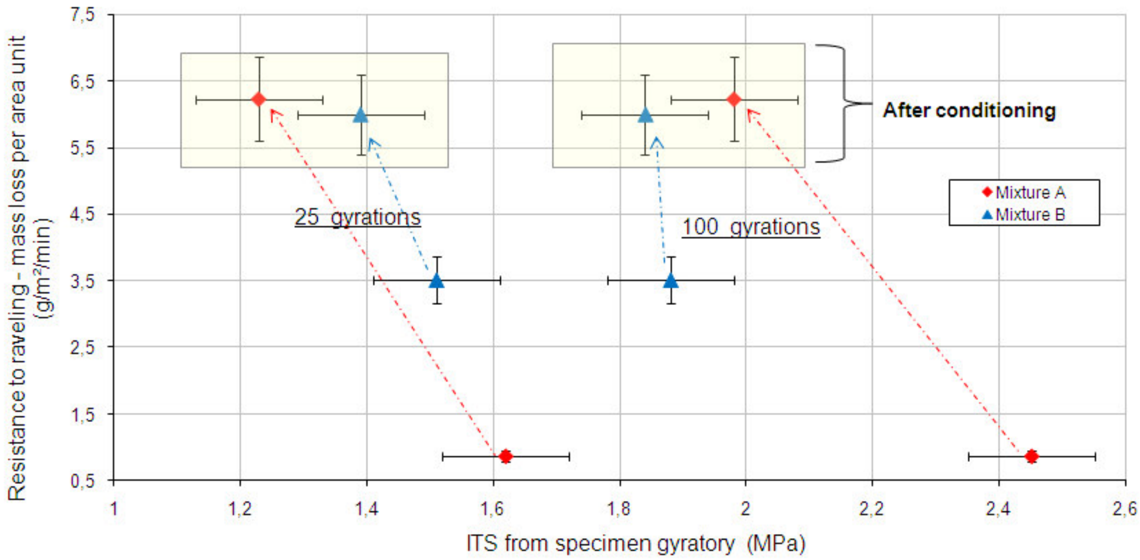

Figure 3: Tribometer results versus ITS results.

Observing the graph ITS strength versus resistance to ravelling (gyrator specimen) it is clear that after conditioning a nearly same mass loss for mixture A and B is obtained. As we expected, the mixture A shows a high decrease in ITS value after conditioning, this degradation is much smaller with mixture B. Out of this results we can conclude that the mixture A is indeed a water sensitive mixture (x-axis) but not necessary a more ravelling sensitive mixture (y-axis) if we compare to the mixture B. Without conditioning the water sensitive mixture A shows even a better resistance to ravelling than the more water resistant mixture B. The relative difference in material loss after and before conditioning is smaller within the mixture B than A (e.g. after 12000 cycles for B=0,361 kg/m² and for A= 1,091 kg/m²).

c) Evaluation of the ravelling resistance with the RSAT

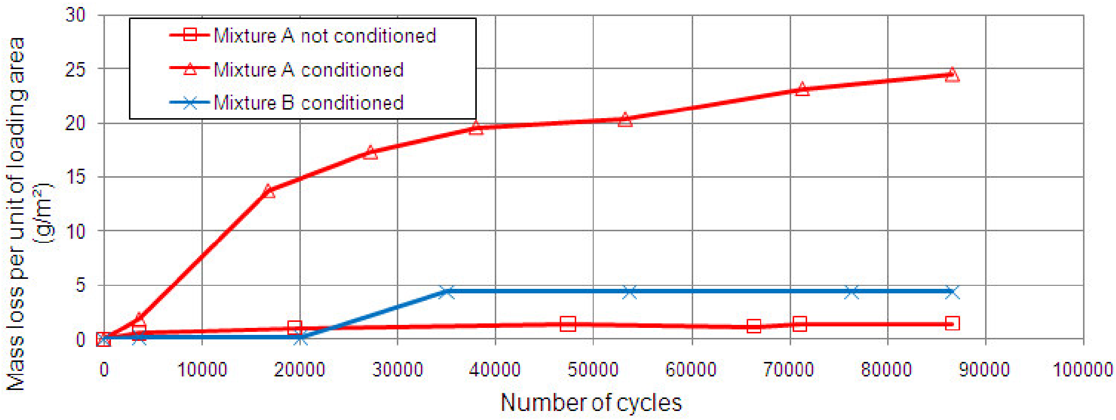

Figure 4: RSAT results.

The RSAT results before conditioning show a low mass loss for mixture A, for mixture B there is no test result with the RSAT. After conditioning one can observe that mixture A has a significant steep slope compared to the mixture B. If one compares the mass loss at the end of the tests with the values mentioned in table6, a normal life span is expected.

Table 6: Classification of asphalt mixes based on stone loss RSAT (Hartjes et al, 2008)

	stone loss (g/m²) (*1)					
asphalt type	0-91g/m²	91-151g/m²	151-303g/m²	303-454g/m²	>454g/m²	>605g/m²
ZOAB 11	normal lifetime expectancy			reduced lifetime expectancy (±2 years)	Strongly reduced lifetime expectancy (>5 years)	
SMA	normal lifetime expectancy		reduced lifetime expectancy (±2 years)	strongly reduced lifetime expectancy (>5 years)		

*1 : the values in this table are calculated in (g/m²). The values in the mentioned reference are expressed in (g).

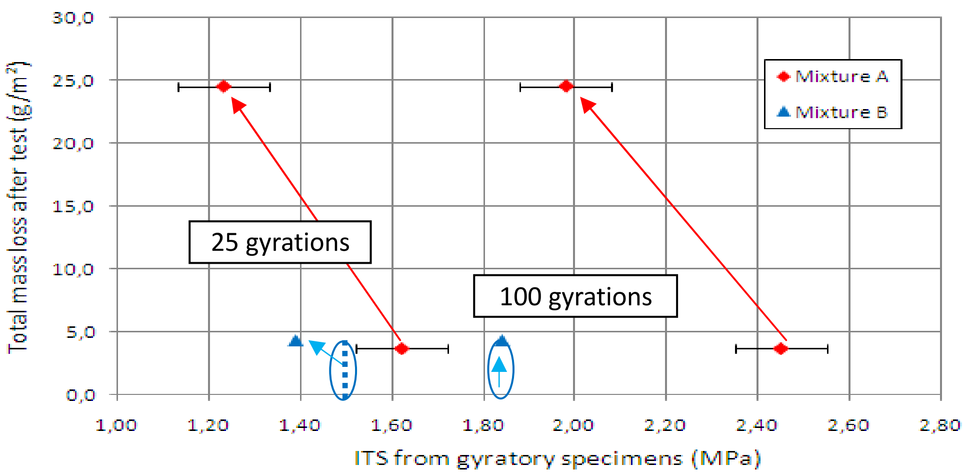

Figure 5: RSAT results versus ITS results.

The values of mixture B before conditioning are expected in the blue circles. The difference between mixture A and B becomes clear after conditioning: the mixture A has a large increase in mass loss compared to the mixture B (mixture A= 24,5g/m² ; mixture B= 4,34g/m²). Out of these RSAT results we can conclude that the water sensitive mixture is also a more ravelling sensitive mixture compared to the mixture B. This is a different result than the result obtained with the tribometer.

6 CONCLUSIONS

In this paper 3 different 'ravelling' tests were compared with the ITS-R test method. The brush test was founded not suitable to give an indication of the ravelling ability of an SMA mixture. The tribometer and RSAT gave in some cases a similar result (e.g. good resistance to ravelling of the water sensitive mixture before conditioning) in other cases a different result. If one follows the results of the tribometer one could conclude that the ITS-R method can't be used as a ravelling indicator because the (limited) results shows that a water sensitive is not necessary a ravelling sensitive mixture. However, to rank the two extreme mixtures by means of the water sensitivity, the tribometer and the ITS-R tests give the same conclusion.
In the case of the RSAT the water sensitive mixture A was founded to be a more ravelling sensitive mixture, compared to the water resistant mixture B. However if we compare the results to the classification table (table6) the water sensitive mixture shows still a good performance on the resistance to ravelling. It must be mentioned that the RSAT database for SMA results must be updated to get a better and more precise classification.
According to these limited RSAT results the ITSR-test tend to give an indication for ravelling for these two extreme mixtures. More research with the RSAT, tribometer and different SMA mixtures are needed to confirm the usability of the ITS-R method as a ravelling indicator.

ACKNOWLEDGEMENTS

The authors wish to thank the IWT Vlaanderen (Agency for Innovation by Science and Technology) for the financial support (Tetrafonds project n° 70065) and all members of the IWT users commission for the follow up of the research project.

REFERENCES

Hartjes, J. M., & Voskuilen, J. L. M., 2008. *Classificatie van asfaltmengsels met behulp van de RSAT proef*. Proceedings Infradagen 2008, Delft, Nederland.

Van Buël, T., & Buijs, J., 2001. *Chemische resistentie van asfalt*. Opleiding civiele techniek aan de academie van bouwkunde en civiele techniek van de Hogeschool 's-Hertogenbosch, Nederland.

Hammoum, F., Hamlat, S., Hicher, P-Y., Terrier, J-P., 2008. *Laboratory evaluation of the resistance to tangential forces of bituminous surfacing*. Proceedings E&E congress, Copenhagen, Denmark.

Kiggundu, B. M., & Roberts F. L., 1988. *Stripping in HMA mixtures: state- of- the- art and critical review of test methods*. NCAT, Auburn University, USA.