

1 **COMPARATIVE ASSESSMENT OF THE INTERLAYER SHEAR-BOND**
2 **STRENGTH OF GEOGRID REINFORCEMENTS IN HOT-MIX ASPHALT**

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1 ABSTRACT

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3 With the increasing use of geogrid reinforcements to mitigate reflective cracking in hot-mix
4 asphalt (HMA) overlays, interlayer (interface) bonding has become an even more critical aspect
5 of HMA placement/construction to mitigate delamination and debonding of the HMA overlay.
6 To comparatively evaluate the interlayer bond strength due to the effects of the geogrid
7 reinforcements, the shear bond strength test was conducted in this laboratory study, using
8 unreinforced control HMA samples as the reference datum. Cylindrical HMA samples (150 mm
9 diameter) gyratory compacted in two 75-mm lift thicknesses, with the geogrid reinforcement
10 in-between the two lifts, were used for testing at room temperature under a monotonically shear
11 loading rate of 5 mm/min. Emulsified asphalt was used as the interlayer tack coat and six
12 different geogrid materials, which are polyester-based (FA) and fiberglass-based (FG), were
13 comparatively evaluated. As theoretically expected, the control (unreinforced) HMA samples
14 exhibited superiority followed closely by samples reinforced with polyester-based geogrids.
15 Although comparable to the values reported in the literature, HMA samples reinforced with
16 fiberglass-based geogrids performed the poorest with the lowest interlayer bond strengths – that
17 is the polyester-based outperformed the fiberglass-based geogrids. Overall, the interlayer bond
18 strength exhibited a general decreasing trend with a decrease in the geogrid mesh size (open
19 area), increase in the geogrid strand thickness, and material grade. Thus, in as much as reflective
20 crack mitigation is structurally desired, due diligence must be cautiously exercised when
21 selecting the geogrid type/grade for use in HMA reinforcement to ensure sufficient interlayer
22 bonding and minimize any potential delamination/debonding problems in service.

23

24 *Keywords:* Reflective Cracking, Geogrid, Fortgrid Asphalt (FA), Fiberglass (FG), Shear, Bond
25 Strength

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1 INTRODUCTION

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3 One of the common maintenance/rehabilitation methods used to mitigate reflective cracking in
 4 old existing cracked pavements, be it flexible hot-mix asphalt (HMA) or concrete, is the
 5 structural application of crack-impeding and interlayer grid reinforcements. Quite often, these
 6 grid reinforcements are used as part of the HMA overlay construction in maintenance and/or
 7 rehabilitation projects because of their effectiveness in arresting reflective cracking and cost-
 8 effectively increasing the service life and longevity of HMA overlays (1-8). Figures 1 and 2
 9 shows an example of an old cracked pavement and geogrid interlayer construction, respectively.

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11

12 **FIGURE 1 Example of an Old Cracked HMA Pavement.**

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14

15 **FIGURE 2 Geogrid Interlayer Reinforcement and HMA Overlay Construction.**

16

17 As shown in Figure 2, one of the fundamental functions of the interlayer grid reinforcement is to
 18 inhibit the upward propagation of cracks from an old existing cracked pavement to the surface,
 19 i.e., to mitigate the cracks from reflecting through the HMA overlay to the surface. Thereby,
 20 aiding in cost-effectively prolonging the cracking resistance and service life of the pavement (8).

21

22 Many types of interlayer grid reinforcement materials including geogrids, geotextiles, paving
 23 mats, paving fibers, etc., are presently available on the commercial market and widely used in
 24 HMA overlay projects during maintenance and rehabilitation activities (9,10). With the
 25 increasing use of these interlayer grid reinforcements, interlayer (interface) bonding becomes an
 26 even more critical aspect of HMA placement/construction to prevent delamination and
 27 debonding during service that could negatively impact the long-term performance, longevity, and
 28 durability of the overlay.

29

30 To comparatively evaluate the interlayer bond strength arising from the effects of the geogrid
 31 reinforcements, the shear bond strength test was conducted in this laboratory study, using
 32 unreinforced control HMA samples as the reference datum. Six different geogrid materials were
 33 comparatively evaluated for their corresponding interlayer shear bond strengths and are
 34 discussed in this paper.

In the subsequent section, a summation of the literature review findings on interlayer bond strength is presented. The experimental design plan for laboratory testing is subsequently presented followed by the laboratory test results, analysis, and synthesis of the findings. The paper then concludes with a summary of key findings and recommendations.

LITERATURE REVIEW

Based on the literature reviewed, there is currently no universally standardized test method or screening criteria for characterizing and quantifying the interlayer (interface) bond strength in HMA. Worldwide, many institutions, states, and countries appear to have their own standards and/or recommended bond strength values/limits that were determined based on different test methods and testing conditions (11). An example of some reviewed values from the literature is summarized in Table 1 and shows bond strength values ranging from as low as 100 kPa to as high as 1500 kPa for varying test methods/conditions. Based on field core testing, values ranging from 103 to 655 kPa have been measured with satisfactory in-service (field) interlayer bonding performance (12).

TABLE 1 Literature Review Results - HMA Interlayer Shear Bond Strength.

Reference Source	Institution/ State/Country	HMA Interlayer Bond Strength		Test /Comment
		Reported Values (kPa)	Recommendation	
(13)	MnDOT, USA	255-1379 (37-200 psi)	690 kPa	
(14)	NCHRP, USA	241-552 (35-80 psi)	276 kPa	Direct shear
(15)	NCAT, AL	483-1448 (70-210 psi)	600 kPa	Direct-shear, 25 °C
(16)	-	-	310 kPa	-
(17)	-	235-351	235 kPa	-
(18)	Jordan	150-740 (21-107 psi)	-	-
(19)	Canada	967 – 1298	-	Direct shear, 25 °C
(20)	South Africa	535-1184	400 kPa	Torque-based
(12)	Texas, USA	Lab = 276-1379 (40-200 psi) Field = 103-655 (15-95 psi)	-	Direct shear
(21)	FH, NZ	100-1200	275 kPa	Direct shear, 25-40 °C
(22)	NJ, USA	483-1103 (70-160 psi)	483 kPa	Direct shear
(11)	WV, USA	855-1500	-	Direct shear, 25 °C
(23)	VA, USA	1613-2124 (234-308 psi)	-	Torque-based







Most of the HMA bond strength tests reported in the literature are either direct-shear, tension, or torque-shear based. These include the interface-shear (PINE, ASTRA, etc), Leutner-shear, Superpave-shear, Limoges double-shear, layer-parallel direct shear, Pull-off, Arcan, A-tacker, Torque bond tests, etc. (11, 12, 20, 21, 24). As was used in this study, the direct-shear based tests have prominence due to their practicality, cost-effectiveness, repeatability, and ability to readily fit the already existing laboratory loading frames such as the Marshall stabilometer, universal testing machine (UTM), or material testing system (MTS).

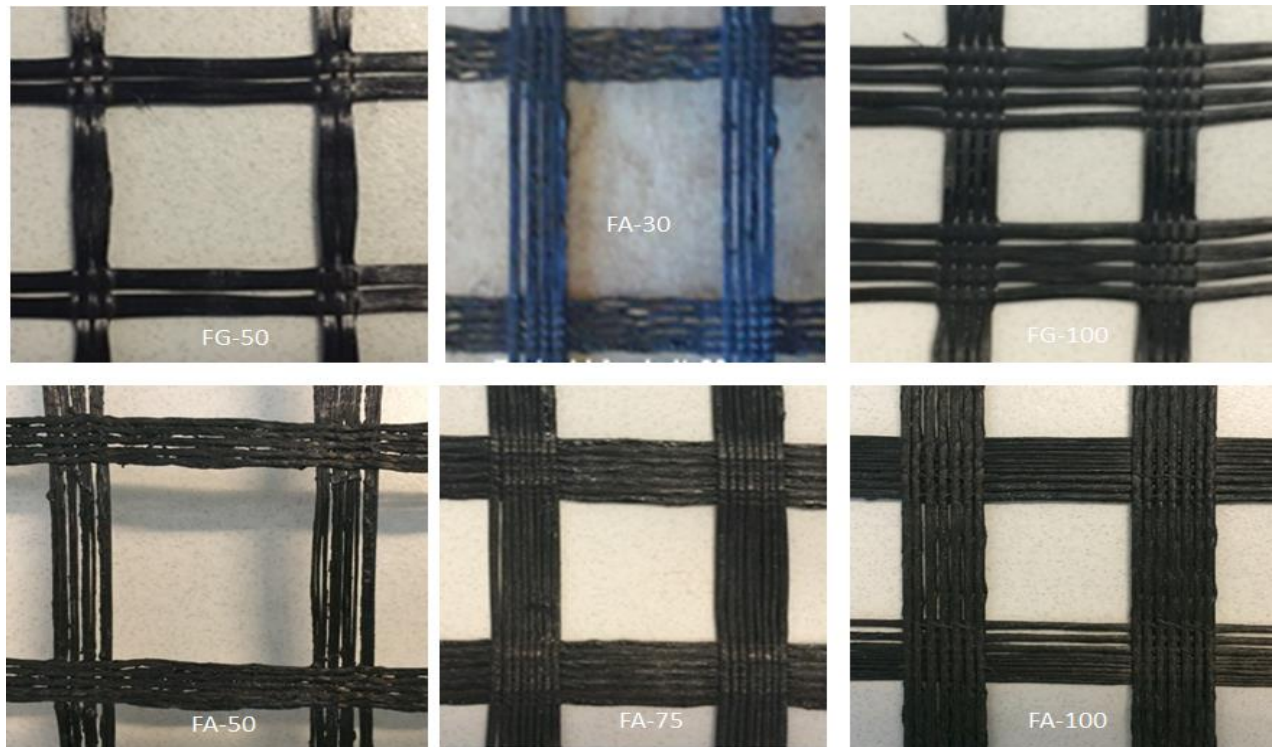
1 Numerous studies have evaluated the various factors that influence the interlayer HMA bond-
 2 strength including mix-type, temperature, aggregate size, tack coat type, tack coat application
 3 rate, surface roughness, age, traffic, etc. (11, 14, 15, 21,25–30). However, limited studies have
 4 specifically focused on the geogrid bond-strength effects. For instance, Tran et al. (15) reported
 5 that the interlayer bond strength generally improved with rougher milled surfaces than non-
 6 milled surfaces. By contrast, West et al. (24) and Al-Qadi et al. (31) observed a declining bond
 7 strength with an increase in temperature. However, the majority of these studies have been
 8 predominantly based on unreinforced HMA with or without tack coat – but, without any
 9 interlayer geogrid reinforcements in the HMA. Thus, the contribution of this study is primarily
 10 on evaluating the effects of the interlayer geogrid reinforcement on the bond strength in HMA,
 11 i.e., *What is the effect on the interlayer bond strength with the addition of geogrid reinforcements*
 12 *in HMA?* Whilst the interface bond can be measured, characterized, and quantified in terms of
 13 strength, modulus (stiffness), or work (energy), the monotonic shear bond strength parameter
 14 was used in this study (21).

15 LABORATORY TEST PLAN

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 17
 18 Six different geogrid interlayer materials, which are a polyester-based coated with bitumen
 19 copolymer (fortgrid asphalt denoted as FA) and fiberglass-based (denoted as FG), were arbitrary
 20 selected and comparatively evaluated. As listed in Table 2, three FA and two FG material grades
 21 were evaluated against unreinforced HMA samples. The key characteristic differences and
 22 geometrical attributes as related to the interlayer bonding properties of the geogrids are also
 23 included in Table 2 along with pictorial illustrations in Figure 3. More technical details and other
 24 index properties of the individual geogrid materials can be found elsewhere (9).

25
 26 **TABLE 2 Geogrid Materials.**

Geogrid	Mesh View	Aperture (Mesh Opening) $L \times W = \text{Area}$ (mm^2)	Strand Thickness (mm)	Strand Width (mm)	%age HMA-HMA Contact over 150-mm diameter Area
FA-30		$28.3 \times 28.3 \approx 801$	~ 0.63	~ 7.15	64%
FA-50		$27.3 \times 27.3 \approx 743$	~ 0.88	~ 9.15	54%
FA-75		$25.5 \times 25.5 \approx 651$	~ 1.01	~ 11.01	45%
FA-100		$22.5 \times 22.5 \approx 507$	~ 1.15	~ 12.65	42%
FG-50		$21.4 \times 21.4 \approx 457$	~ 0.55	~ 5.11	67%
FA-100		$15.9 \times 15.9 \approx$ 253	~ 1.15	~ 11.01	40%
Control	-	-	-	-	100%



1
2 **FIGURE 3 Pictorial Illustration of the Geogrid Materials.**

3
4 **HMA Mix and Sample Fabrication**

5
6 A typical dense-graded 12.5 mm Nominal Maximum Aggregate Size (NMAS) mix, with
7 limestone/dolomite/granite aggregates and 4.5% PG 64-22 asphalt-binder, was used. As
8 illustrated in Table 3 and Figure 4, HMA cylindrical samples (150 mm diameter) were
9 compacted in two 75-mm lift thicknesses using the Superpave gyratory compactor (SGC) –
10 with the geogrid reinforcement in-between the two lifts, except for the control (unreinforced)
11 HMA samples.

12
13 **TABLE 3 HMA Sample Molding and Compaction Process.**

#	HMA Sample (150-mm diameter)	Molding and Compaction Process
1	Control (unreinforced)	75-mm bottom lift + tack coat + 75-mm top lift = 150 mm total thickness
2	Geogrid reinforced	75-mm bottom lift + tack coat + <i>grid</i> + 75-mm top lift = 150 mm total thickness

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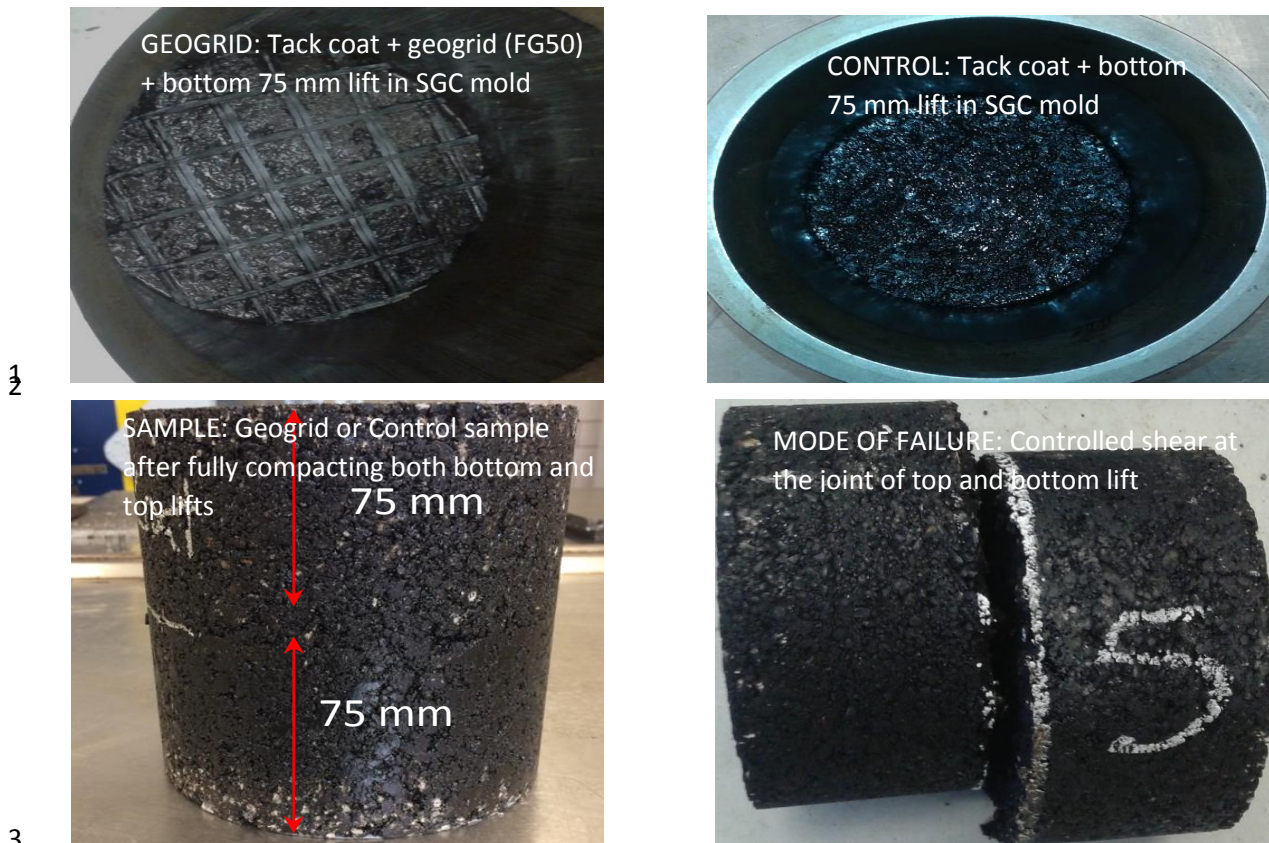


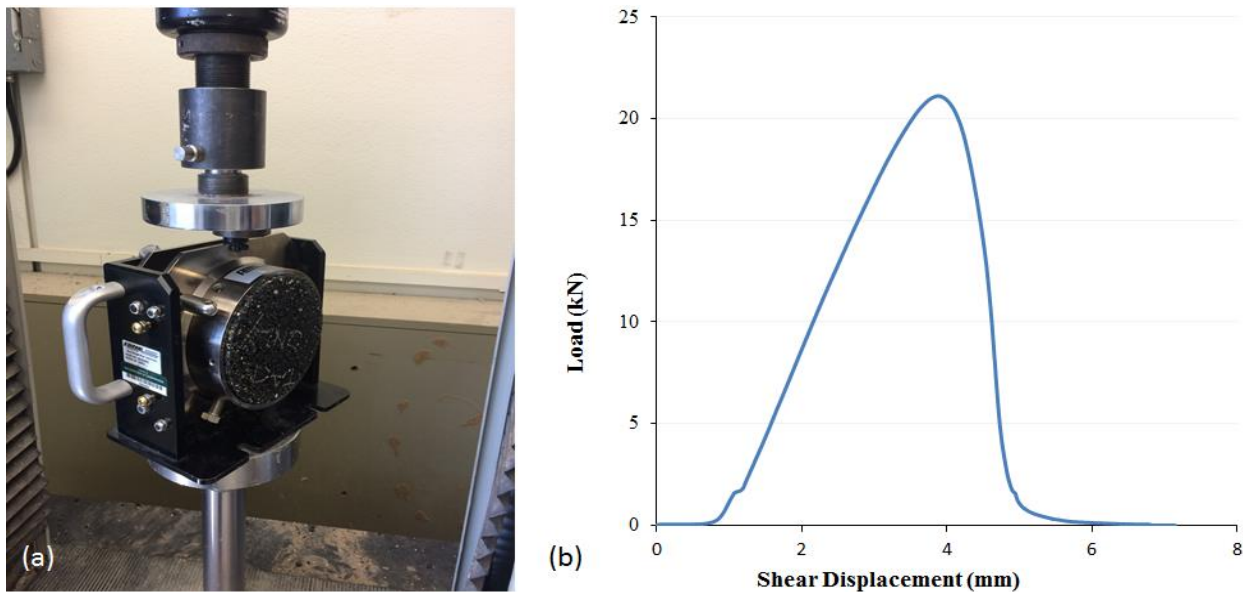
FIGURE 4 HMA Sample Fabrication and Interlayer Geogrid Reinforcement.

Emulsified asphalt, with a weight equivalent application rate of 0.45 liters/m² (~8 grams per sample surface area) was used as the interlayer tack coat (32). Although it is generally suggested to use the same asphalt-binder for the HMA as the tack coat, emulsified asphalt was intentionally selected and used in this study to simulate the worst-case scenario, as it is generally considered to be one of the weakest tack coat materials. Four hours cooling time period was allowed between compacting the bottom and top HMA lifts, respectively. Consistent with the standard PG 64-22 temperature requirements, the mixing and compaction temperatures for the HMA were 144 and 127 °C, respectively (33). Both the bottom and top 75-mm thick HMA lifts were compacted to a target density of 93±1%, i.e., 7±1% air voids (33). Density and air void (AV) determination were based on dimensional and volumetric computations within the target of 7±1% AV for both the control and geogrid reinforced HMA samples. Three HMA sample replicates were fabricated per geogrid type including the control.

Note that while 50 mm (or thinner) is the typical field HMA overlay thickness, 75 mm thick HMA lifts were adapted in this study (Table 3 and Figure 4) for the practical convenience of the laboratory test setup and protocol used as shown subsequently in Figure 5. Theoretically, 75 mm thickness was also considered to be conservative in terms of simulating the worst-case scenario for compaction (i.e., a thick lift will result in a slightly lower compaction density at the interface, and translating to a weaker bond). In future follow-up studies, however, it is strongly warranted to investigate typical HMA overlay thicknesses such as 50 mm and other thinner lifts like 25 mm thickness.

1 The Interlayer Shear-Bond Strength Test

2
3 As previously stated, there exist several test methods to evaluate the interlayer (interface)
4 bonding of HMA layers including the PINE interface shear, Pull-off (tension), and torque-bond
5 tests (11-12, 20-21). The PINE interface shear test, that has been proven to be a more practical
6 and repeatable test, was used in this study (12). As shown in Figure 5a, the HMA sample is
7 inserted with the bond interface oriented vertically. The PINE interface shear apparatus consists
8 of two parts: namely, a ridged sleeve and a sliding sleeve. A ridged sleeve is used to hold one
9 side of the test specimen rigidly and to provide a reaction force, while the sliding sleeve is used
10 to hold the other side of the specimen that freely slides vertically perpendicular to the specimen's
11 vertical axis and produces the shear load.



13
14 **FIGURE 5 Shear Bond-Strength Test Setup (a) and Example Output Data (b).**

15
16 In this study, the test was conducted at a monotonic loading rate of 5 mm/min at room
17 temperature in accordance with the Texas standard test procedure Tex-249-F until sample
18 failure (i.e., after the maximum load is achieved and the load has decreased substantially) (33).
19 From the test data, a load-displacement (L-D) graph as exemplified in Figure 5b is generated and
20 the peak load is used to determine the bond strength as illustrated in Equation 1 (12):

$$21 \quad S_{max} = \frac{4P_{max}}{\pi D^2} \quad \text{(Equation 1)}$$

22
23
24 In Equation 1, S_{max} is the maximum shear bond strength, P_{max} is peak (maximum) shear failure
25 load, and D is the sample diameter, i.e., 150 mm in this study. After testing, the HMA samples
26 would be sheared and split into the two HMA lifts as shown in Figure 6. Note that as illustrated
27 in Equation 1 and the subsequently presented test results/analysis, this study was limited to
28 primarily evaluating and quantifying the shear loading effects without consideration of the
29 normal stresses on the tested samples.

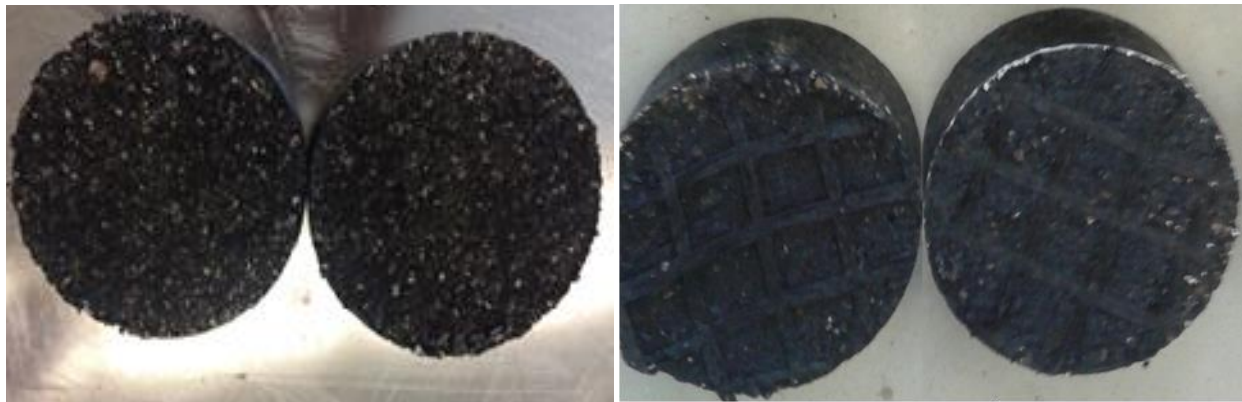
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2 **FIGURE 6 Example HMA Sample Failure Mode (FA-50 Reinforced).**

3
4 **LABORATORY TEST RESULTS AND ANALYSIS**

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6 The failed HMA samples after testing and a plot of the average shear bond strength versus shear
7 displacement are shown in Figures 7 and 8, respectively. All the HMA sample were tested after 5
8 days of molding to allow for curing and setting time of the emulsified asphalt so as to build
9 ample bond strength. As theoretically expected, the control HMA samples without interlayer
10 reinforcement exhibited the highest interlayer bond strength, averaging 747 kPa, and failed at the
11 highest shear deformation of about 4.01 mm. The second-ranking in performance superiority was
12 FA-30 at about 653 kPa. At a bond strength of about 225 kPa, FG-100 performed the poorest
13 with the least shear displacement of about 2.55 mm.
14

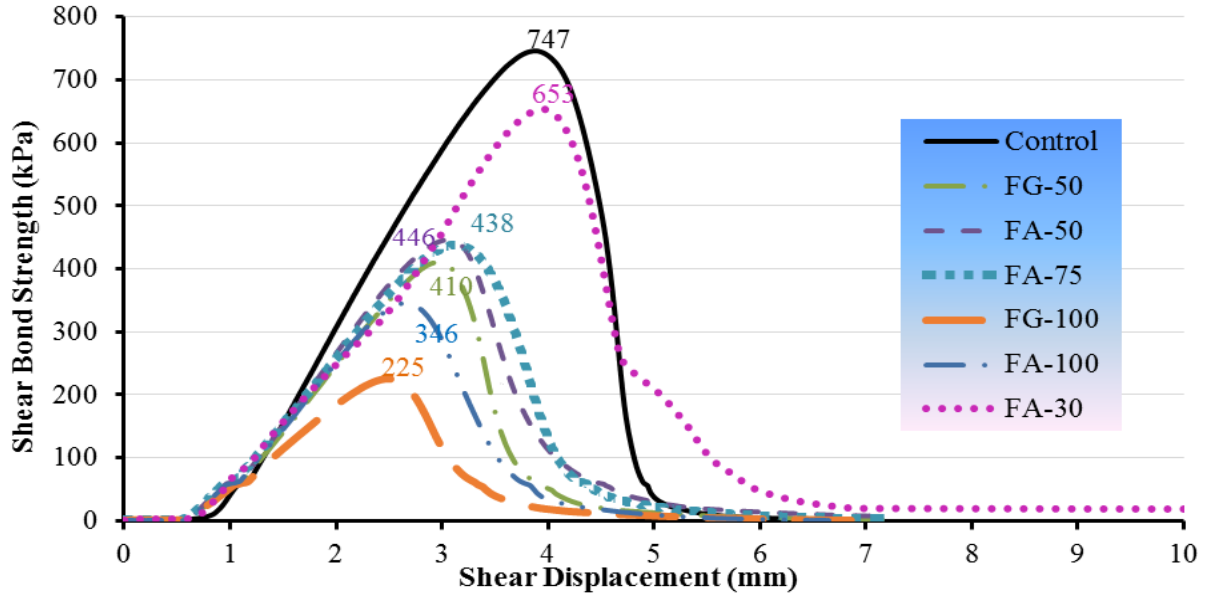


15 **Control**

16 **Geogrid Reinforcement**

17 **FIGURE 7 Example HMA Samples After Testing.**

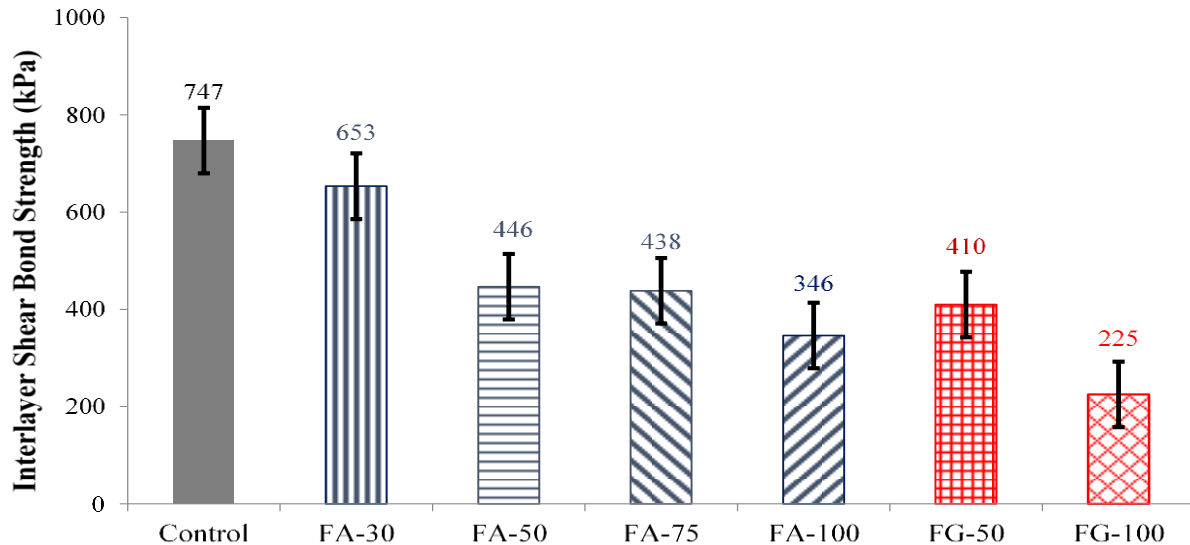
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1
2 **FIGURE 8 Interlayer Shear Bond Strength versus Displacement Plots.**

3
4 **Interlayer Shear-Bond Strength Results**

5
6 Figure 8 shows that FA-50 and FA-75 are insignificantly different in terms of their interlayer
7 bond strength performance and shear displacement failure. Furthermore, Figure 8 shows that the
8 FA-50 and FA-75 grids offered superior shear bond strength over the tested FG grids. These
9 results are distinctively evident in Figure 9 where the average (peak) interlayer bond strength is
10 plotted as a function of the geogrid material grade in a bar chart. Figure 9 is also supplied with
11 standard error bars that overlaps - indicating that only FA-30 is insignificantly different from the
12 control. Statistically, if the error bars overlap, it means that the results/values are statistically
13 insignificantly different.



14
15 **FIGURE 9 Interlayer Shear Bond Strength versus Geogrid Material Grade.**

1 For the HMA mix evaluated and the test conditions considered, Figure 9 shows that FA
 2 (polyester-based) is superior to FG (fiberglass-based) in terms of the interlayer bond strength
 3 performance. That is, at all equivalent geogrid grades, the magnitude of the interlayer bond
 4 strength for the HMA samples reinforced with FA material was at least 1.1 times higher than
 5 those reinforced with FG material. By comparison, the interlayer bond strength of the control
 6 HMA samples is about 1.14 times better than the best geogrid performer (FA-30) and about 3.32
 7 times better than the poorest performer (FG-100) in terms of the interlayer bond strength.
 8 Nonetheless, these measured bond strength values, ranging from 225 to 653 kPa, are
 9 insignificantly different from the values reported in the reviewed literature that range from 100
 10 kPa to about 1500 kPa as shown in Table 1 for largely unreinforced HMA without any interlayer
 11 geogrid reinforcements.

12
 13 When comparing FA-50 versus FA-75, it is evident in Figure 9 that the bond strength value of
 14 446 kPa is hardly different from 438 kPa – theoretically suggesting that their in-service bonding
 15 strength performance would be insignificantly different. Thus, these two geogrid materials (FA-
 16 50 and FA-75) can be used in lieu of one another in as far as optimizing the interlayer bond
 17 strength is concerned. Furthermore, Figure 9 also shows a decay and loss in interlayer bond
 18 strength with an increase in the geogrid material grade. For instance, FA decreased from 653 kPa
 19 (Grade 30) to 346 kPa for Grade 100. Similarly, FG drastically declined by almost 50% from 410
 20 kPa (Grade 50) to 225 kPa (Grade 100). Using the control as the reference datum, a reduction in
 21 the interlayer bond strength of as much as 69.9% due to the effects of interlayer reinforcement
 22 with FG-100 can be inferred from Figure 9. The least reduction in interlayer bond strength was
 23 computed for FA- 30 at 12.5%, i.e., 747 kPa to 653 kPa.

24 25 **Test Data Variability and Statistical Analysis**

26
 27 The results plotted in Figures 8 and 9 represent an average of three replicates for both the control
 28 (unreinforced) and geogrid reinforced HMA samples, respectively. As shown in Table 4, the test
 29 was fairly repeatable with a coefficient of variation (COV) less than 30% - but with more data
 30 variability indicated for the FG reinforced samples based on its relatively higher COV values (8).
 31 One-way ANOVA and *t*-tests were also conducted at 95% confidence level (CL) to statistically
 32 quantify if the materials were statistically different and rank them accordingly (34). These
 33 statistical results are shown in Table 4.

34

35 **TABLE 4 Data Variability and Statistical Analysis.**

Material (Geogrid)	COV (≤30%)	Is the Geogrid-interlayer performance Statistically Significantly different from the Control at 95% CL ($\alpha = 0.05$)?			Statistical Ranking
		Shear bond strength	<i>P</i> -value	Decision: Yes, if $P < \alpha$	
Control	09.8%	(678, 857, 706; Avg = 747 kPa)	1.000	No (control)	A
FA-30	11.3%	(653, 586, 719; Avg = 653 kPa)	0.235	No	A
FA-50	14.7%	(441, 514, 383; Avg = 446 kPa)	0.011	Yes	B
FA-75	11.9%	(386, 490, 438; Avg = 438 kPa)	0.008	Yes	B
FA-100	15.6%	(381, 373, 284; Avg = 346 kPa)	0.003	Yes	B
FG-50	17.5%	(461, 442, 328; Avg = 410 kPa)	0.008	Yes	B
FG-100	19.0%	(247, 176, 253; Avg = 225 kPa)	0.001	Yes	C

1 Except for FA-30, Table 4 shows that all the geogrid reinforced samples are statistically different
2 from the control (unreinforced) and that FA-50, FA-75, FA-100, and FG-50 are statistically
3 indifferent and have the same statistical ranking. Therefore, either one of them can be used in
4 lieu of the other in terms of bond strength – subject to meeting other performance requirements
5 including their effectiveness in mitigating reflective cracking. Similarly, the results show that
6 there is no major statistical difference between the “Control” and FA-30 reinforcement in as far
7 interlayer bond strength performance is concerned. Statistically, the “Control” and FA-30 ranks
8 at the top (at A) while FG-100 ranks at the bottom-most or poorest (at C). The rankings can also
9 be traced to the standard error bars in Figure 9 that overlaps for the Groups A, B, and C,
10 respectively, as shown in Table 4.

11

12 **DISCUSSION AND SYNTHESIS OF THE FINDINGS**

13

14 Interlayer (interface) bonding of the HMA pavement layers is very critical during construction,
15 long-term performance, and durability, particularly where interlayer reinforcements such as
16 geogrids are used (12, 24). This study has undoubtedly added valuable data/information to the
17 pool of knowledge and literature on interlayer bond strength with respect to geogrid
18 reinforcements in HMA. In particular, the study results have demonstrated that use of interlayer
19 reinforcements in HMA has a profound effect on the interlayer bond strength and that due
20 diligence must be cautiously exercised when selecting both the geogrid type and grade for use in
21 HMA reinforcement to ensure optimum interlayer bonding.

22

23 **Geogrid Material Comparison**

24

25 Comparing the two geogrids evaluated, FA (polyester-based geogrid) outperformed FG
26 (fiberglass-based) by over 10%, presumably due to the bitumen copolymer coating that
27 contributed to its effective adhesiveness and bonding with the HMA and tack coat. This factor
28 (bitumen copolymer coating) along with the relatively large mesh opening area and thin strands
29 (Table 2) probably contributed to FA-30’s statistically indifferent performance from the control
30 (Table 4). The brittle characteristics of fiberglass may have contributed to FG’s comparatively
31 poor performance and relatively lower interlayer bond strength. By contrast, the flexibility
32 characteristics of polyester enabled FA to properly embed itself into the rough HMA surface to
33 form relatively strong interlayer bonds.

34

35 **Effects of Geogrid Type and Grade**

36

37 Both Figures 8 and 9 indicated reduction in the interlayer bond strength with the use of geogrid
38 interlayer reinforcement, and, that both geogrid type and grade were influencing factors – with
39 FG exhibiting more decay than FA. The loss in interlayer bond strength with increasing material
40 grade for both the geogrids is partly attributed to the decreasing aperture (mesh opening) area
41 and increasing strand dimensions (Table 2). This, in turn, decreases the HMA-tack-HMA
42 contact/bonding area, as exemplified by the percentage HMA-HMA contact over a 150-mm
43 diameter area. For the HMA mix and test conditions considered herein, FA material would be
44 preferred over FG, with FA-30 that exhibited statistically indifferent performance from the
45 control being recommended for optimum interlayer bond strength whilst simultaneously
46 mitigating reflective cracking. Nonetheless, the measured interlayer bond strength values

(ranging from 225 to 653 kPa) are comparable to the reviewed literature values (100-1500 kPa) of mostly unreinforced HMA shown in Table 1. Theoretically, this suggests that these geogrid interlayer reinforcement materials could be used with acceptable field bonding performance expectation – with FA (Grade 30) material being given preference over FG.

Simulating Field Conditions – New HMA over Field Core

To further supplement/validate the laboratory test results and simulate field conditions, 7.5-years old field cores were also used to evaluate the effects of the geogrid reinforcement (FA-30) on the interlayer bond strength. For this supplementary testing, only one geogrid type, namely FA-30, was demonstratively evaluated based on the assumption that the ranking/trend of the shear-bond strengths of field cores, under the same test conditions was theoretically not expected to be significantly different from that of the laboratory prepared specimens. Like the top HMA lift, the field cores (bottom lift) also comprised of 12.5-mm NMAS aggregates. As exemplified in Figure 10, a similar test configuration as listed in Table 3 was adapted albeit that the bottom 75-mm lift comprised of a field core and the top 75-mm lift a new HMA overlay.

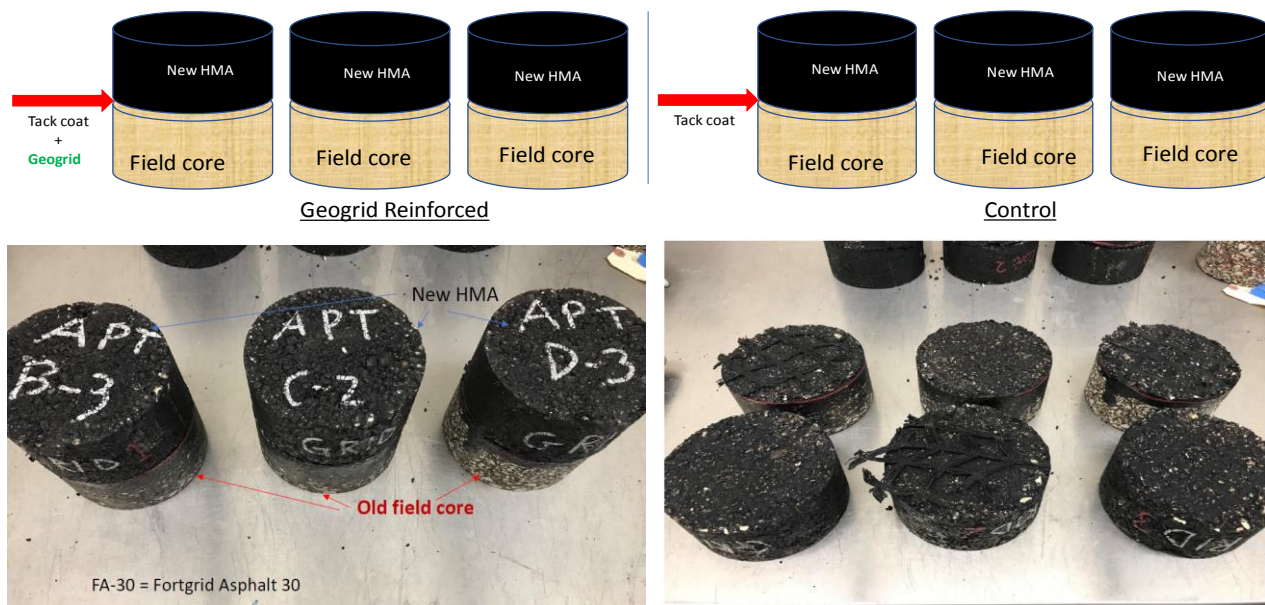


FIGURE 10 Test Configuration for New HMA Over Field Cores.

Three replicate tests were conducted for the “Control” and “FA-30” grid reinforcement, respectively; see Figure 10. Similar test conditions shown in Figure 5 were used. The test results are summarized in Table 5 and shows that the interlayer shear-bond strengths with the field core are statistically indifferent from those reported in Table 4 for both the “Control” and “FA-30” grid reinforcement, respectively. Similarly, “FA-30” and the “Control” are statistically indifferent. Considering that field cores simulating field conditions were used, these test results are plausible and to some degree validates the findings of this study. In addition, the calculated COV values were significantly less than 30% (Table 5) as was the case with the earlier test results reported in Table 4. This vindicates that the PINE interface shear test is repeatable with low data variability and statistically acceptable results.

1 **TABLE 5 Shear-Bond Strength Results for New HMA Over Field Cores.**

Parameter	Control	Geogrid Reinforcement (FA-30)
Test sample configuration	New HMA (75 mm thick) + tack coat + field core (75 mm thick)	New HMA (75 mm thick) + <i>grid</i> (FA-30) + tack coat + field core (75 mm thick)
Sample01	705 kPa	623 kPa
Sample02	738 kPa	608 kPa
Sample03	724 kPa	679 kPa
Average	722 kPa	637 kPa
COV ($\leq 30\%$)	2.29%	5.88%
<i>P-value</i>	0.684 ($> \alpha = 0.05$)	0.735 ($> \alpha = 0.05$)
Statistical ranking	A	A

2
3 As stated above, the lab-sample and field-core results for the Control and FA, are statistically
4 indifferent, slightly differing only by about 2.5%, i.e., 637 kPa (cores) versus 653 kPa (lab-samples).
5 This is theoretically speculated to be due to similar controlled test conditions and sample preparation
6 procedures as well as good workmanship. On the other hand, these findings could analytically infer that
7 with proper construction practices and QC/QA protocols, interlayer bond strength close or equivalent to
8 fresh HMA is attainable.

9 **HMA Lift Thickness and Correlations to Field Conditions**

10
11 Note that in both the lab-samples (Figure 4) and field-cores (Figure 10), 75 mm thickness was
12 used (as opposed to the typical field 50 mm overlay thickness or less) for the practical
13 convenience of the laboratory shear-bond test setup (Figure 5) as well as being conservative in
14 terms of simulating the worst-case scenario for sample-edge compaction and bond strength.
15 Therefore, future follow-up studies should focus on thinner HMA lifts including 50 and 25 mm
16 thicknesses to comparatively assess their impacts on shear-bond strength results and
17 supplement/substantiate the findings of this study. As this study only focused on the shear
18 loading effects, another aspect worth investigating in future studies is the effects of the normal
19 stresses on the shear behavior of the samples that was not considered in this study.

20

21 **SUMMARY AND CONCLUSIONS**

22

23 This laboratory study was conducted to comparatively evaluate and quantify the interlayer bond
24 strength in HMA due to the effects of the geogrid reinforcements using unreinforced control
25 HMA samples as the reference datum. Cylindrical HMA samples (150 mm diameter) gyratory
26 compacted in two 75-mm lift thicknesses, with the geogrid reinforcement in-between the two
27 lifts, were used for testing at room temperature under a monotonically shear loading rate of 5
28 mm/min. Emulsified asphalt was used as the interlayer tack coat and six different geogrid
29 materials, polyester-based (FA) and fiberglass-based (FG), were comparatively evaluated. For
30 the HMA mix and test conditions considered, the key findings and recommendations drawn from
31 the study are summarized as follows:

32

- 33 ■ Structurally, the interlayer geogrid reinforcements are needed to enhance reflective crack
34 mitigation in HMA overlays. However, as the study has shown, they may have an impact
35 on the interlayer shear-bond strength and that the degree of impact is partly a function of

1 the geogrid type/grade. For the geogrid materials evaluated in this study, the measured
2 bond strength ranged from 225 to 653 kPa versus 747 kPa for the control (unreinforced) –
3 which were all, nonetheless, satisfactorily comparable to the reviewed literature range of
4 100 to 1500 kPa for mostly unreinforced HMA.

- 5 ■ As theoretically expected, the unreinforced control HMA samples exhibited the highest
6 interlayer bond strength closely followed by the FA (polyester) reinforcements, and lastly,
7 FG (fiberglass).
- 8 ■ By comparison, FG-30 (polyester-based) was statistically indifferent from the control –
9 substantiating that geogrid reinforcements while mitigating reflective cracking, can be
10 satisfactorily used without any significant loss in the interlayer shear-bond strength
11 provided that the right geogrid type/grade is used.
- 12 ■ FA geogrids out-performed FG by over 10% at all the material grades evaluated. HMA
13 samples reinforced with FG exhibited the lowest interlayer bond strength, averaging
14 about 57.5% lower than the control.
- 15 ■ Statistically, FA-50 performed indifferently from FA-75, FA-100, and FG-50 in terms of
16 the interlayer shear-bond strength magnitude – thus, either one of them can be used in
17 lieu of the other in as far as optimizing interlayer bond strength is concerned, subject to
18 meeting other performance requirements including their effectiveness in mitigating
19 reflective cracking.
- 20 ■ The simulation of field conditions using FA-30 and 7.5-years old field cores indicated
21 that the interlayer shear-bond strengths of laboratory compacted HMA samples and the
22 field cores did not differ significantly.

23
24 Overall, the study results have demonstrated that addition of interlayer reinforcements in HMA
25 may have an impact on the interlayer shear-bond strength and that while interlayer reinforcement
26 is structurally desired to mitigate reflective cracking in HMA overlays, due diligence must be
27 cautiously exercised when selecting the geogrid type/grade to ensure sufficient interlayer
28 bonding and minimize any potential delamination/debonding problems in service. Nonetheless,
29 future follow-up studies should incorporate more field validation along with an array of HMA
30 mixes and tack coat types for laboratory testing to substantiate these findings and to propose a
31 standardized interlayer bond strength test procedure and screening criteria for geogrid
32 reinforcement in HMA. Other aspects to consider in future follow-up studies should include
33 thinner HMA lift-thicknesses (i.e., 50 mm, 25 mm, etc), using the same asphalt-binder as the
34 HMA for the tack coat, testing more field cores with different geogrid types, and assessing the
35 impacts of the normal stresses on the interlayer shear-bond strength.

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38
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44
45 The contents of this paper reflect the views of the authors who are responsible for the facts and
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4 endorsement, advertisement, or certification.
5

6 REFERENCES

- 7
- 8 1) Ali, K., Shahab, F., & Fereidoon, M. N. (2009). [Effects of Geosynthetics on Reduction of](#)
9 [Reflection Cracking in Asphalt Overlays](#). *Elsevier Journal of Geotextiles and*
10 *Geomembranes*. Vol. 27 (1), PP 1–8.
 - 11 2) AG (2013). [Alliance Geosynthetics – Pavement Interlayer System](#). Technical Brochure,
12 NILEX Civil Environmental Group, USA.
 - 13 3) Cleveland, G.S., Button, J.W., & Lytton, R.L (2002). Geosynthetics in Flexible and Rigid
14 Pavement Overlay Systems to Reduce Reflection Cracking. Research Report# FHWA/TX-
15 02/1777. PP 1-297. Texas Department of Transportation (TxDOT) - RTI, TX, USA.
 - 16 4) Thin Bituminous Surfacing Systems. Agrément South Africa (ASA).
 - 17 5) Fyfe, G. (2011). [Geotextile Reinforced Seals under Asphalt](#). Paper Publication. Geofabrics
18 Australasia, Australia.
 - 19 6) Mostafa, E., & Bandaru, R. (2011). Cost Effective Prevention of Reflective Cracking of
20 Composite Pavement. Research Report FHWA/LA.11/478. LSU, Baton Rouge, USA.
 - 21 7) TI (2015). Tensar International. [GlasGrid Pavement Reinforcement System - The GlasGrid®](#)
22 [System Extends Pavement Life Thus Reducing Maintenance and Life Cycle Costs](#). GlassGrid
23 Brochure, USA.
 - 24 8) Walubita, L.F., Faruk, A.N., Zhang, J., & Hu, X. (2015). [Characterizing the Cracking and](#)
25 [Fracture Properties of Geosynthetic Interlayer Reinforced HMA Samples using the Overlay](#)
26 [Tester \(OT\)](#). *Elsevier Journal of Construction and Building Materials*, Vol. 93, PP 695-702.
 - 27 9) Geomatrix (2016). [Geomatrix Product Website](#). Accessed September 2016.
 - 28 10) Zornberg, J.G. (2011). [Advances in the Use of Geosynthetics in Pavement Design](#).
29 Conference Proceedings. Geosynthetics India'11, IIT Madras, Chennai, Sept 23-24, 2011.
 - 30 11) Zaniwski, J.P., Knihtila, S.F., & Rashidi, H.N. (2015). [Evaluation of the Bond Strength of](#)
31 [Asphalt Overlay](#). Proceedings of International Airfield & Highway Pavements Conference
32 2015.
 - 33 12) Wilson, B., Seo, A., & Sakhaeifar, M. (2013). Performance Evaluation and Specification of
34 Trackless Tack. FHWA/TX-16/0-6814-1. Texas Transportation Institute, College Station, TX,
35 2013.
 - 36 13) Johnson, E., Cruz, N., & Wood, T. (2015). [Using the Florida Bond Test to Improve HMA](#)
37 [Bond Strength and Durability – Technical Summary Report](#). MN, USA.
 - 38 14) Mohammad, L., Elseifi, B., & Patel (2012). NCHRP Report# 712: Optimizing Tack Coat for
39 HMA Placement. Washington DC – The National Academies Press.
 - 40 15) Tran, N.H., Willis, R., & Julian, G. (2012). [Refinement of the Bond Strength Procedure and](#)
41 [Investigation of a Specification](#). NCAT Report# 12-04. Auburn, AL.
 - 42 16) Solaimanian, M. (2013). Paving the Way. APA, Harrisburg, PA.
 - 43 17) PI (2017). Pavement Interaction: [http://www.pavementinteractive.org/article/de-bonding-of-](http://www.pavementinteractive.org/article/de-bonding-of-hma-pavementslayer-bonding-2/)
44 [hma-pavementslayer-bonding-2/](http://www.pavementinteractive.org/article/de-bonding-of-hma-pavementslayer-bonding-2/) Accessed July 2017.

- 1 18) Gharaybeh et al. (2010). [Evaluation of Bond Strength Between Old and New Pavement](#)
2 [Overlays. Paper extract from Maters Thesis](#). JUST, Irbid, Jordan.
- 3 19) Vacin, O., Ponniah, J., & Tighe, S. (2002). [Quantifying the Shear Strength at the Asphalt](#)
4 [Interface](#). Technical Paper.
- 5 20) Denneman, E., Steyn, W.J.vdM., Visser, A.T., 2008. Guidelines for the Assessment and
6 Certification of Thin Bituminous Surfacing Systems. Agrément South Africa (ASA).
- 7 21) White, G. (2015). [Asphalt Overlay Bond Strength](#). Conference Proceeding - Airfield
8 Pavement and Lighting Forum, At Sydney, New South Wales, Australia.
- 9 22) Wang, H., et al. (2015). HMA Pay Adjustment. Report# FHWA NJ-2015-007, Piscataway,
10 NJ.
- 11 23) McGhee, K.K., & Clark, T (2009). Bond Expectations for Milled Surfaces and Typical Tack
12 Coat Materials Used in Virginia. Research Report# 09-R21. VTRC, VA.
- 13 24) West, R.C., Zhang, J., & Moore, J. (2005). Evaluation of Bond Strength between Pavement
14 Layers. NCAT Report 05-08. National Center for Asphalt Technology, Auburn, AL.
- 15 25) Brown, S.F., Thom, N.H., & Sanders, P.J. (2001). A study of grid reinforced asphalt to
16 combat reflection cracking. *Journal of the Association of Asphalt Paving Technologists*. Vol.
17 90, pp 543-569.
- 18 26) Pasquini, E., Bocci, M., & Canestrari, F. (2014). Laboratory Characterisation of Optimized
19 Geocomposites for Asphalt Pavement Reinforcement. *Geosynthetics International*. Vol. 21
20 (1), pp 24-36.
- 21 27) Safavizadeh, S.A. et al. (2015). Investigating Reflective Cracking Mechanisms in Grid-
22 Reinforced Asphalt Specimens. *Journal of the Transportation Research Board*. TRR 2507,
23 pp 29-38.
- 24 28) Saride, S., & Kumar, V.V. (2017). Influence of Geosynthetic-Interlayers on the Performance
25 of Asphalt Overlays on Pre-Cracked Pavements. *Geotextiles and Geomembranes*. Vol 45(3),
26 pp 184-196.
- 27 29) Kumar, V.V., Saride, S., & Peddinti, P.R.T. (2017). Interfacial Shear Properties of
28 Geosynthetic Interlayered Asphalt Overlays. *Geotechnical Frontiers 2017*. March 12-17,
29 Orlando, Florida, USA, GSP 277, 442-451.
- 30 30) Romeo, E., Freddi, F., & Montepara, A. 2013. Mechanical Behaviour of Surface Layer
31 Fibreglass-Reinforced Flexible Pavements. *International Journal of Pavement Engineering*.
32 Vol. 15 (2), pp 95-109.
- 33 31) Al-Qadi, I.L. et al. (2012). Best Practices for Implementation of Tack Coat: Part 2 – Field
34 Study. Springfield, IL.
- 35 32) USDOT (2016). [Tack Coat Best Practices](#). TechBrief FHWA-HIF-16-017. US Department of
36 Transportation, Washington DC, USA.
- 37 33) TxDOT (2018). TxDOT– Texas Department of Transportation. [Online Manuals and Test](#)
38 [Procedures](#). Austin, TX, USA. Last accessed September 2018.
- 39 34) Ross, S.M. (2009). [Introduction to Probability and Statistics for Engineers and Scientist – 4th](#)
40 [Edition](#). UC – Berkeley, USA | Academic Press (AP) – Elsevier.