Asphalt mixture performance and testing

Bonding of bituminous layers: a new tool for qualifying in situ

DONY Anne[1], GODARD Eric[2], MILLIEN Anne[3], OLLIER Stéphane[4], KOUTIRI Imade[5], POUTEAU Bertrand[6]
[1]Université Paris Est, IRC, ESTP, Cachan, France, [2]CST, COLAS, Magny Les Hameaux, France, [3]Université de Limoges, Egletons, GC2D, France, [4]PERENNISE CHAUSSEES, Bourg-Lastic, France, [5]Arts et Métiers ParisTech, PIMM UMR CNRS 8006, Paris, France, [6] CRM, EUROVIA, Mérignac, France

Abstract

The infrastructure maintenance represents an important socio-economic issue. Its effective planning goes through the knowledge of the behavioural evolution of pavement over time and its residual life, requiring the development of relevant experimental and modelling tools (DVDC: collaborative French national research project on Roadways lifespan, introduced in 2016). So one of the essential characteristics to optimise the durability is the quality of bonding between roads layers. A draft European project 12697-48:2014 provides seven different methods with different loadings (Torque Bond Test, Shear Bond Test, and Tensile Adhesion Test, monotonic or cyclic), temperatures, loading rate but no one can be used on construction site. Within the framework of the DVDC national project and in cooperation with the French road trade association, a consortium of academic and industrial partners leads the development of a reliable tool, usable in situ and in laboratory. The objective is the proposal of a performance test (including setup and method description) that is applicable on construction site. The various technical constraints and requirements were identified leading to a first prototype (torque control with a controlled climb speed and an estimated trial limit). In addition to the technical aspects of the test, several specific points were identified such as the control of the initial core drilling (mainly not to embrittle the material in place), the gripping of the core, the need to control the test temperature, the ergonomic design, precision and quickness execution on site, the ease of transport …. A program test on asphalts complexes produced in lab (three types of emulsion, temperatures, loading rate) allowed validating the interest of the experimental set-up, to define the most relevant parameters but also to identify the ways of improvement. The first tests on construction site give interesting results and have completed the different analyses in situ.

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1. INTRODUCTION

The maintenance of road network requires a good knowledge of the state of infrastructure to optimize scenarios and maintenance techniques. One of the difficulties of the manager is the knowledge of the residual life of the structure, which would allow to prioritize interventions by planning the right technique at the right time; that's the aim of the French national DVDC project, since 2015, with the major actors of the road sector. In this context it was essential at first to identify the mechanisms of pavement deterioration (working group WG 1). The two criteria limiting the current French pavement design are based on the modulus level and the good fatigue behaviour of the materials [1] (Alize-LCPC software) with an qualitative hypothesis for the interlayers (an presumed bonded, half-bonded or unbonded layers). The bonding quality of the road layers should also be a factor of degradation and should be taken into account. How to evaluate this tack coat? A European draft standard proposes seven different tests; most of them are carried out in the laboratory and none can be reliably achieved in situ. The exchanges within the WG1confirmed the interest of this evaluation in the field.

The work presented in this paper aims to propose a new tool for in situ evaluation of this tack coat.

2. OVERVIEW OF LITTERATURE AND OBJECTIVE

2.1. Large selection of tests in American studies and in a European pre-normative document

Lot of research studies have already been done on the evaluation of bonding layers, both in Europe and internationally, with synthesis of documents. Several tools are proposed with different common methods of load application (tension, shear, and torsion, with a destructive or non-destructive test, cyclic or monotonic load). In the United states, the purpose of NCHRP Report of 2012 [2] was to give recommendation for tack coat applications with an experimental program but also a synthesis of twenty listed methods with five usable in laboratory or in situ and three limited in situ. Since then other States intended to control the tack coat by a test in the future [3]. The most popular test is the shear test conducted at 25°C, proposed in the forecast standard AASHTO TP 114-17 and can be performed on laboratory or in situ samples. According to Johnson [3] it is repeatable, fast and using materials available in the laboratories. However some States prefer to use a tension test with internal norms (Kansas with KT-78, Texas with Tex-243-f, Virginia with VTM-128). It should be noted, however, that no consensus can be reached on specifications: different threshold values between shear test and tension test, but also for a same type of test.

At the same time, the draft European standard EN 12697-48 (begun in 2011) [4] proposed seven different methods for testing the interface quality of pavements, based on previous studies from different European laboratories. The testing conditions are variable: three loading modes (torsion, shear, traction) different temperatures, speeds and core diameters. An evaluation of the three principal methods (Torque Bond Test – TBT; Shear Bond Test – SBT; tensile Adhesion Test - TAT) were applied at the laboratory level to compare these different approaches [5], [6]. The first result was a certain inaccuracy on the methods without data on the precision of the measurements. According to this study, the temperature is the most important parameter affecting the measurements compared to other parameters such as the emulsion type and rate, the void contents of the two asphalts, the loading speed.

In this study, the TBT was first tested with the requested manual equipment (application of a rotational speed of 90° in 30 s (+-15s)) but despite its use in lab, this device was found difficult to control (Figure 1). The other TBT were carried with a controlled press with another existing device [7] (Figure 2).

Several studies have been published on the analysis of this draft European standard. So Alexandra Destrée and al. [8] confirmed this difficulty with the standard TBT; she proposed to evaluate a new test method in situ, named “Layer Adhesion Measuring Instrument” (LAMI) used since many years in Quebec for testing tensile bond strength on site as well as in laboratory (Figure 3). On job site the test must be conducted for temperatures between 10 and 25°C; temperature variation on job site is managed by applying a correction on maximum fracture stress proposed by the MTQ. The conclusions of Destrée are encouraging but highlight precautions to be taken, including a significant number of field tests before proposing limit specifications. Recently Somé and al. [9] has also conducted a laboratory comparative study on different methods (Shear Bond Test with two modalities and tensile adhesion test) by varying sample diameters, types and rates of emulsion: they confirmed the different results depending on the methods. Finally, considering the great variety of devices and methods, Petit and al. [10] gave recommendations for the principal standard methods with advantages and disadvantages according the pavement interface fracture debonding modes (tension mode (I) and shear mode (II)).

Figure 1. Manual torque meter usable on site

Figure 2. Mechanical torsion device on a controlled press in lab [7]

Figure 3. LAMI – Quebec traction device [11]

Among the latest developed tests, the OFTT (Oregon Field Torque Tester) presented by Coleri [12] is a torsion test with mechanized and non-manual driving (figure 6).

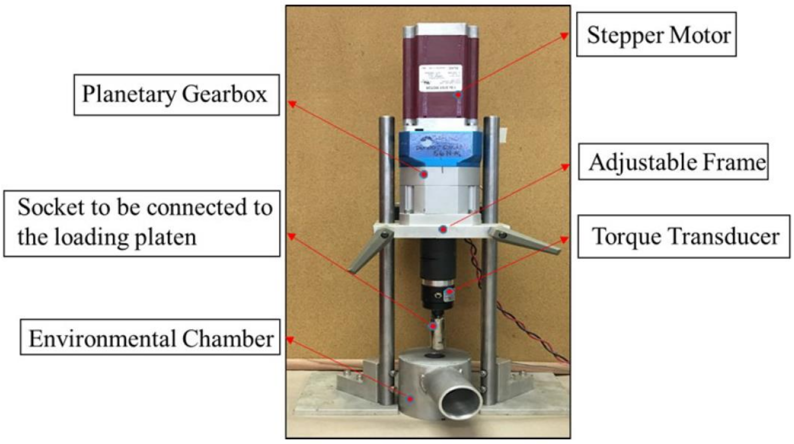


Figure 4. OFTT device with an environmental chamber [12]

The cores diameters are fixed (2,5 inch or 63,5 mm). The test is conducted by a control of loading and rotational speed to apply a torque. In order to overcome the temperature problems, a control box is located near the test area to regulate the required temperature. After coring at one inch below the interface, drying the sample and gluing the platen to the core sample (with about 1 hour for curing), a portable heat gun is used to regulate the temperature at 25°C. Then the peak torque stress (strength) at the interface is measured. The results of in situ tests were compared to laboratory shear tests conducted with a controlled press with optimal conditions. The shear strength values range between 40 to 80 psi, (0.28 to 0,48 MPa). The authors showed a good correlation with tests carrying in a same section (figure 5) and concluded that the Oregon Field Torque Tester (OFTT) is a practical, low cost, less destructive field test device.

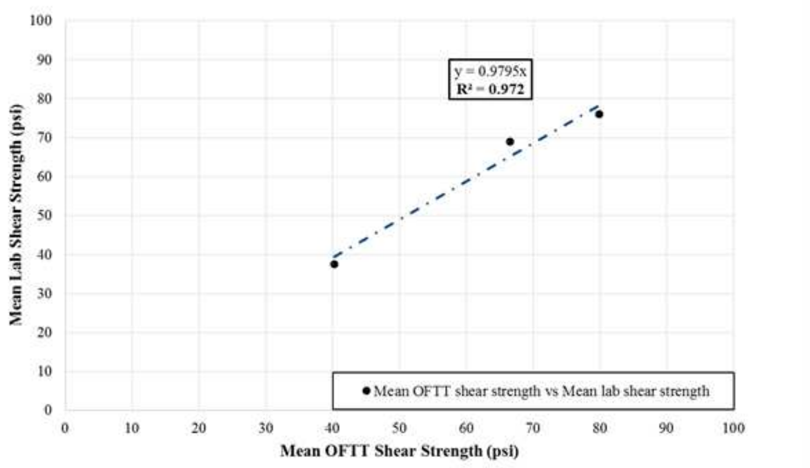


Figure 5. Correlation between average OFTT shear strength (psi) vs. average laboratory shear strength (psi) [12]

2.2. Technical position and drafting specifications of the study

The interlayer bonding condition has significant effect on the performance of a pavement structure and the no-bonding is one of the causes of pavement degradation. In the French pavement design method, the hypothesis for bonding are qualitative and not quantitative [1].
The objective of this study, part of a larger project (DVDC PN), is to refine this hypothesis, with the development on a new, easy to use, and reliable, in situ test.
Currently in France, no test is used in situ except coring, visual control and sometimes the "screwdriver test". A relevant test should then be proposed taking into account previous work and experience and not defining a new test.
According literature, the main component of the stresses generated by the solicitations (traffic and climatic cycles) on the interface is shear, under vertical compression stress [10]. Different options could be considered to produce shear stresses at an interface:

- Shear mode with a shear bond tests (Leutner for example) or torque bond test
- Mixed mode with combination of shear stress and normal stress (tensile, compression, torsion or shear stress)

The torque test, alone or with combination, is the only feasible in situ. For this first approach, we have chosen the option "single torque test". But the TBT, proposed in the draft European standard [4], is manual and uncontrollable in the state [5], [10].
Our aim is to provide a reliable, ergonomic, relatively low-cost equipment which allows a quick and in situ test, namely:

- the test is carried out with controlled stresses and quantified conditions to qualify the bonding layer.
- the equipment moves easily on site to carry out spot measurements on a previously cored area.
- the test requires a reasonable time for a road site.

The work was divided into different steps:

- reception of a first prototype developed by one of the partners
- calibration of test parameters in a controlled environment (laboratory)
- first field experiments

A specific study was carried on the temperature control.

3. PROTOTYPE PRESENTATION

3.1. Principle

The new tool has been developed to realize torsion tests in laboratory and on site by referring the operating of other tools and taking into account the feedback from past experiences.
After an initial pre-coring in the asphalt structure (2 cm below the interlayer), a gripper system is installed and tightened before the interface and a displacement sensor is positioned in contact with the apparatus. This solution should enable a quick installation of the device without gluing platen. A pre-load is applied to avoid the slip between gripper system and asphalt.

A torque of 500N.m is applied in an optimized fixed time to obtain a homogenous result. The value of 500 N.m was chosen arbitrary in the early design of the first version of the prototype.

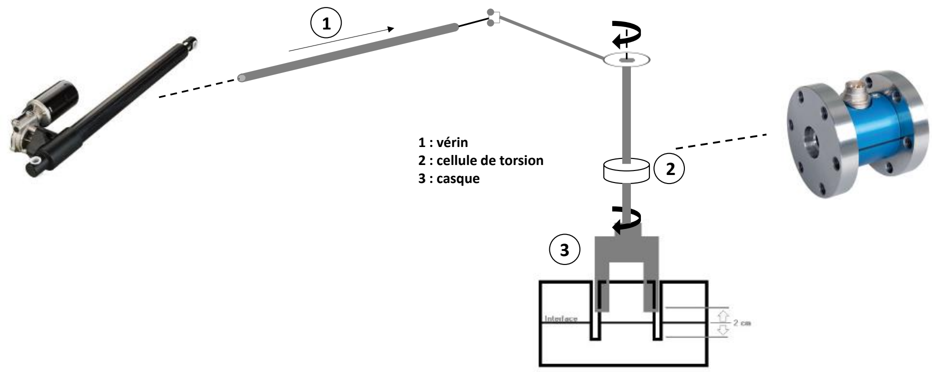


Figure 6: Schematic layout

3.2. Apparatus

The device, placed on a mobile platform equipped with 4 wheels, can be moved and used easily on a pavement with a total autonomy thanks to a battery power supply (Figure 7). The wheels are locked during the test to ensure that the apparatus doesn't move. Fixing it to the surface is also note required.

An electromechanical actuator provides the speed and displacement during the test. For the first test, the device has a torsion cell of 500Nm (maximum capacity).
A gripping device is adjusted in the pre-coring Ø150 mm and tightened to ensure a good gripping of the sample. Some slippage could be observed and so a sandpaper is bonded inside the device to have a better adhesion with asphalt's core. An optical sensor, positioned on the asphalt, enable to determine the angle of rotation of the gripping device during the test and so to check the possible slippage.

An software interface allows to perform the test with automatic data acquisition by software (torsion moment and rotational displacement).

The torsion strength at failure τ_{TBT} (MPa) is determined with the following formula:

$$\tau_{TBT} = \frac{16 * M * 10^{-6}}{\pi * D^3} \qquad (1)$$

With: M the torsion Moment (N.m) and D the diameter of core (mm)

Figure 7. Installation of the equipment and gripping device for cores

General view in lab (a) and in site (a') ; (b) zoom of the gripping device

(c) monitoring of temperature and rotation ; (d) test on site

3.3. Monitoring of temperatures

The temperature has been identified by previous work as a major impacting parameter. Several factors are identified as influencing the temperature of the interface:

- Ambient outdoor temperature, considering that the tests are carried out in situ with fluctuating outside temperatures

- Wet pre-coring of the sample

Finally, the measurement to evaluate the temperature at the interface is delicate. A controlled temperature chamber wasn't used because of the non-compatible delay for requirement a homogeneous and controlled temperature on site.

In the first version, the torsion tool isn't equipped with an automatic measurement of temperature. For the first laboratory tests, different devices were tested (classic as PT100 and infrared temperature sensor). Finally, a double input thermometer with continuous recording of values was adopted which could be directly integrated into the torsion tool with an acquisition on the data acquisition software.

Additional tests were carried out on two sites in different configurations to assess the suitability of temperature measurements and propose an adapted procedure:

- Old national road RN 89 at Ussel (Massif Central in France) in April 2019 (ambient temperatures ranging from 3 to 9°C, similar to the previous days- Source Météo France)

- The pavement fatigue carrousel of Ifsttar on Nantes site in May 2019 (Pays de Loire- France) (ambient temperatures between 9 and 24°C with 11 hours of sunshine and no rain- Source Météo France)

Figure 8. Monitoring of temperatures in lab and on sites

Temperatures monitoring was conducted in these various weather conditions (in lab and outdoor) with temperature measurements of ambient air, pavement surface, in drilled holes near the cores at different depths and in the pre-coring of the sample before torsion testing.

The first analysis of the results still in progress already provides to draw initial conclusions:

- A simple outdoor temperature reading doesn't enable to predict the temperature at the interface of the layers (influence of wind, solar radiation, the thermal history of the pavement, etc.); it seems essential to perform a measurement at the depth of the interface.

- The temperature is homogeneous at a same depth in the pavement (6 areas tested at -6 cm on the fatigue carrousel ring) and its small daily variation is associated with a greater thickness of pavement layer. The realization of a hole (with a good isolation) at the depth of the interface with a reference temperature sensor would allow a monitoring of the temperature evolution over time.

4. EXPERIMENTAL QUALFICATION IN LABORATORY

4.1. Materiels

The pavement structure consists of two asphalt layers of dimensions (L x l x h) 600x400x60 mm and bonded with an bitumen emulsion (Figure 9). The mix designs are identic to those tested in a previous study in 2015 [5] with microdiorite aggregates and a same pure bitumen:

- Upper layer: BBSG 0/10 class 3 with 8% void content
- Lower layer: GB 0/14 class 3 with 10% void content
- Three emulsions with rapid setting and different bitumen (A, B, C) with a same residual rate (300g/m^2).

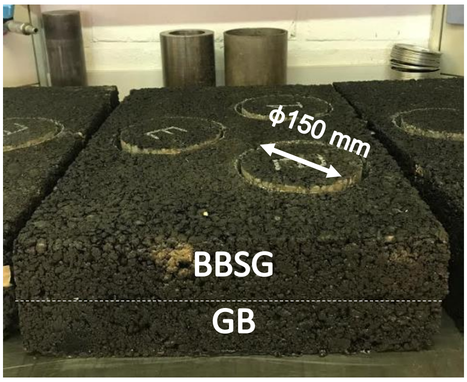


Figure 9. Specimen plate with pre-coring

Three samples are pre-cored by specimen plate up to – 2 cm under the interlayer.

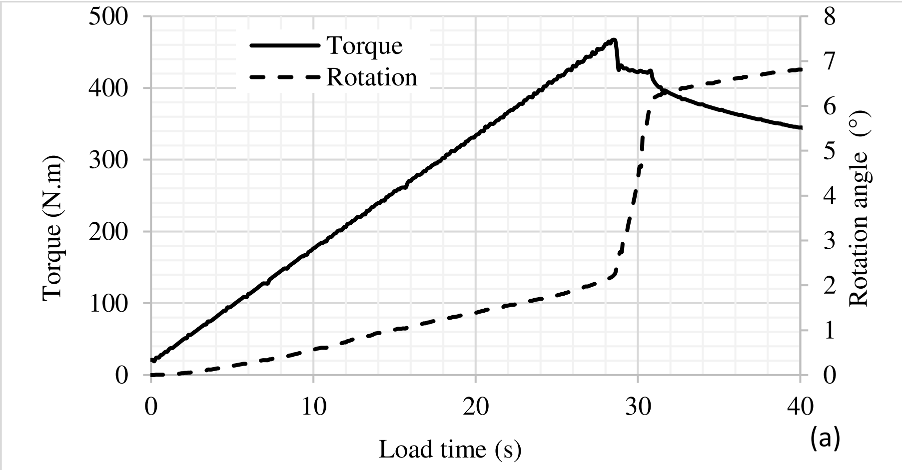
4.2. Varying test parameters

The torsion test was conducted without or with pre-load and with various times of load application (10; 30 or 90s). Three temperatures were tested, namely 10°C, 20°C, 30°C.

4.3 Calibration of the torsion tool

-Control of slippages:

To realize the torsion test quickly on site, no glue was used to fix the sample but a gripping device. The potential slippage between the core and the gripping device was evaluated by the comparison of evolution of torque and the rotation of the core during the test. On the Figure 10, the graph (a) shows a good concordance between the two curves, contrary to the graph (b). A good grip produces a change in the slope of the rotation measurement corresponding to a drop of torque. A bad grip can produce increases in the slope of rotation while the maximum torque is not achieved.



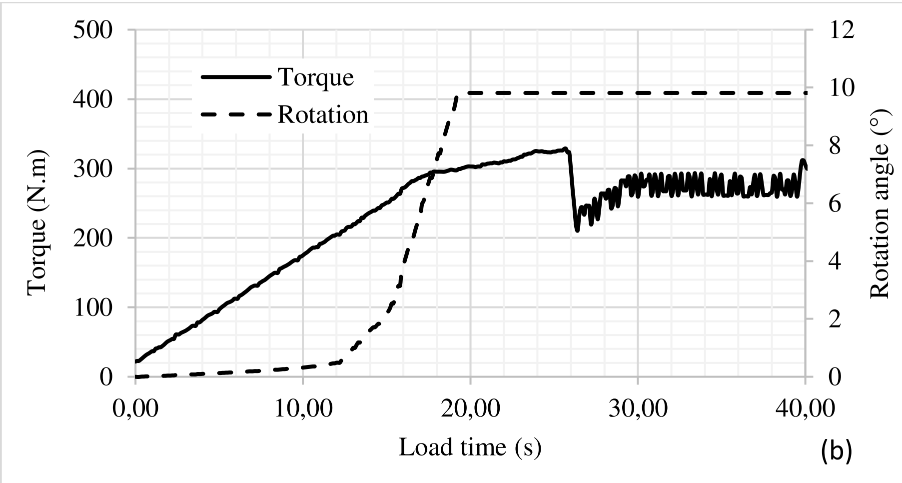


Figure 10. Comparison of torque and rotation evolution during the test (emulsion A- 20°C) - No slippage (a) and slippage (b)

Specific attention is paid on the slippage during all the tests.

-Need of pre- load:

A comparison was conducted on tests without pre-load and with pre-load (20 à 25 N.m). We note some oscillations of the load control during the load application. So the pre-load ensures the stability test, no slippage, and to correct the mechanical alignment.

-Choice of load time

The figure 11 gives the evolution of raw data of torque with the three load time. With 10 s of load application, the torque isn't continuous (a small break on the curve), with 90s of application load, some oscillations are observed perhaps due to viscoelasticity of bituminous material with this long time). Without an optimisation of the value, the time of load application was fixed to 30 s, the best compromise considering the results.

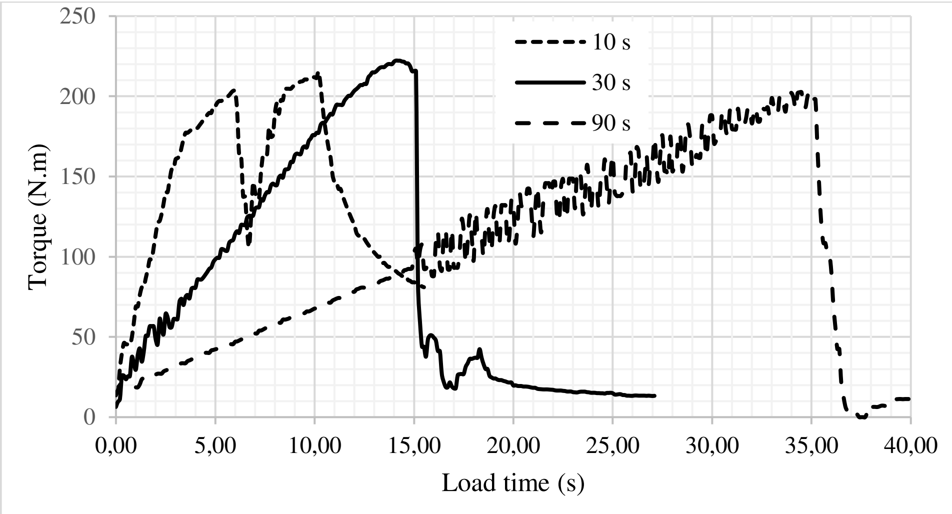


Figure 11. Comparison of torque evolution during the test (30°C) with the three load time (emulsion C)

The continuation of the study will therefore be carried out with a pre-load of 25 kN, an application load of 30 second, with a maximum torque of 500 N.m.

4.4 First results with different emulsions

The first results of tests conducted on samples in laboratory with the fixed conditions at 3 temperatures with the 3 emulsions are given in the Table 1. The emulsion C contained the softer bitumen and the emulsion A and B contained the same grade of bitumen (unmodified and modified).

Table 1. Results of specimens tested at 10°C, 20°c and 30°C with A, B and C emulsions.

Emulsion	T(°C)	Number of samples	Torque (N.m)			Rotation angle (°)			Torsion strength at failure (MPa)		
			Mean	Stdev.	CV	Mean	Stdev.	CV	Mean	Stdev.	CV
A	10	3	Max	-	-	0,89	0,37	-	No fracture	-	-
	20	5	458,1	49,64	11%	1,90	0,22	12%	0,673	0,06	10%
	30	3	206,8	44,57	22%	-	-	-	0,312	0,07	22%
B	10	2	Max	-		1,16		-	No fracture	-	-
	20	6	423,7	54,91	13%	1,96	0,40	20%	0,64	0,08	13%
	30	2	168,0	-		-	-	-	0,254	-	-
C	10	1	Max	-		1,27	-	-	No fracture	-	-
	20	4	381,3	25,24	7%	2,24	0,68	31%	0,575	0,04	7%
	30	1	222,3	-	-	-	-	-	0,335	-	-

Nota: Max is 500N.m, the limit of the possible torque achievable by the version 1 of the prototype.

Concerning the experimental conditions, at 20°C, the failures of samples were clean and always in the interlayer without degradation of specimen. The variability of the test results is relatively good with coefficients of variation for 4-5 replicates lower than 15% for the torsion strength at failure. The torque values applied often are near the limit of the possible torque:

Mean for A = 458,1 N.m mean for B= 423,7 N.m mean for C= 381.3 N.m

This explains why at 10°C, for all specimen, no failure was obtained whatever the type of emulsion.

For the 10°C, we have calculated the rotation angle at the max torque but with failure. We note a small increase of rotation angle between 10°C and 20°C.

The Figures 13 presents a comparison of the evolution of torsion strength according the temperature. The higher the temperature, the lower torsion strength at failure is: the bitumen inside emulsion is softer at high temperature. We noted few differences between emulsions; at 30°C we have only tested one or two specimens. The further tests should be completed these first results.

If we determine an average value between all tests at 20°C and 30°C we find an average torsion strength at failure of 0,53 MPa (range between 0.21 and 0.74 MPa). In comparison with the study of Coleri [12], our results are similar (0.28 to 0.48 MPa)

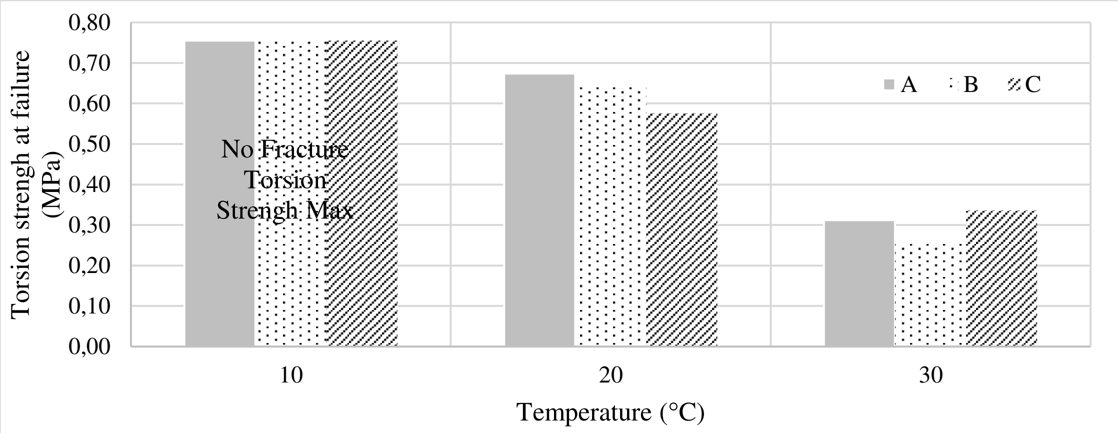


Figure 12. Evolution of torsion strength at failure depending of temperature for 3 emulsions.

5. FIRST ON-SITE VALIDATIONS

5.1 Ergonomics and transportation

The main objective of the first tests performed on sites was to estimate the application on field of this new tool: logistic, ease of implementation, ergonomic aspects, duration of test. To date, three sites were tested.

The results were positive: the equipment can be easily transported (in a standard van), easily set up and manipulated with perfect autonomy (Figure 13).

With a good organisation i.e. a good sequence of tasks, one test lasts no more than 15 minutes. It's important to know preliminarily the thickness of materials to set up the device.

We note some possible improvements on the tool:

- The slippage was confirmed and magnified on site because of the presence of water after coring
- The visibility on computer was reduced outdoor due to the sun.
-

Figure 13. Evaluation of the new tool on sites
(a) transportable in a work van (b) and (c) stand-alone for the test

5.2 First results

After the replacement and validation of the new gripping device, the results on a reference zone (BBSG/BBSG with a tack coat of 350g/m2 of residual bitumen) of the pavement fatigue carrousel (Nantes) seems to confirm those found in lab (one specimen per temperature). We note the same expected influence of temperature on the torsion strength at failure.

Table 2. Results of specimens tested on the pavement fatigue carrousel.

	Test 1	Test 2	Test 3
Interlayer temperature (°C)	21.5	32.5	30.0
Torque at failure (N.m)	489	281	294
Torsion strength at failure (MPa)	0.74	0.42_5	0.44_5
Rotation angle at failure (°)	3.6	2.9	3.9

6. CONCLUSIONS AND PERSPECTIVES

This study is part of the French national project DVDC, more particularly in the understanding of the mechanisms of degradation of the pavement layers. The final objective is to propose a new relevant tool for quantitative and in situ assessment of layer bonding. This paper presents the progress of the mid-term work.
First, we have positioned our approach in relation to other research work in laboratory but also in situ, at European and international level, while recalling the diversity of existing tests.
Our tool is a stand-alone material, equipped with a gripping device, not requiring the application of glue and working in couple.
A first laboratory study on known specimen was carried out by varying the parameters identified as influencing the result (mainly temperature).
The sample diameter has been fixed to allow working on many structures (Φ=150mm).
Preliminary laboratory tests were used to validate the most relevant test conditions (preload, load time) and to identify some modifications to improve the reliability of the tests (without slippage).
A specific work has been carried out to take into account and control a highly influential variable parameter (temperature) and recommendations could be made; it has been confirmed that there is a high dependence on the torsion strength at failure. Limits of uses would be defined. Additional tests are ongoing.
First field trials have completed the study at the logistical level and validated the initial lab tests.
The new tool is thus validated on its principle. The next step will be to improve the tool from the first results and complete the investigations.
A new version is currently being studied with further tests in the laboratory but also on site (especially with semi or unbonded structures). The possible definition of acceptability thresholds or specification seem at the moment difficult: it will however require measurement campaigns on different supports with different age to be relevant and must take account the temperature.

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