Construction and Building Materials, vol. 43 (2013), pp. 372–381.
http://dx.doi.org/10.1016/j.conbuildmat.2013.02.011
http://www.sciencedirect.com/science/article/pii/S0950061813001165

Test methods and influential factors for analysis of bonding between bituminous pavement layers

A.C. Raposeiras, D. Castro-Fresno*, A. Vega-Zamanillo, J. Rodriguez-Hernandez
GITECO Research Group, School of Civil Engineering, University of Cantabria, Santander, 39005, Spain

ABSTRACT
The durability and maintenance of pavements depend on several factors. One of the most influential is the bond between layers. This bond is responsible for ensuring all layers behave as a single entity, reducing cracks and deformation of the pavement. Several methods, developed by different authors over the past 30 years, to measure bonding between layers are analyzed in this paper. Different research lines are discussed, concluding that the most influential variables are: tack coat type, dosage, mixture type, surface characteristics, temperature, and emulsion breaking time. In order to reach the highest bond strength values, the following factors should be considered: high values of surface macro-texture, low temperatures, the use of heat-adhesive emulsion, a dosage from 300 to 450 g/m2 of residual bitumen and the compaction after emulsion break. Moreover, a non-destructive test method to assess tack coat dosage on site is proposed.
Keywords: *Tack coat; Bituminous pavement; Bond strength; Asphalt layer*

1. Introduction

Throughout history, both asphalt and concrete pavement conditions and performance have been improved. With the analysis of the different failure mechanisms and their possible causes, the pavement construction procedure as well as the selection of the materials used has been improved. The selection and dosage of materials and the damage of the pavement due to the increasing traffic loads produce different types of failure in pavements. Moreover, poor control of the bond between layers has to be considered. This is one of the most influential factors in the appearance of cracks and slippage between layers, making it one of the fields that produces most research [1, 2, 3, 4].

The basic element to improve the bond between two layers is the tack coat. This tack coat is generally made with bituminous emulsions, which are small particles of carbohydrate binder (between 3 and 8 microns) in a water solution with an anionic or cationic emulsifying agent. This characteristic of the emulsifier gives name to the emulsion. Cationic emulsions are the most commonly used. The amount of residual bitumen in the emulsion depends on emulsion type, usually being from 57 to 63%. The emulsifier is responsible for providing the dispersion of water and binder, preventing the agglomeration of particles, charging them electrically, and facilitating the adherence and resistance to displacement from the aggregates. The water also helps the setting on site. When the water and binder particles are separated and the particles are merged again, producing a bituminous film, the emulsion is broken. Depending on this factor, there are fast, medium and slow breaking emulsions. The fast breaking emulsions are used for tack coats.

According to the Spanish standard applicable on site, emulsions applied as tack coats must have more than 200 g/m2 of residual binder in general and more than 250 g/m2 if the top layer is a discontinuous hot asphalt mixture, a porous asphalt layer or a layer of dense or semi-dense asphalt used for pavement repair. However, this standard does not take into account many other factors, such as type of aggregate or type of asphalt mixture used in each layer. The time needed to break the emulsion is not specified, which is another source of failures, since a premature placement of the top asphalt layer on the emulsion layer can reduce the bonding between layers.

2. Bond verification test

Several researchers have developed different methods to measure the quality of tack coats in different types of pavement layers and conditions, which can be grouped into tensile, torque and shear tests.

2.1. Tensile tests

There are several studies where tensile tests have been used. In 1994, Litzka et al. [2] used the Schenck-Trebel Test to study different asphalt layer combinations. Several years later, Intecasa developed the ENDACMA tensile test (Fig. 1), a Schenck-Trebel-based Test device. These tests have the layers stuck to the clamping jaws. Unfortunately, they realized that results from this test method could be erroneous due to the influence of the variations in the eccentricities.

Based on these tests, in 1995 Tschegg et al. [5] developed the on site Pull-Off Test, where the bottom layer was still bonded to the pavement while the top layer was fixed to a steel plate to generate a vertical load on it and produce the layer de-bonding. Afterwards, Tschegg [6] in 1997 developed the Wedge-Splitting Test (Fig. 2). A wedge is placed at the bonded area between layers to apply a load there and separate the layers.

In 2003, the company Instro Tek developed the ATacker device [7] to measure longitudinal strength, perpendicular to the joint surface, which can be used both in laboratory and on site. The test procedure consisted in placing a steel plate on thesurface of the bottom layer right after the tack coat is applied. When the emulsion is dry, a tensile vertical load is applied, to produce the de-bonding between the steel plate and the bottom layer. The UTEP Pull-Off Device (Fig. 3) [8] and the Louisiana Tack Coat Quality Tester (LTCQT) [9], both ATacker-based devices, were later developed for several bond strength analyses.

2.2. Torque tests

The first registered torque test was the Torque Bond Test, certified by the British Board Agreement in 1998 [10]. In this test, a torque on a metal plate attached to the surface of the top layer is applied to cause the layer separation. Based on this test, Collop et al. [11] developed a laboratory-based automatic torque bond test with quasistatic and repeated load interface testing, with a controlled torque rate and a controlled rotation rate.

The ATacker device [7] could also be used to measure torque strength in laboratory and on site. The test procedure is the same as for the tensile test, but for these analyses a torque is applied instead of a tensile vertical load.

2.3. Shear tests

One of the first studies related to bonding between asphalt layers was developed by Uzan et al. [12] in 1978. They used a device to test prismatic samples with two layers. The sample bottom layer was attached to the test table. A load was vertically applied to the top layer, combined with a constant horizontal load applied to the upper mould. Based on the Uzan device but with some modifications for testing cylindrical samples, the ASTRA (Ancona Shear Testing Research and Analysis, Fig. 4) [13, 14] and the SuperPave Shear Test [15] were developed and used in several studies.

Leutner [16] designed a device where the cylindrical sample was placed in a shear cast. Then a load was applied to the top layer, while the bottom layer was held to produce displacement between the layers. Later, this type of test was included in the preprint of the German Standard [17], and it was the basis for several newer shear test devices. The LPDS Tester (Fig. 5) [18], the LCB (Laboratory of Civil engineering of Barcelona) Shear Test (Fig. 6) [19], the FDOT (Florida Department of Transportation) Bond Strength Device [20], the ALDOT-NCAT Bond Strength Device [21] and the Louisiana Interlayer Shear Strength Tester [22], all Leutner-based devices, were also developed and used for several studies. The LPDS Tester was included later in the Swiss Standard SN 670 461 [23], and the LCB Shear Test was included in the NLT-328/08 Standard [24] as a shear testing method to evaluate shear strength of interface areas between pavement layers. There is a potential problem with all these tests due to the gap between the load application area and the bonded zone between layers, so Raab et al. [25] developed a laboratory analysis of the influence of the width of the gap between interface and load applied, and they found that, in some cases, maximum shear strength and stiffness value decreases when increasing gap width.

In the Double Shear Test (Fig. 7), used in 1996 by Millien et al. [26], a prismatic sample of three asphalt layers with tack coat applied at the joint surface is tested by holding the two external layers and applying a specific load in the intermediate layer to produce the shear at the joint surface between layers.

Two different tests were developed by Romanoschi & Metcalf [27] in 1999. The Direct Shear Test with Normal Load (Fig. 8), where a normal load is applied close to the joint surface between the layers, also considering different test temperatures, and the Shear Fatigue Test (Fig. 9), where the sample is broken through the joint surface by applying a lateral displacement of the faces, with a load inclination angle of 25.5 º from the applied side.

After the analysis of the different bond verification tests, it can be concluded that the most commonly used method for the analysis of bond characteristics is the shear test. This type of test is the most commonly used because of the similar behaviour of the sample compared to a real case of slippage between layers. It is also used due to the simple test procedure and the load-displacement curve obtained, which can be used to develop behavioural models depending on different factors in the test.

A precise non-destructive test method to ensure a proper tack coat dosage on site is must be developed. Depending on the different factors that will be analysed in the following point, a test method will be proposed.

3. Factors influencing interlayer strength

Since Uzan et al. [12] began to analyse the bond between layers in 1978, several researchers have tried to identify the most influential factors on tack coat effectiveness. The main factors analyzed were: binder dosage, type of binder, type of bituminous mixture to bond, surface characteristics in the contact layer, compact load applied and temperature during the installation. According to the results of these researchers, several recommendations could be extracted.

3.1. Tack coat characteristics

3.1.1. Binder dosage

In order to know the influence of the use of binder, several researchers analysed strength of samples with and without binder between layers. Romanoschi et al. [28] used three parameters (modulus obtained from the curve slope, maximum shear strength and the coefficient of friction before the break), but only modulus and maximum shear strength are affected in samples without tack coat. Diakhate et al. [29] and Collop et al. [11] found that samples without tack coat decreased their bonding fatigue performance.

It is necessary to compare the results without tack coat with other binder dosages. Molenaar [30], Collop et al. [31], Raab et al. [32] and Piber et al. [33] developed their research with several tack coat dosages, including “no binder condition”. The highest strength is obtained for the usual range of tack coat dosage, and the strength is lower for samples without applied tack coat [31]. In some combinations of surface and intermediate layers, better results are obtained without tack coat application [34]. This could be produced by the high temperature of the bituminous mixture when it is placed, because the contact area could be bonded with the bitumen of the layers. This could also be due to the high surface void volume of the intermediate layer, because the union area could have high friction values due to the interlocking between layers. Finally, the results indicate that an excess of tack coat produces a slippage between layers [32].

In the same way, Sholar et al. [32, 20], Zamora-Barraza et al. [35] and Raposeiras et al. [36] analysed several tack coat dosages, concluding that the least effective were for less than 300 g/m2 of residual bitumen, with the optimal dosage from 300 to 450 g/m2 of residual bitumen.

In order to complete the information obtained from these studies, an analysis with different emulsion types would be useful, because conventional, modified and heat-adhesive emulsions, and asphalt binders have different behaviour, water percentage and application characteristics.

3.1.2. Type of binder

The type of binder used has an influence on bond strength. West et al. [21], Liu et al. [37] and Du et al. [38] concluded the type of tack coat had more influence than the dosage applied. Millien et al. [26], Mohammad et al. [39] and Raab et al. [40, 3] also included that the binder type was an influential factor. They found that heat-adhesive emulsion is as suitable as traditional emulsions, with an appropriate performance when it is applied between two layers. Moreover, it improves the strength regarding traffic loads when compared to traditional emulsions. However, it was necessary to know whether this type of emulsions is used for pavement construction. Several surveys of state departments of transportation, FHWA, Asphalt Institutes, contractors, and highway agencies in other countries were done [39]. These found that usually asphalt emulsion is preferred to asphalt cement or cutback asphalt, and slow-setting is preferred to fastsetting emulsion, so this emulsion type is not the most commonly used.

Mohammad et al. [41], Bae et al. [42], Collop et al. [11], Leng et al. [43], Zamora-Barraza et al. [35] and Du et al. [38] have developed several studies with different binder types and dosages. Some research included samples with three types of emulsified tack coats (CRS-1, SS-1h, and Trackless) at three residual emulsion dosages (0.14, 0.28, 0.70 1/m2), and the highest bond strength was obtained for trackless tack coat at the three application rates, and the lowest strength was obtained for CRS-1 [41]. Zamora-Barraza et al. [35] also found that heat adhesive ones are the most suitable emulsions, with the most adequate dosage from 300 to 400 g/m2 of residual bitumen.

However, other researchers obtained better results for other types of binders. While Liu et al. [37] obtained better fatigue behaviour for asphalt binders, Du et al. [38] obtained higher bond strength for asphalt emulsion. Related to the character of the emulsifier, while Leng et al. [43] obtained better rutting strength for PG 64-22 and SS-1hP (anionic and slow break), Collop et al. [11] obtained the highest bond strengths for cationic emulsion.

Higher dosages increased bond strength, but an excess of tack coat decreased the air void content in HMA layers during compaction. An increase in the binder rheology parameter “G*/sin delta” produced an increase in the bond strength [42]. Reduced influence of the tack coat type was observed, but more influence of tack coat type was found in thinner rather than on thicker layers, with higher influence of pavement structure. While thin structures experienced fatigue damage for the majority of tack coat materials and dosages, thick structures performed satisfactorily against fatigue damage for most of the tack coat material types and dosages analyzed [44].

Nowadays, it is necessary to carry out more profound research to compare results with different binders. According to these tests, there is not a great difference between the emulsions used, but heat-adhesive emulsions performed better than conventional ones or asphalt binders. Nevertheless, these results could be influenced by the breaking time of each binder, so this factor has to be considered.

3.1.3. Emulsion breaking time

Deysarkar [8], Tashman et al. [45] and Chen et al. [46] also considered the breaking time of each binder used and when the second layer was placed, in order to know if breaking time could have an influence on bond strength due to the presence of water in the emulsion. These studies also included different binder dosages.

Deysarkar [8] observed that an increase of 0.27 l/m2 of tack coat applied caused no bonding differences if strength was analyzed 5 minutes after tack coat application, but differences were greater if bonding was analyzed 30 and 60 minutes after tack coat application, relative to the emulsion break. Chen et al. [46] found that bond strength increased when the tack coat is applied and compaction of the second layer is carried out right after the emulsion break.

Another study found that curing time and increase in tack coat dosage had a minimal effect on bond strength [45], but in order to obtain the correct behaviour of the tack coat, an optimal curing time of 40 to 50 minutes per gram of emulsion applied was established [36].

3.2. Surface characteristics

3.2.1. Material type

Another influential factor on the bond strength between layers is related to the materials used for pavement construction. Chen et al. [47], Utzan et al. [12], Caltabiano et al. [1] and Raab et al. [18] analysed different materials in their research, and some of them observed that slippage cracks were related to poor tack coat quality, dosage, asphalt content and also aging rate [47].

In order to obtain more precise data, the type of mixture used was considered by West et al. [21], Raab et al. [48, 25] and Mohammad et al. [44], and they realized that the type of mixture is one of the most influential factors, because of the different void content of each type of bituminous mixture.

From these studies it is found that the types of bituminous mixtures to bond have influence on final bond strength. However, deeper analysis should be carried out in order to study the differences between the mixtures analyzed and how to evaluate them. This could have a great influence on the dosage needed and it is necessary to establish some correlations according to this parameter. This point of view has been considered by some other researchers who realized that surface roughness and macro-texture are important factors related to bond strength.

3.2.2. Surface roughness and texture

Several studies have included the surface roughness and texture as influential factors. Canestrari et al. [49], Recasens et al. [50, 51], Tashman et al. [45], Mohammad et al. [39], Santagata et al. [52], Leng et al. [43] and Liu et al. [37] realized that interface condition has direct influence on fatigue resistance. Higher strength is obtained for milled surface, with a minimal effect of the absence of tack coat applied, whereas this tack coat's absence severely decreases the strength for the non-milled sections [45].

When the surface options are smooth, transverse tined, and milled, again milled sections obtained the best results [43].

Surface roughness and texture could vary depending on the type of bituminous mixture used. Some researchers analyzed different mixture types. While Raab et al. [32], Collop et al. [34] and Chen et al. [46] found less bond strength when roughness values increased, Raposeiras et al. [36] found better strength values for bituminous mixtures with higher macro-texture values (AC22S or AC22G according to the European Standard [53]). This could be produced by the different dosages used in these studies, and also the different type of top layer used. Each bituminous mixture has a specific macro-texture value, and according to this value, a tack coat dosage and an optimal top layer should be used. The test for measuring pavement surface macrotexture by the volumetric technique is recommended due to the accurate values obtained with it.

3.2.3. Surface state

In order to complete the analysis, surface state should also be included in these studies. Raab et al. [32], Sholar et al. [20], Mohammad et al. [39] and Leng et al. [43] included different surface conditions (i.e. moisture and dust) in their studies. They concluded that a pavement with no tack coat has worse adherence in the presence of water or moisture [32]. The bonding is also reduced if there is water on the tack coat surface [20].

Mohammad et al. [39] obtained different results. While differences appear between clean and dusty conditions, dry and wet conditions have the same results. This wet condition has more influence on PG 64-22 than for emulsion-based tack coat materials [39]. There is a great influence of the Portland Cement Concrete (PCC) cleaning methods on the Hot Mix Asphalt (HMA)-PCC interface bonding as was observed in [43].

According to all the test results, the mixture type and its surface state and roughness have a large influence on final bond strength. Better results are obtained for lower layers with high surface roughness (macro-texture). However, it is necessary to correlate the mixture type and its surface macro-texture with tack coat dosage, because each surface macro-texture needs different binder dosage. Moreover, it is recommended to measure the surface macro-texture on site before binder application in order to select the proper tack coat dosage according to prior correlations. It is also important to ensure the best surface conditions, with no dust, water or moisture on the bottom layer surface, because these factors highly reduce bond strength.

3.3. Temperature

However, one important factor should be included in all the previous analyses in order to check its influence: the temperature. This could be a very influential factor on all studies carried out because temperature produces changes in binder behaviour. An increase or decrease of temperature also produces changes in bitumen characteristics.

Partl et al. [54], Romanoschi et al. [27], Mohammad et al. [15], West et al. [21], Recasens et al. [50, 51], Canestrari et al. [49], Piber et al. [33], Chen et al. [46], Du et al. [38] and Diakhate et al. [29] found that temperature is an important factor. They found that temperature has a high influence on bond strength [38] and that the modulus obtained from the curve slope, the maximum shear and the coefficient of friction before the break are influenced by temperature [28]. The surface characteristics have more influence at higher temperatures [46]. To evaluate the tack coat quality on site, tests have to be developed at the bitumen softening point temperature [9].

West et al. [21], Bae et al. [42], Collop et al. [11] and Du et al. [38] also found in their research that the bond strength decreased when temperature increased. This is due to the emulsion characteristics, because when temperature increased, the emulsion reached the softening point and became more liquid, with a decrease of bond strength. Moreover, longer lifetime under fatigue and greater sensitivity to shear stress levels were found for lower temperatures [11].

However, Deysarkar [8] found that bond strength increased with higher temperature. This result is related to the faster water evaporation of the tack coat, accelerating the emulsion break. This bond strength increase depends on the waiting time to place the top layer. When the top layer is placed without considering the breaking time of the emulsion, a high temperature produces faster water evaporation, with an increase of bond strength.

Bae et al. [42] obtained the best results for heat-adhesive emulsions, concluding that modified emulsions behaved better with low temperature and the non-modified ones were more suitable under high temperature.

According to these studies, temperature has more influence on bond strength than the pressure and load applied. Generally, a decrease in temperature produces an increase in bond strength, but this factor is more related to the region where the pavement is constructed. For regions where temperatures could be lower than -10 °C, conventional emulsion should be used, while for regions where temperatures are usually higher than 5 °C, non-modified heat-adhesive emulsion is recommended. Between these temperatures, modified heat-adhesive emulsions will provide the best behaviour.

The temperature also has to be considered when tack coat is applied in order to choose a suitable waiting time for the emulsion break, because actual waiting parameters are related to a 20 °C standard and changes in temperature produce different water evaporation speeds.

3.4. Other factors analyzed: loads and displacements

Several studies have analysed bonding between layers under different pressures and load conditions. While Raab & Partl [4, 3] confirmed that the influence of traffic loads improves the bond between layers from 40 to 57% after 10 years of road life-time, due to pavement re-compaction, West et al. [21] found that pressure applied is one of the least important factors.

Other researchers included an analysis based on variations in layer dynamic stiffness modulus, layer thickness and the degree of lateral displacement available at the interface [55], or different confinement pressures [41]. The test results could be used to establish different behavioural laws in order to improve pavement fatigue strength behaviour, where bond strength is related to number of loads applied [28] or the displacement imposed [56].

From the above mentioned researches is obtained that binder dosage is the most important factor to assure the proper bond between layers. There is one standardized method to control this dosage: ASTM D2995, where pieces of geotextile are placed on the surface where the coat is going to be spread before binder is applied. The geotextile absorbs the binder and finally the piece of geotextile is weighed in order to obtain the emulsion applied on the surface analyzed.

However, researchers who used this method observed huge differences between theoretical binder dosages to be obtained from these tests compared to the real final quantities obtained. In some of these researches, these differences were obvious, with differences between analyzed ranges higher than 200 g/m2. Due to these problems, researchers had to use theoretical values instead of real values from the tests to continue their researches [21, 45, 57].

Moreover, inconveniences during test execution have been observed: the lack of fasteners in the geotextile pieces may cause movements during coat extension; time elapsed from binder application to weighing of the geotextile is not measured; lack of control of the surface texture on areas where binder is applied and the measurement is done; inefficient control of the dosage in the areas where binder is manually applied.

In order to solve this, a non destructive method to control the dosage applied on site is suggested, which considers both surface texture where binder is applied and the binder dosage to guarantee that binder quantity staying on surface is enough for the proper bond between layers. This produces a highly adequate control of the two main influential factors on the bond: dosage and surface macro-texture.

4. Tack coat dosage verification test on site (DoVeCan Test)

4.1. Proposed methodology

A steel plate covered by a geotextile is used to apply a specific pressure to the pavement right after the emulsion is applied. Then the geotextile is encharged of the absorption of a percentage of the binder spread. The necessary load is applied through a load-ring with a maximum load of 50 kg and modulus of 55.87 kg/mm. The necessary pressure is measured through the vertical compression achieved by the ring. The whole system is held by a support where vertical displacement of the system is applied (Fig. 10).

In order to keep the equipment in working order, and also to select the proper geotextile and pressure, conventional ECR-1 emulsion (60 % bitumen) has been applied, with 6 different dosages from 200 to 700 g/m2 of residual bitumen, on several AC16 surf D field samples. These samples have been tested under pressures of 1.65 and 3.14 kPa with the steel plate covered by non-woven geotextiles PP-500 and PP-1000 (Table 1). The waiting time to apply the test pressure after the emulsion is 5 minutes, and the test time duration is also 5 minutes, in order to allow the geotextile to absorb a large quantity of emulsion.

4.2. First results obtained

Correlations between the applied and the absorbed binder and surface macrotexture could be established with this method, in order to use the results to check that proper binder dosage is applied on site. A wide range of dosages has been used in order to obtain different binder absorption percentages. While for 1.65 kPa, the absorption values vary from 24 to 62 % of emulsion absorbed, for 3.14 kPa, these values vary from 33 to 91 % (Fig. 11). The percentage range is higher for 3.14 kPa (58 %) than for 1.65 kPa (38 %), and there are larger differences between minimum and maximum emulsion dosages applied, so the most adequate pressure to apply during the test development is 3.14 kPa.

An appropriate geotextile has to be selected according to its characteristics. This geotextile has to absorb at least 30% of the binder and the differences between the binder dosages used for the tests must be as clear as possible. While for PP-500, a useful range of 58 % (from 33 to 91 % of emulsion absorbed) is obtained, for a PP-1000 geotextile, this range was 36 % (from 18 to 54 % of emulsion absorbed) (Fig. 12). The most adequate behaviour was obtained for the PP-500 geotextile, with greater differences between minimum and maximum dosages applied, with an adequate absorption value for the minimum and maximum dosage values.

When the most adequate pressure and geotextile type are established, the first absorption tests are developed. Clear absorption differences are obtained for the different macro-texture values, with a logical relation between texture and absorption values, with a decrease of the absorption percentage of the emulsion when macrotexture increases. Also clear differences between the two binder dosages analyzed (250 and 500 g/m2), with a similar behaviour and a constant absorption difference between both dosages of 20 % aprox. R2 value is high in both cases, so the prediction model and device performance are adequate.

For the highest macro-texture values (higher than 0.800 mm) both dosages are insufficient because in order to assure the proper tack coat behaviour, the emulsion quantity staying on surface should be from 40 to 60 % of the total dosage extended (Fig. 13), the same value of the emulsion absorbed by the geotextile, which in these cases is below 40 %.

5. Conclusions

Through the analysis of all the research carried out, it has been observed that shear tests are the most commonly used methods to verify the bond strength between pavement layers, due to the similar behaviour obtained when compared to real cases of de-bonding and slippage, and the simple methodology used to carry out the test. These shear tests are based on the Leutner method, and the most commonly used devices are the LPDS Tester and the LCB Shear Test.

Tack coat application is necessary to ensure proper bonding between asphalt layers, because it can increase the bond strength. However, tack coat must be applied in appropriate dosages, because an insufficient dosage reduces the bond strength, and an excess of binder produces slippage between layers. In order to avoid these problems, previous research indicates that the proper dosages are from 300 to 450 g/m2 of residual bitumen.

The type of binder used does not have a great influence on final bond strength. Anyway, the use of heat-adhesive (trackless) emulsions is most recommendable, followed by conventional cationic emulsions, conventional anionic emulsions and finally asphalt binders.

Pouring of the top asphalt layer must be carried out after the emulsion break. The breaking time depends on the type of emulsion used and its water percentage. This time should vary from 40 to 50 minutes per gram of emulsion applied.

Temperature is one of the most important factors influencing bond strength, because emulsions and asphalt binders have different characteristics when temperature varies. Better strength values are obtained for lower temperatures. For low temperatures, conventional emulsions are recommended; while for regular and high temperature values, heat-adhesive emulsions are the most adequate. The emulsion curing time may be adapted to different water evaporation speeds according to different temperatures.

The bottom layer surface must be clean and without water or moisture before tack coat application. Bond strength increases when surface roughness increases. Higher macro-texture values are obtained for mixtures such as AC22S, AC22G or AC32G. Dosages from 250 to 375 g/m2 of residual bitumen are recommended for lower macrotexture values, and 375 to 500 g/m2 for higher values of macro-texture.

In order to ensure proper binder application on site, a device and a test methodology are proposed. This on-site tack coat dosage verification test (DoVeCan Test) applies a controlled pressure through a steel plate covered by a geotextile, and a percentage of binder is absorbed. In order to obtain proper correlations between binder applied, binder percentage absorbed and surface macro-texture, a pressure must be applied and a non-woven geotextile must be used. From the first results, it has been demonstrated that the proposed methodology offers suitable sensitivity to analyse the influence of the different parameters studied.

Acknowledgements
We would like to acknowledge Emilio Bolado S.L., the Society for the Development of the Region of Cantabria (SODERCAN) and the Machining Department of CIFP La Laboral in Gijon for the support provided.

References

[1] Caltabiano, M.A. & Brunton, J.M. 1991, "Reflection cracking in asphalt overlays", Asphalt Paving Technology 1991Publ by Assoc of Asphalt Paving Technologists, St. Paul, MN, United States, pp. 310.
[2] Litzka, J.H., Pass, F. & Zirkler, E. 1994, "Experiences with thin bituminous layers in Austria", Transportation Research Record, vol. 1454, pp. 19-22.
[3] Raab, C. & Partl, M.N. 2008, "Investigation into a long-term interlayer bonding of asphalt pavements", Baltic Journal of Road and Bridge Engineering, vol. 3, no. 2.
[4] Raab, C. & Partl, M.N. 2009, "Interlayer bonding of binder, base and subbase layers of asphalt pavements: Long-term performance", Construction and Building Materials, vol. 23, no. 8, pp. 2926-2931.
[5] Tschegg, E.K., Kroyer, G., Tan, D.-., Stanzl-Tschegg, S.E. & Litzka, J.H. 1995, "Investigation of bonding between asphalt layers in road construction", Journal of Transportation Engineering, vol. 121, no. 4, pp. 309-316.
[6] Tschegg, E.K. 1997, "An efficient fracture test method for bituminous materials and layer bonds", Réunion Internationale des Laboratoires et Experts des Materiaux, Systèmes de Construction et Ouvrages (RILEM) [International Union of Laboratories and Experts in Construction Materials, Systems, and Structures] RILEM, Liege, Belgium, pp. 405.
[7] InstroTek Inc. 2003, ATACKER™ A Tack Coat Testing Device, USA.
[8] Deysarkar, I. 2004, Test set-up to determine quality of tack coat, University of Texas at El Paso.
[9] Mohammad, L.N., Bae, A., Elseifi, M.A., Button, J. & Scherocman, J.A. 2009, "Evaluation of bond strength of tack coat materials in field: Development of pull-off test device and methodology", Transportation Research Record, vol. 2126, no. 1, pp. 1-11.
[10] British Board Agreement 1998, Guideline document for the assessment and certification of thin surfacing systems for highways.
[11] Collop, A.C., Sutanto, M.H., Airey, G.D. & Elliott, R.C. 2011, "Development of an automatic torque test to measure the shear bond strength between asphalt", Construction & Building Materials, vol. 25, pp. 623-629.
[12] Uzan, J., Livneh, M. & Eshed, Y. 1978, "Investigation of adhesion properties between asphaltic-concrete layers", Asphalt Paving Technology, vol. 47, pp. 495-521.
[13] Santagata, E. & Canestrari, F. 1994, "Tensile and shear tests of interfaces in asphalt mixes: A new perspective on their failure criteria", Proceedings of the 2nd International Symposium on Highway Surfacing.
[14] Santagata, E., Canestrari, F. & Santagata, F.A. 1993, "Laboratory shear testing of tack coat emulsion", Proceedings of the 1st Congress on Emulsion.
[15] Mohammad, L.N., Raqib, M.A. & Huang, B. 2002, Influence of asphalt tack coat materials on interface shear strength.
[16] Leutner, R. 1979, "Investigation of the adhesion of bituminous pavements [Untersuchungen des Schichtenverbunds beim bituminösen Oberbau]", Bitumen, , no. 3, pp. 84-91.
[17] Forschungsgesellschaft für Straben- und Verkehrswesen 1998, Testing of layered composite according to Leutner. Sampling and analysis [Prüfung des Schichten-verbundes nach Leutner. Probenahme und durchführung der prüfung], 1st edn, Society for Research and Road Transport, German Standard, Berlin, Germany.

[18] Raab, C. & Partl, M.N. 1999, "Methods to determine the bond of asphalt pavements [Methoden zur Beurteilung des Schichtenverbunds von Asphaltbelägen]. ASTRA-Project FA 12/94".

[19] Recasens, R.M., Jiménez, F.P., González, J.M.B. & Partl, M.N. 2003, "Evaluation of the effect of tack coats. LCB shear test", , pp. 550-556.

[20] Sholar, G.A., Page, G.C., Musselman, J.A., Upshaw, P.B. & Moseley, H.L. 2004, "Preliminary investigation of a test method to evaluate bond strength of bituminous tack coats", Asphalt Paving Technology 2004, pp. 771.

[21] West, R.C., Zhang, J. & Moore, J. 2005, "Evaluation of bond strength between pavement layers", National Center for Asphalt Technology, Auburn University, Alabama.

[22] Mohammad, L.N., Bae, A., Elseifi, M.A., Button, J. & Patel, N. 2010, "Effects of pavement surface type and sample preparation method on tack coat interface shear strength", Transportation Research Record, vol. 2180, pp. 93-101.

[23] Schweizer Norm SN 670 461 2000, Determination of the adhesion between asphalt layers (according to Leutner) [Bestimmug des Schichtenverbunds (nach Leutner)], 5th edn, Swiss Standard, Zürich, Switzerland.

[24] NLT-328/08 2008, Evaluation of the adhesion between asphalt layers, through shear test [Evaluacuón de la adherencia entre capas de firme, mediante ensayo de corte], 1ª edn, CEDEX Spanish Standard, Madrid.

[25] Raab, C., Partl, M.N. & Abd El Halim, A.O. 2010, "Effect of gap width on interlayer shear bond results", International Journal of Pavement Research and Technology, vol. 3, no. 2, pp. 79-85.

[26] Millien, A., Petit, C. & Rosier, J. 1996, "Shear behavior of the tack coats on pavements [Comportement au cisaillement des couches d'accrochage dans les chaussées]", Rapport Interne.

[27] Romanoschi, S.A. & Metcalf, J.B. 1999, "Characterization of pavement layer interfaces".

[28] Romanoschi, S.A. & Metcalf, J.B. 2001, Characterization of asphalt concrete layer interfaces.

[29] Diakhate, M., Millien, A., Petit, C., Phelipot-Mardele, A. & Pouteau, B. 2011, "Experimental investigation of tack coat fatigue performance: Towards an improved lifetime assessment of pavement structure interfaces", Construction and Building Materials, vol. 25, no. 2, pp. 1123-1133.

[30] Molenaar, A.A.A., Heerkens, J.C.P. & Verhoeven, J.H.M. 1986, "Effect of stress absorbing membrane interlayers", Proceeding of the Association of Asphalt Paving Technologists, vol. 55.

[31] Collop, A.C., Thom, N.H. & Sangiorgi, C. 2003, "Assessment of bond condition using the Leutner shear test", Proceedings of the Institution of Civil Engineers: Transport, vol. 156, no. 4, pp. 211-217.

[32] Raab, C. & Partl, M.N. 2004, "Effect of tack coats on interlayer shear bond of pavements", Proc., 8th Conference on Asphalt Pavements for Southern Africa.

[33] Piber, H., Canestrari, F., Ferrotti, G., Lu, X., Millien, A., Partl, M.N., Petit, C., Phelipot-Mardele, A. & Raab, C. 2009, "RILEM interlaboratory test on interlayer bonding of asphalt pavements", 7th International RILEM Symposium on Advanced Testing and Characterisation of Bituminous Materials, RILEM, Rhodes, Greece, pp. 1181-1189.

[34] Collop, A.C., Sutanto, M.H., Airey, G.D. & Elliott, R.C. 2009, "Shear bond strength between asphalt layers for laboratory prepared samples and field cores", Construction and Building Materials, vol. 23, no. 6, pp. 2251-2258.

[35] Zamora-Barraza, D., Calzada-Peréz, M., Castro-Fresno, D. & Vega-Zamanillo, A. 2010, "New procedure for measuring adherence between a geosynthetic material and a bituminous mixture", Geotextiles and Geomembranes.

[36] Raposeiras, A.C., Vega-Zamanillo, A., Calzada-Pérez, M.A. & Castro-Fresno, D. 2012, "Influence of surface macro-texture and binder dosage on the adhesion between bituminous pavement layers", Construction and Building Materials, vol. 28, no. 1, pp. 187-192.

[37] Liu, L. & Hao, P.W. 2010, Investigation of interface shear fatigue performance and evaluating index between asphalt layers, International Workshop on Energy and Environment in the Development of Sustainable Asphalt Pavements, Proceedings, Changan Univ., China.

[38] Du, J.-. 2011, "Evaluation of shear strength on pavement layers by use tack materials", Advanced Materials Research, vol. 255-260, no. 1, pp. 3176-3179.

[39] Mohammad, L.N., Saadeh, S., Qi, Y., Button, J. & Scherocman, J. 2008, "Worldwide state of practice on the use of tack coats: A survey", Asphalt Paving Technology: Association of Asphalt Paving Technologists-Proceedings of the Technical Sessions, Texas Transportation Institute, Texas A and M University System, College Station, Texas, USA, pp. 1-34.

[40] Raab, C. & Partl, M.N. 2008, "Influence of tack coats on the adhesion properties of asphalt pavements", Efficient Transportation and Pavement Systems: Characterization, Mechanisms, Simulation, and Modeling - Proceedings of the 4th International Gulf Conference on Roads, Department of Road Engineering and Sealing Components, Empa, Duebendorf, Switzerland, pp. 517-527.

[41] Mohammad, L.N., Bae, A., Elseifi, M.A., Button, J. & Scherocman, J.A. 2009, "Interface shear strength characteristics of emulsified tack coats", Asphalt Paving Technology: Association of Asphalt Paving Technologists-Proceedings of the Technical Sessions, Texas Transportation Institute, Texas A. and M. University, United States, Texas, USA, pp. 249.

[42] Bae, A., Mohammad, L.N., Elseifi, M.A., Button, J. & Patel, N. 2010, "Effects of temperature on interface shear strength of emulsified tack coats and its relationship to rheological properties", Transportation Research Record, vol. 2180, no. 1, pp. 102-109.

[43] Leng, Z., Al-Qadi, I.L., Carpenter, S.H. & Ozer, H. 2009, "Interface bonding between hot-mix asphalt and various Portland cement concrete surfaces: Assessment of accelerated pavement testing and measurement of interface strain", Transportation Research Record, vol. 2127, no. 1, pp. 20-28.

[44] Mohammad, L.N., Hassan, M. & Patel, N. 2011, "Effects of shear bond characteristics of tack coats on pavement performance at the interface", Transportation Research Record, vol. 2209, no. 1, pp. 1-8.

[45] Tashman, L., Nam, K., Papagiannakis, T., Willoughby, K., Pierce, L. & Baker, T. 2008, "Evaluation of construction practices that influence the bond strength at the interface between pavement layers", Journal of Performance of Constructed Facilities, vol. 22, no. 3, pp. 154-161.
[46] Chen, J.S. & Huang, C.C. 2010, "Effect of surface characteristics on bonding properties of bituminous tack coat", Transportation Research Record, vol. 2180, no. 1, pp. 142-149.
[47] Chen, D.H. 2011, "Slippage failure of a new Hot-Mix Asphalt overlay", Journal of Performance of Constructed Facilities, vol. 24, no. 3, pp. 258-264.
[48] Raab, C., Abd El Halim, A.O. & Partl, M.N. 2012, "Interlayer bond testing using a model material", Construction and Building Materials, vol. 26, no. 1, pp. 190-199.
[49] Canestrari, F. & Santagata, E. 2005, "Temperature effects on the shear behaviour of tack coat emulsions used in flexible pavements", International Journal of Pavement Engineering, vol. 6, no. 1, pp. 39-46.
[50] Recasens, R.M., Martínez, A. & Jiménez, F.P. 2006, Evaluation of effect of heat-adhesive emulsions for tack coats with shear test: From the road research laboratory of Barcelona.
[51] Recasens, R.M., Martínez, A. & Jiménez, F.P. 2005, "Assessing heat-adhesive emulsions for tack coats", Proceedings of the Institution of Civil Engineers: Transport, vol. 158, no. 1, pp. 45-51.
[52] Santagata, F.A., Ferrotti, G., Partl, M.N. & Canestrari, F. 2009, "Statistical investigation of two different interlayer shear test methods", Materials and Structures/Materiaux et Constructions, vol. 42, no. 6, pp. 705-714.
[53] UNE-EN 13108-1 2008, Bituminous mixtures. Material specifications. Part 1: Asphalt concrete. [Mezclas bituminosas. Especificaciones de materiales. Parte 1: Hormigón bituminoso.], European Standard edn.
[54] Partl, M.N. & Raab, C. 1999, "Shear adhesion between top layers of fresh asphalt pavements in Switzerland", 7th Conference on asphalt pavements for Southern Africa, .
[55] Khweir, K. & Fordyce, D. 2003, "Influence of layer bonding on the prediction of pavement life", Proceedings of the Institution of Civil Engineers: Transport, vol. 156, no. 2, pp. 73-83.
[56] Diakhate, M., Millien, A., Phelipot-Mardele, A. & Petit, C. 2004, "Fatigue behaviour of tack coats in the pavement structures under shear [Comportement à la fatigue en cisaillement des couches d'accrochage dans les structures de chaussée]", 22 ème rencontres universitaires de génie civil, pp. 3-4.
[57] Muench, S.T. & Moomaw, T. 2008, De-bonding of hot mix asphalt pavements in Washington State: An initial investigation, 1st edn, Washington State Dept. of Transportation, Office of Research & Library Services, Washington.

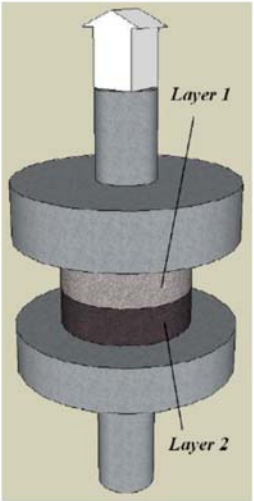

Fig. 1. ENDACMA tensile test.

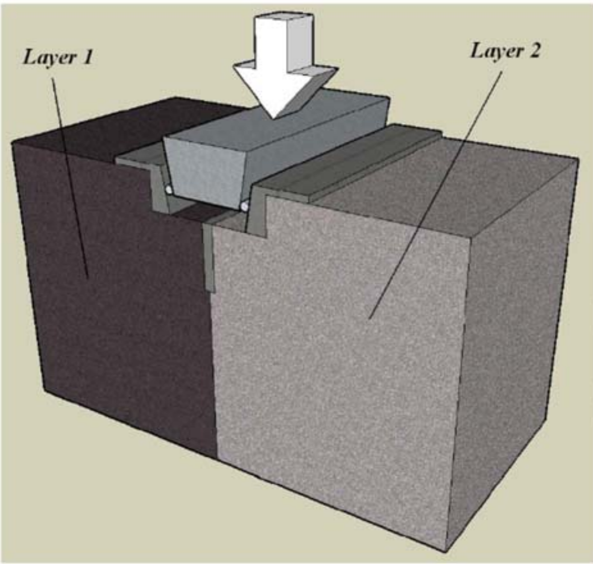

Fig. 2. Wedge-Splitting Test.

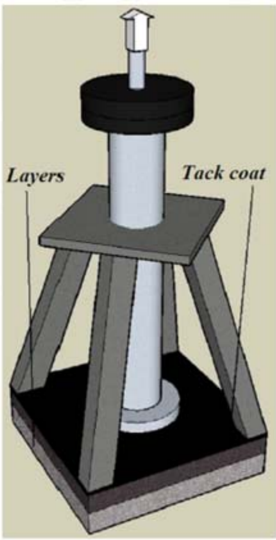

Fig. 3. UTEP Pull-Off Device.

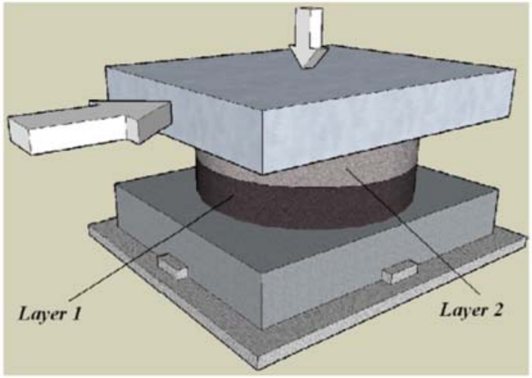

Fig. 4. ASTRA Shear Test.

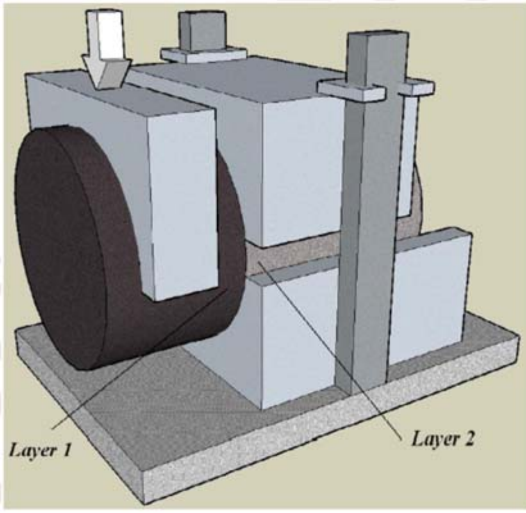

Fig. 5. LPDS Tester.

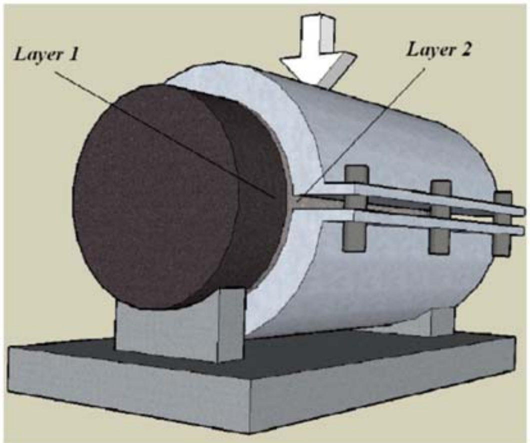

Fig. 6. LCB Shear Test.

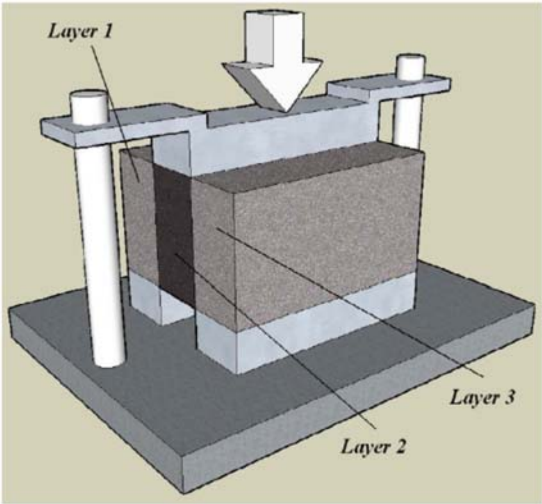

Fig. 7. Double Shear Test.

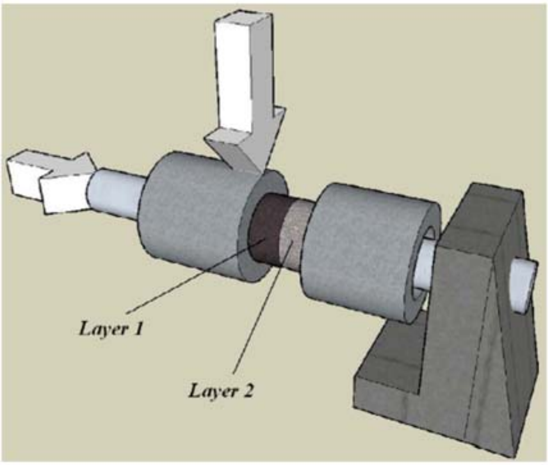

Fig. 8. Direct Shear Test with Normal Load.

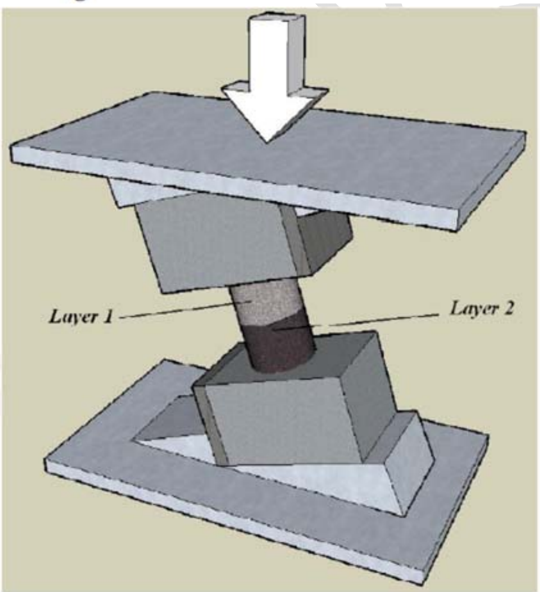

Fig. 9. Shear Fatigue Test.

Fig. 10. DoVeCan Test.

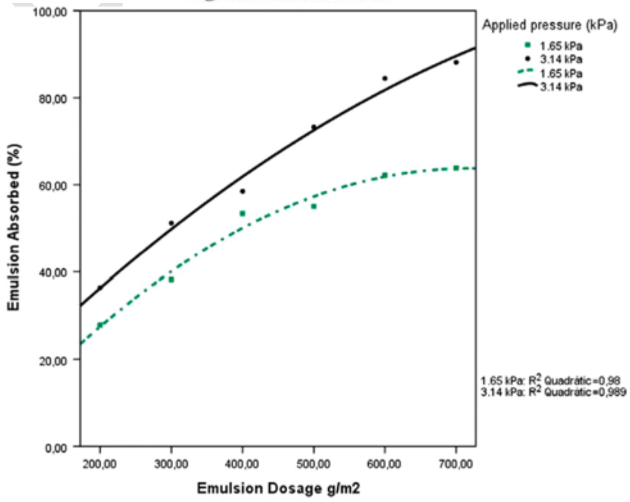

Fig. 11. Absorbed emulsion for pressures of 1.65 and 3.14 kPa.

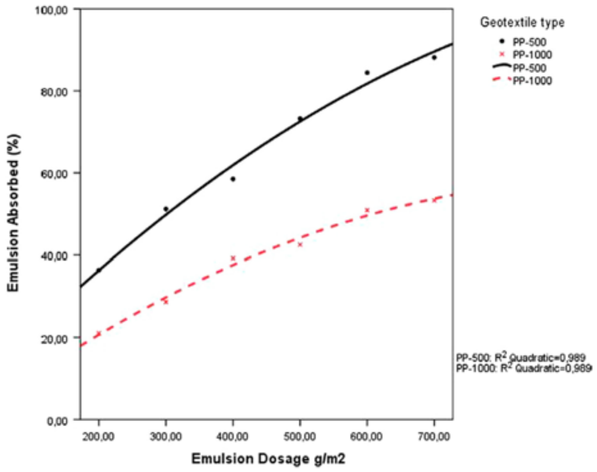

Fig. 12. Absorbed emulsion for PP-500 and PP-1000 geotextile types.

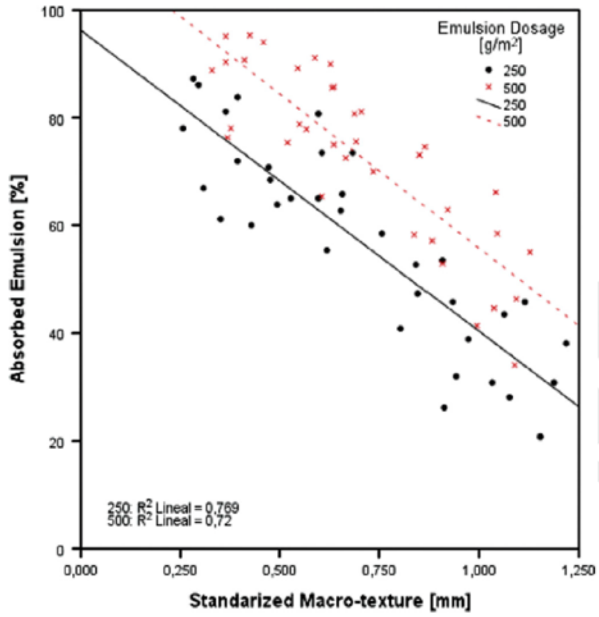

Fig. 13. Absorption tests.

Table 1
Geotextile characteristics.

	PP-500	PP-1000
Weight (g/m^2)	500	1000
Tensile strength *L*/*T* (kN/m)	11.3/8.2	33.6/24.
Break stretching *L*/*T* (%)	58/68	82/111
CBR static punching (N)	1840	5570
Water permeability (mm/s)	12	6
Water flow capacity in the plane (l/ms 10^{-5})	4.1	2.5