

UNIVERSITÀ POLITECNICA DELLE MARCHE Repository ISTITUZIONALE

Interlayer bonding characterization of interfaces reinforced with geocomposites in field applications

This is the peer reviewd version of the followng article:

Original

Interlayer bonding characterization of interfaces reinforced with geocomposites in field applications / Canestrari, F.; Cardone, F.; Gaudenzi, E.; Chiola, D.; Gasbarro, N.; Ferrotti, G. - In: GEOTEXTILES AND GEOMEMBRANES. - ISSN 0266-1144. - STAMPA. - 50:1(2022), pp. 154-162. [10.1016/j.geotexmem.2021.09.010]

Availability: This version is available at: 11566/295083 since: 2024-04-29T13:18:44Z

Publisher:

Published DOI:10.1016/j.geotexmem.2021.09.010

Terms of use:

The terms and conditions for the reuse of this version of the manuscript are specified in the publishing policy. The use of copyrighted works requires the consent of the rights' holder (author or publisher). Works made available under a Creative Commons license or a Publisher's custom-made license can be used according to the terms and conditions contained therein. See editor's website for further information and terms and conditions. This item was downloaded from IRIS Università Politecnica delle Marche (https://iris.univpm.it). When citing, please refer to the published version.

note finali coverpage

(Article begins on next page)

1	Interlayer bonding characterization of interfaces reinforced with
2	geocomposites in field applications
3	
4	F. Canestrari ¹ , F. Cardone ¹ , E. Gaudenzi ^{*1} , D. Chiola ² , N. Gasbarro ³ , G. Ferrotti ¹
5	¹ Department of Civil and Building Engineering and Architecture, Università Politecnica delle
6	Marche, 60131 Ancona, Italy; <u>f.canestrari@staff.univpm.it</u> ; <u>f.cardone@staff.univpm.it</u> ;
7	g.ferrotti@staff.univpm.it;
8	² Autostrade Tech, Via A. Bergamini 50, 00159 Roma, Italy, <u>davide.chiola@autostrade.it</u> ;
9	³ Autostrade per l'Italia, Via A. Bergamini 50, 00159 Roma, Italy,
10	nicoletta.gasbarro@autostrade.it;
11	*Corresponding author.
12	E-mail address: <u>e.gaudenzi@pm.univpm.it</u> (E. Gaudenzi ¹)
13	¹ Department of Civil and Building Engineering and Architecture, Università Politecnica delle
14	Marche, 60131 Ancona, Italy;
15	
16	Abstract
17	Geocomposites are extensively used in asphalt pavements as they provide significant long-
18	term pavement benefits. Indeed, when correctly installed, geocomposites enhance road
19	pavement performance thanks to their waterproofing properties, stress absorbing membrane
20	interlayer (SAMI) action and improved mechanical strength of the pavement. Nevertheless, the
21	presence of an interlayer causes de-bonding effects that negatively influence the overall
22	pavement characteristics. This paper presents an experimental investigation aimed at

23	comparing the interlayer bonding characteristics of four different geocomposites with an
24	unreinforced reference configuration, laid on an Italian motorway section, in which the
25	reinforcement depth and the lower layer surface condition (milled or new) were also varied.
26	Interlayer shear strength (ISS) was measured, on both cores and laboratory produced
27	specimens, through Leutner and Ancona Shear Testing Research and Analysis (ASTRA)
28	equipment. The ISS results showed that geocomposites can be successfully applied directly on
29	milled surfaces. Moreover, the application of a normal stress, as in the ASTRA device, tends to
30	mitigate any difference related to the specimen heterogeneity. Finally, existing laws, which
31	correlate the results obtained with different shear equipment on unreinforced interfaces, were
32	generalized by considering the presence of geocomposites and the corresponding ISS
33	specification limits were proposed for both ASTRA and Leutner test.
34	
35	KEYWORDS: Asphalt pavements, Interlayer bonding, Geocomposites, Reinforcements,
36	Interface Shear Strength, Field Performance
37	
38	1. Introduction
39	Reinforcement systems are often employed within asphalt pavement layers for
40	maintenance and rehabilitation purpose, with the aim of preventing or delaying the
41	development of cracks. Nowadays, increasing traffic loadings generate accelerated functional
42	and structural distresses, requiring frequent and expensive maintenance activities. In this
43	scenario, geocomposites can be used as cost-effective, long-lasting and sustainable
44	rehabilitation methods. Indeed, they should allow an extension on the service life or a
45	reduction in the overall pavement thickness (Correia & Zornberg, 2016), also providing
46	significant environmental benefits.
47	Geocomposites are usually obtained as a combination of geomembranes with
48	geosynthetics (e.g. geogrids), in order to achieve benefits in terms of stress absorbing and

49 waterproofing effects (due to presence of the geomembrane) as well as improved tensile

50 properties provided by the geosynthetic reinforcement (Canestrari et al., 2016; Khodaii et al.,

51 2009; Pasquini et al., 2014). Nevertheless, the presence of any type of reinforcement at the

52 interface causes an interlayer de-bonding effect (Brown et al. 2001; Canestrari et al., 2012;

53 Ferrotti et al., 2011; Khodaii et al., 2009; Noory et al., 2017) that influences pavement

54 response in terms of stress-strain distribution, resulting in near-surface cracking (Ingrassia et

55 al., 2020; Park et al, 2021; Pasquini et al., 2015).

56 A good interlayer bonding condition is a key factor when the asphalt pavement

57 performance is considered as good bonding allows a better distribution of the bending stresses

58 induced by the traffic loads. In fact, improved interlayer bonding conditions can guarantee a

59 decrease in the tensile strain at the bottom of each layer (Uzan et al., 1978) and reduce the

60 slippage effect which can occur at the interface, especially in areas where high shear forces

61 can arise due to braking and turning of heavy vehicle. In synthesis, when de-bonding occurs at

62 the interface, the asphalt pavements can no longer act as a monolithic system and provide the

63 expected load-bearing capacity, leading to a more rapid pavement failure (Ferrotti et al., 2011;

64 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

66 interlayer reinforced systems are employed (Noory et al. 2019).

67 The evaluation of interlayer bonding can be carried out through many different equipment

68 characterized by different parameters, such as test speeds, specimen size and loading

69 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)

71 and allows performing pure direct shear test without the application of normal stresses at the

- 72 interface. However, several studies showed that a normal stress approximately equal to 0.2
- 73 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.

79 Within a RILEM (Réunion Internationale des Laboratoires d'Essais et de Recherches sur les 80 Matériaux et les Constructions) interlaboratory test on interlayer bonding (Canestrari et al., 81 2013), analytical laws were proposed to model the effect of several parameters (such as 82 normal load, specimen size, temperature and test speed) on the Interlayer Shear Strength (ISS) 83 measured with different shear testing equipment. These laws were obtained for interfaces 84 located between two new asphalt concrete layers laid on field trials ("new on new"), with and 85 without tack coat application and in absence of interlayer systems such as geocomposites. 86 Given this background, this research study aims at evaluating the bonding characteristics of 87 asphalt pavements when rehabilitation techniques with geocomposites are considered. For 88 this purpose, a field trial with the application of four different geocomposites was built on an 89 Italian motorway section, by considering different surface conditions for the lower layer 90 (milled or new) and different positions of the reinforcement within the rehabilitated pavement 91 structure, since as these variables have a crucial incidence in absorbing tensile strains 92 mobilized during loading (Saride & Kumar, 2017). Cores taken from the field trial and 93 laboratory prepared specimens (with the same materials used in the field) were subjected to 94 shear tests with both Leutner and ASTRA devices, by comparing the interlayer performance of 95 geocomposites with an unreinforced reference configuration. Then, the existing correlations 96 between different shear testing equipment (Canestrari et al., 2013) were generalized by 97 considering the presence of geocomposites. Finally, ISS specification limits were proposed for 98 both Leutner and ASTRA device when geocomposites interlayer systems are considered.

99

100

101 2. Field trial

102 The experimental investigation is based on the construction of a field trial along an in-

103 service Italian motorway consisting of three sections with initial homogeneous characteristics,

104 identified by using project historical data and visual inspections.

105 The sections, named as T1, T4 and T6, are located on the first right lane (width equal to 4

106 m), as represented in Figure 1. Maintenance works planned on Sections T1 and T6 represent a

107 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

109 Sections (T1 and T6) have the same stratigraphy (11 cm base course and 4 cm porous wearing

110 course) but a different subgrade bearing capacity. Specifically, a Heavy Weight Deflectometer

111 (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,

116 it is not compatible with the one-night construction.

117 Each section was further divided into five subsections, characterized by different interface 118 configurations (Figure 2). Four different types of geocomposites available on the market for 119 road applications (coded as A, B, C and D) were compared with a reference unreinforced 120 configuration (coded as N), where an unmodified bituminous emulsion was spread at the 121 interface. In each section, the position of the geocomposites inside the pavement structure 122 was also varied, as shown in Figure 2. Specifically, the geocomposites were applied on a milled 123 lower layer surface in sections T1 and T6 (below the new base layer) and on a new surface in 124 section T4 (between the two new base layers). It is worth noting that geocomposites were 125 directly positioned over the lower layer surface without the application of a tack coat which 126 seems to provide no improvement in the overall interlayer performance of the system, as

- 127 shown by Pasquini et al., 2014; Pasquini et al., 2015. This procedure also guarantees
- 128 compliance with the deadlines for carrying out the rehabilitation works, thanks to the reduced
- 129 number of activities to be performed in one night.

130 3. Materials

- 131 3.1 Asphalt concrete
- 132 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).

134 The RA was an un-fractioned 0/14 class deriving from the milling of old binder and base

135 motorway layers. The bitumen contained in the RA was an SBS polymer modified bitumen and

- its content was equal to 5% by aggregate weight.
- 137 The total bitumen content of the AC is equal to 4.05% by the aggregate weight, and the
- 138 maximum theoretical density was 2.501 g/cm³.
- 139 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
- 141 and a 0.3% by aggregate weight of cellulose-glass fibre was added to prevent drain-down
- 142 problems. In both cases, an SBS polymer modified bitumen was employed as virgin binder,
- 143 whose characteristics are listed in Table 1.
- 144
- 145 *3.2 Unmodified bituminous emulsion*

146 The cationic bituminous emulsion used as tack coat in the reference unreinforced interface

- 147 configuration N, is classified as C55B3 according to EN 13808 and is composed of 55% of
- 148 unmodified residual bitumen. It is characterized by a medium-fast breaking class (class 3) and
- 149 was applied with a dosage of 0.6 kg/m² (0.33 kg/m² of residual bitumen), typical value for new

150 construction applications. The characteristics of the emulsion and of the residual bitumen are

151 shown in Table 2.

153 3.3 Geocomposites

154 The geocomposites used in this study are coded as A, B, C and D and are supplied by 155 producers in rolls 10+15 m long and 1 m wide. They are classified as self-thermo-adhesive 156 membranes and are provided with a removable silicone bottom film that preserves the 157 thermo-adhesive compound (Figure 3.a). The upper surfaces of geocomposites B, C and D 158 (Figure 3.b) are coated with sand and minerals which avoid sticking the roll coils and act as 159 intermediary adhesion. Differently, the geocomposite A has a non-stick selvedge as upper 160 surface (Figure 3.b). The reinforcement of geocomposites A, C and D consists of a fiberglass 161 mesh, whereas the geocomposite B is characterised by a continuous sheet of non-directional 162 glass fibers and high-duty non-woven polyester fabric. In addition, the products A, B and D are 163 isotropic, whereas the geocomposite C is slightly more resistant to tensile stress in the 164 transversal direction. The main characteristics of the geocomposites are summarized in 165 Table 3. 166

167 4. Specimen preparation

168 *4.1 Field cores*

169 After the laying of the field trial, six cores with a nominal diameter of 100 mm were

170 extracted for each interface configuration (N, A, B, C and D) from each section (T1, T4 and T6)

171 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%.

183 *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).

187 Double-layered square slabs (305x305 mm²) were prepared through a Roller Compactor 188 according to the EN 12697-33 standard. The underlying layer was compacted with a thickness 189 of 40 mm and a target air void content of 5%. It was then cooled at room temperature for 3 190 hours before applying the tack coat (configuration N) or the geocomposites (A, B, C and D) on 191 its surface. A 40 mm upper layer was then compacted with the same target air void content 192 (5%). The compaction direction was then marked to carry out shear tests by applying interface 193 shear displacements along the direction parallel to the traffic flow in the field. A set of five 194 double-layered slabs were compacted, one for each interface configuration, i.e. one slab for 195 the unreinforced reference interface (N) and one slab for each type of geocomposite (A, B, C 196 and D). From each slab, five cylindrical specimens with a nominal diameter of 100 mm were 197 cored. This condition was coded as T4_lab as the lower layer surface is new and can be 198 compared with the cores extracted from section T4, where the geocomposites were applied on 199 the surface of the new lower base course.

200

201 5. Experimental program and test methods

202 The interlayer bonding characteristics of geocomposite-reinforced interfaces (A, B, C and D)

203 were compared with a reference unreinforced configuration (N) for evaluating the

204 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).

210 Two different types of shear tests were used to measure the Interlayer Shear Strength (ISS): 211 the Leutner device and the Ancona Shear Testing Research and Analysis (ASTRA) device. The 212 same number of specimens were tested with both equipment in each configuration and 213 surface condition, as shown in Table 4. As above-mentioned, the cores extracted from section 214 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 215 216 Standard prEN 12697-48. The lower part moves upward with a constant displacement rate 217 equal to 50.8 ± 2 mm/min, while the upper part is in contrast with a load cell, which produces 218 the shear load at the interface without normal stress. The shear force and the shear 219 displacement are continuously measured during the test, allowing the determination of the 220 ISS, i.e. the maximum interlayer shear stress calculated as ratio between the maximum shear 221 force and the specimen interface area. The shear device can test cylindrical specimen with 150 222 mm or 100 mm nominal diameter. The tests were performed at a temperature of 20 °C and all 223 the specimens were conditioned in a climatic chamber for at least 4 hours before testing. 224 The ASTRA device (Figure 4b) is a direct shear box, compliant with the European Standard 225 prEN 12697-48. The double-layered specimen is located between two half-boxes, opportunely 226 spaced to create an unconfined interlayer shear zone. During the test, the lower half-box is 227 moved with a constant horizontal displacement rate equal to 2.5 mm/min, while a constant 228 vertical load can be applied in order to obtain the target confining normal stress. Cylindrical 229 specimens with a nominal diameter of 100 mm can be tested. The horizontal force, the 230 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
- 235 testing.
- 236
- 237 6 Results and Analysis
- 238 6.1 Leutner test results
- 239 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
- 241 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
- 243 interface of the cores was highly disturbed during their extraction from the core drill, as
- 244 demonstrated by ISS values lower than those of T6 (identical to T1), especially for the
- 245 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.
- 247 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.,
- 250 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
- 253 more influential than the roughness induced by the milling operations. On the contrary,
- 254 section T6 showed higher ISS values than section T4 in the presence of geocomposites (except
- 255 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).

258 The geocomposite C applied on section T6 showed the lowest de-bonding effect, providing

259 ISS values similar to the unreinforced interface N. On the contrary, the other reinforced

260 interfaces (A, B and D) provided a higher de-bonding compared to the unreinforced interface

261 N, as testified by lower ISS values. Differently, the laboratory prepared specimens (T4_lab)

262 showed similar ISS values for the geocomposites B, C and D, whereas the geocomposite A

263 provided the lowest value.

264

265 6.2 ASTRA test results

266 The average ISS results of ASTRA tests and the corresponding error bars for all the

267 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

269 because the cores were highly disturbed during their extraction from the core drill.

270 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.

272 This can lead to the conclusion that the application of geocomposites (having lower

273 dispersions) could mitigate differences related to specimen production or core extraction.

274 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

276 could probably cause lower adhesion properties with the milled surface. In fact, the

277 geocomposite B is the only one that does not have a reinforcement grid but is composed of a

278 continuous and quite rigid sheet of non-directional glass fibres and high-duty non-woven

- 279 polyester fabric. For this reason, it probably establishes lower adhesion with the milled
- 280 surface, creating a higher separation effect, which is expressed in lower ISS values. When a
- 281 more regular surface is considered, as in the case of section T4, analogous ISS values were

282 obtained for all the reinforced interfaces, with slightly higher strengths for the geocomposite 283 B. However, the substantially equivalent results obtained for the two field lower layer surface 284 conditions (milled T6 and new T4) in the reinforced interface configurations (A, B, C and D), 285 demonstrated that the presence of the geocomposites tends to mitigate also differences 286 between milled and new lower layer surface, leading to the conclusion that they can be 287 successfully applied directly on the top of milled surfaces. Differently, the unreinforced 288 interface N showed slightly higher strengths for the section T4 (new), probably due to the 289 availability of "fresh" modified bitumen on the lower layer surface.

290 The ISS results obtained on specimens prepared in laboratory (T4_lab) showed that

291 geocomposites B and D provided the higher strengths between the reinforced interfaces,

292 whereas A and C provided almost identical performance.

293

294 7 Influence of testing speed and normal stress on ISS

295 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

297 (0.0 MPa and 0.2 MPa, respectively). The higher dispersion of Leutner results (Figure 5) with

298 respect to ASTRA results (Figure 6) allows observing that the application of the normal stress

299 $\sigma_n = 0.2$ MPa in the ASTRA tests seems to mitigate possible differences linked to the

300 heterogeneity of the specimens.

301 In this section, existing laws which correlate ISS values obtained with different shear testing

302 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.

304 The interlaboratory test on interlayer bonding carried out within the RILEM Technical

305 Committee "Advances in Interlaboratory Testing and Evaluation of Bituminous Materials"

306 (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:

$$309 \qquad ISS_{vx} = ISS_{v1} \cdot \left(\frac{v_x}{v_1}\right)^{0.22} \tag{1}$$

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):

313
$$ISS_{Leut2.5} = ISS_{Leut50.8} \cdot \left(\frac{2.5}{50.8}\right)^{0.22}$$
 (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:

318
$$ISS_{ASTRA} = (1 + 0.38 \cdot \sigma_n) \cdot ISS_{Leut2.5} + (0.74 \cdot \sigma_n)$$
 (3)

where the parameter $(1+0.38 \cdot \sigma_n)$ is associated with the contribution of the cohesion (which includes also the dilatancy, equal to $0.38 \cdot \sigma_n$) and the parameter $(0.74 \cdot \sigma_n)$ 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.

324 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):

326
$$ISS_{Leut2.5} = ISS_{Leut50.8} \cdot \left(\frac{2.5}{50.8}\right)^{\alpha_1}$$
 (4)

327
$$ISS_{ASTRA} = (1 + \alpha_2 \cdot \sigma_n) \cdot ISS_{Leut2.5} + (\alpha_3 \cdot \sigma_n)$$
(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.

336 It can be observed that the values obtained for α_1 , α_2 and α_3 are consistent and 337 meaningful when compared with the corresponding parameters obtained in previous study for 338 unreinforced interfaces. In fact, a higher value of α_1 (0.35 versus 0.22 of the unreinforced 339 interface) can be explained by the presence of the geocomposite, which is rich in bitumen and 340 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 341 342 interlocking, causing a reduction of the dilatancy contribution, as shown by the reduction of 343 the value α_2 (0.20 versus 0.38). Finally, in the case of geocomposites, characterized by non-null 344 values of residual cohesion (Pasquini et al., 2014; Pasquini et al., 2015), the α_3 value is not 345 directly associated with the residual friction but with the overall interlayer shear strength after 346 the interface failure (combination of residual cohesion and residual friction). 347 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 348 349 agreement between the measured and calculated data. Therefore, the practical equations to

350 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:

352
$$au_{Leut2.5} = au_{Leut50.8} \cdot \left(\frac{2.5}{50.8}\right)^{0.35}$$
 (6)

353
$$\tau_{ASTRA} = (1 + 0.20 \cdot \sigma_n) \cdot \tau_{Leut2.5} + (0.73 \cdot \sigma_n)$$
 (7)

354

355 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

358 specification limits. All of them are based on the results obtained with the Leutner device or 359 with similar equipment, such as the Swiss Layer-Parallel Direct Shear (LPDS) apparatus. 360 Specifically, Germany and Switzerland technical specifications (07 ZTV Asphalt-StB, 2007) 361 require that the ISS value obtained with Leutner test performed on field cores with a diameter 362 of 150 mm must be \geq 0.85 MPa for the upper interface (i.e. between wearing and binder 363 course) and ≥ 0.65 MPa for lower interfaces (e.g. between binder and base course). 364 Differently, in the United Kingdom (UK), the technical specifications (MCDHW, 2018) require 365 ISS \ge 1.0 MPa for interfaces located at depths \le 75 mm, and ISS \ge 0.50 MPa for interfaces 366 located at greater depths. 367 Since geocomposites are characterized by a high dosage of bituminous materials to ensure 368 stress absorbing and waterproofing effects, their application is not recommended in 369 correspondence of the upper interface where a high bonding level is required. For this reason, 370 the UK criterion which considers ISS \geq 0.50 MPa for interfaces located at depths greater than 371 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

373 (σ_n =0.2 MPa) is equal to 0.33 MPa, which is obtained by applying Eq. (6) and Eq. (7) starting

374 from $\tau_{Leut50.8}$ = 0.50 MPa.

372

375 In order to check if these limits can be considered suitable for verifying the field

376 requirements of interfaces reinforced with geocomposites, ASTRA and Leutner test results of

377 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

380 "equivalent" specification limits in the evaluation of the field performance after

381 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

383 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.

387 The comparison between the laboratory produced specimens and the corresponding field 388 cores was thus performed in parity of new lower layer surface condition, by plotting the results 389 obtained for T4_lab and T4 condition, respectively. Figure 9 shows that the field cores (T4) 390 without reinforcement (configuration N) are characterized by higher strengths than the 391 analogous laboratory specimens (T4_lab). On the contrary, the field cores of the reinforced 392 interface configurations (A, B C and D) are characterized by lower ISS values with respect to 393 the specimens prepared in laboratory, for both ASTRA and Leutner test. This is due to the 394 possibility of applying more properly the geocomposites in laboratory with respect to the field 395 condition, guaranteeing higher strengths.

396 Therefore, during the laboratory qualification phase, more restrictive criteria for the

397 definition of specification limits must be defined in order to achieve the required field

398 performance. The results shown in Figure 9.a can be used for the definition of these pre-

399 qualification limits for the Leutner test. Specifically, an increase by 50% of the value accepted

400 for field cores, i.e. 0.75 MPa, was reasonably proposed as specification limit for the

401 qualification phase of laboratory produced specimens, based on the comparison of the data

402 collected from the Leutner test for Sections T4_lab and T4 (Figure 5). Analogously, Eqs. (6) and

403 (7) can be used to obtain the qualification phase specification limit for ASTRA test, by

404 considering $\tau_{Leut50.8}$ = 0.75 MPa. A value equal to 0.42 MPa was obtained and reported in

405 Figure 9.b.

406 The defined ISS minimum specification limits for interfaces reinforced with geocomposites

407 are summarized in Table 6. The analysis of Figure 9 shows that all laboratory specimens and

408 cores meet the proposed ISS minimum specification limits and, given this promising outcome,

409 their validation by further laboratory and/or field investigation is recommended.

411

412

413 9 Conclusions

414 This research aimed at evaluating the effectiveness of asphalt pavement rehabilitation

415 techniques by using different geocomposites. The interlayer bonding characteristics of four

416 different geocomposites were compared with an unreinforced reference configuration, by

417 using laboratory compacted specimens and cores taken from a field trial built on an Italian

418 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

420 strength (ISS) was measured through Leutner and Ancona Shear Testing Research and Analysis

421 (ASTRA) equipment, allowing the following conclusions to be drawn:

422 - the application of geocomposites causes a de-bonding effect at the interface of asphalt

423 concrete pavements proved by the reduction of ISS values;

424 – geocomposites can be successfully applied directly on the top of milled surfaces as they can

425 mitigate differences related to specimen characteristics and lower layer surface conditions.

426 Moreover, this operation allows the speeding up of maintenance activities while avoiding

427 users discomfort and satisfying construction needs;

428 - the application of a normal stress during shear tests, as in the case of ASTRA device, can
 429 reduce the dispersion of the ISS results;

430 - the laws which correlate the results obtained with different shear testing equipment in the

- 431 case of unreinforced interfaces were generalized for Leutner and ASTRA test results by
- 432 considering the presence of geocomposites;

433 – ISS minimum technical specification limits for interfaces reinforced with geocomposites

434 were proposed for Leutner and ASTRA tests, both in the qualification phase and in the

435	performance field assessment (after pavement rehabilitation). These limits are intended as
436	initial proposal that has to be validated with further investigations.
437	
438	
439	Acknowledgements
440	The activities presented in this paper were sponsored by Autostrade per l'Italia S.p.A. (Italy),
441	which gave both financial and technical support within the framework of the Highway
442	Pavement Evolutive Research (HiPER) project. The results and opinions presented are those of
443	the authors.
444	
445	References
446	07 ZTV Asphalt-StB. (2007). Zusätzliche Technische Vertragsbedingungen und Richtlinien für
447	den Bau von Verkehrsflächenbefestigungen aus Asphalt. Forschungsgesellschaft für
448	Straßen- und Verkehrswesen Arbeitsgruppe Asphaltbauweisen.
449	Brown, S.F., Thom, N.H., Sanders, P. J. (2001). A study of grid reinforced asphalt to combat
450	reflection cracking. J. Assoc. Asphalt Paving Technol., 70, 543–569.
451	Canestrari, F., Ferrotti, G., Abuaddous, M., & Pasquini, E. (2016). Geocomposite-reinforcement
452	of polymer-modified asphalt systems. 8th RILEM Bookseries, 11.
453	https://doi.org/10.1007/978-94-017-7342-3_31
454	Canestrari, F., Ferrotti, G., Lu, X., Millien, A., Partl, M. N., Petit, C., Phelipot-Mardelé, A., Piber,
455	H., & Raab, C. (2013). Mechanical testing of interlayer bonding in asphalt pavements. In
456	Advances in Interlaboratory Testing and Evaluation of Bituminous Materials. State-of-the-
457	Art Report of the RILEM Technical Committee 206-ATB. https://doi.org/10.1007/978-94-
458	007-5104-0_6

- 459 Canestrari, F., Ferrotti, G., Partl, M. N., & Santagata, E. (2005). Advanced testing and
- 460 characterization of interlayer shear resistance. *Transportation Research Record; 1929(1)*,
 461 69–78. https://doi.org/10.3141/1929-09
- 462 Canestrari, F., Pasquini, E., & Belogi, L. (2012). Optimization of geocomposites for double-
- 463 layered bituminous systems. *7th RILEM Bookseries*, *2*, 1229. https://doi.org/10.1007/978464 94-007-4566-7_117
- 465 Correia, N. S., & Zornberg, J. G. (2016). Mechanical response of flexible pavements enhanced
 466 with Geogrid-reinforced asphalt overlays. *Geosynthetics International*, *23*(3), 183–193.
- 467 https://doi.org/10.1680/jgein.15.00041
- 468 Ferrotti, G., Canestrari, F., Virgili, A., & Grilli, A. (2011). A strategic laboratory approach for the
- 469 performance investigation of geogrids in flexible pavements. *Construction and Building*

470 *Materials*, 25(5), 2343–2348. https://doi.org/10.1016/j.conbuildmat.2010.11.032

- 471 Ingrassia, L. P., Virgili, A., & Canestrari, F. (2020). Effect of geocomposite reinforcement on the
- 472 performance of thin asphalt pavements: Accelerated pavement testing and laboratory
- 473 analysis. *Case Studies in Construction Materials*, 12(February), e00342.
- 474 https://doi.org/10.1016/j.cscm.2020.e00342
- 475 Karshenas, A., Carolina, N., Cho, S., Carolina, N., Tayebali, A. A., Carolina, N., Guddati, M. N.,
- 476 Carolina, N., & Kim, Y. R. (2014). The importance of normal confinement on shear bond
- 477 failure of interface in multilayerasphalt pavements. *Transport. Res. Rec.: J. Transport. Res.*
- 478 Board, 2456(1), 170–177.
- 479 Khodaii, A., Fallah, S., & Moghadas, F. (2009). Geotextiles and Geomembranes Effects of
- 480 geosynthetics on reduction of reflection cracking in asphalt overlays. *Geotextiles and*
- 481 *Geomembranes*, 27(1), 1–8. https://doi.org/10.1016/j.geotexmem.2008.05.007
- 482 MCDHW. (2018). Manual of Contract Documents for highway works volume 2 notes for

483 guidance on the specification for highway Works.

484 Noory, A., Moghadas Nejad, F., & Khodaii, A. (2017a). Evaluation of shear bonding and

485 reflective crack propagation in a geocomposite reinforced overlay. *Geosynthetics*

486 International, 24(4), 343–361. https://doi.org/10.1680/jgein.17.00007

- 487 Noory, A., Moghadas Nejad, F., & Khodaii, A. (2019). Evaluation of geocomposite-reinforced
- 488 bituminous pavements with Amirkabir University Shear Field Test. *Road Materials and*
- 489 Pavement Design, 20(2), 259–279. https://doi.org/10.1080/14680629.2017.1380690
- 490 Optimization of Tack Coat for HMA Placement. (2012). In Optimization of Tack Coat for HMA
- 491 *Placement*. https://doi.org/10.17226/13652
- 492 Ortiz-Ripolla, J., Miró, R., & Martínez, A. H. (2020). Semi-empirical method for the calculation
- 493 of shear stress, stiffness and maximum shear strength of bituminous interfaces under in-

494 service conditions. *Construction and Building Materials*, 258.

495 https://doi.org/10.1016/j.conbuildmat.2020.120374

- 496 Ozer, H., Al-Qadi, I. L., Wang, H., & Leng, Z. (2012). Characterisation of interface bonding
- 497 between hot-mix asphalt overlay and concrete pavements: Modelling and in-situ
- 498 response to accelerated loading. International Journal of Pavement Engineering, 13(2),
- 499 181–196. https://doi.org/10.1080/10298436.2011.596935
- 500 Park B., Zou J., Hernando D., Roque R., A. M. W. J. (2021). Investigating the use of Equivalent
- 501 Elastic Approach to Identify the Potential Location of bending-induced Interface
- 502 Debonding Under a Moving Load. *Materials and Structures*, 54(18).
- 503 Pasquini, E., Bocci, M., & Canestrari, F. (2014). Laboratory characterisation of optimised
- 504 geocomposites for asphalt pavement reinforcement. *Geosynthetics International*, 21(1),
- 505 24–36. https://doi.org/10.1680/gein.13.00032
- 506 Pasquini, E., Pasetto, M., & Canestrari, F. (2015). Geocomposites against reflective cracking in

507	asphalt pavements: laboratory simulation of a field application. Road Materials and
508	Pavement Design, 16(4), 815–835. https://doi.org/10.1080/14680629.2015.1044558
509	prEN 12697-48. (n.d.). "Bituminous mixtures – Test methods fot hot mix asphalt – Part 48:
510	Interlayer Bonding."
511	R. Leutner. (1979). Untersuchung des Schichtverbundes beim bituminösen Oberbau. In
512	Bitumen 3.
513	Raab, C., Partl, M. N., & El Halim, A. E. H. O. A. (2009). Evaluation of interlayer shear bond
514	devices for asphalt pavements. Baltic Journal of Road and Bridge Engineering, 4(4), 186–
515	195. https://doi.org/10.3846/1822-427X.2009.4.186-195
516	Ran, W., Zhang, Y., Li, L., Shen, X., Zhu, H., & Zhang, Y. (2019). Characterization of bonding
517	between asphalt concrete layer underwater and salt erosion. <i>Materials</i> , 12(19).
518	https://doi.org/10.3390/ma12193055
519	Santagata, E., Canestrari, F., & Santagata, F. A. (1993). Laboratory shear testing of tack coat
520	emulsion. Proceedings of the 1st Congress on Emulsion, Paris, France.
521	Saride, S., & Kumar, V. V. (2017). Influence of geosynthetic-interlayers on the performance of
522	asphalt overlays on pre-cracked pavements. Geotextiles and Geomembranes, 45(3), 184–
523	196. https://doi.org/10.1016/j.geotexmem.2017.01.010
524	UNI/TS 11214, (2007). (n.d.). "Mechanical properties of road and airport pavements. Shear
525	performance characterization of interfaces. ASTRA test method".
526	Uzan, J., Livneh, M., & Eshed, Y. (1978). Investigation of adhesion properties between
527	asphaltic-concrete layers. Asphalt Paving Technol, 495–521.

- 528 Zamora-Barraza, D., Calzada-Peréz, M., Castro-Fresno, D., & Vega-Zamanillo, A. (2010). New
- 529 procedure for measuring adherence between a geosynthetic material and a bituminous
- 530 mixture. *Geotextiles and Geomembranes*, 28(5), 483–489.

531 https://doi.org/10.1016/j.geotexmem.2009.12.010

533 Tables

534 Table 1. Characteristics of Polymer Modified Binder

	Binder characteristics	Standard	Unit	Reference	Measured
				values	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
535					
536					
537					
538					
539					
540					
541					
542					
543					
544					
545					
E A C					
540					
5/17					
547					
548					
540					
5/19					
545					
550					
550					
551					
552					
-					
553					

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

Requirements	Characteristics	Unit	it Performa		nce
			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	Penetration at 25°C	dmm		220	5
Consistency at high service	Softening point	°۲	25		Q
temperatures	Softening point	C	22		0

575 Table 3. Characteristics of the geocomposites

Broperty	Geocompo	sites		
Property	А	В	С	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

	Lower layer		Interface configuration				
	Specimen type	surface condition	Ν	Α	В	С	D
	Field	T1	1	2	2	3	3
		T4	3	3	3	3	3
		Т6	3	3	3	3	3
	Laboratory	T4_lab	2	2	2	2	2
596							
597							
598							
599							
600							
601							
602							
603							
604							
605							
606							
607							
608							
609							
610							
611							
612							
613							
614							
615							
616							
617							

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

	Section	Interface configuration	<i>ISS_{Leut50.8}</i> (MPa)	ISS _{Leut2,5} (MPa)	$(ISS_{ASTRA})_{meas}$ (MPa)	(<i>ISS_{ASTRA}</i>) _{calc} (MPa)
	T4	A	0.492	0.171	0.326	0.324
		В	0.516	0.180	0.384	0.333
		С	0.706	0.246	0.372	0.402
		D	0.662	0.231	0.358	0.386
	T4 lab	А	0.783	0.273	0.431	0.430
	-	В	0.997	0.347	0.585	0.507
		С	0.940	0.327	0.423	0.487
		D	1.015	0.354	0.522	0.514
619 620						
621						
623						
624						
625						
626						
627						
628						
629						
630						
631						
632						
634						
635						
636						
637						
638						

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

	Leutner		ASTRA
-	Phase	@20°C; 50.8 mm/min; 0.0 MPa	@20°C; 2.5 mm/min; 0.2 MPa
	Laboratory qualification	≥ 0.75 MPa	\geq 0.42 MPa
-	In the field	\geq 0.50 MPa	≥ 0.33 MPa
640			
641			
642			
643			
644			
645			
646			
647			
648			
649			
650			
651			
652			
653			
654			
655			
656			
657			
658			
659			
660			
661			
662			

639 Table 6. ISS specification limits for interfaces reinforced with geocomposites

663 Figures

664		
665	(a)	(b)
666	Figure 1. Field trial: (a) milled surface; (b) geoco	mposite application
667		
668		
669		
670		
671		
672		
673		
674		
675		
676		
677		



679 Figure 2. Field trial characteristics, stratigraphy and interface configuration



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



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

- . _ .











789 Figure 9. Comparison between laboratory and field specimens for the new lower layer surface

790 condition: (a) Leutner; (b) ASTRA