Inter-laboratory Shear Evaluation of Reinforced Bituminous Interfaces

Article *in* RILEM Bookseries · October 2015

DOI: 10.1007/978-94-017-7342-3_25

7 authors, including:

Gilda Ferrotti
Università Politecnica delle Marche
53 PUBLICATIONS **1,528** CITATIONS


Maciej Maliszewski
Instytut Badawczy Dróg i Mostów
39 PUBLICATIONS **207** CITATIONS


Manfred N Partl
Partl Road Research Consulting
264 PUBLICATIONS **5,375** CITATIONS


Cesare Sangiorgi
University of Bologna
122 PUBLICATIONS **1,949** CITATIONS

RILEM Bookseries

Francesco Canestrari
Manfred N. Partl *Editors*

8th RILEM International Symposium on Testing and Characterization of Sustainable and Innovative Bituminous Materials

Springer

Editors
Francesco Canestrari
Università Politecnica delle Marche
Ancona
Italy

Manfred N. Partl
Road Engineering/Sealing Components
EMPA—Swiss Federal Laboratories
for Materials Science and Technology
Dübendorf
Switzerland

ISSN 2211-0844 ISSN 2211-0852 (electronic)
RILEM Bookseries
ISBN 978-94-017-7341-6 ISBN 978-94-017-7342-3 (eBook)
DOI 10.1007/978-94-017-7342-3

Library of Congress Control Number: 2015946092

Springer Dordrecht Heidelberg New York London

Printed on acid-free paper

Springer Science+Business Media B.V. Dordrecht is part of Springer Science+Business Media
(www.springer.com)

Inter-laboratory Shear Evaluation of Reinforced Bituminous Interfaces

Gilda Ferrotti, Antonio D'Andrea, Maciej Maliszewski, Manfred N. Partl, Christiane Raab, Cesare Sangiorgi and Francesco Canestrari

Abstract Over the last decades, the use of grids between asphalt layers has been gaining interest. Several test methods have been proposed in order to simulate the complex mechanical behavior of reinforced pavements and to assist practitioners in the selection of the appropriate reinforcement product. For this purpose, the Task Group 4 (*Pavement Multilayer System Testing*) of the RILEM technical committee TC 237-SIB (*Testing and Characterization of Sustainable Innovative Bituminous Materials and Systems*) organized an inter-laboratory experiment, constructing one trial test section to obtain double-layered asphalt pavement samples for the participating laboratories. The experiment placed two grid types (a glass fiber reinforced polymer grid and a carbon fiber/glass fiber pre-bituminised grid) between two asphalt layers, thereby creating two reinforced double-layered systems. As a control, an unreinforced interface was also realized. This paper presents the overall

G. Ferrotti (✉) · F. Canestrari
Università Politecnica delle Marche, Ancona, Italy
e-mail: g.ferrotti@univpm.it

F. Canestrari
e-mail: f.canestrari@univpm.it

A. D'Andrea
Sapienza, Università di Roma, Rome, Italy
e-mail: Antonio.dandrea@uniroma1.it

M. Maliszewski
IBDiM, Road and Bridge Research Institute, Warsaw, Poland
e-mail: mmaliszewski@ibdim.edu.pl

M.N. Partl · C. Raab
EMPA—Swiss Federal Laboratories for Materials Science and Technology, Dübendorf, Switzerland
e-mail: Manfred.partl@empa.ch

C. Raab
e-mail: christiane.raab@empa.ch

C. Sangiorgi
Università di Bologna, Bologna, Italy
e-mail: cesare.sangiorgi4@unibo.it

F. Canestrari and M.N. Partl (eds.), *8th RILEM International Symposium on Testing and Characterization of Sustainable and Innovative Bituminous Materials*, RILEM Bookseries 11, DOI 10.1007/978-94-017-7342-3_25

results of interlayer shear tests carried out by five participating laboratories using five different shear testing methodologies. The objective is to show the effect of two grid types on the shear behaviour of reinforced double-layered systems and to compare the findings which emerged from using different test devices and methods under different testing conditions (e.g. sample geometry, temperature, loading time, normal stress). Consistent and reliable results have been obtained through the various methodologies adopted. It has been observed that grid-reinforced samples provide lower interlayer shear strength compared with unreinforced samples. Glass-fiber grid system, which is of greater thickness and greater torsional stiffness, displayed less shear strength than carbon fiber/glass fiber-reinforced grid systems.

Keywords Asphalt concrete · Inter-laboratory test · Interface shear · Grid reinforcement

1 Introduction

Service life of asphalt pavements is affected by many factors, such as traffic loading, ageing, environmental and subgrade conditions. These factors accelerate degradation and could lead to premature failure of the pavement structure if they are not adequately considered during design and construction phases. Depending on the type of distress and its development, suitable rehabilitation and maintenance solutions become fundamental in order to restore (and, in some cases, to upgrade), the original mechanical and/or functional characteristics of asphalt pavements.

The use of reinforcement systems within bound layers is mainly addressed to prevent or delay reflective cracking and rutting and improve fatigue life (Austin and Gilchrist 1996; Brown et al. 2001; Montestruque et al. 2004; Nguyen et al. 2013; Prieto et al. 2007; Sobhan and Tandon 2008; Zielínski 2008). However, the presence of reinforcements at the interface can cause an interlayer de-bonding effect (Brown et al. 2001; Canestrari et al. 2012; Vanelstraete et al. 1997; Zamora-Barraza et al. 2010) that could affect the overall pavement behaviour. Both quasi-static (Canestrari et al. 2013) and dynamic (Brown et al. 2001) shear tests performed on double-layered specimens with or without the application of a constant normal stress showed that a general shear strength decrease is observed when a reinforcement is placed at the interface of asphalt concrete layers.

Although interface bonding conditions influence pavement response in terms of stress–strain distribution (Shukla and Yin 2004; Sobhan and Tandon 2008), de-bonding is not necessarily a negative aspect for pavement mechanical performance. In this sense, when geosynthetics are employed to improve load spreading ability, rutting resistance and fatigue resistance, reinforcements should guarantee high interlayer bonding between the lower and the upper layer (Lee 2008). However, this may result in a limited capability to prevent crack propagation from the underlying pavement layers, which is instead promoted by de-bonding.

The Task Group 4 (*Pavement Multilayer System Testing*) of the RILEM technical committee TC 237-SIB (*Testing and Characterization of Sustainable Innovative Bituminous Materials and Systems*), decided to investigate the effectiveness deriving from the installation of reinforcements between asphalt layers through the preparation of an experimental test section.

This paper presents the overall results of interlayer shear tests carried out by five different laboratories with the objective of studying the effects of two geogrid types on the shear behavior of reinforced double-layered systems and compare findings emerged with different devices and testing conditions (e.g. sample geometry, temperature, normal stress).

2 RILEM Project Description and Material Characteristics

This study is part of the research project "Advanced Interface Testing of Geogrids in Asphalt Pavements" promoted by Task Group 4 of RILEM Technical Committee 237-SIB.

In order to compare experimental procedures and devices for the mechanical characterization of geogrid reinforced interfaces in asphalt concrete pavements, a full-scale pavement test section, using real scale paving equipment and geogrid installation techniques, was constructed (Canestrari et al. 2013). This section consists of three double-layered asphalt concrete sub-sections, characterized by different interfaces: an unreinforced (UN) and two reinforced (CF and FP).

The two bituminous layers, having a thickness of 50-mm-each, were prepared with the same Asphalt Concrete (AC) mixture. It is a typical Italian dense graded mix with 12 mm maximum aggregate size (AC 12) and 70/100 penetration bitumen dosed at 5.5 % by aggregate weight. In both reinforced and unreinforced sub-sections, an SBS polymer-modified tack coat emulsion, classified as C 69 BP 3 (EN 13808), was applied on the surface of the lower layer with a rate of 0.25 kg/m^2 of residual binder. The residual binder of the modified emulsion is characterized by a penetration value at 25 °C of 55–65 dmm, a Ring and Ball Temperature of 65–75 °C, a viscosity value at 160 °C of 0.2–0.8 Pa s and a Fraass Breaking Point <−18 °C.

In the reinforced interfaces, two different geogrids were installed. The Carbon Fiber/Glass Fiber geogrid (CF) is pre-coated with bitumen and characterized by carbon fiber rovings in the transversal direction and glass fiber rovings in the longitudinal direction, with a 20 mm-square mesh. The product is sanded on the upper side, whereas a burn off film is applied on the lower side. The Glass Fiber Reinforced Polymer geogrid (FP) is obtained by weaving continuous alkaline-resistant pre-tensioned glass fibers, covered with a thermosetting epoxy resin (vinylester). The grid has a bi-directional square geometry with flat transversal strands woven into longitudinal twisted strands, with a 33 mm-square mesh and a thickness of about 3 mm. The main characteristics of CF and FP geogrids are shown in Table 1. Apart from the constituent material and mesh size, the main difference

Table 1 Characteristics of CF and FP geogrids

Geogrid	Direction	Material	Grid size (mm)	Tensile modulus (N/mm^2)	Elongation at rupture (%)	Tensile force mesh (kN/m)
CF	Longitudinal	Glass fiber	20	73,000	3–4.5	111
	Transversal	Carbon fiber	20	240,000	1.5	249
FP	Longitudinal	Glass fiber reinforced polymer	33	23,000	3	211
	Transversal	Glass fiber reinforced polymer	33	23,000	3	211

among the two geogrids is their torsional rigidity, also called aperture rigidity (Kinney and Yuan 1995). In fact, the FP geogrid is extremely stiff as twisting and distorting its square mesh is very difficult, whereas the CF geogrid mesh is highly flexible and deformable.

From the full-scale pavement test section, slabs of different sizes (52 × 52 cm and 65 × 65 cm) were cut and sent to the participating laboratories. From these slabs, each laboratory obtained double-layered asphalt concrete specimens to be tested for the evaluation of the interlayer shear properties.

3 Shear Test Devices and Procedures

3.1 *Pure Direct Shear Configuration*

3.1.1 Leutner Test

The Leutner test (Leutner 1979) consists in applying a constant shear displacement rate across the interface of a layered specimen while recording the resulting shear force and the applied displacement. The testing frame is installed into an ordinary Marshall testing machine and allows testing 100 or 150 mm-diameter specimens, taken either from a pavement structure or prepared in the laboratory. The standard shear displacement rate is 50.8 mm/min. The test output is a shear force-shear displacement curve, that allows the interlayer shear strength (τ_{peak}) to be obtained, corresponding to the failure conditions.

3.1.2 Layer-Parallel Direct Shear (LPDS) Test

The Layer-Parallel Direct Shear (Raab and Partl 2009) is an EMPA modified version of equipment developed in Germany by Leutner, being more versatile in geometry and more defined in the clamping mechanism. It allows pure direct shear testing of multi-layered cylindrical samples with a nominal diameter of 150 mm. One part of the pavement core is laid on a circular u-bearing and held with a well-defined pressure of 0.5 MPa by a pneumatic clamping system. The other part, the core head, remains unsuspended. Shear load is induced to the core head by a semicircular shear yoke with a displacement rate of 50 mm/min, thus producing fracture within the pre-defined shear plane (Partl and Raab 1999). The gap width between the shearing rings is 2.5 mm.

3.2 *Direct Shear Configuration with Normal Stress*

3.2.1 Ancona Shear Testing Research and Analysis (ASTRA) Test

The ASTRA device, compliant with the European Standard prEN 12697-48 and the Italian Standard UNI/TS 11214, is a direct shear box. A double-layered specimen, with a nominal diameter of 100 mm, is installed in two half-boxes separated by an unconfined interlayer shear zone (Canestrari et al. 2013). During the test, a constant shear displacement rate of 2.5 mm/min (standard conditions) occurs while a constant vertical load, perpendicular to the interface plane, can be applied in order to generate a given normal stress (σ_n). This test returns a data-set where the interlayer shear stress (τ), the horizontal (ξ) and the vertical (η) displacements are reported as a function of time, allowing the calculation of the interlayer shear strength (τ_{peak}). The whole apparatus is located in a climatic chamber with temperature and relative humidity control.

3.2.2 Sapienza Direct Shear Test Machine (SDSTM)

The Sapienza Direct Shear Testing Machine (SDSTM) is able to test double-layered cylindrical specimens with a nominal diameter of 100 mm (Tozzo et al. 2014). In the working scheme, the specimen is held in two moulds with a gap between the two restraints of 10 mm. The specimen interface is placed in the middle, leaving 5 mm from the edge of each mould. A loading machine applies the shear load (T) on one half of the specimen while the other half is fixed, preventing movement. A normal load (N) can also be applied. The device is equipped with LVDT for the interface displacement measurement. In standard conditions, a constant shear displacement rate of 2.5 mm/min is applied. A shear force-shear displacement curve is obtained in order to determine the interlayer shear strength τ_{peak}. The device can also evaluate the interface shear fatigue behavior under dynamic conditions. The maximum vertical capacity of the loading machine is 100 kN with load frequencies up to 5 Hz.

3.2.3 Shear Tester (ST)

The Shear Tester is a device that allows testing double-layered specimens in shear configuration, through a MTS servohydraulic 100 kN loading frame (Gajewski and Mirski 2012). The apparatus allows fixing the specimen and applying the shear load in correspondence with the interface plane, parallel to the basis of the specimen. Additionally, a normal load, perpendicular to the specimen interface, can be applied through a pneumatic standalone controller. Tests were performed on 150-mm-diameter specimens, applying a constant displacement rate of 50.8 mm/min. ST returns a shear force-shear displacement curve that can be used to determine the interlayer shear strength τ_{peak}. The apparatus is placed in a climatic chamber in order to perform controlled temperature tests.

4 Laboratory Experimental Program

The laboratory experimental program focuses on the evaluation of interlayer shear characteristics of reinforced and unreinforced double-layered bituminous systems in order to compare their mechanical behavior. To achieve this aim, three different interface types (UN, CF and FP) were investigated according to the test program shown in Table 2.

Table 2 Laboratory experimental program for each interface type (UN, CF, FP)

Laboratory	Specimen diameter D (mm)	Test speed v (mm/min)	Test temperature T (°C)	Normal stress σ_n (MPa)	Number of repetitions for each σ_n
EMPA	150	50.8	10	0.00	7
			20		7
			30		7
			40		6
IBDiM	150	50.8	10	0.00; 0.15	1
			20		1
			30		1
UNIRM	100	2.5	20	0.00; 0.20; 0.40	3
UNIBO	150	50.8	20	0.00	9
UNIVPM	100	2.5	10	0.00; 0.20; 0.40	4
			20		4
			30		4

The five laboratories, participating on a voluntary basis in this study are listed as follows:

- Swiss Federal Laboratories for Materials Science and Technology (EMPA), Dübendorf, Switzerland
- Road and Bridge Research Institute (IBDiM), Warsaw, Poland
- Sapienza, Università di Roma (UNIRM), Italy
- Alma Mater Studiorum, Università di Bologna (UNIBO), Italy
- Università Politecnica delle Marche, Ancona (UNIVPM), Italy

As it is shown in Table 2, each laboratory considered different test conditions in terms of specimen diameter, test speed, test temperature, normal stress applied to the interface and number of repetitions, depending on the characteristics of the adopted methodology.

The interlayer shear strength τ_{peak} and the corresponding displacement of each specimen were measured and the average values were considered. When different normal stress levels σ_n were applied, a complete assessment of interface failure properties was obtained according to the following equation:

$$\tau_{peak} = c_0 + \sigma_n \cdot \tan \Phi_p \tag{1}$$

where c_0 is the pure shear strength and Φ_p is the peak friction angle.

5 Results and Analysis

In order to check the statistical significance of the interface type (UN, CF and FP) on the interlayer shear strength τ_{peak}, a one-way analysis of variance (one-way ANOVA) at 95 % confidence level, was performed.

Results of ANOVA of each participating laboratory are summarized in Table 3, where the relevant p-value is shown for each test condition, in terms of normal stress σ_n and test temperature T. For an easier interpretation of ANOVA results, the p-values that represent non-significant differences between two interface types are reported in bold in Table 3. As far as IBDiM laboratory is concerned, ANOVA was not performed due to the low number of repetitions.

The analysis of variance shows that there is no statistical difference between UN and CF results in all laboratories and for almost all of test conditions. This result suggests that the presence of CF geogrid does not significantly influence interlayer shear properties of double-layered systems. On the contrary, Table 3 clearly shows that FP geogrid has a significant influence on interlayer shear strength, highlighting statistical differences with both UN and CF interface types.

In order to investigate the influence of test temperature and define a possible ranking between the different interface types (UN,CF and FP), interlayer shear

Table 3 ANOVA: influence of interface type (UN, CF, FP) on interlayer shear strength

Lab	σ_n (MPa)	T (°C)	p-value UN versus CF	p-value UN versus FP	p-value CF versus FP
EMPA	0.00	10	**0.688**	2.6E-5	9.1E-6
		20	**0.256**	4.1E-3	1.2E-3
		30	**0.634**	1.4E-2	9.4E-3
		40	2.3E-2	**0.095**	**0.627**
UNIRM	0.00	20	**0.284**	1.1E-3	4.8E-4
	0.20		**0.380**	1.2E-3	1.6E-3
	0.40		**0.175**	4.5E-3	5.9E-3
UNIBO	0.00	20	**0.705**	3.0E-6	6.0E-6
UNIVPM	0.00	10	**0.076**	2.8E-4	1.7E-4
		20	**0.258**	1.6E-3	7.3E-4
		30	**0.394**	2.9E-3	1.5E-2
	0.20	10	**0.641**	5.3E-5	1.2E-4
		20	**0.161**	6.4E-4	1.4E-3
		30	3.2E-2	2.3E-3	1.3E-2
	0.40	10	**0.216**	1.9E-4	3.3E-4
		20	**0.202**	4.6E-2	2.3E-3
		30	**0.088**	**0.120**	**0.986**

strength results were represented at a given normal stress σ_n, considering the laboratories that performed tests at different temperatures (Fig. 1). Interlayer shear strength decreases with increasing temperature for both reinforced and unreinforced interfaces, for all the investigated shear test devices and test conditions (normal stress and interface type).

Figure 1 shows that UN and CF interfaces provide very similar results, as it was already observed with the statistical analysis, even if it seems that UN interface guarantees, in general, a slightly higher interlayer shear strength with respect to CF interface. On the contrary, FP geogrid provides the lowest interlayer shear strength with respect to the other two interface types. This is probably due to the greater thickness and stiffness of the FP geogrid, which inhibit the achievement of an optimal compaction of the upper AC layer in the interface proximity, and reduces the interlocking between the two bituminous layers in contact (Santagata et al. 2008). Nevertheless, at higher temperatures the difference between the three interface types becomes almost negligible (Fig. 1). Here, higher temperatures lead to reduced differences between geogrids so that τ_{peak} appears mainly controlled by the characteristics of the asphalt concrete layers in contact.

The correlation between interlayer shear strength and temperature can also be represented in a semi-logarithmic plane and can be described with a relationship obtained in a previous RILEM research project on interlayer bonding of asphalt pavements (Canestrari et al. 2012):

FP) on interlayer shear strength

p-value UN versus FP	p-value CF versus FP
2.6E-5	9.1E-6
4.1E-3	1.2E-3
1.4E-2	9.4E-3
0.095	**0.627**
1.1E-3	4.8E-4
1.2E-3	1.6E-3
4.5E-3	5.9E-3
3.0E-6	6.0E-6
2.8E-4	1.7E-4
1.6E-3	7.3E-4
2.9E-3	1.5E-2
5.3E-5	1.2E-4
6.4E-4	1.4E-3
2.3E-3	1.3E-2
1.9E-4	3.3E-4
4.6E-2	2.3E-3
0.120	**0.986**

al stress σ_n, considering the lab-
atures (Fig. 1). Interlayer shear
both reinforced and unreinforced
ces and test conditions (normal

de very similar results, as it was
n if it seems that UN interface
hear strength with respect to CF
lowest interlayer shear strength
is probably due to the greater
inhibit the achievement of an
nterface proximity, and reduces
ers in contact (Santagata et al.
difference between the three
Here, higher temperatures lead
$_{ak}$ appears mainly controlled by
contact.

h and temperature can also be
e described with a relationship
interlayer bonding of asphalt

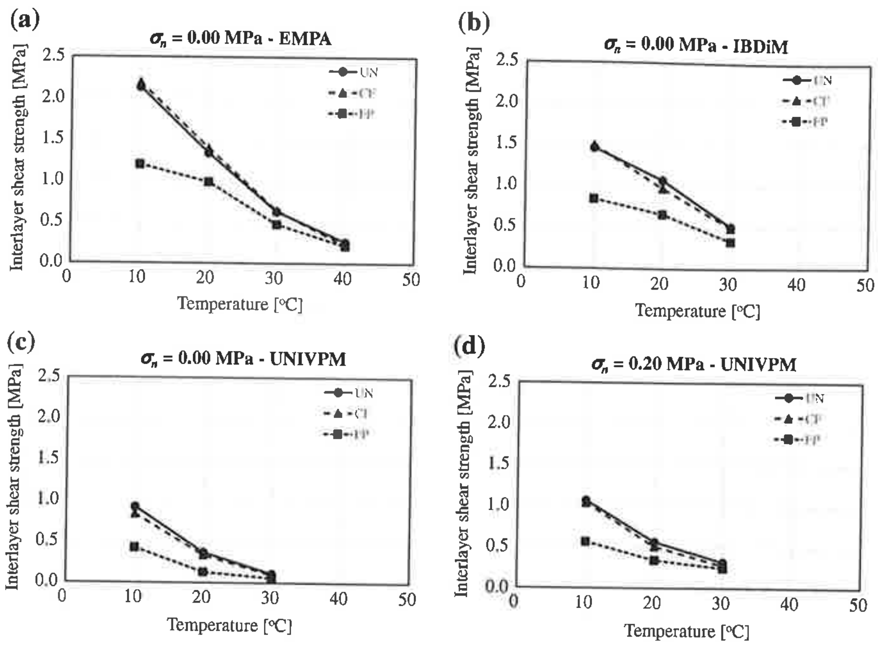
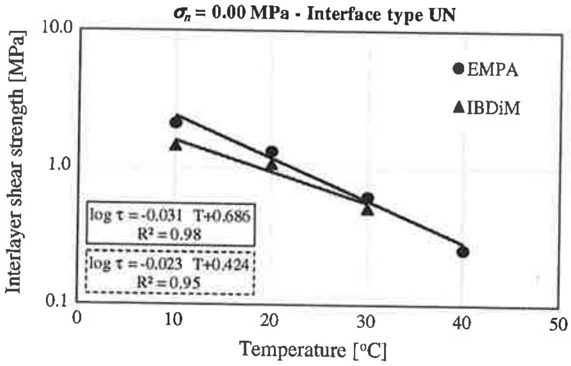


Fig. 1 Correlation between interlayer shear strength and temperature for different laboratories and different test conditions

$$\log \tau_{peak} = a \times T + b \qquad (2)$$

where the parameters a and b were determined in different test conditions. In particular, for unreinforced and polymer modified tack-coated interfaces, the parameters a and b were found $a = -0.026$, $b = 0.586$ when $D = 150$ mm and $v = 50.8$ mm/min. The comparison of these values with the parameters a and b determined in this investigation (Fig. 2) shows that EMPA and IBDiM results,

Fig. 2 Correlation between interlayer shear strength and temperature for UN interface type, without normal stress



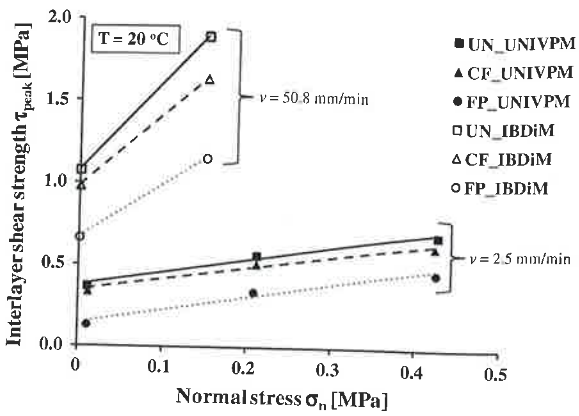


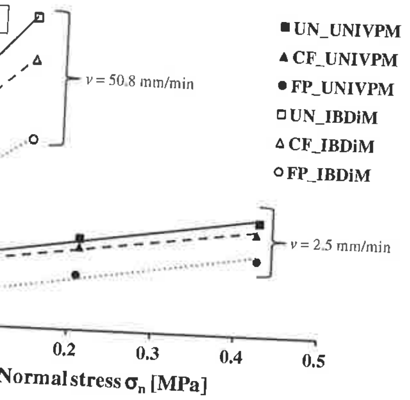
Fig. 3 Peak envelopes of different interface types and for different laboratories

obtained with $D = 150$ mm and $v = 50.8$ mm/min, are in reasonable agreement with previous results (Canestrari et al. 2012).

The peak envelopes of the interlayer shear strength obtained for the three interface types and for the three laboratories that investigated different normal stresses are presented in Fig. 3. Contrarily to Fig. 1, where differences between UN and CF interfaces were not so evident, Fig. 3 clearly shows that geogrid-reinforced interfaces (CF and FP) provide lower interlayer shear strength compared to the unreinforced interface (UN), particularly in terms of pure shear strength (c_0). This is in accordance with previous investigations, carried out with various experimental devices (Brown et al. 2001; Canestrari et al. 2013; Zamora-Barraza et al. 2010; Zielínski 2008), where a similar interlayer de-bonding effect was measured after the installation of geogrid reinforcement. As already observed in Fig. 1, FP interface provides lower τ_{peak} values with respect to CF interface, due to the higher thickness and stiffness of FP geogrid.

Figure 3 clearly shows that in absolute terms, the two laboratories (UNIVPM and IBDiM) provide different τ_{peak} results, mainly due to the different displacement rates (50.8 and 2.5 mm/min).

The effects of the two geogrid types on the shear behavior of reinforced double-layered systems were also compared through the normalization of τ_{peak} of CF and FP interfaces with respect to τ_{peak} of UN interface, for all the investigated shear test devices, considering $T = 20$ °C and $\sigma_n = 0.0$ MPa. Results are shown in Fig. 4, where LPDS, Leutner and ST data are obtained with $D = 150$ mm and $v = 50.8$ mm/min, whereas SDSTM and ASTRA data are obtained with $D = 100$ mm and $v = 2.5$ mm/min. Figure 4 shows that different devices provide very similar normalized τ_{peak} values for CF interface whereas more scattered results were observed for FP interface. This is probably due to FP geogrid mesh dimension (33 mm-square), resulting in a different number of strands in the single specimen and thus influencing the corresponding interlayer shear strength.



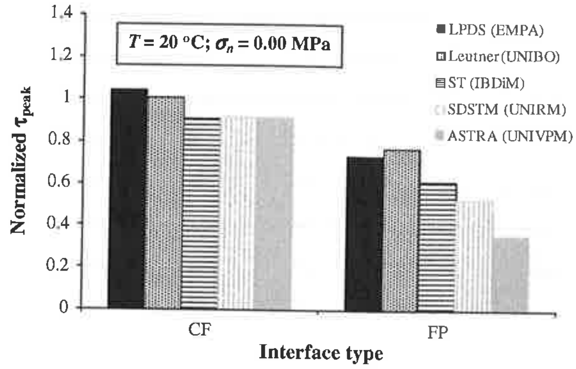
in, are in reasonable agreement with

ar strength obtained for the three
that investigated different normal
g. 1, where differences between UN
early shows that geogrid-reinforced
er shear strength compared to the
s of pure shear strength (c_0). This is
ied out with various experimental
013; Zamora-Barraza et al. 2010;
nding effect was measured after the
y observed in Fig. 1, FP interface
erface, due to the higher thickness

s, the two laboratories (UNIVPM
due to the different displacement

e shear behavior of reinforced
ugh the normalization of τ_{peak} of
interface, for all the investigated
= 0.0 MPa. Results are shown in
btained with D = 150 mm and
STRA data are obtained with
s that different devices provide
e whereas more scattered results
e to FP geogrid mesh dimension
f strands in the single specimen
hear strength.

Fig. 4 Comparison between CF and FP interfaces



As far as the interlayer shear strength of the two interface types is concerned, whatever the experimental device and test conditions are, it is confirmed that FP geogrid produces a significant de-bonding effect with respect to the unreinforced interface, whereas CF geogrid results are very similar to those of UN interface.

Starting from these results, it is expected that the FP geogrid provides in the field an improved reflective cracking resistance thanks to the de-bonding effect highlighted by shear tests. In a different way, a similar reflective cracking pattern should be observed for UN and CF reinforced pavements.

6 Conclusions

This paper focuses on the effects of geogrid reinforcement on the interlayer shear behavior of asphalt pavements. It is part of the RILEM research project "Advanced Interface Testing of Geogrids in Asphalt Pavements" promoted by Task Group 4 of the TC 237-SIB. Several laboratories participated in this interlaboratory investigation performing tests, with their own shear test device, on three interface types: unreinforced, reinforced with a carbon fiber/glass fiber pre-bituminised geogrid and reinforced with a fiber reinforced polymer geogrid.

Results showed that the studied grid-reinforced interfaces provide lower interlayer shear strength with respect to the unreinforced one even if the analysis of variance highlighted a difference not statistically significant between the unreinforced interface and the carbon fiber/glass fiber grid reinforcement. On the contrary, a significant de-bonding effect is evident with the fiber reinforced polymer geogrid characterized by greater thickness and torsional stiffness as compared to the carbon fiber/glass fiber geogrid.

As far as the temperature effect is concerned, it was observed that interlayer shear strength decreases with increasing temperature for both reinforced and unreinforced interfaces and for all the test conditions considered. However, higher temperatures lead to reduced differences between geogrids.

Finally, it was also observed that the correlation between interlayer shear strength and temperature for unreinforced interface is in good agreement with results obtained in a previous RILEM research project on interlayer bonding of asphalt pavements.

References

Austin RA, Gilchrist AJT (1996) Enhanced performance of asphalt pavements using geocomposites. Geotext Geomembranes 14(3-4):175–186. doi: 10.1016/0266-1144(96)00007-6.

Brown SF, Thom NH, Sanders, PJ (2001) A study of grid reinforced asphalt to combat reflection cracking. J Assoc Asphalt Pav 70:543–569.

Canestrari F, Ferrotti G, Lu X, Millien A, Partl MN, Petit C, Phelipot-Mardelé A, Piber H, Raab C (2012) Mechanical Testing of Interlayer Bonding in Asphalt Pavements. In: Partl MN, Bahia HU, Canestrari F, de la Roche C, Di Benedetto H, Piber H, Sybilski D (ed) State-of-the-Art-Reports 9: Advances in Interlaboratory Testing and Evaluation of Bituminous Materials, 1st edn. Springer, Berlin, p 303–360. doi: 10.1007/978-94-007-5104-0_6.

Canestrari F, Belogi L, Ferrotti G, Graziani A (2013) Shear and flexural characterization of grid-reinforced asphalt pavements and relation with field distress evolution. Mater Struct. doi: 10.1617/s11527-013-0207-1.

Gajewski M, Mirski K (2012) Shear tests of two-layer asphalt specimens made in a proposed apparatus allowing side pressure application. Logistyka Journal, 3: 593-602.

Kinney TC, Yuan X (1995) Geogrid aperture rigidity by in-plane rotation. Paper presented at Geosynthetics '95, Nashville, 1995: 525-537.

Lee SJ (2008) Mechanical performance and crack retardation study of a fiberglass-grid-reinforced asphalt concrete system. Can J Civil Eng 35(10):1042–1049. doi: 10.1139/L08-049.

Leutner R (1979) Untersuchung des Schichtverbundes beim bituminösen Oberbau. Bitumen 3: 84-91.

Montestruque G, Rodrigues R, Nods M, Elsing A (2004) Stop of Reflective Crack Propagation with the Use of PET Geogrid as Asphalt Overlay Reinforcement. Paper presented at the 5th International RILEM Conference on Cracking in Pavements, Limoges, 5-8 May 2004.

Nguyen ML, Blanca J, Kerzréhoa JP, Hornych P (2013) Review of glass fibre grid use for pavement reinforcement and APT experiments at IFSTTAR. Road Mater Pavement. 14 (1): 287-308.

Partl MN, Raab C (1999). Shear Adhesion between Top Layers of Fresh Asphalt Pavements in Switzerland. Proceedings, 7th Conf. on Asphalt Pavements for Southern Africa, CAPSA '99, Victory Falls, Zimbabwe, 5.130-5.137.

Prieto JN, Gallego J, Perez I (2007) Application of the wheel reflective cracking test for assessing geosynthetics in anti-reflection pavement cracking systems. Geosynth Int 14(5):287-297. doi: 10.1680/gein.2007.14.5.287.

Raab C, Partl MN (2009) Interlayer bonding of binder, base and subbase layers of asphalt pavements: Long-term performance. Constr Build Mater 23: 2926-2931. doi:10.1016/j.conbuildmat.2009.02.025.

Santagata FA, Partl MN, Ferrotti G, Canestrari F, Flisch A (2008) Layer characteristics affecting interlayer shear resistance in flexible pavements. J Assoc Asphalt Paving 77:221–256.

Shukla SK, Yin JH (2004) Functions and installation of paving geosynthetics. Paper presented at the 3rd Asian Regional Conference on Geosynthetics, Seoul, 21-23 June 2004.

Sobhan K, Tandon V (2008) Mitigating reflection cracking in asphalt overlay using geosynthetic reinforcements. Road Mater Pavement 9(3):367–387. doi: 10.1080/14680629.2008.9690124.

elation between interlayer shear
face is in good agreement with
project on interlayer bonding of

of asphalt pavements using geocom-
10.1016/0266-1144(96)00007-6.
einforced asphalt to combat reflection

Phelipot-Mardelé A, Piber H, Raab C
lt Pavements. In: Partl MN, Bahia HU,
lski D (ed) State-of-the-Art-Reports 9:
tuminous Materials, 1st edn. Springer,

hear and flexural characterization of
distress evolution. Mater Struct. doi:

phalt specimens made in a proposed
Journal, 3: 593-602.
n-plane rotation. Paper presented at

study of a fiberglass-grid-reinforced
049. doi: 10.1139/L08-049.
n bituminösen Oberbau. Bitumen 3:

top of Reflective Crack Propagation
rcement. Paper presented at the 5th
nts, Limoges, 5-8 May 2004.
Review of glass fibre grid use for
AR. Road Mater Pavement. 14 (1):

yers of Fresh Asphalt Pavements in
ts for Southern Africa, CAPSA '99,

reflective cracking test for assessing
ems. Geosynth Int 14(5):287-297.

ase and subbase layers of asphalt
er 23: 2926-2931. doi:10.1016/j.

008) Layer characteristics affecting
Asphalt Paving 77:221–256.
g geosynthetics. Paper presented at
l, 21-23 June 2004.
asphalt overlay using geosynthetic
10.1080/14680629.2008.9690124.

Tozzo C, Fiore N, D'Andrea A (2014) Dynamic shear tests for the evaluation of the effect of the normal load on the interface fatigue resistance. Constr Build Mater 61: 200-205. doi: 10.1016/j.conbuildmat.2014.03.010.

Vanelstraete A, de Bondt AH, Courard L (1997) Characterization of overlay systems. In: Vanelstraete A. and Franken L (Ed) Prevention of Reflective Cracking in Pavements, RILEM Report 18, 1st edn. E & FN Spon, London, p 61-83.

Zamora-Barraza D, Calzada-Pérez MA, Castro-Fresno D, Vega-Zamanillo A (2010) New procedure for measuring adherence between a geosynthetic material and a bituminous mixture. Geotext Geomembranes 28(5):483-489. doi: 10.1016/j.geotexmem.2009.12.010.

Zielínski P (2008) Fatigue investigations of asphalt concrete beams reinforced with geosynthetics interlayer. Paper presented at the 6th RILEM International Conference on Cracking in Pavements, Chicago, 16-18 June 2008: 751-759. doi: 10.1201/9780203882191.ch73.