EVALUATION OF TACK COAT PERFORMANCE FOR THIN AND ULTRA-THIN ASPHALT PAVEMENTS

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ABSTRACT

Over the past ten years, adhesion testing of pavement layers has gained more and more importance throughout Europe. The performance and durability of multilayered pavements depends strongly on interlayer bonding, particularly for pavements with a thin or ultra-thin surface course. These are often subject to premature distress (delamination, peeling, slippage cracking, corrugation…) that may be due to poor adhesion at the interface. This paper discusses three types of test for measuring interlayer bond strength: the direct tensile test, the (Leutner) shear test, and the torque bond test. These tests are now in the process of European standardization. The object of this study is to evaluate the capability of these tests of discriminating between the various factors that affect bond strength. Among these factors are the type and application rate of the tack coat, and the type of both the surface course (Stone Mastic Asphalt-SMA, Ultra-Thin Layer Asphalt Concrete-UTLAC) and the base course (cement concrete or bituminous layer). This paper discusses the results of, and draws conclusions from, adhesion tests on both laboratory-prepared specimens and field specimens. Field specimens are necessary for the validation of laboratory tests and will provide information for defining recommendations or specifications for interlayer bond strength.

Keywords: Tack coat, interlayer bonding, direct tensile test, shear test, torsion test

1. INTRODUCTION

Pavements are multilayered structures. The overall bearing capacity and lifetime of pavements depend not only on the thickness and stiffness of each individual layer, but also on the bond between them. The purpose of a tack coat is to provide the necessary bond between layers. The European standardization committee CEN/TC 227 has recently started developing a prestandard prEN 12697-48 [1] for the determination of interlayer bond strength. In this document, three different loading modes are considered: direct tension, direct shear, and torsion. Recommendations are still missing in prEN 12697-48 about the differences between these methods and the selection of a given method for the assessment of damages related to adhesion between layers and internal cohesion of these layers. In this paper, these three methods are compared with the aim to determine their advantages, disadvantages and their differences (precision, discriminating capability, practical use, ...); comparisons are also made with a BRRC tensile test. The study was performed on both laboratory and field samples in order to validate these methods and to obtain values for interlayer adhesion strength. With this study, carried out within a NBN (Belgian Standards Office)-funded research project for the "Development of performance tests for thin and ultra-thin asphalt layers", BRRC wishes to contribute to the development of the prestandard prEN 12697-48 and to provide information for defining future interlayer bond strength recommendations or specifications.

2. INTERLAYER ADHESION TESTS

Technical committee CEN/TC 227 "Test methods for bituminous mixtures" recently proposed a draft European test method prEN 12697-48 in which three interlayer bonding tests are considered. In addition, a fourth test was used in this study: a direct tension test developed at BRRC before the appearance of prEN 12697-48. The types of equipment and the procedures used in this study are described in 2.1 to 2.4.

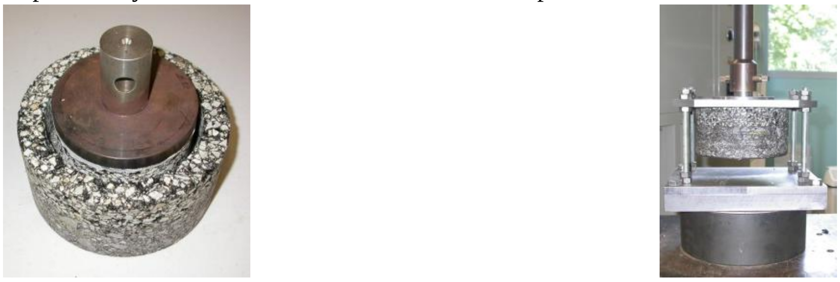
2.1 Direct tensile test-BRRC method

Metal plates are glued to both sides of the specimens (80 by 80 mm). These are conditioned and tested at 10 °C (± 1 °C). A tensile load is applied (Figure 1) in strain-controlled mode (0.5 mm/min) until the specimen fails. Tensile strength is calculated as the average of five specimens.

Figure 1: Specimen clamped in the pulling device

2.2 Direct tensile test-European method (prEN 12697-48)

The specimens are cores 150 mm in outer diameter. A concentric ring-shaped groove [100 mm (± 2 mm) in diameter] is drilled into the top surface of the specimen, to a depth of approximately 10 mm below the interface. The plunger is bonded to the surface circumscribed by the groove, over its full area (Figure 2a). The specimens are conditioned and tested at 10 °C (± 1 °C). The test is stress-controlled by applying a tensile force (200 N/s) until failure (Figure 2b). Repeatability tests at BRRC have shown that six specimens should be tested to calculate average strength.



(a) **(b)**

Figure 2: Core bonded with the plunger (a) and clamped in the pulling device (b)

2.3 Shear test (prEN 12697-48)

At BRRC, the specimens are cores 150 mm (± 2 mm) in diameter. In the case of ultra-thin surface courses, a metal extension plate is glued to the surface, to avoid deformation of this layer and distribute the shear load correctly over the interface. The specimens are conditioned and tested at 20 °C, using a Leutner shear test device (Figure 3) with a 5-mm gap between the shearing rings. The test is strain-controlled at a rate of 50 mm/min (± 2 mm/min). Tests at BRRC have shown that three specimens are needed for thin surface courses and six specimens for ultra-thin surface courses.

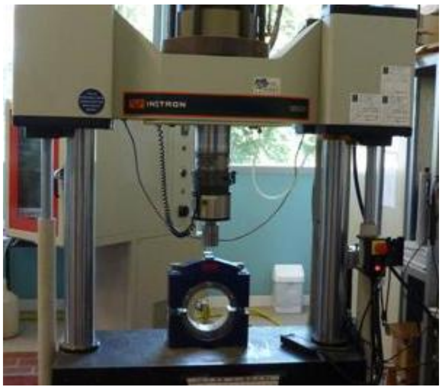


Figure 3: Shear test device fitted into the testing machine

Some countries have already set specifications for shear strength as measured under the test conditions described above (Table 1).

Table 1: Leutner test specifications

Country	Source	Specimen size (mm)	Shear strength [MPa]	
Germany	[2]	150	1.42	
	[3]		0.85	
Switzerland	[4]		0.85	
Austria	[5]	100	0.8 (unmodified tack coat)	1.2 (polymer-modified tack coat)

2.4 Torsion test

The torsion test is carried out either in situ or in the laboratory. For laboratory testing the core (100 mm in diameter) is placed and fixed in a mould, so that the surface course and the interface to be tested are 20 mm (± 10 mm) above the rim of the mould. A steel disc is fixed to the core and the specimen is conditioned at 20 °C. The test procedure consists of applying a torque with a dynamometric key (Figure 4) at a steady rate, so that the torque wrench sweeps an angle of 90° within 30 s (± 15 s). The torque is applied until failure occurs. Torque bond strength is calculated as the average value of six specimens.

Figure 4: Laboratory torsion test

3. LABORATORY STUDY

3.1 Materials and specimen preparation

Several combinations of surface and base courses were used:

- surface courses: thin-layer stone mastic asphalt (SMA) and ultra-thin-layer asphalt concrete (UTLAC);
- base courses: cement concrete type MC (0.45) and asphalt concrete (AC 14)

An overview with the most important parameters is given in Table 2. For the sake of simplicity, we will refer to these courses by the name given in the column "Nomenclature".

Table 2: Characteristics of the laboratory manufactured specimens

Course type	Mixture type	Binder content [% mass]	Binder type	Void content [%] 100 gyrations	Layer thickness [mm]	Nomenclature
Wearing	SMA 6.3	6.6	PmB 50/85-50	N/A	30	SMA-P
Wearing	SMA 6.3	7.2	B70/100	9.5	30	SMA-R
Wearing	UTLAC 6.3	4.9	B50/70	19.9	15	UTLAC-P
Wearing	UTLAC 6.3	5.5	B70/100	17.4	15	UTLAC-R
Base	AC 14	4.6	B35/50	N/A	50	AC14
Base	MC (0,45)	N/A	N/A	N/A	50	MC

The asphalt courses were manufactured in the laboratory according to EN 12697-33+A1:2007 and EN 12697-35+A1:2007. The cement concrete base layers were manufactured according to EN 1766:2000. The characteristics of the cationic emulsions used as tack coats for the preparation of the two-layer slab specimens are shown in Table 3.

Table 3: Characteristics of the emulsions

Denomination according EN 13808	Breaking value (Sikaisol)	pH	Penetration at 25°C (1/10mm)	Softening point (°C)	Elastic recovery at 25°C (%)
C60B1	130	1.6	164	40.2	---
C60B6	120	5.6	88	47.0	---
C60BP1	108	2.1	108	50.8	92
C60B4 (AA)*	35	2.6	60	49.4	---
C60B1 (AA)*	112	4.5	59	50.6	---
C60BP4 (AA)*	65	2.6	48	52.3	29
C65BP3	50	2.7	90	53.0	91
C67B1	83	2.3	173	39.4	---
C65BP4-a	61	3.2	135	46.4	51
C65BP4-b	107	1.6	86	46.0	58
C65BP4-c	86	2.8	74	50.5	64
C70BP3	55	N/A	101	60.9	N/A

* AA: anti-adhesive, emulsion of hard bitumen

3.2 Test results

3.2.1 Direct tensile tests

A. SMA wearing courses

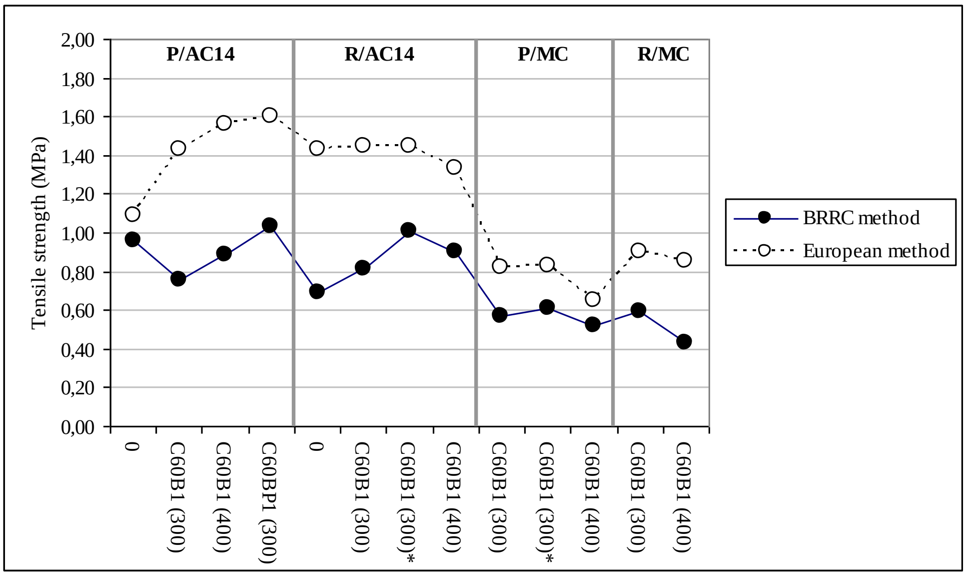
According to regional specifications in Belgium, SMA requires the application of an unmodified emulsion (C60B1), a polymer-modified emulsion (C60BP1) or an emulsion of hard bitumen (C60B4 (AA)) with all 60% of binder. For the specimens with a cement concrete base additional tests were done with the emulsions C60B6 and C60B1 (AA) to see the effect of its acid-alkaline nature. The minimum application rate of the tack coat is 300 g/m² of residual binder. Tests were performed without tack coat (0), with the minimum rate (300) and with a higher rate (400). The results are listed in Table 4 and Figure 5. The data show a difference between the tensile strength values obtained with the two tensile methods due to the difference in test conditions and particularly the loading rate. Both methods show a significant impact from the type of base course. For the cement concrete base layer, both the alkaline nature and the lack of roughness of the cement concrete are unfavourable to the mechanical and chemical interlock of the tack coat.
We have always a breaking at the interface for all the cement concrete base layers; it means that the cohesion of the two layers is better than the interlayer adhesion. The hardness of the binder and the acid-base character of the emulsion are two parameters that may improve this, as shown by the tensile strength obtained with both alkaline (C60B6) and hard bitumen (C60B4 (AA), C60B1 (AA)) emulsions. Apart from that, there are no significant differences between the SMA

with high or low bitumen content and between different application rates. In the case of an asphalt concrete base course, it seems that even without tack coat the tensile strength is not significantly different. This could be explained by the fact that the « new » base courses have a light coating of binder which is believed to have been adequate to form a good bond formation under final compaction in laboratory. We have in general a mixed failure which means that the cohesion of the two layers is lower than the interlayer adhesion. Apart from that, the BRRC method demonstrated the beneficial effect of a longer curing time on the interlayer bonding of specimens with an asphalt concrete base, but this impact is small compared to the standard deviation.

Table 4: Results of direct tensile testing of thin surface courses by the European and BRCC methods (COV for coefficient of variation)

Material combination	**Tack coat type**	**Tack coat rate (g/m²)**	**Tensile strength *BRRC method***		**Tensile strength *European method***	
			Average (MPa)	**COV (%)**	**Average (MPa)**	**COV (%)**
SMA-P/AC14	---	0	0.96 ± 0.09	9	1.09 ± 0.22	20
	C60B1	300	0.76 ± 0.06	8	1.43 ± 0.16	11
	C60B1	400	0.89 ± 0.07	8	1.56 ± 0.16	10
	C60BP1	300	1.03 ± 0.06	6	1.60 ± 0.1	6
	C60B4 (AA)	300	0.96 ± 0.03	3	N/A	N/A
SMA-R/AC14	---	0	0.69 ± 0.05	7	1.43 ± 0.26	18
	C60B1	300	0.81 ± 0.06	8	1.45 ± 0.18	12
	C60B1*	300	1.01 ± 0.05	4	1.45 ± 0.16	11
	C60B1	400	0.90 ± 0.04	4	1.33 ± 0.13	9
SMA-P/MC	C60B1	300	0.57 ± 0.04	8	0.82 ± 0.07	8
	C60B1*	300	0.61 ± 0.09	15	0.83 ± 0.04	4
	C60B1	400	0.52 ± 0.11	21	0.65 ± 0.05	8
	C60B6	400	0.65 ± 0.09	14	N/A	N/A
	C60B4 (AA)	300	0.92 ± 0.1	11	N/A	N/A
	C60B1 (AA)	400	1.01 ± 0.06	6	N/A	N/A
SMA-R/MC	C60B1	300	0.59 ± 0.10	17	0.90 ± 0.04	4
	C60B1	400	0.43 ± 0.08	18	0.85 ± 0.1	11
	C60B6	400	0.58 ± 0.04	7	N/A	N/A

* Curing time of 24h



* Curing time of 24h

Figure 5: Tensile strength values for the thin layer specimens (BRRC and European methods)

B. UTLAC wearing courses

The tests on the UTLAC were limited to the BRRC method. Six cationic emulsions were selected:

- a polymer-modified tack coat (C65BP3) and an unmodified tack coat (C67B1) applied at the rates of 150 g/m² (outside the Belgian specifications) and 400 g/m² (within the Belgian specifications);
- a polymer-modified tack coat (C70BP3);
- two latex-modified emulsions (C65BP4-a and C65BP4-c) ;
- an alkaline tack coat (C60B6).

The results are presented in Table 5 and Figure 6 (only for UTLAC on cement concrete base course).

Table 5: Results of direct tensile testing of ultra-thin surface courses (BRCC method)

Material combination	Tack coat type	Tack coat rate (g/m²)	Tensile strength (MPa)	COV (%)
UTLAC-P/MC	C65BP3	150	0.30 ± 0.05	16
	C65BP3	400	0.40 ± 0.04	9
	C67B1	150	0.36 ± 0.04	12
	C67B1	400	0.26 ± 0.03	11
	C65BP4-a	400	0.44 ± 0.05	11
	C65BP4-c	400	0.63 ± 0.05	8
	C60B6	400	0.81 ± 0.06	8
UTLAC-R/MC	C65BP3	150	0.30 ± 0.03	9
	C65BP3	400	0.30 ± 0.06	18
	C67B1	150	0.21 ± 0.07	31
	C67B1	400	0.22 ± 0.04	17
UTLAC-P/AC	C65BP3	400	1.03 ± 0.08	8
	C67B1	400	0.84 ± 0.03	4
	C70BP3	400	1.15 ± 0.16	14

The polymer-modified emulsion has, generally speaking, a beneficial effect, but both the latex-modified and alkaline tack coats gave the best tensile strength for the cement concrete base layer. This is due to the synergetic effect of the penetration value of the bitumen and the acid-alkaline nature of the emulsion. As for the studied SMA (Table 4), there are no significant differences between the UTLAC with high or low bitumen content and between different application rates. We have a breaking at the interface for all the cement concrete base layers. There is however an exception with the tack coat C60B6, we obtain a failure partly at the interface and partly in the wearing course, as for the asphalt concrete base course. When comparing SMA and UTLAC investigated with the BRCC method:

- the precision is similar but the tensile strength is always higher for the SMA than for the UTLAC specimens. This means that the UTLAC layers investigated will be more sensitive to suction forces generated by tyres on the pavement surface;
- the results clearly revealed the potential of tack coat ton ensure/promote the bonding properties in case of an inadequate base layer in terms of surface roughness or alkaline nature.

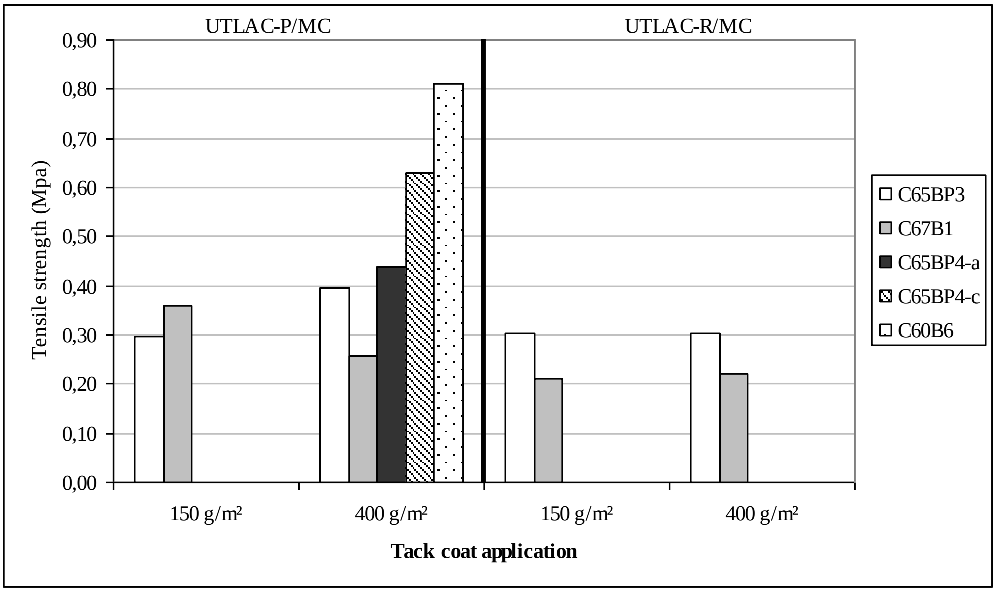


Figure 6: Strength values for UTLAC layers as determined by direct tensile testing (BRCC method)

3.2.2 Shear test

A. SMA wearing courses

Three emulsions were used: an emulsion of hard bitumen [C60B4 (AA)], its polymer-modified version [C60BP4 (AA)] and two alkaline emulsions (C60B6 and C60B1 (AA)). An overview of the results is presented in Table 6, with a coefficient of variation generally lower than 10 %. When checking against the Leutner test specifications (Table 1), it can be seen that the lower value of 0.85 MPa would exclude almost all the specimens with a cement concrete base layer, except those with the alkaline tack coats C60B6 and C60B1 (AA). For the cement concrete base layer, the use of tack coat clearly improves the results; but there are no significant differences between the different application rates. All the specimens with an AC base course satisfied the specifications for shear strength; even those without tack coat. The higher specification value of 1.42 MPa would lead to accept only two of all the combinations investigated.

Table 6: Results of shear testing of thin surface courses

Material combination	Tack coat type	Tack coat rate (g/m²)	Shear strength (MPa)	COV (%)
SMA-P/AC	---	0	1.3 ± 0.1	4
	C60B4 (AA)	150	1.4 ± 0.2	2
	C60B4 (AA)	300	1.5 ± 0.1	2
	C60BP4 (AA)	300	1.4 ± 0.1	2
SMA-P/MC	---	0	0.37 ± 0.04	11
	C60B4 (AA)	150	0.71 ± 0.04	6
	C60B4 (AA)	300	0.71 ± 0.03	4
	C60BP4 (AA)	300	0.83 ± 0.02	2
	C60B6	400	0.87 ± 0.06	7
	C60B1 (AA)	400	0.86 ± 0.04	5

B. UTLAC wearing courses

The following emulsions were used:

- two polymer-modified tack coats (C65BP3 and C70BP3) and an unmodified tack coat (C67B1);
- three latex-modified emulsions (C65BP4-a, C65BP4-b and C65BP4-c) and an alkaline tack coat (C60B6).

In accordance with Table 7 and Figure 7, the use of a polymer-modified tack coat did not seem to have a beneficial effect on interlayer shear strength. The penetration value of the bitumen and the acid-alkaline nature of the emulsion are two important parameters – particularly for concrete cement base courses, as shown by the higher shear strengths obtained with some of the latex and alkaline emulsions. When checking against the Leutner test specifications given in

Table 1, the lower value of 0.85 MPa would exclude almost all the specimens with a cement concrete base, except the specimen with a latex emulsion and that with the alkaline emulsion. All the specimens with an AC base course met this shear strength specification. The higher specification value of 1.42 MPa would lead to accept only two of all the combinations investigated. When comparing the UTLAC results (Table 7) to the SMA results (Table 6) as obtained with the modified Leutner shear test method, it can be seen that the specimens with the UTLAC surface course exhibit greater variability. Therefore, in the case of ultra-thin surface courses six specimens are needed to find a reliable average value. It is also interesting to note that the shear strength values depend little on the type of wearing course: SMA and UTLAC results are comparable. This was not the case for the tensile tests, where the UTLAC specimens failed at lower loads. Another difference between both shear and tensile loading is that in tensile test, the strength of the courses also affects the results in the case the courses are weaker than the interface.

Table 7: Results of shear testing of ultra-thin surface courses

Material combination	Tack coat type	Tack coat rate (g/m²)	Shear strength (MPa)	COV (%)
UTLAC-P/MC	C65BP3	150	0.70 ± 0.08	11
	C65BP3	400	0.7 ± 0.1	21
	C67B1	150	0.7 ± 0.2	32
	C67B1	400	0.8 ± 0.2	19
UTLAC-R/MC	C65BP3	150	0.6 ± 0.1	16
	C65BP3	400	0.54 ± 0.02	4
	C67B1	150	0.6 ± 0.1	23
	C67B1	400	0.8 ± 0.2	23
UTLAC-P/MC	C65BP4-a	400	0.6 ± 0.1	19
	C65BP4-b	400	0.69 ± 0.08	12
	C65BP4-c	400	1.2 ± 0.2	14
	C70BP3	400	0.7 ± 0.1	14
	C60B6	400	1.0 ± 0.1	13
UTLAC-P/AC	C65BP3	400	N/A	N/A
	C67B1	400	1.5 ± 0.1	10
	C65BP4-a	400	1.1 ± 0.1	11
	C65BP4-b	400	1.4 ± 0.1	6
	C65BP4-c	400	1.4 ± 0.1	7
	C70BP3	400	1.3 ± 0.3	23

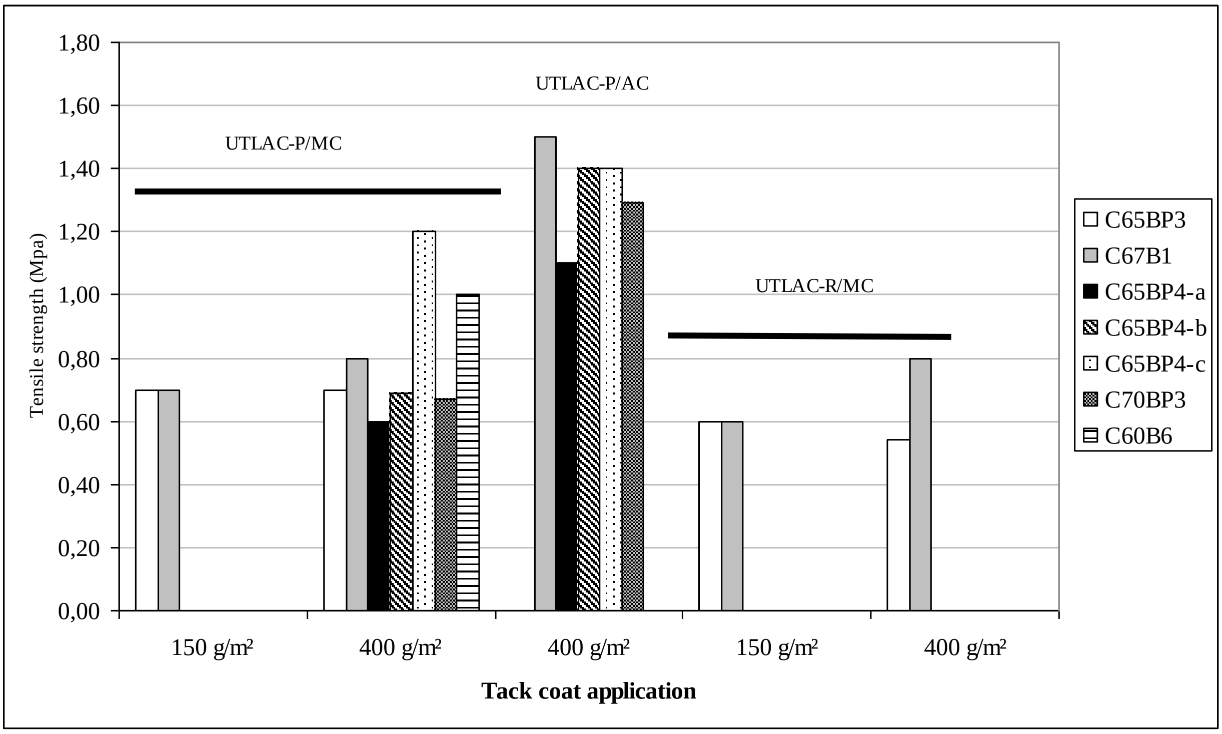


Figure 7: Shear strength values of ultra-thin surface courses as determined by shear testing

3.2.3 Torsion test

As first step, we have determined the adequate test procedure conditions to develop at CRR a laboratory-based torsion test: choice of the cement mortar, the mould to clamp the specimens, the metallic plate which acts as an adapter between the specimen and the dynamometric key, the adhesive … [6,7]. The purpose was to control as many mix manufacturing parameters as possible and also to be able to perform the test under controlled conditions (temperature, humidity…) as these have a great effect on the torque bond strengths that can be found. At BRRC, the torsion test is performed manually by a technician who applies the torque and reads the value at failure. This requires a certain degree of experience and strength; it is physically difficult to exceed a torque of 400 Nm. The reading precision is also limited: results are read on a scale with a precision of 20 Nm. Unlike the shear test, the torsion test induces shear stresses at the interface as well as in the surface course of the specimen. As a result, failure often occurs in the surface course rather than at the interface. Also, the preparation of the specimens is more difficult and takes much more time than in the shear test. Because of these drawbacks, only a limited number of laboratory tests were performed with this device. Like in the tensile and shear tests, we observed that the effect of tack coat type and rate depended strongly on the nature of the base course. The results obtained with this test method test will be shown in the Section on the field study (see 4.3), where a direct comparison will be made with the results of shear tests.

Table 8: Results of torsion testing of the of ultra-thin surface courses

Material combination	Tack coat type	Tack coat rate (g/m²)	Torque (N.m)	Torque bond strength (MPa)	COV (%)
UTLAC-P/AC	C65BP4-a	400	233 ± 36	0.9 ± 0.1	16
UTLAC-P/MC	C65BP4-b	400	130 ± 21	0.49 ± 0.08	16
	C65BP4-c	400	155 ± 30	0.6 ± 0.1	20

4. FIELD STUDY

4.1 Objectives

The first objective of the field study was to see if laboratory prepared specimens are representative of a real multilayered pavement. The preparation of specimens in the laboratory can not exactly simulate the actual construction process (mixing and compaction, spreading of the emulsion). Also, ambient conditions in the laboratory (controlled temperature and moisture, no wind, cleanness, no ageing of the base layer…) are very different from field conditions. That is why the laboratory study was complemented by a validation study, in which laboratory and field specimens could be compared. A second objective of the field study was to collect strength data and to see if the data can be related to observed damage. This is necessary for the validation of strength recommendations or specifications.

4.2 Specimens

4.2.1 Field cores

Cores were extracted from a newly laid asphalt pavement constructed in the spring of 2011 (motorway E40). These specimens were taken from the emergency lane from two sections: A and B. An overview with the most important parameters of these two sections is given in Table 9.

Table 9: Characteristics of core samples taken from motorway E40

Section	Pavement layer	Mixture type	Pavement layer thickness [mm]	Tack coat type	Tack coat rate (g/m²)
A	Wearing	SMA 6.3	25	C60B1 (AA)	300
	Base	HMA 14*	80		
B	Wearing	SMA 6.3	25	C60B4 (AA)	300
	Base	AC 10	40		

*HMA: High Modulus Asphalt

4.2.2 Laboratory prepared specimens

Differences due to specimen preparation were assessed by comparing results of field specimens from the E40 to results of laboratory-prepared specimens. The latter were prepared with base courses 50 mm thick (with the same components as on site), surface courses 30 mm thick (with bulk mixtures sampled on the work site during construction) and tack coats [C60B1 (AA) and C60B4 (AA)] as used on the work site.

4.3 Test results

4.3.1 Direct tensile tests (BRRC Method)

Two cylindrical core samples per zone were taken from the emergency lane of the E40. From each core, three cubic specimens were easily extracted. Table 10 shows direct tensile strength values for the two studied sections with little dispersion within each zone. If we compare the laboratory prepared specimens and the field cores, the tensile strengths are similar but we observe that the bond strengths of the field specimens were invariably higher; this trend is however small compared to the standard deviation This could be explained by the positive effect of trafficking and curing time. For laboratory prepared specimens and field cores the failure occurred in the wearing course for the section A and in the base course for section B. This means that the interface was not the weak point of these two-layered pavements and that the interlayer bond strength was higher than the measured values.

Table 10: Results from direct tensile testing (BRCC method)

Material combination	Tack coat type	Tack coat rate (g/m²)	Cores type	Testing zone	Tensile strength (MPa)	COV (%)
SMA 6.3/HMA 14	C60B1 (AA)	300	Field	A1	1.5 ± 0.1	6
				A2	1.83 ± 0.04	2
				A3*	1.64 ± 0.03	2
				A1 to A3*	1.7 ± 0.2	10
			Laboratory		1.05 ± 0.08	8
SMA 6.3/AC 10	C60B4 (AA)	300	Field	B1	1.53 ± 0.07	4
				B2	1.32 ± 0.06	5
				B3	1.4 ± 0.1	8
				B1 to B3	1.4 ± 0.1	8
			Laboratory		1.3 ± 0.1	8

*****on a slip road

4.3.2 Shear test

Six specimens per testing zone were investigated. Table 11 shows shear strength values for the two sections with little dispersion in the results within each zone (except for the testing zone B1). When comparing the laboratory-prepared specimens and the specimens prepared from field cores, we observe that the latter always exhibited higher shear strength; this trend is however small compared to the standard deviation. This could be explained by the duration between laying and compaction, coring and testing which influences the test results. From these results it appears that a minimum storage time (curing of the tack coat) is required for the specimens to attain their maximum bonding performance. The fact that tests on laboratory-prepared specimens underestimate the strength obtained in the field is, however, an encouraging conclusion, as this gives us a safe estimation.

Table 11: Results from shear testing

Material combination	Tack coat type	Tack coat rate (g/m²)	Cores type	Testing zone	Shear strength (MPa)	COV (%)
SMA 6.3/HMA 14	C60B1 (AA)	300	Field	A1	1.71 ± 0.07	4
				A2	1.80 ± 0.07	4
				A3*	2.5 ± 0.2	9
				A1 to A3*	2.0 ± 0.4	20
			Laboratory		1.52 ± 0.06	4
SMA 6.3/AC 10	C60B4 (AA)	300	Field	B1	2.1 ± 0.4	19
				B2	1.98 ± 0.08	4
				B3	2.0 ± 0.1	7
				B1 to B3	2.0 ± 0.2	11
			Laboratory		1.8 ± 0.2	8

*****on a slip road

4.3.3 Torsion test

Six specimens per testing zone were studied. Table 12 shows the torque bond strengths for the two studied sections, with little dispersion in the data. The average values from section A and B are the same but they are not are comparable in terms of failure. We observed in general a failure in the surface layer for section A and in the base layer for section B. This means that the bond strength at the interface is higher than the values reported in the Table 12. When comparing the laboratory-prepared specimens and the specimens prepared from field cores, we observe that the latter exhibited similar torque bond strength, but, generally speaking, they failed at the interface.These observations indicate the difficulty to interpret correctly the torsion test in terms of type of failure, since it induces both a torque at the interface and in the upper layer itself.

Table 12: Results from torsion testing

Material combination	Tack coat type	Tack coat rate (g/m²)	Cores type	Testing zone	Torque (N.m)	Torque bond strength (MPa)	COV (%)
SMA 6.3/HMA 14	C60B1 (AA)	300	Field	A1	400 ± 0	1.34 ± 0.00	0
				A2	400 ± 0	1.34 ± 0.00	0
				A3*	373 ± 39	1.3 ± 0.1	10
				A1 to A3*	391± 26	1.31 ± 0.08	6
			Laboratory		413 ± 24	1.41 ± 0.08	6
SMA 6.3/AC 10	C60B4 (AA)	300	Field	B1	400 ± 0	1.33 ± 0.01	0
				B2	375 ± 38	1.3 ± 0.1	10
				B1 to B2	390 ± 25	1.30 ± 0.08	7
			Laboratory		427 ± 35	1.5 ± 0.1	8

*****on a slip road

5. CONCLUSIONS

From the laboratory study described in this article, the following conclusions can be drawn:

The three tests lead to the same conclusions, the adhesive strength is much lower in case of a cement concrete base layer. Only for this type of base layer, a significant improvement is seen when using a tack coat. Some latex emulsions and especially the alkaline emulsion have an important effect. A difference between both tensile and shear loading is that in tensile test, the strength of the courses also affects the results in the case the courses are weaker than the interface. The tensile strength can generally be obtained with the same precision for thin and ultra-thin layers, but this does not apply to the shear test. In order to obtain a reliable estimation of interlayer shear strength, three specimens are sufficient for thin surface courses, while six specimens are needed for ultra-thin surface courses.
In the shear test, the nature of the base layer seems to play an even more important role. This could be due to the effect that mechanical interlocking plays a larger role and this is expected to be weak as the cement concrete has a smoother texture. The two loading modes (direct tension, direct shear) appear to be complementary, which means that one cannot replace the other to analyse the mechanical performance of the interface. From a practical point of view, the implementation of the shear test is easier than the torsion test; this latter needs a long time for the preparation of samples and higher costs of execution.

At this stage of the study, it is too early to give specifications for adhesion strengths. More field studies are needed to correlate field strength data to observed distress phenomena.

From the field study analysed in this article, the following conclusions can be drawn:

The interlayer bond strengths obtained on laboratory prepared specimens are similar to the interlayer bond strengths obtained on field cores. To obtain a correct diagnosis of the interlayer adhesion of the multilayered pavements, at this stage of this research project, the use of the shear test and direct tensile test is recommended. However, it is clear that these findings should be confirmed by more field data and that many more parameters need to be investigated (ageing, milling surface…). The torsion test is less precise than the shear test and also more difficult to interpret in terms of type of failure, since it induces both a torque at the interface and in the upper layer itself, unlike the shear test which concentrates the shear loading exclusively on the interface. The idea had been that this test would be applicable directly on site, but in view of the precision, combined with variable environmental conditions and the practical difficulty to glue the metallic plates to the surface, we doubt that this will be a reliable and practical method.

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