Field study to evaluate different pre-normative interlayer adhesion tests

Alexandra Destrée[1, a], Joëlle De Visscher[1, b], Ann Vanelstraete[1, c]

[1] *Division Asphalt Pavements, Bituminous Applications and Chemistry, BRRC, Sterrebeek, Belgium*

[a] a.destree@brrc.be
[b] j.devisscher@brrc.be
[c] a.vanelstraete@brrc.be

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ABSTRACT

An effective and durable bond between the various constituent layers is an absolute prerequisite for the durability of a road pavement. To ensure the adhesion between successive road construction layers, cationic bitumen emulsions are the most frequently used type of tack coats. Several tests are currently available to evaluate the bonding performance between layers based on different loading modes (shear, torque and tensile) They vary in regard of test devices, test temperature, loading mode as well as sample geometry and preparation and hence they lead to different results. In this context, the European standardisation committee

CEN TC227/WG1/TG2 "Test methods for bituminous mixtures" has developed a prestandard prEN12697-48 "Bituminous mixtures – Test methods for hot mix asphalt – Part 48: Interlayer Bonding" for the determination of interlayer bond strength where three main normative test methods are considered: tensile adhesion test (TAT), shear bond test (SBT), torque bond test (TBT). A site test method to evaluate the tensile bond strength making use of a practical clamping device and used for many years in Quebec, called layer adhesion measuring instrument (LAMI), was recently included in the prestandard. This article gives an overview of the different methods and discusses the results of a study in the laboratory (SBT, TAT) and on site (LAMI) in which these pre-normative interlayer adhesion tests were used. The study leads to recommendations for the methods described in prEN 12697-48 and shows the differences between the methods. The ultimate aim of this study is to come to recommendations for improving the adhesion performance of multilayer pavements and to propose values for minimum interlayer bond strength to be achieved on site.

Keywords: Adhesion, Emulsions, Tack coats

1. INTRODUCTION

Over the past ten years, adhesion testing of pavement layers has gained more and more importance throughout Europe and in many other countries (USA, Switzerland…) [1], [2], [3]. Several tests are currently available to evaluate the bonding performance between layers based on different loading modes (shear, torque and tensile). They vary in regard of test devices, test temperature, loading mode as well as sample geometry and preparation and hence they lead to different results [4], [5], [6], [7]. Due to these dissimilarities in experimental conditions, the comparison of the test results obtained from these test methods is often not possible.

In this context, the European standardisation committee CEN/TC227/WG1/TG2 “Test methods for bituminous mixtures” is working on a pre-standard prEN 12697-48 [8] for the determination of interlayer bond strength where three main normative test methods are considered: tensile adhesion test (TAT), shear bond test (SBT), torque bond test (TBT). Further five test methods are described in informative annexes: compressed shear bond test, cyclic compressed shear bond test, alternative shear bond test and a site tensile test making use of the layer adhesion measuring instrument (LAMI). This paper compares some of these methods.

2. OBJECTIVE

The paper gives an overview of three pre-normative interlayer adhesion tests (SBT, TAT, LAMI) and discusses the results of a study in the laboratory and on site in which these different interlayer bond test methods were used. The objectives of this study supported by the Belgian Bureau for Standardisation are mainly:

- To lead to recommendations for the three interlayer bond test methods described in prEN 12697-48 and to show the differences between the methods;
- To come to recommendations for improving the adhesion performance of multilayer pavements and to propose values for minimum interlayer bond strength to be achieved on site.

3. INTERLAYER BONDING TESTS

3.1 Shear bond test

The most popular test configuration for assessment of bonding condition is currently based on interlayer direct shear testing. The shear bond test (SBT) described in the prestandard prEN 12697-48 can only be carried out in laboratory. The specimens are cores (cored from the pavement or laboratory prepared samples) with a diameter of (150 ± 2) mm or (100 ± 2) mm and the thickness of the layer above the interlayer of interest shall be higher than or equal to 15 mm. For this work (Figure 1), they have a diameter of (150 ± 2) mm and they are conditioned and tested at 20 °C, using a shear bond test device according to Leutner [9] with a 5-mm gap between the shearing rings. The test is conducted displacement-controlled at a rate of (50 ± 2) mm/min. In the case of ultra-thin surface courses (thickness < 20 mm), a grooved metal extension plate is glued to the surface, to avoid deformation of this layer and distribute the shear load correctly over the interface. According to the pre-standard, at least two specimens shall be tested. In this paper six replicates were used to determine the average shear stress.

Germany [10] and Switzerland [11] specify minimum average shear strength specifications for tack coat in function of the tested interface on 150 mm diameter cores and a temperature of 20 °C (Table 1). But these values are currently criticised and some authors [12], [13] made new recommendations for higher limits which are based on their experience and their research (Table 2).

Shear bond test device

Core clamped in the shear bond test device

Core after failure

Figure 1: Shear bond test device and experimental setup

(with metal extension plate in the case of ultra-thin surface courses)

Table 1: Shear bond test specifications for Germany [10] and Switzerland [11]

Source	**Minimum average shear strength in N/mm^2 (shear force in kN)**	
	Surface/Binder	Binder/Base or Base/Base
[10]	0.85 (15)	0.68 (12)
[11]	0.85 (15)	0.68 (12)

Table 2: Shear bond test recommendations for Germany [12] and Switzerland [13]

Source	**Minimum average shear strength in N/mm^2 (shear force in kN)**	
	Surface/Binder	Binder/Base or Base/Base
[12]	1.41 (25)	1.13 (20)
[13]	1.3 (23)*	—

** For asphalt concrete (AC) and stone mastic asphalt (SMA)*

3.2 Tensile adhesion test

The tensile test which adopts the pulling mechanism is another method used to quantify pavement interface bond strength. The tensile adhesion test (TAT) described in the prestandard prEN 12697-48 can only be carried out in laboratory. The specimens are cores (cored from the pavement or laboratory prepared samples) with an outer diameter of (150 ± 2) mm and with a height of at least (60 ± 5) mm. A concentric ring-shaped groove with a diameter of (100 ± 2) mm is drilled into the surface layer of the specimen, to a depth of 10 mm below the interface. A plunger is bonded to the core surface inside the ring groove using a suitable adhesive. The specimens are conditioned and tested at either (0.0 ± 0.5) °C or (10.0 ± 0.5) °C. For this study, they are conditioned and tested at (10 ± 1) °C. The test is stress-controlled by applying a tensile force (200 N/s) until failure. According to the prestandard, at least two specimens shall be tested. In this paper six replicates were used to determine the average tensile bond strength. Very few countries specify tensile bond strength limits for tack coat. Austria [14], [15] specifies minimum tensile strength at a test temperature of 0 °C depending on the nature of the tack coat (see Table 3). Knowing that in this temperature range, tensile strength decreases with increasing temperature [16-18], we will be able to use these specifications as a good support to guide us in our interpretations.

Core bonded with the plunger

Core clamped in the tensile adhesion test device

Core after failure

Figure 2: Tensile adhesion test device (TAT) and experimental setup

Table 3: Tensile adhesion test specifications [14], [15]

Tack coat type	**Minimum average tensile strength (Test temperature = 0 °C)**
Unmodified	1.0 MPa
Polymer-modified	1.5 MPa

3.3 Layer adhesion measuring instrument

Our investigation in 2012 [19] on the on site torque bond test proposed in the prEN12697-48, showed that in view of the precision, combined with variable environmental conditions and the practical difficulty to glue the metallic plates to the surface, this method is not a reliable nor practical method. BRRC proposed therefore in 2014 to add a new test method to the prestandard named “Layer Adhesion Measuring Instrument” (LAMI) which is used since many years in Quebec for testing tensile bond strength on site as well as in laboratory.

The LAMI is a portable hydraulic tensile testing device, developed by the Ministère des transports du Québec (MTQ), which determines the tensile bond strength between a surface layer and the bottom layer, perpendicular to the plane of the road surface (Figure 3). The tensile test with LAMI is carried out on site according to the prestandard but it can also be used in laboratory to evaluate the tensile bond strength at 20 °C. The principle is simple, a 100 mm diameter groove is cut through the upper layer down into the bottom layer, and to a depth between 5-20 mm below the interface to be tested (Figure 3). An adhesive-free gripper system is applied to the incised surface of the top layer and is pulled off at constant load rate (240 ± 40) N/s with a LAMI, until the specimens fails or when the LAMI reaches its limit (Figure 4).

The temperature dependence of the tensile bond strength will influence the test result. According to the Quebec standard test method [20], a correction factor that takes into account the test temperature has to be applied in case of on site testing. For tests performed on site the tensile bond strength obtained at test temperature shall be corrected to 20 °C. The field of applicability of this correction factor ranges between 10 ° C and 25 ° C. According to prEN 12697-48, six tests are performed. According to the Quebec requirements [21], for a segment to be considered as adequately bonded, the average of the three results in a wheel track and that of the three results outside the wheel tracks must be equal to, or greater than, 0.20 MPa at 20 °C if the tested interface is situated 40 mm or deeper below the surface, and equal to, or greater than, 0.30 MPa at 20 °C if the tested interface is situated less than 40 mm below the surface. In addition, only one result in three may be lower than the former or the latter of these values. The fate of a segment can, therefore, be sealed after only three tests, if the first two results in a wheel track or outside the wheel tracks are individually lower than the former or the latter of the values mentioned above. In this paper only four replicates were used to determine the tensile bond strength with a LAMI.

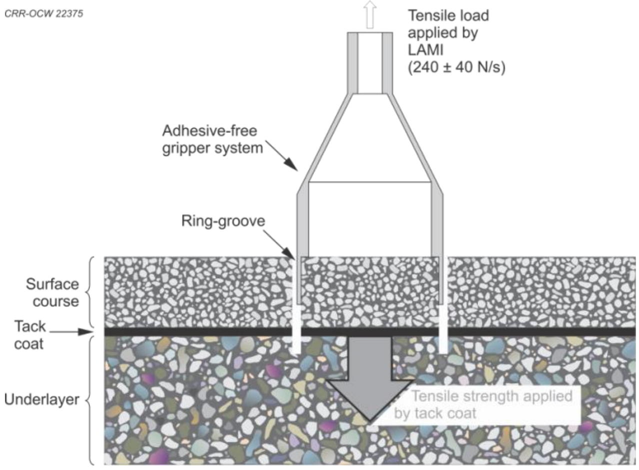

Figure 3: Principle of the layer adhesion measuring instrument (LAMI)

Adhesive-free gripper system — LAMI on site — No failure — After failure

Figure 4: Experimental setup of LAMI

For the two last above-mentioned interlayer bonding tests (TAT, LAMI), if the specimens fail, they are visually inspected to determine what mode of failure has occurred according to the classification depicted in Table 4 and illustrated in Figure 5. In this study, this kind of table 4 was also used for the visual assessment of the core tested with the shear bond test (SBT).

Table 4: Failure modes for TAT and LAMI according to prEN 12697-48

Classification	Visual assessment	Mode of failure
A	Within the surface layer	Cohesion
B	Partly at the interface, partly in the surface layer	Mixed
C	At the interface	Adhesion
D	Partly in the bottom layer, partly at the interface	Mixed
E	In the bottom layer	Cohesion
F*	In the adhesive between plunger and specimen	/

** Only for tensile adhesion test (TAT)*

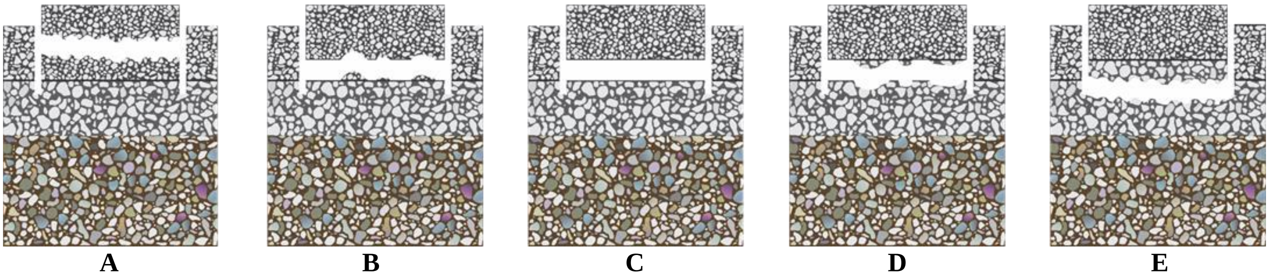

Figure 5: Illustration of the failure modes A to E for TAT and LAMI

4. EXPERIMENTAL SETUP

4.1 Test site for SBT and TAT

The test site was constructed in the summer season of 2014 on the regional road N975 at Hymiée in Belgium, consisting of four test sections (Figure 6, Table 5). The pavement of these four test sections was tri-layered:

- A 50 mm thick surface course in stone mastic asphalt (SMA-14);
- A 60 mm thick binder course in smooth-textured asphalt concrete (AC-20);
- A fine-textured milled underlayer cleaned with a high pressure washing equipment.

In Belgium cationic bituminous emulsions are used as tack coats [22]. In this study four types of emulsion were chosen (from two suppliers, named “a” and “b” for reasons of confidentiality):

- Unmodified: C60B3-a; C60B3-b
- Polymer-modified: C60BP6-a
- Unmodified “Anti-adhesive-AA”: C60B3(AA)-a; C60B3(AA)-b
- Polymer-modified “anti-adhesive”: C60BP3(AA)-a

“Anti-adhesive “emulsions (unmodified or polymer-modified) prepared with harder bitumens made their appearance in Belgium in the first decade of this century [23]. In comparison with the emulsions prepared with softer binders (unmodified or polymer-modified), they have the advantage of breaking very rapidly and sticking better to the underlayer than to the tyres of work site vehicles. Hence, they are used with the aim of preventing damage to the tack-coat by work site vehicles. These above mentioned four types of tack coats were applied to the milled underlayer and AC-20 binder course of the four test sections at a same target residual binder rate of 200 g/m² prior to the HMA overlay construction (AC-20, SMA-14). Close attention was paid to the tack coat application so that the measured tack coat application rate (according to [24]) was within a reasonable range of the target rate. In general, they were relatively close to 200 g/m²; but in some cases (section 3 for the two interfaces and section 4 for the second interface) the deviation from target was clearly large. The curing time (one night) was the same for the four types of tack coat.

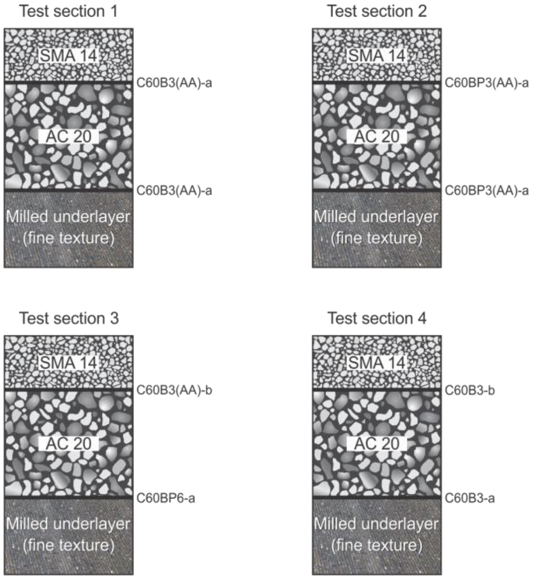

Figure 6: Broad outline of the construction layout of the four test sections

Table 5: Experimental conditions of the interfaces for the four test sections

Test section	Tested interface	MTD* of the underlayer (mm)	Tack coat type	Measured residual binder (g/m²)	Target residual binder
1	Between SMA-14 and AC-20 binder course *(First interface)*	0.48	C60B3(AA)-a	217	200 g/m²
2		0.50	C60BP3(AA)-a	208	
3		0.31	C60B3(AA)-b	253	
4		0.28	C60B3-a	184	
1	Between AC-20 and milled underlayer *(Second interface)*	1.69	C60B3(AA)-a	171	
2		1.71	C60BP3(AA)-a	206	
3		1.72	C60BP6-a	118	
4		1.73	C60B3-a	154	

* MTD = Mean texture depth measured according to [25]

4.2 Test site for LAMI

A 12 years old pavement constructed in 2003 next to the BRRC laboratories in Sterrebeek in Belgium was used to gain practical experience with the LAMI and to estimate the accuracy of the test. The site was arbitrarily divided in four test zones taken in the longitudinal direction of the road with four samples in each zone [26]. There are no data available on the type of tack coat and the application rate.

The existing pavement was tri-layered:

- A 40 mm thick surface course in asphalt concrete (AC-10);
- A 50 mm binder course in asphalt concrete (AC-14);
- A crushed stone base.

The LAMI was used to determine the tensile bond strength between the surface course and binder course of the four test zones. Before its use, the main steps on these four sections were the following:

- A 100 mm diameter groove was cored to a depth between 40-45 mm;
- The debris (in majority mud and water) was removed from the cut line formed by the coring;
- The surface to be tested was cleaned and dried overnight.

5. RESULTS AND DISCUSSION

To obtain repeatable results that are representative of the laying conditions implemented in the four test sections (test site for SBT and TAT), the core samples required for the interlayer adhesion tests were taken in two pre-selected zones for each test section. The choice of the coring zones was dictated by the need for homogeneity in conditions relating to the spreading of the tack coat, the texture of the underlying layer …For each pre-selected zones, located between 50 and 100 m from each other, three cores were taken spaced 10 cm apart.

When comparing the two series (three cores per series) for each test section, there is no significant difference in the mean shear and tensile strengths between the two series. So we can consider the two series as a single set and use the average shear and tensile strengths based on six cores (See Chapters 5.1 and 5.2).

The adhesive strength is normally calculated as the average of six cores for SBT and TAT, and as the average of four cores for LAMI. An analysis of variance (ANOVA) was performed using Microsoft Excel statistical analysis. The ANOVA was conducted with level of significance, α of 0.05, in order to analyse and compare the maximum average shear or tensile bond strength. For the sake of simplicity and concision this paper will not present the ANOVA analysis results of the interlayer bonding tests but they have been taken into account in our interpretations and our conclusions.

5.1 Shear bond test results

The investigation was based on six cores for each test section and tested interface. With the "guillotine" procedure of SBT, it is possible to test both interfaces on a same core. The shear bond test results are given in Table 6 which lists the minimum (Min.) and the maximum (Max.) shear bond strength, the mean value of the shear bond strength, the standard deviation (Stdev.) and the coefficient of variation (CV) for each test section.

Table 6: Results of shear bond tests on the two interfaces of the four test sections

Test section	Tested interface	Tack coat	Rate* (g/m^2)	Shear bond strength				
				Min.	Max.	Mean**	Stdev.	CV
				(in MPa)				
1	Between SMA-14 and AC-20 binder course *(First interface)*	C60B3(AA)-a	217	1.50	1.77	1.58	0.11	7 %
2		C60BP3(AA)-a	208	1.49	1.66	1.59	0.07	4 %
3		C60B3(AA)-b	253	1.42	1.94	1.71	0.23	13 %
4		C60B3-a	184	1.31	1.56	1.46	0.09	6 %
1	Between AC-20 and milled underlayer *(Second interface)*	C60B3(AA)-a	171	2.00	2.32	2.18	0.11	5 %
2		C60BP3(AA)-a	206	1.81	2.25	2.07	0.17	8 %
3		C60BP6-a	118	1.74	2.15	2.00	0.18	9 %
4		C60B3-a	154	1.73	2.20	1.92	0.17	9 %

* Expressed in measured residual binder
** According to prEN12697-48, the shear bond strength of the interface in (MPa) is expressed to the nearest 0.01 MPa

The analysis of the shear bond test results in Table 6 leads to the following findings:

- Whatever the type of tack coat used (unmodified, polymer-modified, anti-adhesive or not) and their respective measured residual binder content, the nature (new, milled) and the macrotexture (smooth, fine milled) of the two underlayers analysed :

  - The mean shear bond strength values reach comfortably and even exceed the stricter average German recommendations specified in Table 2 (1.41 MPa for the first interface; 1.13 MPa for the second interface). These results also illustrate clearly the consequences on performance of a proper installation on site e.g. when the tack coats cover evenly the surface, when the underlayers are clean, dry and not too coarse textured…
  - The mean shear bond strength values for the second interface are statistically higher in comparison with the first interface. The interlocking of the two asphalt layers is probably better in case of a milled surface, resulting in higher mean shear strength values.
  - The failure occurs for all the tested cores at the interface; the latter seems therefore the limiting factor in the interlayer adhesion.
  - The variability of the test results is relatively good, the coefficients of variation for six replicates are in general lower than 10 %.

- From the comparative investigation on the two tested interfaces, it can be concluded that:

  - For the first interface, in general no significant statistical difference in mean shear strength is recorded between the three “anti-adhesive” tack coats (polymer-modified or not). We note nevertheless that the tack coat with the softer bitumen (C60B3-a) gives a slightly lower average shear strength value, but this could also be explained by the lower application rate. Regardless the type of tack coat, the first interface seems also more sensitive to variations in tack coat rate, in comparison with the second interface. The impact is small, but there is a trend for average shear strength to increase with application rate.
  - For the second interface, in general no significant statistical difference in mean shear strength is recorded between the three tack coats with lower penetration bitumen (polymer-modified or not). We note nevertheless that the tack coat with the softer bitumen (C60B3-a) gives the lower average shear strength value; the difference is negligible compared to standard deviation, except for the unmodified harder bitumen (C60B3 50/70-a).

5.2 Tensile adhesion test results

The investigation was in general based on six cores for each test section and tested interface. With the procedure of TAT, it is only possible to test one interface per core. The tensile adhesion tests results are given in Table 7.

Whatever the type of tack coat used (unmodified, polymer-modified, anti-adhesive or not) and their respective measured residual binder content, the nature (new, milled) and the macrotexture (smooth, fine) of the two underlayers analysed, the analysis of the tensile adhesion bond test results in Table 7 leads to the following findings:

- The failure modes are mostly a cohesion break or a mixed break. These observations indicate the difficulty to interpret correctly the tensile adhesion test in terms of interlayer bonding performance, since the core does not necessarily fail at the interface. In fact, debonding happens at the weakest point which is in this field study one of the two constitutive pavement layers of the studied core. This means also that the interlayer tensile bond strength values are higher than the measured values.

- The mean tensile bond strength values reach comfortably and even exceed the average Austrian specifications specified in Table 3 (1.00 MPa for unmodified tack coat; 1.50 MPa for polymer-modified tack coat). Despite the fact that the different existing modes of failure of the tensile test results do not allow to distinguish the real performances of the four types of tack coat, they all perform very well.
- The variability of the tensile adhesion test results is relatively good for the first interface (CV = 5 %, except for the section 4 with a CV of 10%) and is slightly less good for the second interface (CV > 10 %).
- The mean tensile bond strength values are not different for the different sections. This does not allow to conclude that the different tack coats perform equally well, since the failure mode was mostly cohesion break.
- The mean tensile bond strength is higher at the first interface than at the second. This is different than in the shear bond test. A possible explanation is that the mechanical interlocking with a milled surface plays a greater role in shear than in tension.

Table 7: Results of tensile adhesion tests on the two interfaces of the four test sections

Test section	**Tested interface**	**Tack coat**	**Rate* (g/m^2)**	**Tensile bond strength**				
				Min.	**Max.**	**Mean****	**Stdev.**	**CV**
				(in MPa)				
1	Between SMA-14 and AC-20 underlayer *(First interface)*	C60B3(AA)-a	217	1.9	2.1	2.0	0.1	5 %
2		C60BP3(AA)-a	208	1.7	2.0	1.9	0.1	5 %
3		C60B3(AA)-b	253	2.0	2.2	2.1	0.1	5 %
4		C60B3-a	184	1.7	2.3	2.0	0.2	10 %
1	Between AC-20 and milled underlayer *(Second interface)*	C60B3(AA)-a	171	1.4	1.8	1.7	0.2	12 %
2		C60BP3(AA)-a	206	1.4	1.8	1.6	0.2	13 %
3		C60BP6-a	118	1.4	1.8	1.7	0.2	12 %
4		C60B3-a	154	1.6	2.0	1.8	0.2	11 %

* Expressed in measured residual binder

** According to prEN12697-48, the tensile bond strength of the interface in (MPa) is expressed to the nearest 0.1 MPa

5.3 Layer adhesion measuring instrument results

The investigation was based on four tests for each test zone. The distance between the four test locations was approximately 2 meter. The Table 8 lists the tensile test results with LAMI for the four test zones (individually and together) and shows that all the on site bond strength values (corrected to 20°C) obtained largely exceed the current Quebec requirement of 0.20 MPa [21].

Despite the great care taken in the preparation of the test zones in order to use the LAMI, there is actually a large dispersion in measurements results. This dispersion is most probably related to the heterogeneity of this 12 years old site. The heterogeneity is also seen in the fact that the four test zones are not comparable in terms of failure mode. We observed in general a cohesive failure in the surface layer or in the underlayer or a mixed failure in the two constitutive layers. This means that the tensile bond strength at the interface is higher than the values reported in Table 8.

Table 8: Tensile test results with LAMI for the four test zones

Test zone	**On site tensile bond strength (corrected to 20 °C according to [20])**				
	Min.	**Max.**	**Mean**	**Stdev.**	**CV**
	(in MPa)				
1	0.40	0.85	0.65	0.19	28%
2	0.68	1.08	0.89	0.17	20%
3	1.14	1.38	1.22	0.11	9%
4	0.77	1.09	0.94	0.16	17%
1 to 4	0.40	1.38	0.92	0.25	27%

5.4 Comparison of on site test methods of the prEN12697-48

Unlike the SBT and TAT, the LAMI is not intended as a laboratory test but as a test for on site measurements. Hence, it is expected that the precision is probably lower. As an on site test, the LAMI should be compared to the TBT described in prEN 12697-48. Although this paper contains no TBT test results, we can compare the two tests on the basis of our practical experience with the test execution:

- The LAMI is a well-defined automated test method which uses an adhesive-free gripper system. It is more practical and faster than the TBT, which requires an adhesive to glue the metal plate to the surface of the core (a both manual and time-consuming action, [19]);
- The LAMI has the advantage that if the bond strength is sufficient (no failure up to a maximum force), the test can be done with limited damage to the pavement layers (only the circular groove formed by the coring remains).
- A correction factor exists for the LAMI that takes into account the field test temperature (see Chapter 3.3).

However, from a practical point of view, there are also some drawbacks which cannot be ignored:

- The test procedure of LAMI is still rather time consuming, especially for the coring process and the subsequent cleaning of the cut groove;
- Some care should be taken with the adhesive-free gripper system, it should be fixed strongly and correctly to avoid slippage on the walls of the specimen;
- In case of failure, the different types of holes obtained will maybe necessitate more difficult and expensive subsequent repairs in comparison with the reparation of a “conventional coring” performed on a greater thickness.

6. CONCLUSIONS

The construction work was carried out, in the four test sections on the regional road N975 at Hymiée in Belgium, with weather and site conditions (tack coat type and application rate, nature and roughness of the underlayers…) that were favourable. On the basis of the test results obtained from testing of field specimens from the regional road N975 at Hymiée, the following conclusions are drawn:

- **Shear Bond Test (SBT)** is a good laboratory method to investigate the interlayer bond strength between the different pavement layers. All the field conditions lead to mean shear bond strengths that reached comfortably and even exceed the stricter average German recommendations (1.41 MPa for the bond between surface and binder course and 1.13 MPa for the bond between all other layers); with an acceptable variability described by a coefficient of variation in general lower than 10 %, calculated from six replicates.

- **Tensile Adhesion Test (TAT)** is a laboratory test to assess the capability of tack coats or the internal cohesion of the two involved pavement layers (depending on which zone fails first) but the preparation of the specimens is more difficult and takes much more time than in the shear bond test. The most important limitation of the TAT is that, if the interlayer bond resistance is higher than the in-layer tensile resistance of the two involved core’s layers, the test result is lower than the actual interlayer bond strength. All the mean tensile bond strength values reach comfortably and even exceed the average Austrian specifications (at 0 °C: 1.5 MPa and 1.0 MPa respectively for modified-polymer and unmodified tack coats). It seems to turn out that the surface conditions of the underlayer have an influence on the repeatability of the tensile adhesion test; the coefficients of variation ranging between 5 % and 13 %, calculated in general from six replicates.

- **Adhesion performance of multilayer pavements.** Many parameters may influence adhesion in a significant way (e.g. tack coat type and application rate, nature and preparation of the underlayer…). Even if it could not be demonstrated in this case that a specific type of emulsion was more favorable for a more efficient bonding between the studied pavement layers, the various tack coats used on the N975 seem to work very well if they are applied at a sufficient rate, resulting in a thin and uniform coating covering the entire pavement surface. Proper functioning spraying equipment is therefore clearly recommended and is a prerequisite for ensuring the uniformly spraying of the required application rate.

- **Recommendation limits.** As these test sections were carried out under good conditions, the mean shear strength of the interface measured using the shear bond test used at BRRC should be not less than 1.3 MPa for new surface/new binder course interface and not less than 1.1 MPa for new binder/base course interface. At this stage of the study, it is too early to give recommendations for mean tensile strength limits using the tensile adhesion test.

The **Layer Adhesion Measuring Instrument (LAMI)** was used to evaluate the bond strength directly on site on a 12 years old private test site next to the laboratories of BRRC and the following conclusions can be drawn from our investigation:

- All the on site obtained bond strength values (corrected to 20°C) greatly exceed the current Quebec requirement of 0.20 MPa but with a large dispersion in measurements results which is most probably related to the heterogeneity of the 12 years old test site (CV ranging from 9 % to 28 %, calculated from four tests). As for the TAT, failure occurs not necessarily at the interface because the debonding happens at the weakest point that can be within the pavement layers.

- Unlike the on site torque bond test described in the prEN12697-48, the LAMI seems a relatively simple, fast, and well-defined automated test method which uses an adhesive-free gripper system. This test can also be done with limited damage to the pavement layers if the bond is sufficient but from a practical point of view, its main disadvantage is the time consuming coring process and the subsequent cleaning of the cut groove.

At this stage of the study, it is too early to give recommendations for the use of the LAMI or to draw conclusions regarding the accuracy. More field studies are needed to evaluate correctly this on site tensile test.

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