Geogrid Reinforcement in Hot-Mix Asphalt
Interlayer Shear Bond Strength Assessment

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ABSTRACT

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

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

INTRODUCTION

Reflective cracking is one of the undesirable structural distresses occurring in hot-mix asphalt (HMA) overlays over flexible and concrete pavements; costing highway agencies millions of tax payers' dollars in maintenance and rehabilitation activities. To mitigate reflective cracking in existing cracked pavements, various methods including application of crack-impeding and interlayer reinforcements are often used in maintenance and/or rehabilitation projects as part of the HMA overlay construction (*1*-*8*). Figures 1 and 2 exemplify an old cracked pavement and geogrid interlayer construction, respectively.

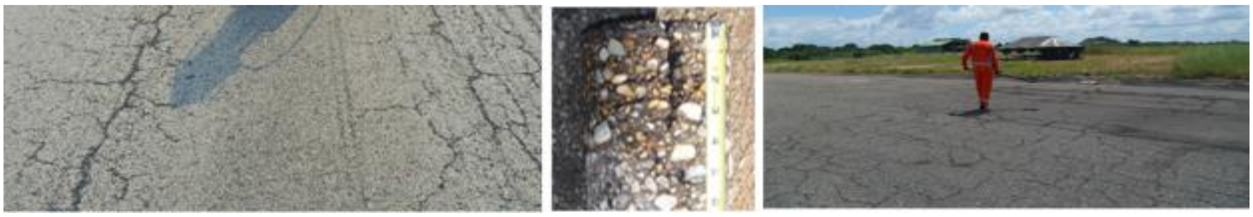


FIGURE 1 Example of an Old Cracked HMA Pavement.

FIGURE 2 Geogrid Interlayer Reinforcement and HMA Overlay Construction.

As illustrated in Figure 2, one of the primary roles of the interlayer reinforcement is to arrest the upward propagation of cracks from an existing cracked pavement to the surface, i.e., to mitigate the cracks from reflecting through the HMA overlay to the surface. And thus, aiding in prolonging the cracking resistance and service life of the pavement (*8*).

Many types of interlayer reinforcement materials including geogrids, geotextiles, paving mats, paving fibers, etc., are presently available on the commercial market and widely used in HMA overlay projects during maintenance and rehabilitation activities (*8*,*10*). With the increasing use of these interlayer reinforcements, interlayer (interface) bonding becomes an even more critical aspect of HMA placement/construction to prevent delamination and debonding during service that could negatively impact the long-term performance, longevity, and durability of the overlay.

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

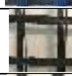
Most of the HMA bond strength tests reported in the literature are either direct-shear, tension, or torque-shear based. These include the interface-shear (PINE, ASTRA, etc), Leutner-shear, Superpave-shear, Limoges double-shear, layer-parallel direct shear, Pull-off, Arcan, A-tacker, Torque bond tests, 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 to the already existing laboratory loading frames such as the Marshall stabilometer, universal testing machine (UTM), or material testing system (MTS).

While there is limited literature on the geogrid bond-strength effects, numerous studies have been conducted to evaluate various factors influencing the interlayer HMA bond-strength including mix-type, temperature, aggregate size, tack coat type, tack coat application rate, surface roughness, age, traffic, etc. (*11*,*14*, *15*, *21*). For instance, Tran et al. (*15*) reported that the interlayer bond strength generally improved with rougher milled surfaces than non-milled surfaces. By contrast, West et al. (*24*) and Al-Qadi et al. (*25*) observed a declining bond strength with an increase in temperature. However, majority of these studies have been predominantly based on unreinforced HMA with or without tack coat – but, without any interlayer geogrid reinforcements in the HMA. Thus, this study is primarily focused on evaluating the effects of the interlayer geogrid reinforcement on the bond strength in HMA, i.e., what is the effect on the interlayer bond strength with the addition of geogrid reinforcements in HMA? Whilst the interface bond can be measured, characterized, and quantified in terms of strength, modulus (stiffness), or work (energy), the monotonic shear bond strength parameter was used in this study (*21*).

LABORATORY TEST PLAN

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

TABLE 2 Geogrid Materials.

Geogrid	Mesh View	Mesh Opening Area (mm^2)	Strand Thickness (mm)	Strand Width (mm)
FA-30		~801	~0.63	~7.15
FA-50		~743	~0.88	~9.15
FA-75		~651	~1.01	~11.01
FA-100		~507	~1.15	~12.65
FG-50		~457	~0.55	~5.11
FA-100		~253	~1.15	~11.01

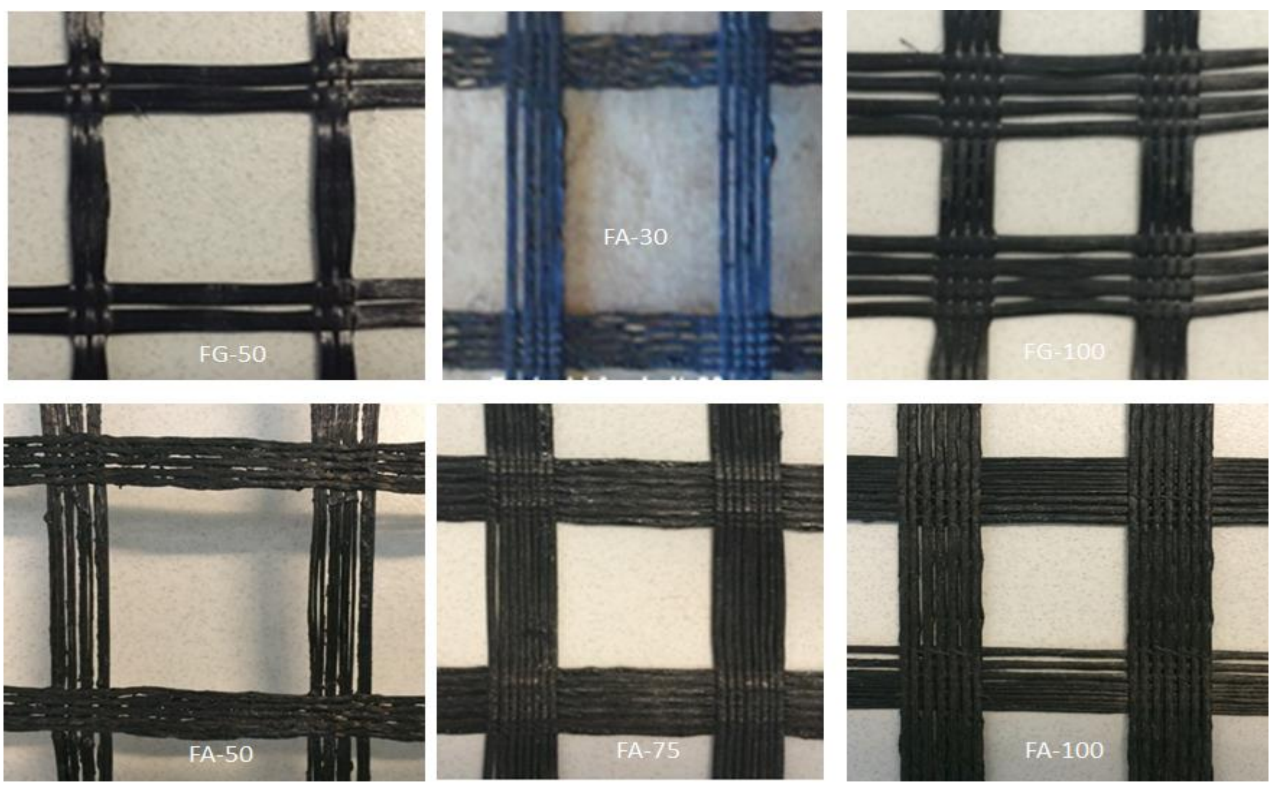


FIGURE 3 Pictorial Illustration of the Geogrid Materials.

HMA Mix and Sample Fabrication

A typical dense-graded 12.5 mm nominal maximum aggregate sized (NMAS) mix, with limestone/dolomite/granite aggregates and 4.5% PG 64-22 asphalt-binder, was used. As illustrated in Table 3 and Figure 4, HMA cylindrical samples (150 mm ϕ) were compacted in two 75-mm lift thicknesses using the Superpave gyratory compactor (SGC) – with the geogrid reinforcement in-between the two lifts, except for the control (unreinforced) HMA samples.

TABLE 3 HMA Sample Molding and Compaction Process.

#	HMA Sample (ϕ=150 mm)	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 + *grid* + 75-mm top lift = 150 mm total thickness

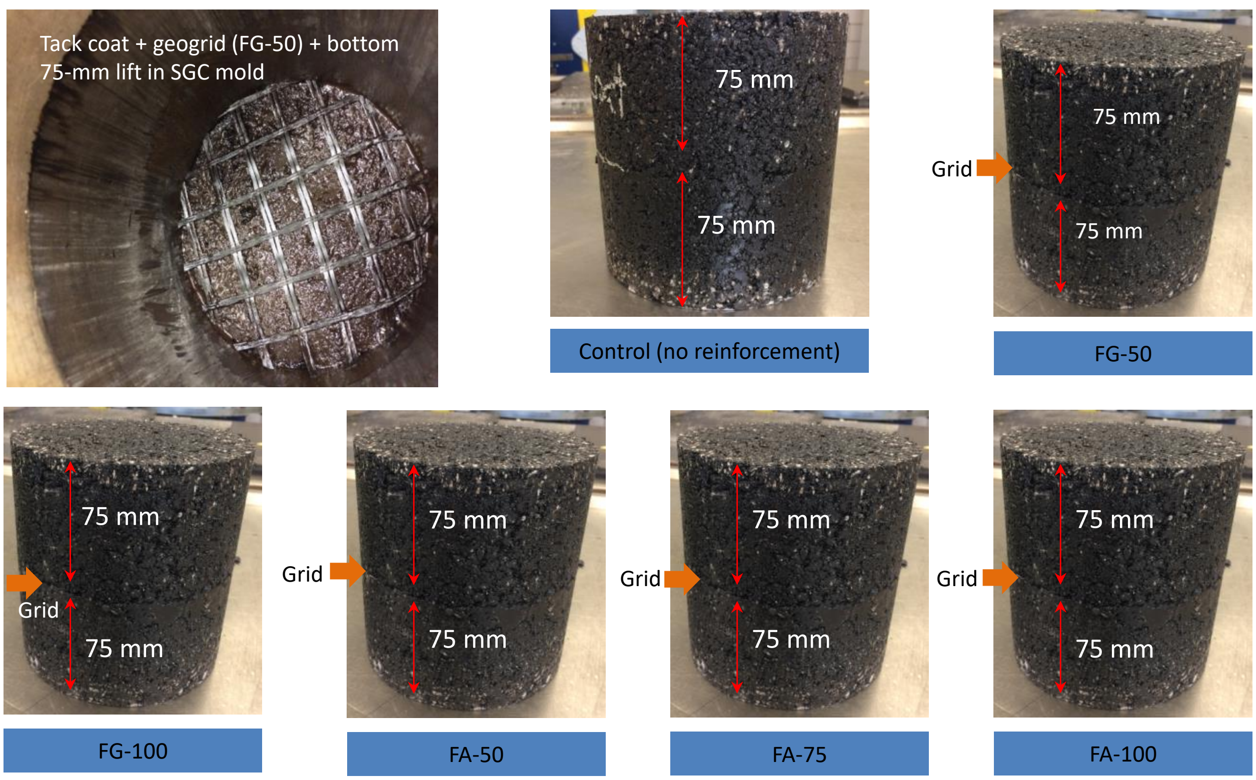


FIGURE 4 HMA Sample Fabrication and Interlayer Geogrid Reinforcement.

Emulsified asphalt, with a weight equivalent application rate of 0.45 liters/m^2 was used as the interlayer tack coat (*26*). 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 (*27*). Both the bottom and top 75-mm HMA lifts were compacted to a target density of 93±1%, i.e., 7±1% air voids (*27*). Density and air void (AV) determination were based on dimensional and volumetric computations; and were all 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.

The Interlayer Shear Bond Strength Test

As previously stated, there exist several test methods to evaluate the interlayer (interface) bonding of HMA layers including the PINE interface shear, Pull-off (tension), and torque-bond tests (*11*-*12*, *20*-*21*). The PINE interface shear test, that has been proven to be a practical and repeatable test, was used in this study (*12*). As shown in Figure 5a, the HMA sample is inserted with the bond interface oriented vertically. One side of the clamp setup holds the sample rigidly with the other side freely slides vertically.

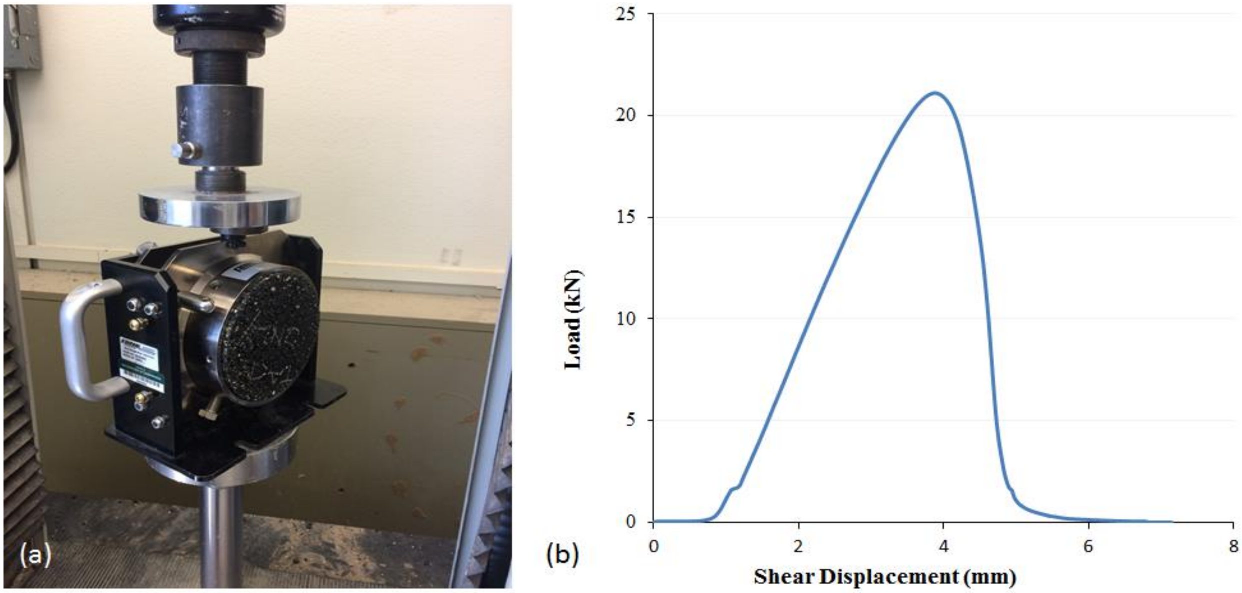


FIGURE 5 Shear Bond Strength Test Setup (a) and Example Output Data (b).

In this study, the test was conducted at a monotonic loading rate of 5 mm/min at room temperature until sample failure. From the test data, a load-displacement (L-D) graph as exemplified in Figure 5b is generated and the peak load is used to determine the bond strength as illustrated in Equation 1 (*12*):

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

In Equation 1, S_{max} is the maximum shear bond strength, P_{max} is peak (maximum) failure load, and D is the sample diameter, i.e., 150 mm in this study. After testing, the HMA samples would be sheared and split into the two HMA lifts as shown in Figure 6.

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

LABORATORY TEST RESULTS AND ANALYSIS

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

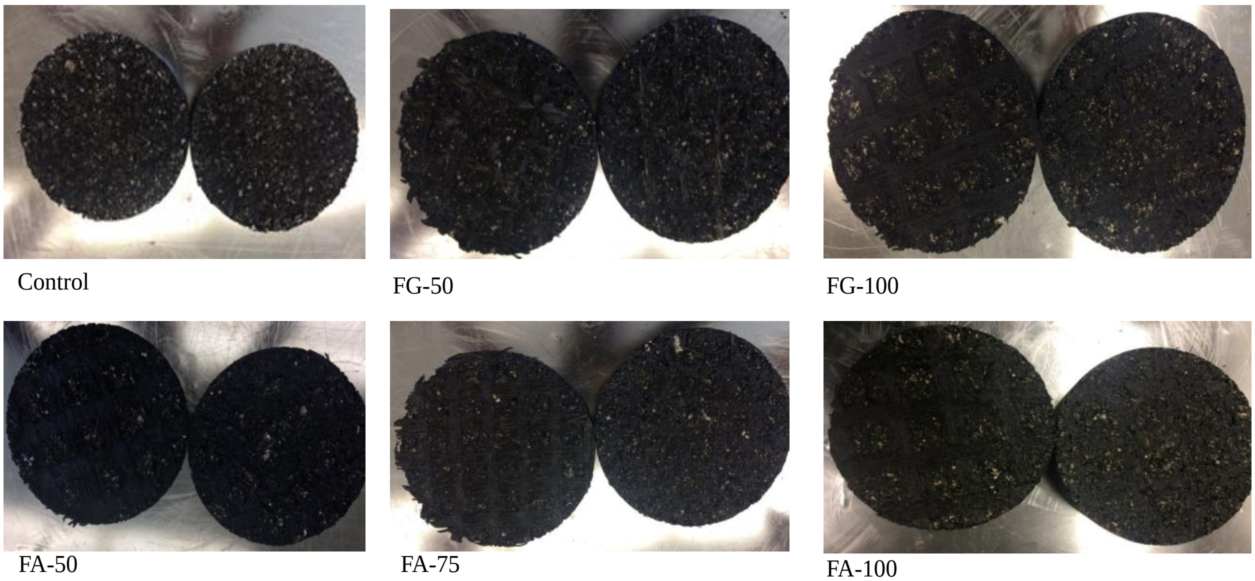


FIGURE 7 Example HMA Samples After Testing.

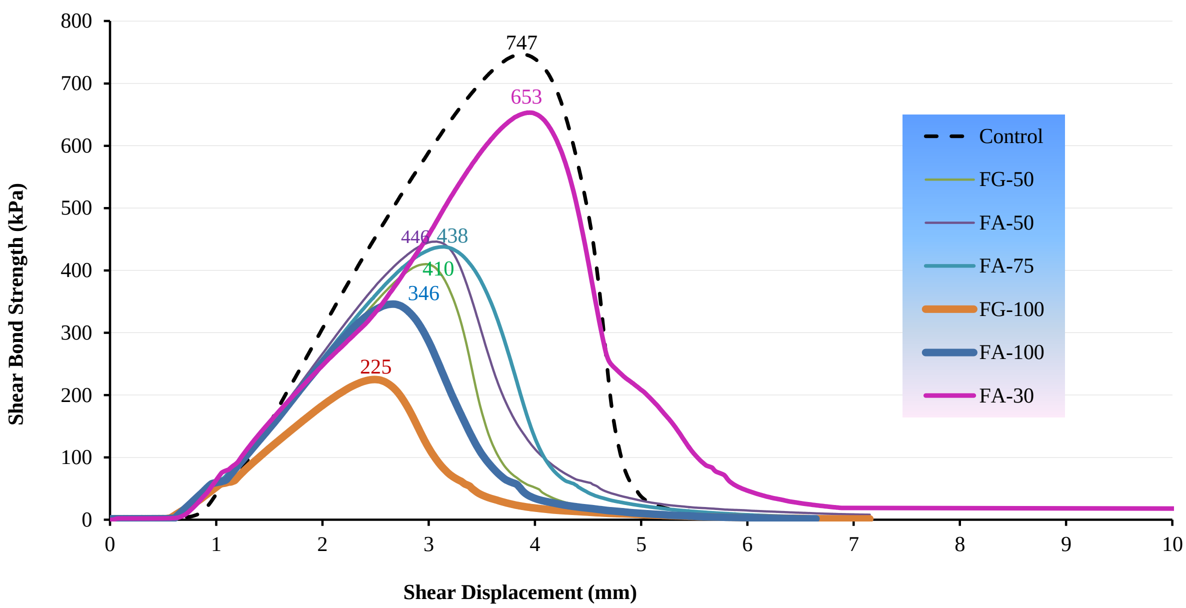


FIGURE 8 Interlayer Shear Bond Strength versus Displacement Plots.

While superior to FG, Figure 8 further shows that FA-50 and FA-75 are insignificantly different in terms of their interlayer bond strength performance and shear displacement failure. These results are distinctively evident in Figure 9 where the average (peak) interlayer bond strength is plotted as a function of the geogrid material grade in a bar chart.

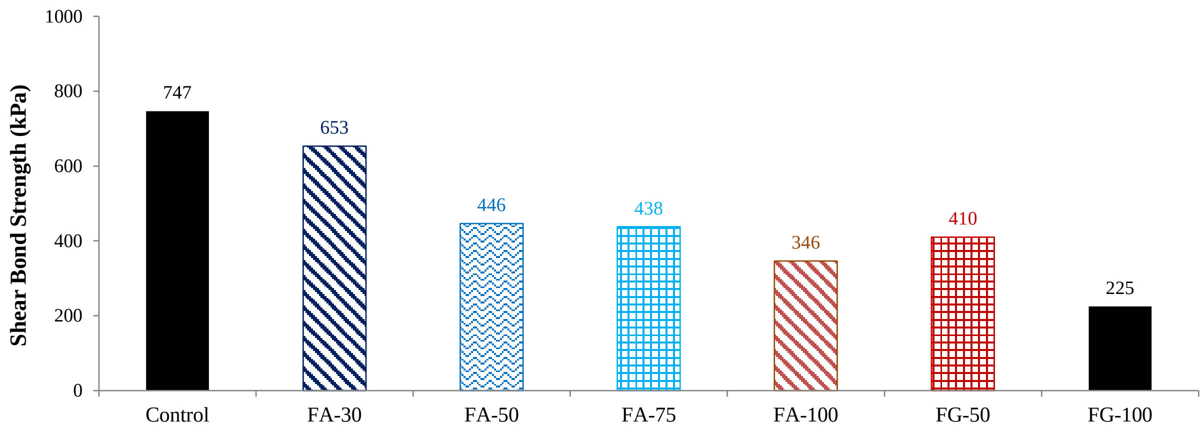


FIGURE 9 Interlayer Shear Bond Strength versus Geogrid Material Grade.

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

When comparing FA-50 versus FA-75, it is evident in Figure 9 that the bond strength value of 446 kPa is hardly different from 438 kPa – theoretically suggesting that their in-service bonding strength performance would be insignificantly different. Thus, these two geogrid materials (FA-50 and FA-75) can be used in lieu of one another in as far as optimizing interlayer bond strength is concerned.

Furthermore, Figure 9 also shows a decaying and loss in interlayer bond strength with an increase in the geogrid material grade. For instance, FA decreased from 653 kPa (Grade 30) to 346 kPa for Grade 100. Similarly, FG drastically declined by almost 50% from 410 kPa (Grade 50) to 225 kPa (Grade 100). Using the control as the reference datum, a reduction in the interlayer bond strength of as much as 69.9% due to the effects of interlayer reinforcement with FG-100 can be inferred from Figure 9. The least reduction in interlayer bond strength was computed for FA- 30 at 12.5%, i.e., 747 kPa to 653 kPa.

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

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?	Statistical Ranking
Control	09.8%	(678, 857, 706; Avg = 747 kPa) N/A	A
FA-30	11.3%	(653, 586, 719; Avg = 653 kPa) No	A
FA-50	14.7%	(441, 514, 383; Avg = 446 kPa) Yes	B
FA-75	11.9%	(386, 490, 438; Avg = 438 kPa) Yes	B
FA-100	15.6%	(381, 373, 284; Avg = 346 kPa) Yes	B
FG-50	17.5%	(461, 442, 328; Avg = 410 kPa) Yes	B
FG-100	19.0%	(247, 176, 253; Avg = 225 kPa) Yes	C

Except for FG-30, Table 4 shows that all the geogrid reinforced samples are statistically different from the control (unreinforced) and that FA-50, FA-75, FA-100, and FG-50 are statistically indifferent and have the same statistical ranking. Therefore, either one of them can be used in lieu of the other in terms of bond strength – subject to meeting other performance requirements including their effectiveness in mitigating reflective cracking. Similarly, the results show that there is no major statistical difference between the control and FA-30 reinforcement in as far interlayer bond strength performance is concerned. Statistically, the "control" and FA-30 ranks at the top (at A) while FG-100 as the bottom-most or poorest (at C).

DISCUSSION AND SYNTHESIS OF THE FINDINGS

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

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

Both Figures 8 and 9 indicated reduction in the interlayer bond strength with the use of geogrid interlayer reinforcement, and, that both geogrid type and grade were influencing factors – with FG exhibiting more decay than FA. By and large, the loss in interlayer bond strength with increasing material grade for both the geogrids is partly attributed to the decreasing mesh opening area and increasing strand dimensions (Table 2) that ultimately decreases the HMA-tack-HMA contact/bonding area. For the HMA mix and test conditions considered herein, FA material would be preferred over FG, with FA-30 that exhibited statistically indifferent performance from the control being recommended for optimum interlayer bond strength whilst simultaneously 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.

SUMMARY AND CONCLUSIONS

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

- Structurally, the interlayer geogrid reinforcements are needed to enhance reflective crack mitigation in HMA overlays. However, as the study has shown, they may have an impact on the interlayer bond strength and that the degree of impact is partly a function of the geogrid type/grade. For the geogrid materials evaluated in this study, the measured bond strength ranged from 225 to 653 kPa versus 747 kPa for the control (unreinforced) – which were all, nonetheless, satisfactorily comparable to the reviewed literature range of 100 to 1500 kPa for mostly unreinforced HMA.
- As theoretically expected, the unreinforced control HMA samples exhibited the highest interlayer bond strength followed by the FA (polyester) reinforcements, and lastly, FG (fiberglass).
- FG-30 (polyester-based) was statistically indifferent from the control – substantiating that geogrid reinforcements, while mitigating reflective cracking, can be satisfactorily used without any significant loss in the interlayer bond strength provide that the right geogrid type/grade is used.
- FA geogrids out-performed FG by over 10% at all the material grades evaluated. HMA samples reinforced with FG exhibited the lowest interlayer bond strength, averaging about 57.5% lower than the control.
- Statistically, FA-50 performed indifferently from FA-75, FA-100, and FG-50 in terms of the interlayer bond strength magnitude – thus, either one of them can be used in lieu of the other in as far as optimizing interlayer bond strength is concerned, subject to meeting other performance requirements including their effectiveness in mitigating reflective cracking.

Overall, the study results have demonstrated that addition of interlayer reinforcements in HMA may have an impact on the interlayer bond strength and that while interlayer reinforcement is structurally desired to mitigate reflective cracking in HMA overlays, due diligence must be cautiously exercised when selecting the geogrid type/grade to ensure sufficient interlayer bonding and minimize any potential delamination/debonding problems in service. Nonetheless, future follow-up studies should incorporate field validation along with an array of HMA mixes and tack coat types for laboratory testing to substantiate these findings and to propose a standardized interlayer bond strength test procedure and screening criteria for geogrid reinforcement in HMA.

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