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Abstract

Geocomposites are extensively used in asphalt pavements as they provide significant long-term pavement benefits. Indeed, when correctly installed, geocomposites enhance road pavement performance thanks to their waterproofing properties, stress absorbing membrane interlayer (SAMI) action and improved mechanical strength of the pavement. Nevertheless, the presence of an interlayer causes de-bonding effects that negatively influence the overall pavement characteristics. This paper presents an experimental investigation aimed at comparing the interlayer bonding characteristics of four different geocomposites with an unreinforced reference configuration, laid on an Italian motorway section, in which the reinforcement depth and the lower layer surface condition (milled or new) were also varied. Interlayer shear strength (ISS) was measured, on both cores and laboratory produced specimens, through Leutner and Ancona Shear Testing Research and Analysis (ASTRA) equipment. The ISS results showed that geocomposites can be successfully applied directly on milled surfaces. Moreover, the application of a normal stress, as in the ASTRA device, tends to mitigate any difference related to the specimen heterogeneity. Finally, existing laws, which correlate the results obtained with different shear equipment on unreinforced interfaces, were generalized by considering the presence of geocomposites and the corresponding ISS specification limits were proposed for both ASTRA and Leutner test.

KEYWORDS: Asphalt pavements, Interlayer bonding, Geocomposites, Reinforcements, Interface Shear Strength, Field Performance

1. Introduction

Reinforcement systems are often employed within asphalt pavement layers for maintenance and rehabilitation purpose, with the aim of preventing or delaying the development of cracks. Nowadays, increasing traffic loadings generate accelerated functional and structural distresses, requiring frequent and expensive maintenance activities. In this scenario, geocomposites can be used as cost-effective, long-lasting and sustainable rehabilitation methods. Indeed, they should allow an extension on the service life or a reduction in the overall pavement thickness (Correia & Zornberg, 2016), also providing significant environmental benefits.

Geocomposites are usually obtained as a combination of geomembranes with geosynthetics (e.g. geogrids), in order to achieve benefits in terms of stress absorbing and waterproofing effects (due to presence of the geomembrane) as well as improved tensile properties provided by the geosynthetic reinforcement (Canestrari et al., 2016; Khodaii et al., 2009; Pasquini et al., 2014). Nevertheless, the presence of any type of reinforcement at the interface causes an interlayer de-bonding effect (Brown et al. 2001; Canestrari et al., 2012; Ferrotti et al., 2011; Khodaii et al., 2009; Noory et al., 2017) that influences pavement response in terms of stress-strain distribution, resulting in near-surface cracking (Ingrassia et al., 2020; Park et al, 2021; Pasquini et al., 2015).

A good interlayer bonding condition is a key factor when the asphalt pavement performance is considered as good bonding allows a better distribution of the bending stresses induced by the traffic loads. In fact, improved interlayer bonding conditions can guarantee a decrease in the tensile strain at the bottom of each layer (Uzan et al., 1978) and reduce the slippage effect which can occur at the interface, especially in areas where high shear forces can arise due to braking and turning of heavy vehicle. In synthesis, when de-bonding occurs at the interface, the asphalt pavements can no longer act as a monolithic system and provide the expected load-bearing capacity, leading to a more rapid pavement failure (Ferrotti et al., 2011; Ran et al., 2019; Zamora-Barraza et al., 2010). For this reason, the evaluation of interlayer bonding is fundamental for a proper estimation of the pavement service life, especially when interlayer reinforced systems are employed (Noory et al. 2019).

The evaluation of interlayer bonding can be carried out through many different equipment characterized by different parameters, such as test speeds, specimen size and loading conditions (Canestrari et al., 2013; "Optim. Tack Coat HMA Place.," 2012; Raab et al., 2009). The most common and simple device has been designed by Leutner in 1979 (R. Leutner, 1979) and allows performing pure direct shear test without the application of normal stresses at the interface. However, several studies showed that a normal stress approximately equal to 0.2 MPa can be recommended when performing interlayer bonding characterization, to better reproduce the most critical traffic loading conditions (Ozer et al., 2012, Karshenas et al., 2014).

For this reason, the Ancona Shear Testing Research and Analysis (ASTRA) device (Canestrari et al., 2005; Santagata et al., 1993), able to carry out direct shear tests with the application of different levels of normal load, is more appropriate to better simulate the real in situ conditions.

Within a RILEM (Réunion Internationale des Laboratoires d'Essais et de Recherches sur les Matériaux et les Constructions) interlaboratory test on interlayer bonding (Canestrari et al., 2013), analytical laws were proposed to model the effect of several parameters (such as normal load, specimen size, temperature and test speed) on the Interlayer Shear Strength (ISS) measured with different shear testing equipment. These laws were obtained for interfaces located between two new asphalt concrete layers laid on field trials ("new on new"), with and without tack coat application and in absence of interlayer systems such as geocomposites.

Given this background, this research study aims at evaluating the bonding characteristics of asphalt pavements when rehabilitation techniques with geocomposites are considered. For this purpose, a field trial with the application of four different geocomposites was built on an Italian motorway section, by considering different surface conditions for the lower layer (milled or new) and different positions of the reinforcement within the rehabilitated pavement structure, since as these variables have a crucial incidence in absorbing tensile strains mobilized during loading (Saride & Kumar, 2017). Cores taken from the field trial and laboratory prepared specimens (with the same materials used in the field) were subjected to shear tests with both Leutner and ASTRA devices, by comparing the interlayer performance of geocomposites with an unreinforced reference configuration. Then, the existing correlations between different shear testing equipment (Canestrari et al., 2013) were generalized by considering the presence of geocomposites. Finally, ISS specification limits were proposed for both Leutner and ASTRA device when geocomposites interlayer systems are considered.

2. Field trial

The experimental investigation is based on the construction of a field trial along an in-service Italian motorway consisting of three sections with initial homogeneous characteristics, identified by using project historical data and visual inspections.

The sections, named as T1, T4 and T6, are located on the first right lane (width equal to 4 m), as represented in Figure 1. Maintenance works planned on Sections T1 and T6 represent a typical maintenance activity which can be completed in one night (avoiding too much discomfort to users), after the milling of the existing pavement layers (Figure 2). The two Sections (T1 and T6) have the same stratigraphy (11 cm base course and 4 cm porous wearing course) but a different subgrade bearing capacity. Specifically, a Heavy Weight Deflectometer (HWD) campaign, carried out immediately after the milling operations, provided a subgrade elastic modulus equal to 2670 MPa and 3720 MPa for Section T1 and T6, respectively.

Differently, section T4 represents a typical full-depth repair maintenance work consisting of the milling of the existing pavement followed by the construction of two base layers of 10 cm and 15 cm, respectively, and one porous wearing course of 4 cm. Since it is laid in three layers, it is not compatible with the one-night construction.

Each section was further divided into five subsections, characterized by different interface configurations (Figure 2). Four different types of geocomposites available on the market for road applications (coded as A, B, C and D) were compared with a reference unreinforced configuration (coded as N), where an unmodified bituminous emulsion was spread at the interface. In each section, the position of the geocomposites inside the pavement structure was also varied, as shown in Figure 2. Specifically, the geocomposites were applied on a milled lower layer surface in sections T1 and T6 (below the new base layer) and on a new surface in section T4 (between the two new base layers). It is worth noting that geocomposites were directly positioned over the lower layer surface without the application of a tack coat which seems to provide no improvement in the overall interlayer performance of the system, as shown by Pasquini et al., 2014; Pasquini et al., 2015. This procedure also guarantees compliance with the deadlines for carrying out the rehabilitation works, thanks to the reduced number of activities to be performed in one night.

3. Materials

3.1 Asphalt concrete

The asphalt concrete (AC) used as base course is characterised by a maximum aggregate size equal to 31.5 mm, with a 30% of Reclaimed Asphalt (RA).

The RA was an un-fractioned 0/14 class deriving from the milling of old binder and base motorway layers. The bitumen contained in the RA was an SBS polymer modified bitumen and its content was equal to 5% by aggregate weight.

The total bitumen content of the AC is equal to 4.05% by the aggregate weight, and the maximum theoretical density was 2.501 g/cm^3.

The porous asphalt concrete used as wearing course is characterized by a maximum aggregate size of 20 mm. The total bitumen content is equal to 5.25% by the aggregate weight and a 0.3% by aggregate weight of cellulose-glass fibre was added to prevent drain-down problems. In both cases, an SBS polymer modified bitumen was employed as virgin binder, whose characteristics are listed in Table 1.

3.2 Unmodified bituminous emulsion

The cationic bituminous emulsion used as tack coat in the reference unreinforced interface configuration N, is classified as C55B3 according to EN 13808 and is composed of 55% of unmodified residual bitumen. It is characterized by a medium-fast breaking class (class 3) and was applied with a dosage of 0.6 kg/m^2 (0.33 kg/m^2 of residual bitumen), typical value for new construction applications. The characteristics of the emulsion and of the residual bitumen are shown in Table 2.

3.3 Geocomposites

The geocomposites used in this study are coded as A, B, C and D and are supplied by producers in rolls 10÷15 m long and 1 m wide. They are classified as self-thermo-adhesive membranes and are provided with a removable silicone bottom film that preserves the thermo-adhesive compound (Figure 3.a). The upper surfaces of geocomposites B, C and D (Figure 3.b) are coated with sand and minerals which avoid sticking the roll coils and act as intermediary adhesion. Differently, the geocomposite A has a non-stick selvedge as upper surface (Figure 3.b). The reinforcement of geocomposites A, C and D consists of a fiberglass mesh, whereas the geocomposite B is characterised by a continuous sheet of non-directional glass fibers and high-duty non-woven polyester fabric. In addition, the products A, B and D are isotropic, whereas the geocomposite C is slightly more resistant to tensile stress in the transversal direction. The main characteristics of the geocomposites are summarized in Table 3.

4. Specimen preparation

4.1 Field cores

After the laying of the field trial, six cores with a nominal diameter of 100 mm were extracted for each interface configuration (N, A, B, C and D) from each section (T1, T4 and T6) for a total of 90 cores, characterized by different types of interface (unreinforced/reinforced and milled/new surface).

However, the cores sampled from section T1 were strongly disturbed during the extraction of the specimens from the core drill (by grabbing and pulling down the lower layer), making even impossible the use of some of them for laboratory investigations, due to the complete separation of the layers. Therefore, it is very important to pay attention during the coring activities to preserve the specimen interface from separation and avoid gathering incorrect testing results.

Before testing, each core was resized by cutting the upper layer about 40 mm above the geosynthetic position and the lower layer about 40 mm below the geosynthetic position, to obtain specimens with a total height equal to about 80 mm. Both layers are characterized by an air void content ranging between 5 and 6%.

4.2 Laboratory specimens

The materials used for the construction of the field trial were also employed in laboratory to obtain cylindrical specimens in order to carry out a laboratory investigation on the same unreinforced and reinforced interface configurations (N, A, B, C and D).

Double-layered square slabs (305x305 mm^2) were prepared through a Roller Compactor according to the EN 12697-33 standard. The underlying layer was compacted with a thickness of 40 mm and a target air void content of 5%. It was then cooled at room temperature for 3 hours before applying the tack coat (configuration N) or the geocomposites (A, B, C and D) on its surface. A 40 mm upper layer was then compacted with the same target air void content (5%). The compaction direction was then marked to carry out shear tests by applying interface shear displacements along the direction parallel to the traffic flow in the field. A set of five double-layered slabs were compacted, one for each interface configuration, i.e. one slab for the unreinforced reference interface (N) and one slab for each type of geocomposite (A, B, C and D). From each slab, five cylindrical specimens with a nominal diameter of 100 mm were cored. This condition was coded as T4_lab as the lower layer surface is new and can be compared with the cores extracted from section T4, where the geocomposites were applied on the surface of the new lower base course.

5. Experimental program and test methods

The interlayer bonding characteristics of geocomposite-reinforced interfaces (A, B, C and D) were compared with a reference unreinforced configuration (N) for evaluating the effectiveness of asphalt pavement rehabilitation techniques carried out with geocomposites.

This comparison was performed on both laboratory-produced specimens and cores extracted from the field trial described in Section 2. Moreover, a comparison between lower layer surface conditions (milled or new) was also carried out for all the five interface configurations (reference N with tack coat, geocomposite A, geocomposite B, geocomposite C and geocomposite D).

Two different types of shear tests were used to measure the Interlayer Shear Strength (ISS): the Leutner device and the Ancona Shear Testing Research and Analysis (ASTRA) device. The same number of specimens were tested with both equipment in each configuration and surface condition, as shown in Table 4. As above-mentioned, the cores extracted from section T1 were disturbed by the drilling operation, reducing the number of available specimens.

The Leutner is a direct "pure" shear device (Figure 4a), compliant with the European Standard prEN 12697-48. The lower part moves upward with a constant displacement rate equal to 50.8 ± 2 mm/min, while the upper part is in contrast with a load cell, which produces the shear load at the interface without normal stress. The shear force and the shear displacement are continuously measured during the test, allowing the determination of the ISS, i.e. the maximum interlayer shear stress calculated as ratio between the maximum shear force and the specimen interface area. The shear device can test cylindrical specimen with 150 mm or 100 mm nominal diameter. The tests were performed at a temperature of 20 °C and all the specimens were conditioned in a climatic chamber for at least 4 hours before testing.

The ASTRA device (Figure 4b) is a direct shear box, compliant with the European Standard prEN 12697-48. The double-layered specimen is located between two half-boxes, opportunely spaced to create an unconfined interlayer shear zone. During the test, the lower half-box is moved with a constant horizontal displacement rate equal to 2.5 mm/min, while a constant vertical load can be applied in order to obtain the target confining normal stress. Cylindrical specimens with a nominal diameter of 100 mm can be tested. The horizontal force, the horizontal displacement and the vertical displacement are recorded during the test, allowing the determination of the ISS. The whole apparatus is located in a climatic chamber for the temperature control. The tests were performed in standard conditions, corresponding to the application of a normal stress equal to 0.2 MPa and a temperature of 20 °C (UNI/TS 11214). All the specimens were conditioned at 20 °C in a climatic chamber for at least 4 hours before testing.

6 Results and Analysis

6.1 Leutner test results

The average values of ISS and the corresponding error bars obtained with the Leutner device for all the lower layer surface conditions (T1, T4, T6 and T4_lab) and interface configurations (N, A, B, C and D) are shown in Figure 5.

As above-mentioned, the results of section T1 cannot be considered reliable because the interface of the cores was highly disturbed during their extraction from the core drill, as demonstrated by ISS values lower than those of T6 (identical to T1), especially for the reinforced specimens. For this reason, T1 results are reported in white in Figure 5 and are only shown for comparison with T6, in order to highlight the relevance of the coring activities.

As expected, the unreinforced interface configuration N is characterized by the highest ISS value in all the conditions tested as compared to the reinforced interface configuration, due to the de-bonding effect provided by the geocomposites (Brown et al., 2001; Canestrari et al., 2012; Ferrotti et al., 2011; Khodaii et al., 2009). Moreover, the interface N showed higher strengths in the new lower layer surface condition (T4) with respect to the milled one (T6). This is probably due to the “fresh” modified bitumen of the AC laid as new lower layer, which is more influential than the roughness induced by the milling operations. On the contrary, section T6 showed higher ISS values than section T4 in the presence of geocomposites (except for D configuration), supporting the possibility of applying the geocomposites directly on the top of milled surfaces, unlike other widely used reinforcement types (e.g. geogrid) which require a levelling thin layer before their application (Pasquini et al., 2015).

The geocomposite C applied on section T6 showed the lowest de-bonding effect, providing ISS values similar to the unreinforced interface N. On the contrary, the other reinforced interfaces (A, B and D) provided a higher de-bonding compared to the unreinforced interface N, as testified by lower ISS values. Differently, the laboratory prepared specimens (T4_lab) showed similar ISS values for the geocomposites B, C and D, whereas the geocomposite A provided the lowest value.

6.2 ASTRA test results

The average ISS results of ASTRA tests and the corresponding error bars for all the conditions tested are presented in Figure 6.

Also in this case, the ASTRA results of section T1 (in white in Figure 6) cannot be considered because the cores were highly disturbed during their extraction from the core drill.

As for the Leutner test, the unreinforced interface N is characterized by the highest ISS values in all the conditions studied, even though it also showed the highest dispersion values. This can lead to the conclusion that the application of geocomposites (having lower dispersions) could mitigate differences related to specimen production or core extraction.

Geocomposites A, C and D applied over the milled surface (T6) provided similar ISS values, which are slightly higher than those obtained for the geocomposite B, whose composition could probably cause lower adhesion properties with the milled surface. In fact, the geocomposite B is the only one that does not have a reinforcement grid but is composed of a continuous and quite rigid sheet of non-directional glass fibres and high-duty non-woven polyester fabric. For this reason, it probably establishes lower adhesion with the milled surface, creating a higher separation effect, which is expressed in lower ISS values. When a more regular surface is considered, as in the case of section T4, analogous ISS values were obtained for all the reinforced interfaces, with slightly higher strengths for the geocomposite B. However, the substantially equivalent results obtained for the two field lower layer surface conditions (milled T6 and new T4) in the reinforced interface configurations (A, B, C and D), demonstrated that the presence of the geocomposites tends to mitigate also differences between milled and new lower layer surface, leading to the conclusion that they can be successfully applied directly on the top of milled surfaces. Differently, the unreinforced interface N showed slightly higher strengths for the section T4 (new), probably due to the availability of “fresh” modified bitumen on the lower layer surface.

The ISS results obtained on specimens prepared in laboratory (T4_lab) showed that geocomposites B and D provided the higher strengths between the reinforced interfaces, whereas A and C provided almost identical performance.

7 Influence of testing speed and normal stress on ISS

As above-mentioned, in standard conditions, Leutner and ASTRA tests are carried out with different testing speed (50.8 and 2.5 mm/min, respectively) and normal stress σ_n applied (0.0 MPa and 0.2 MPa, respectively). The higher dispersion of Leutner results (Figure 5) with respect to ASTRA results (Figure 6) allows observing that the application of the normal stress σ_n= 0.2 MPa in the ASTRA tests seems to mitigate possible differences linked to the heterogeneity of the specimens.

In this section, existing laws which correlate ISS values obtained with different shear testing equipment in the case of unreinforced interfaces and new lower layer surface (Canestrari et al., 2013), are generalized by considering also the presence of geocomposites at the interface. The interlaboratory test on interlayer bonding carried out within the RILEM Technical Committee "Advances in Interlaboratory Testing and Evaluation of Bituminous Materials" (Canestrari et al., 2013), provided Eq. (1) which allows obtaining the ISS value at a generic testing speed v_x (ISS_{vx}) by knowing the ISS at the speed v_1 (ISS_{v1}), in absence of normal stress:

$$ISS_{vx} = ISS_{v1} \cdot \left(\frac{v_x}{v_1}\right)^{0.22} \quad (1)$$

By applying Eq. (1) to the Leutner results measured in laboratory at 50.8 mm/min ($ISS_{Leut50.8}$), the ISS associated with a Leutner test performed at 2.5 mm/min ($ISS_{Leut2.5}$) can be obtained through Eq. (2):

$$ISS_{Leut2.5} = ISS_{Leut50.8} \cdot \left(\frac{2.5}{50.8}\right)^{0.22} \quad (2)$$

Canestrari et al., 2013 also found further relationship, which considers the influence of the normal stress. Specifically, the ISS value when a normal stress σ_n is applied (in this case, ISS_{ASTRA}) can be obtained by knowing the ISS value found in absence of normal stress at the same testing speed (in this case, $ISS_{Leut2.5}$), as follows:

$$ISS_{ASTRA} = (1 + 0.38 \cdot \sigma_n) \cdot ISS_{Leut2.5} + (0.74 \cdot \sigma_n) \quad (3)$$

where the parameter (1+0.38· σ_n) is associated with the contribution of the cohesion (which includes also the dilatancy, equal to 0.38· σ_n) and the parameter (0.74· σ_n) with the residual friction (Canestrari et al., 2005). The laws defined by Canestrari et al., 2013 for unreinforced interfaces were also confirmed by Ortiz-Ripolla et al., 2020 even after the conclusion of the RILEM project.

The generalization of Eq. (2) and Eq. (3) for interfaces with geocomposites can be performed by introducing three parameters α_1, α_2 and α_3, as shown in Eq. (4) and Eq. (5):

$$ISS_{Leut2.5} = ISS_{Leut50.8} \cdot \left(\frac{2.5}{50.8}\right)^{\alpha_1} \quad (4)$$

$$ISS_{ASTRA} = (1 + \alpha_2 \cdot \sigma_n) \cdot ISS_{Leut2.5} + (\alpha_3 \cdot \sigma_n) \quad (5)$$

where $\sigma_n = 0.2$ MPa and α_1, α_2, α_3 were obtained by means of least squares optimization between the ASTRA testing results $(ISS_{ASTRA})_{meas}$ obtained with T4 and T4_lab specimens and the corresponding ASTRA values $(ISS_{ASTRA})_{calc}$ calculated with Eq. (5), as a function of the $ISS_{Leut2.5}$ values obtained by introducing in Eq. (4) the Leutner test results related to the same testing conditions (T4 and T4_lab). The measured data and the results of the data analysis are summarized in Table 5, which allowed the determination of the following values for the three parameters: $\alpha_1 = 0.35$; $\alpha_2 = 0.20$; $\alpha_3 = 0.73$, calculated for $\sigma_n = 0.2$ MPa.

It can be observed that the values obtained for α_1, α_2 and α_3 are consistent and meaningful when compared with the corresponding parameters obtained in previous study for unreinforced interfaces. In fact, a higher value of α_1 (0.35 versus 0.22 of the unreinforced interface) can be explained by the presence of the geocomposite, which is rich in bitumen and tends to amplify the effects of loading speed thanks to its viscoelasticity. The presence of a higher bitumen amount in the geocomposites also tends to reduce the asphalt mixture interlocking, causing a reduction of the dilatancy contribution, as shown by the reduction of the value α_2 (0.20 versus 0.38). Finally, in the case of geocomposites, characterized by non-null values of residual cohesion (Pasquini et al., 2014; Pasquini et al., 2015), the α_3 value is not directly associated with the residual friction but with the overall interlayer shear strength after the interface failure (combination of residual cohesion and residual friction).

By plotting the testing results $(ISS_{ASTRA})_{meas}$ and the calculated $(ISS_{ASTRA})_{calc}$ ASTRA values, it emerges that the data points are very close to the equality line, highlighting the good agreement between the measured and calculated data. Therefore, the practical equations to be used to correlate ISS results obtained with different shear equipment in the case of interfaces reinforced with geocomposites can be written, when $\sigma_n = 0.2$ MPa, as follows:

$$\tau_{Leut2.5} = \tau_{Leut50.8} \cdot \left(\frac{2.5}{50.8}\right)^{0.35} \quad (6)$$

$$\tau_{ASTRA} = (1 + 0.20 \cdot \sigma_n) \cdot \tau_{Leut2.5} + (0.73 \cdot \sigma_n) \quad (7)$$

8 Technical Specification limits for ISS values

Although proper interlayer bonding conditions are fundamental to guarantee good asphalt pavement performance, only a limited number of European Countries have adopted minimum specification limits. All of them are based on the results obtained with the Leutner device or with similar equipment, such as the Swiss Layer-Parallel Direct Shear (LPDS) apparatus. Specifically, Germany and Switzerland technical specifications (07 ZTV Asphalt-StB, 2007) require that the ISS value obtained with Leutner test performed on field cores with a diameter of 150 mm must be ≥ 0.85 MPa for the upper interface (i.e. between wearing and binder course) and ≥ 0.65 MPa for lower interfaces (e.g. between binder and base course). Differently, in the United Kingdom (UK), the technical specifications (MCDHW, 2018) require ISS ≥ 1.0 MPa for interfaces located at depths ≤ 75 mm, and ISS ≥ 0.50 MPa for interfaces located at greater depths.

Since geocomposites are characterized by a high dosage of bituminous materials to ensure stress absorbing and waterproofing effects, their application is not recommended in correspondence of the upper interface where a high bonding level is required. For this reason, the UK criterion which considers ISS ≥ 0.50 MPa for interfaces located at depths greater than 75 mm was selected in this study as specification limit for Leutner tests. The corresponding minimum specification limit to consider when performing ASTRA tests in standard conditions (σ_n=0.2 MPa) is equal to 0.33 MPa, which is obtained by applying Eq. (6) and Eq. (7) starting from $\tau_{Leut50.8}$ = 0.50 MPa.

In order to check if these limits can be considered suitable for verifying the field requirements of interfaces reinforced with geocomposites, ASTRA and Leutner test results of section T4 (new lower layer surface) were plotted in Figure 8. The analysis of the plot shows that the minimum value of 0.50 MPa (taken from the literature) for Leutner device and 0.33 MPa (derived from Eqs. (6) and (7)) for ASTRA equipment, can be likely used as "equivalent" specification limits in the evaluation of the field performance after geocomposites application. Moreover, the experimental data of section T6 (Figure 8) shows that the generalization proposed for interfaces with geocomposites on new lower layer surface seems to be applicable in the case of milled lower layer surface as well.

Nevertheless, it is also necessary to investigate if during the laboratory qualification phase, aimed at selecting the most appropriate geocomposite to be used in the field, these limits need to be revised.

The comparison between the laboratory produced specimens and the corresponding field cores was thus performed in parity of new lower layer surface condition, by plotting the results obtained for T4_lab and T4 condition, respectively. Figure 9 shows that the field cores (T4) without reinforcement (configuration N) are characterized by higher strengths than the analogous laboratory specimens (T4_lab). On the contrary, the field cores of the reinforced interface configurations (A, B C and D) are characterized by lower ISS values with respect to the specimens prepared in laboratory, for both ASTRA and Leutner test. This is due to the possibility of applying more properly the geocomposites in laboratory with respect to the field condition, guaranteeing higher strengths.

Therefore, during the laboratory qualification phase, more restrictive criteria for the definition of specification limits must be defined in order to achieve the required field performance. The results shown in Figure 9.a can be used for the definition of these pre-qualification limits for the Leutner test. Specifically, an increase by 50% of the value accepted for field cores, i.e. 0.75 MPa, was reasonably proposed as specification limit for the qualification phase of laboratory produced specimens, based on the comparison of the data collected from the Leutner test for Sections T4_lab and T4 (Figure 5). Analogously, Eqs. (6) and (7) can be used to obtain the qualification phase specification limit for ASTRA test, by considering $\tau_{Leut50.8}$ = 0.75 MPa. A value equal to 0.42 MPa was obtained and reported in Figure 9.b.

The defined ISS minimum specification limits for interfaces reinforced with geocomposites are summarized in Table 6. The analysis of Figure 9 shows that all laboratory specimens and cores meet the proposed ISS minimum specification limits and, given this promising outcome, their validation by further laboratory and/or field investigation is recommended.

9 Conclusions

This research aimed at evaluating the effectiveness of asphalt pavement rehabilitation techniques by using different geocomposites. The interlayer bonding characteristics of four different geocomposites were compared with an unreinforced reference configuration, by using laboratory compacted specimens and cores taken from a field trial built on an Italian motorway section consisting of three distinct sections, each characterised by a different reinforcement position and lower layer surface conditions (new or milled). The interlayer shear strength (ISS) was measured through Leutner and Ancona Shear Testing Research and Analysis (ASTRA) equipment, allowing the following conclusions to be drawn:

- the application of geocomposites causes a de-bonding effect at the interface of asphalt concrete pavements proved by the reduction of ISS values;
- geocomposites can be successfully applied directly on the top of milled surfaces as they can mitigate differences related to specimen characteristics and lower layer surface conditions. Moreover, this operation allows the speeding up of maintenance activities while avoiding users discomfort and satisfying construction needs;
- the application of a normal stress during shear tests, as in the case of ASTRA device, can reduce the dispersion of the ISS results;
- the laws which correlate the results obtained with different shear testing equipment in the case of unreinforced interfaces were generalized for Leutner and ASTRA test results by considering the presence of geocomposites;
- ISS minimum technical specification limits for interfaces reinforced with geocomposites were proposed for Leutner and ASTRA tests, both in the qualification phase and in the

performance field assessment (after pavement rehabilitation). These limits are intended as initial proposal that has to be validated with further investigations.

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Tables

Table 1. Characteristics of Polymer Modified Binder

Binder characteristics	Standard	Unit	Reference values	Measured values
SBS polymer content by weight	-	[%]	3.8	-
Penetration @25°C	EN 1426	[dmm]	50-70	54
Ring and ball softening point	EN 1427	[°C]	≥65	71
Elastic recovery @25°C, 25 cm/min	EN 13398	[%]	≥50	89
Dynamic viscosity @135°C	ASTM D4402	[Pa·s]		1.24
Mass loss after RTFOT	EN 12607-1	[%]	≤0.5	0.1
Penetration @25°C after RTFOT	EN 1426	[%]	≥50	50
Ring and ball softening point after RTFOT	EN 1427	[°C]	≥65	77

Table 2. Characteristics of the bituminous emulsion for tack coat (EN 13808)

Requirements	**Characteristics**	**Unit**	**Performance**		
			min	**max**	**class**
Binder contents	Azeotropic distillation	[%]	53	57	5
Viscosity	Efflux time at 40°C, 2mm	[s]	15	70	3
Breaking Index	Natural filler method		70	155	3
Characteristics of the binder extracted by evaporation					
Consistency at intermediate service temperatures	Penetration at 25°C	dmm		220	5
Consistency at high service temperatures	Softening point	°C	35		8

Table 3. Characteristics of the geocomposites

Property	**Geocomposites**			
	A	B	C	D
Thickness [mm]	2.5	2.5	1.8/2.5	2.5
Mesh size [mm]	12.5	Non directional	12.5	12.5
Tensile strength L/T [kN/m]	40/40	35/35	40/44	40/40
Elongation at breaking L/T [%]	4/4	30/30	3/3,5	4/4
Geomembrane compound	SBS polymer modified bitumen	SBS polymer modified bitumen	SBS polymer modified bitumen	SBS polymer modified bitumen

Table 4. Number of specimens tested for Leutner and ASTRA investigation

Specimen type	Lower layer surface condition	Interface configuration				
		N	A	B	C	D
Field	T1	1	2	2	3	3
	T4	3	3	3	3	3
	T6	3	3	3	3	3
Laboratory	T4_lab	2	2	2	2	2

Table 5. Test results and data analysis for the calculation of α_1, α_2 and α_3

Section	Interface configuration	$ISS_{Leut50.8}$ (MPa)	$ISS_{Leut2,5}$ (MPa)	$(ISS_{ASTRA})_{meas}$ (MPa)	$(ISS_{ASTRA})_{calc}$ (MPa)
T4	A	0.492	0.171	0.326	0.324
	B	0.516	0.180	0.384	0.333
	C	0.706	0.246	0.372	0.402
	D	0.662	0.231	0.358	0.386
T4_lab	A	0.783	0.273	0.431	0.430
	B	0.997	0.347	0.585	0.507
	C	0.940	0.327	0.423	0.487
	D	1.015	0.354	0.522	0.514

Table 6. ISS specification limits for interfaces reinforced with geocomposites

Phase	**Leutner** **@20°C; 50.8 mm/min; 0.0 MPa**	**ASTRA** **@20°C; 2.5 mm/min; 0.2 MPa**
Laboratory qualification	≥ 0.75 MPa	≥ 0.42 MPa
In the field	≥ 0.50 MPa	≥ 0.33 MPa

Figures

(a) (b)

Figure 1. Field trial: (a) milled surface; (b) geocomposite application

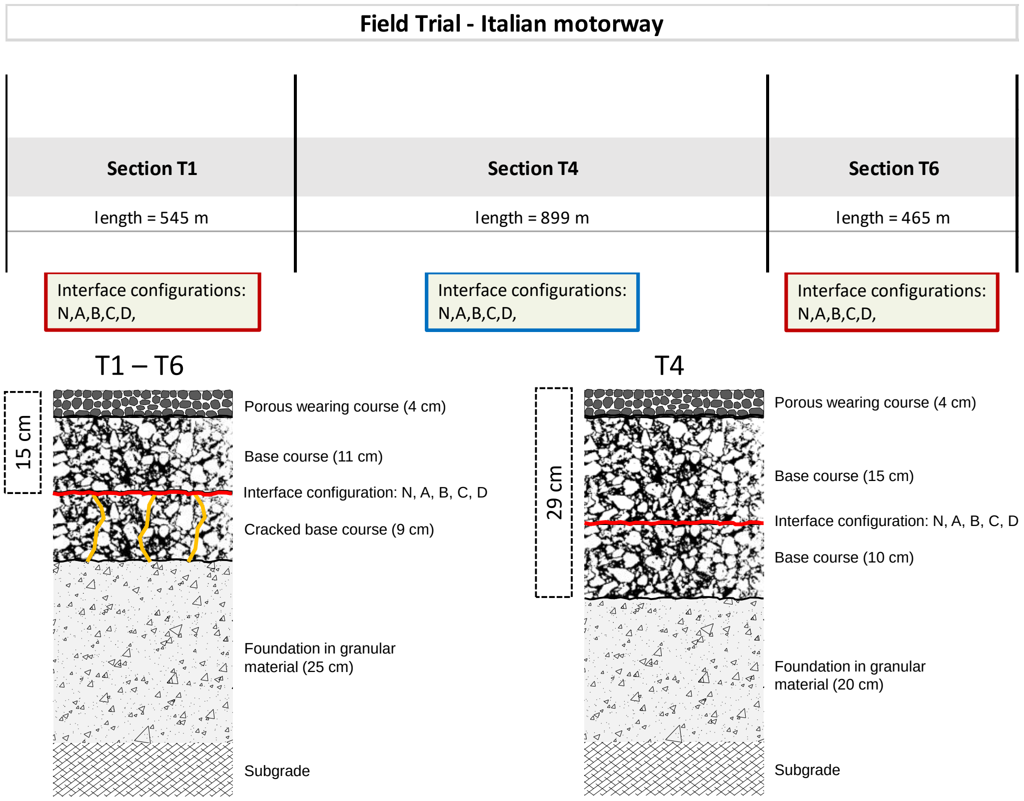

Figure 2. Field trial characteristics, stratigraphy and interface configuration

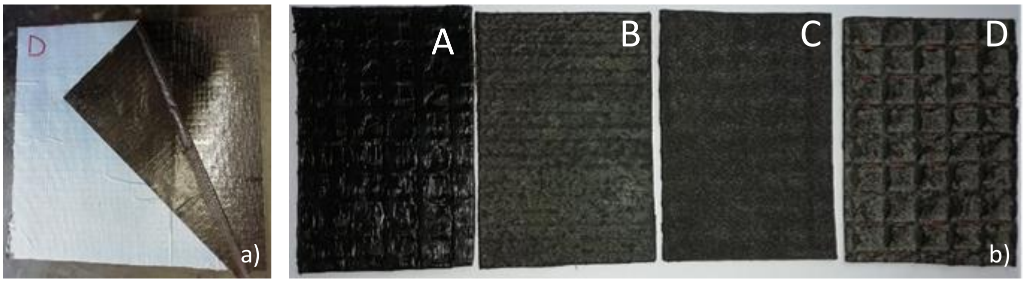

Figure 3. Geocomposites: (a) Lower surface; (b) Upper surfaces

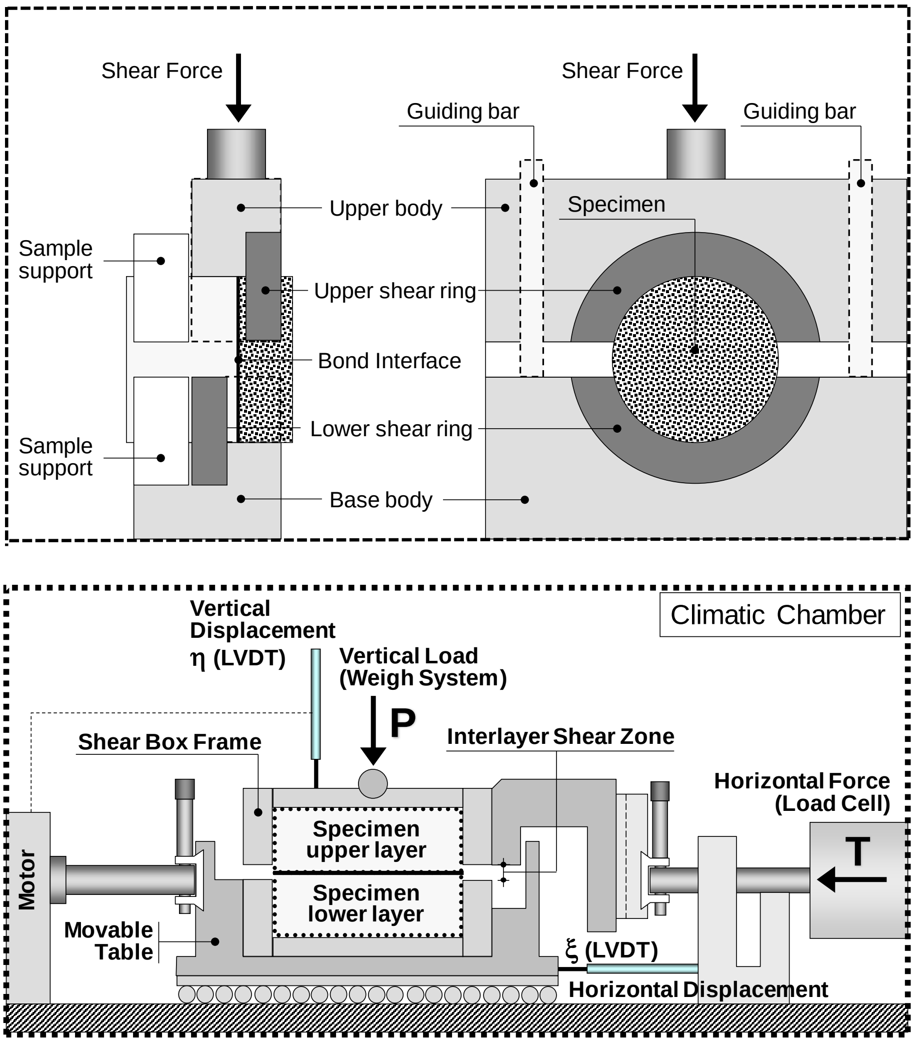

Figure 4. Working scheme: a) Leutner device; b) ASTRA device

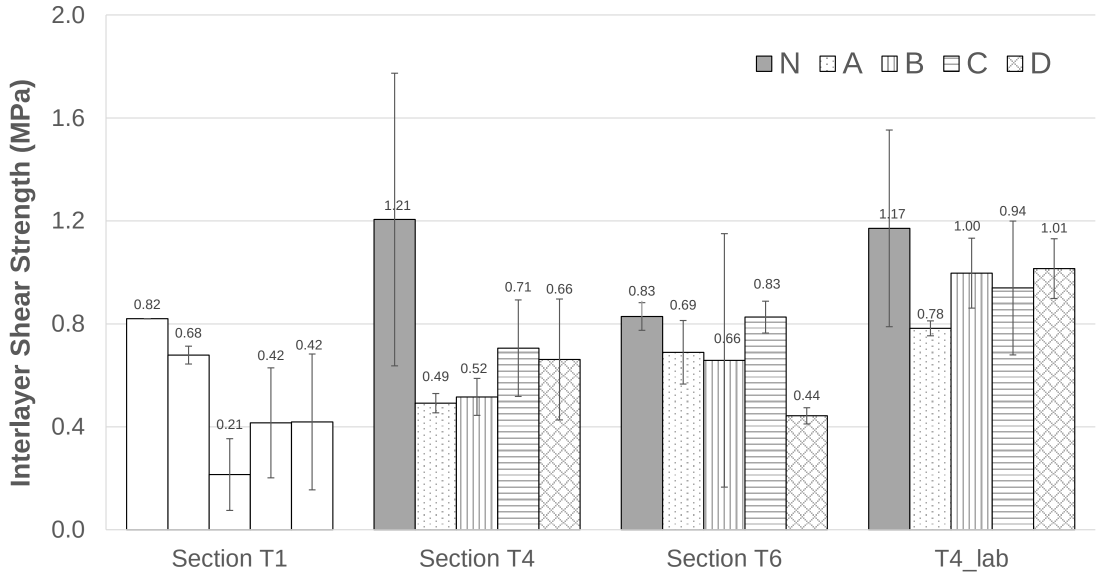

Figure 5. Average values of ISS for Leutner test

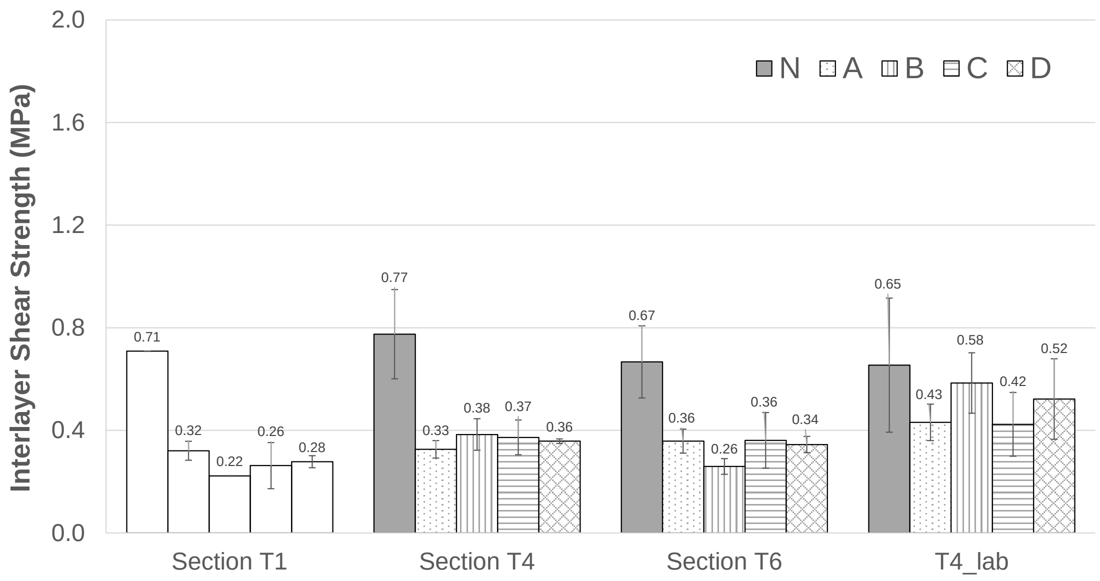

Figure 6. Average values of ISS for ASTRA tests

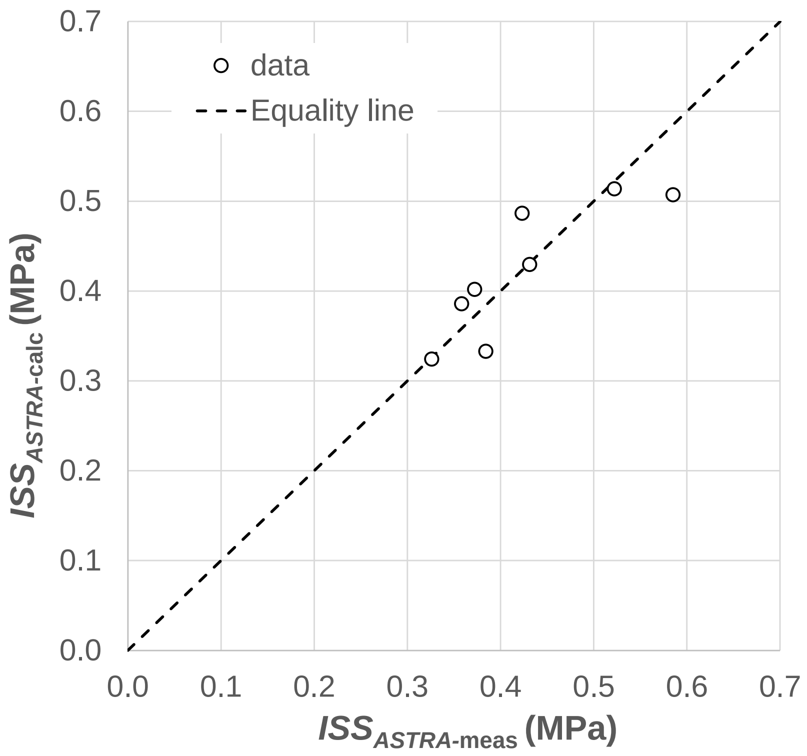

Figure 7. Comparison of measured and calculated ISS values for ASTRA tests

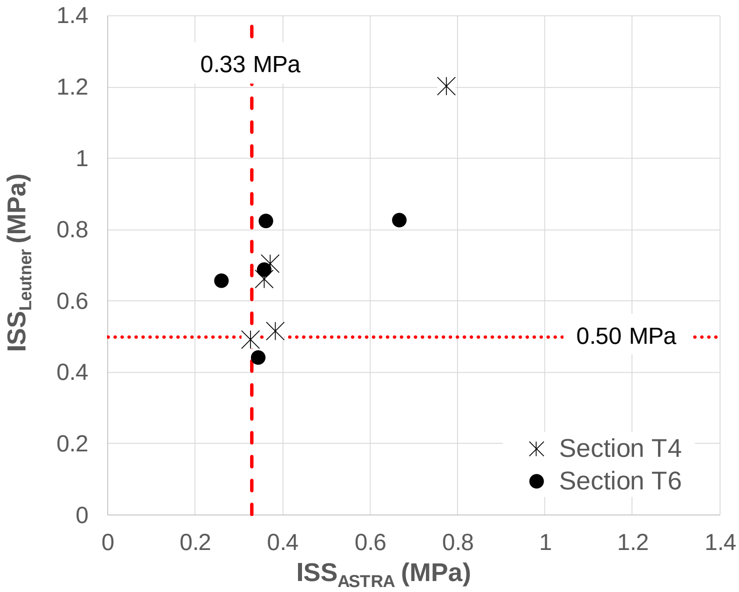

Figure 8. ISS for sections T4 and T6 and specification limits for Leutner and ASTRA tests

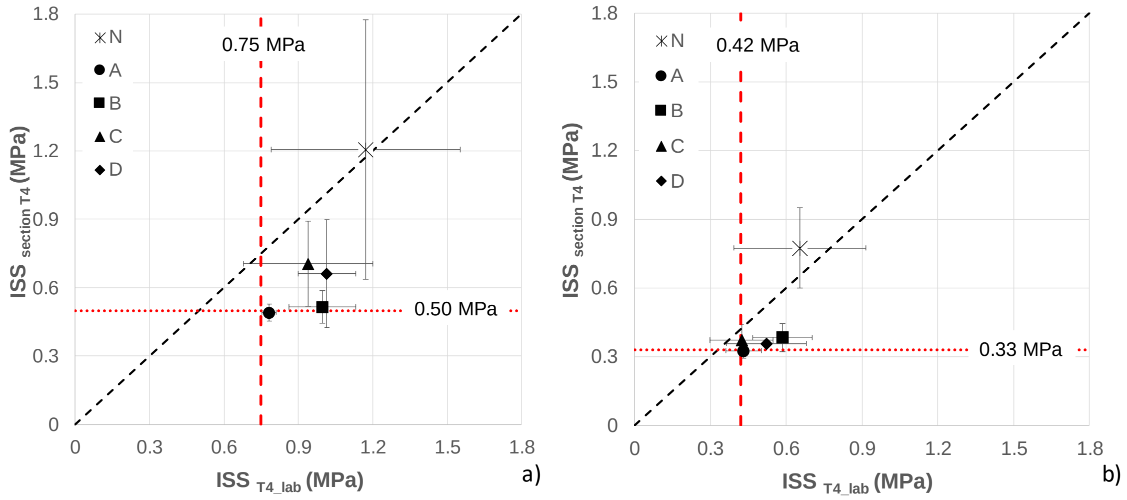

Figure 9. Comparison between laboratory and field specimens for the new lower layer surface condition: (a) Leutner; (b) ASTRA