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Assessment of the Interface of Overlay and Stess Absorbing Membrane Interlayer (Sami) Using Pull-Off Test

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ABSTRACT

The study evaluates the interface bond of overlay – stress absorbing membrane interlayer interface (SAMI) interface. This was carried out using the pull-off test which measures the interface strength in tension mode. The pull-off test was considered for the interface evaluation in this study because the surfacing layer of a road pavement is not only effective in shear but also in tension mode under trafficking, as the moving traffic exerts normal pressure on the interface. The test was also carried out on samples without stress absorbing membrane interlayers. It was found that the introduction of SAMI leads to reduction of the interface tensile strength, except in the case of SAMIs A and B. The reduction in the tensile strength was probably due to the properties of the SAMI. Also, the study shows that the interface tensile strength decreases with increasing temperature. This is thought to because the stiffness of the overlay and SAMIs decreases with increasing temperature.

INTRODUCTION

The pull off test was developed at the University of Texas at El Paso (UTEP) (Tashman *et al*. 2008). The test measures the tensile strength of the interface. The pull-off test is usually considered for the interface evaluation because the surfacing layer of a road pavement is not only effective in shear but also in tension mode under trafficking, as the moving traffic exerts normal pressure on the interface. Debondt (1999) observed that due to the action of wheel loads at locations next to discontinuities (cracks/joints) in the existing pavement structure, quite large tensile stresses perpendicular to the plane of the interface were found to occur.

A number of researchers have investigated the bond between layers of pavement with and without interlayers using different approaches. Some of them are reviewed in this section. This was done to understand the importance of bond between pavement layers in pavements with and without interlayers. Hughes (1986) developed a shear box to study the strength of various interface conditions. He noted that there were some limitations with its use. The test specimens were constructed in two lifts. Normal and shear forces were applied. The normal load was held approximately constant and the shearing force was supplied at a constant rate of strain (5mm/min). He examined five interface conditions namely: chip seal only; chip seal and grid; grid only; no treatment; and no interface (specimen compacted in one lift). He observed that both chip seal only and grid and chip seal interfaces had a reduction in shear strength of approximately 20% when compared to the no treatment condition. He observed that the chip seal rich in bitumen combined with the slow rate of loading in the test (5 mm/min) created a viscous failure along the predetermined failure plane. The grid only condition reduced the shear strength of the interface by 10% compared to the untreated surface. He concluded that the reduction in shear strength should not be a problem in general practice, since rates of loading are significantly higher under traffic loading and viscous failure of the chip seal would be unlikely. Also, Caltabiano (1990) used the same shear box developed by Hughes to determine the interface shear strength for materials used to prevent reflection cracking employing a vibrating hammer instead of static pressure adopted by Hughes. He stated that the greatest reduction in shear strength was recorded for a geotextile interlayer (30% of control) placed with a bituminous seal in accordance with the manufacturer’s recommendations. He observed that the geogrid interlayer with chip seal and the timber/emery paper interlayer showed a reduction of approximately 20% in shear strength from the control sample, which agreed with earlier findings of Hughes. Also, he concluded like Hughes that reduction in shear strength of the order of 20-30% obtained for laboratory testing should not cause any problems with overlay slippage for in-situ conditions, as field loading rates are significantly higher than the shearing rate used during testing. Sanders (2001) showed in his research on interface bonding in pavements with a reinforced interlayer using the same shear box as Hughes and Caltabiano that failure occurred on the interface between the

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reinforcement and the lower layer of asphalt. He concluded that the bonds between freshly-applied asphalt and the reinforcement were better than the bonds between the reinforcement and the 'older' pavement. The shear box apparatus used by Hughes, Caltabiano and Sanders has the advantage that large specimen can be tested, allowing a representative sample of an interlayer to be examined. While it has been used successfully to study interface properties of pavement, it has a number of limitations. These include non-uniform stress distribution at the interface and stress concentration at the front and rear edges of the specimen causing failure along the shear plane, without the full shear strength of the interface being mobilized. This underestimates the shear strength of the interface. However, their tests showed that the introduction of interlayers in cracked pavement gave a reduction in shear strength of the interface of the order of 10-30% of specimens without interlayer.

Tschegg *et al* (1995) used a different approach from Caltabiano, Hughes and Sanders. He developed a wedge splitting test to characterize the fracture mechanical behaviour of layer bonding. The test involved introducing a rectangular groove into the specimen and placing a starter notch in the interface at the bottom of the groove, from where a crack started to grow into the interface during loading. Their results indicated that the specimens with an interface had less specific fracture energy than the ones without an interface, indicating a decrease in the interface stiffness. Although, the wedge splitting test is able to determine the maximum strength of interlayer bond, the fracture properties of an interlayer and differentiate between brittle and ductile behaviour, the loading method is not the type dominant in the field (an overlay over a cracked pavement). Therefore the method is considered inappropriate for the present study. Raab and Partl (2004) reported the research carried out by Swiss Federal Road Authority to determine the interface properties of a 30-year old concrete pavement of a motorway test section rehabilitated with an asphalt surface layer using three different intermediate bituminous layers: glass fibre mesh reinforced, steel wire grid reinforced and unreinforced. In the first system, before the application of the glass fibre mesh, as a first step, they sprayed a hot tack coat on the concrete pavement and the stone mastic asphalt was built (thickness 4 cm). The second system consisted of a steel wire grid reinforcement and slurry generally used for cold micro surfacing. In this case the steel wire grid was directly applied on the concrete pavement and slurry (thickness 0.5 to 1cm) was applied onto the steel wire grid and after the breaking of the emulsion the surfacing was finished with the application of a stone mastic layer (thickness 4.5cm). For the bituminous interlayer without reinforcement a hot tack coat was applied and spread with gravel, which was compacted afterwards. After sucking off the surplus gravel, a 4 cm asphalt concrete surface was applied. They examined the interlayer adhesion with the Layer-Parallel Direct Shear Device (LPDS) and the modified pull-off device according to the Swiss standard. For the pull off test, they reported that the specimens with still wire reinforcement were broken; hence the test could not be conducted, indicating insufficient bond. Their results showed the importance of interlayer shear performance, because the pavement with no reinforcement had the highest shear and pull-off force. The pavement with steel wire had less shear force than the one with glass fibre, while the maximum pull-off force for glass fibre was considerably less than that of the pavement with no reinforcement. They concluded that when using stress absorbing intermediate bituminous layers, it is important to choose appropriate and sufficiently established systems and construction techniques in order to minimize negative effects on adhesion. In the context of the present study, the test modes (shear and tension) used by Raab and Partl are very important because the an overlay over a cracked pavement is subjected to shear and tensile stresses as the wheel approaches the edge of the crack and tensile stresses when the wheel is directly over the crack. Therefore the tension mode is considered in the present study.

Investigations have also been carried out to evaluate the effects of the interface conditions such as the type and amount of tack coat, construction practice etc on the bond strength of the interface. Collop *et al* (2003) used the Leutner shear test to assess the bond condition between surfacing and binder course materials and binder course and base materials without any interlayer. They investigated the bond at the upper two interfaces in a typical flexible or semi-rigid pavement structure. The cores 150 mm in diameter were conditioned in a temperature-controlled cabinet at 20^{o}C and tested at 20^{o}C using a standard test loading rate (50mm/min), and the shear force and shear displacement were measured. They observed that for HRA/20DBM, SMA/20DBM and 20DBM/28DBM interfaces, in the cases where a standard tack coat application was used, the interface shear strengths approached those obtained from tests directly through each of the materials comprising the upper layer. For the HRA/20DBM and SMA/20DBM combinations, where no tack coat was used the interface shear strength was reduced, but not greatly. However, for the 'very dirty' condition extra tack coat did not compensate, and the interface shear strengths were significantly reduced. The results for the 20DBM/28DBM combinations show significantly higher levels of variability (in terms of shear strength) compared with the results for the surfacing/binder course interfaces. They reported that it was likely due to the fact that significantly larger aggregates were involved compared with the surfacing/binder course combinations. In the 20DBM/CBM combination, it proved impossible to achieve a good bond, reflecting common experience on site. They stated that zero penetration of stones from the DBM into the CBM (that is, reduced aggregate interlock) may be the main reason. Their tests clearly showed that a number of factors influence the bond achieved at the interface. These factors include the interface condition, the amount of tack coat and materials in contact, with the principal factors that reduce the interface bond significantly being the interface condition and materials in contact. This implies that when an interlayer is used in pavement, it is very important to take into consideration the type of overlay or maximum nominal aggregates in the overlay and the interlayer as this may have influence on the interface properties.

Kruntcheva *et al* (2006) investigated the factors affecting bond development between pavement layers using the Nottingham shear box. Their main set of test cases included a constant base material (20 mm DBM) and two distinct surfacing materials: 10 mm stone mastic asphalt (SMA); and porous asphalt (PA) with 15% voids. For these materials, they examined four different interface conditions: normal tack coat K1-40 application at 0.33 L/m^2 within the limits recommended by the British Standards Institute; excess tack coat rate (1.0 L/m^2); dirty interface (a clay-water slurry was placed on the interface); and no tack coat. They observed like Collop *et al* (2003) that the interface bond depends on the materials in contact, but not the amount of the applied tack coat. Also, contrary to the finding of Collop *et al*, they found that the interface condition did not have significant effect on the interface bond. It was pointed out, that using materials that require more compaction time will ensure good bond at interface. Tashman *et al* (2008) investigated the influence of several construction practices on the bond strength at the interface between existing HMA surface and a newly constructed 50mm HMA overlay (Superpave 12.5 mm nominal maximum aggregate). The factors studied included the following: surface treatment (milled versus non-milled); Curing time (broken versus unbroken); approximate target residual binder (0.00, 0.08, 0.22 and 0.32 L/$m^{2)}$; and equipment tracking (wheel path (WP) versus middle of lane (ML)). They performed three tests namely Florida Department of Transportation (FDOT) shear test, the torque bond test, and the University of Texas El Paso (UTEP) pull-off test. In the FDOT test, the field core was conditioned at a temperature of 25^{o}C for 2hr before the test. The laboratory torque bond test was conducted at 20^{o}C. They observed that the results from the UTEP pull-off test were generally different from the other two tests. Overall, milling provided a significantly better bond at the interface between the existing surface and the new overlay. For milled sections, the absence of tack coat did not significantly affect the bond strength at the interface. This was not true for the non-milled sections, where their results showed the absence of tack coat severely decreased the bond strength (there was no bond at all). They reported curing time had minimal effect on the bond strength at the interface and the residual rates in the range of 0.08–0.32 L/m^2 did not generally affect the bond strength at the interface which agreed with the findings of Kruntcheva *et al* (2006). Also, he stated that the equipment tracking did not occur to the extent expected during the experiment; hence its effect on the bond strength was insignificant. Their tests showed that the interface condition play a great role in the quality of adhesion achieved at the interface. This means that it is important that when SAMIs are to be introduced, the existing pavement surface must be free of dirt, dust, water and other things that may have negative impact on adhesion.

In summary, researchers have used different methods to determine the interface properties. It is important to consider the stresses that are dominant in the field before choosing any of the methods to assess the interface properties. In the present study, tensile and shear stresses are generated when an overlay is placed on a cracked pavement Therefore, the interface properties between the SAMIs and the overlay have been studied using pull-off test shown in Figure 1. The pull-off test measures the strength of the interface in tension mode.

In this study, the overlay material is 10 mm asphalt concrete with 40/60 penetration bitumen. This has been used with the SAMIs to produce specimens and examine the interface bond.

Fig. 1: Pull-off test set up.

MATERIALS AND METHODS

Materials:

The materials used for the study were 10 mm Asphaltic Concrete (AC) with 40/60 straight run bitumen, 10 mm AC with 10/20 straight run bitumen and the SAMIs are termed SAMIs A, B, C, D, and sand asphalt . The mix composition for 10 mm AC in Table 1 was prepared in accordance with BS standard (BS 2006a), also the mix compositions for the SAMIs A and B were as shown in Table 2. The mix composition for sand asphalt in Table 3 was in accordance with British standard (BS 2006b). SAMIs C and D were prepared by sandwiching glass fibres chopped to 60 mm at a rate of 120 g/m^2 between two layers of bitumen emulsion spread at a rate of 0.9 L/m^2 with 6 mm aggregate compacted on them. SAMI C was produced using ordinary bitumen emulsion while SAMI D was produced with polymer modified bitumen emulsion. The indirect tensile stiffness moduli of the asphalt concrete, SAMIs A and B and sand asphalt are shown in Table 4. The indirect tensile stiffness moduli were determined in accordance with British Standard (BSI, 1993)

Table 1: Mix composition for 10 mm asphalt concrete.

Sample	Percentage by composition of aggregates
10 mm aggregate	37%
6mm aggregate	26%
Dust	36%
Filler	1%
Binder type	40/60 bitumen
Binder content	5.3% by mass of total mix
Target air void	5%

Table 2: Mix compositions design for SAMIs A and B.

Sample type	% by composition of aggregate	% by composition of aggregate
	SAMI A	SAMI B
0/4 Crushed rock fill	95%	74.5%
Fine sand	-	20%
Filler	5%	5.5%
Binder type	Polymer modified bitumen	Polymer modified bitumen
Binder content	9 % by mass of total mix	9.1 % by mass of total mix
Target air void	2%	2%

Table 3: Mix design for Sand asphalt.

Sample	Percentage by composition of aggregates
Sand	84%
Filler	16%
Binder type	160/220 bitumen
Binder content	10.3% by mass of total mix
Target air void	5%

Table 4: Indirect tensile stiffness moduli.

Asphalt concrete (AC)	Stiffness (MPa)		
	Temperature		
	10^{o}C	20^{o}C	30^{o}C
AC (40/60)	10000	3900	1100
AC (10/20)	15400	9600	5000
SAMI A	8550	2730	640
SAMI B	7650	2440	510
Sand asphalt	640	210	120

Methods:

Sample preparation:

The test specimen for the pull-off test was a 3-layer asphaltic slab of dimension 305 mm × 305 mm × 80 mm. The base layer was 30 mm thick 10 mm asphaltic concrete with 10/20 bitumen (see Table 1), the middle layer was SAMI (20 mm thick proprietary SAMIs A and B (see Table 2) and sand asphalt (see Table 3) and about 7 mm proprietary SAMIs C and D and the top layer (overlay) was 30 mm thick 10 mm asphaltic concrete with 40/60 bitumen. The control specimen was manufactured in two layers without a SAMI, the base layer was 30 mm thick 10 mm asphaltic concrete with 10/20 bitumen and the top layer (overlay) was 30 mm thick 10 mm asphaltic concrete with 40/60 bitumen.

For the base layer, the aggregates and binder were heated at 185^{o}C and compacted in a mould of dimension 500 mm × 500 mm × 205 mm with a roller compactor at a temperature of 180^{o}C to a thickness of 30 mm. The aggregates and binders for sand asphalt were heated at 140^{o}C and compacted at 130^{o}C, while the aggregates and binder for SAMIs A and B were heated at a temperature of 180°C, and compacted at a temperature of 150°C. The overlay aggregates were heated at 160°C and compacted to the required thickness at 150°C. All the mixtures were mixed and compacted in accordance with British Standards (BSI 2003, BSI 2004). SAMIs C and D were prepared by sandwiching 60 mm glass fibre strands between layers of bitumen emulsion and 6 mm aggregates compacted over them. SAMI C was prepared with ordinary bitumen emulsion while SAMI D was prepared with polymer modified bitumen emulsion.

The top layer of the slab was isolated by cutting down to the top of the middle layer (SAMI) without damage to the SAMI. The plan for the cut was as shown in Figure 2. The cutting was done such that there were two isolated areas of 100 mm × 100 mm at the top layer. A steel plate of dimension 100 mm × 100 mm × 10 mm was glued to each of the areas with epoxy glue.

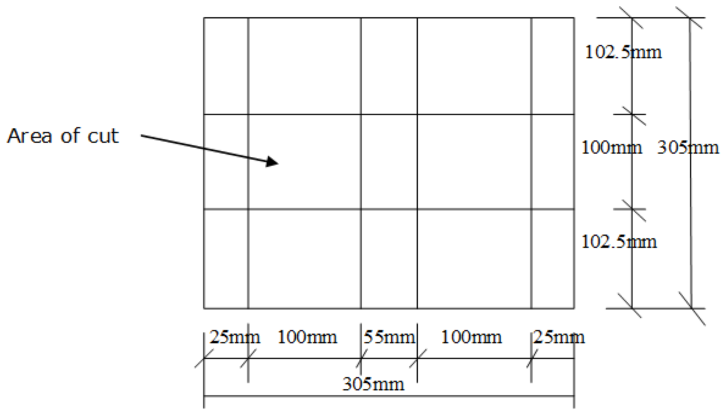

Fig. 2: Plan of cuts for the 305 mm × 305 mm slab.

Test procedure:

The test was carried out in a tensile pull-off apparatus (Instron hydraulic machine). The sample for the test was placed in a temperature conditioning cabinet at test temperature for a minimum of 5 hours. The specimen was attached to the Instron hydraulic machine using a hook on the steel plate. It was loaded at a rate of 20 mm/min until the interface bond failed. The maximum load required to pull-off the top layer from the interlayer was recorded and the tensile strength of the interface was calculated.

Results and analysis:

The results of the pull off test are shown in Tables 5, 6, and 7. It can be seen from the tables that the overlay-SAMI A and overlay-SAMI B interface did not fail at 10°C, 20°C and 30°C. The values are recorded with a greater than (>) sign because they are the maximum values to failure of the steel plate at the glue interface. This showed they were well bonded and had stronger bond than the control (AC10 (40/60)/AC10 (10/20)), thus, confirming the results of the shear test (Ogundipe, 2011). Also, as shown in Table 5, the control (AC10 (40/60)/AC10 (10/20)) interface did not fail at 10°C.

Table 5 shows that at 10°C, the overlay-sand asphalt interface has a greater tensile strength than the overlay-SAMI C or overlay-SAMI D interface, which had the same strength. Also, this was in agreement with the shear test results. Tables 6 and 7 show that the overlay-SAMI C interface had slightly better interface tensile bond than the overlay-SAMI D interface at 20°C and 30°C, respectively, but both interfaces had lower tensile strengths than the overlay-sand asphalt interface. The control (AC10 (40/60)/AC10 (10/20)) interface had the highest tensile strength. This indicates that the introduction of the stress absorbing membrane interlayer at the interface between the old pavement and overlay leads to a reduction in the tensile strength of the interface.

Table 5: Pull off test results at 10°C.

Interface	Peak Tensile force (kN)	Mean Peak Tensile force (kN)	Peak Tensile Stress (MPa)	Mean Peak Tensile Stress (MPa)
AC10 (40/60)/SAMI C	5.27	4.48	0.53	0.45
	3.69		0.37	
AC10 (40/60)/SAMI D	5.30	4.64	0.49	0.45
	3.98		0.40	
AC10 (40/60)/SAMI A)	>14.74	>15.30	>1.47	>1.53
	>15.85		>1.59	
AC10 (40/60)/SAMI B)	>11.44	>12.56	>1.10	>1.21
	>13.67		>1.31	
AC10 (40/60)/Sand asphalt	14.91	12.98	1.49	1.31
	11.04		1.13	

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AC10 (40/60)/AC10(10/20)	>10.02	>10.09	>1.00	>1.00
	>10.16		>1.00	

Table 6: Pull off test results at 20°C.

Interface	Peak Tensile force (kN)	Mean Peak Tensile force (kN)	Peak Tensile Stress (MPa)	Mean Peak Tensile Stress (MPa)
AC10 (40/60)/SAMI C	2.17	1.79	0.22	0.18
	1.4		0.14	
AC10 (40/60)/SAMI D	2.36	1.66	0.24	0.17
	0.96		0.10	
AC10 (40/60)/SAMI A)	>9.05	>10.30	>0.90	>1.03
	>11.56		>1.16	
AC10 (40/60)/SAMI B)	>11.48	>11.58	>1.15	>1.15
	>11.67		>1.16	
AC10 (40/60)/Sand asphalt	6.40	6.06	0.63	0.60
	5.72		0.58	
AC10 (40/60)/AC10(10/20)	7.00	7.04	0.69	0.69
	7.08		0.69	

Table 7: Pull off test results at 30°C.

Interface	Peak Tensile force (kN)	Mean Peak Tensile force (kN)	Peak Tensile Stress (MPa)	Mean Peak Tensile Stress (MPa)
AC10 (40/60)/SAMI C	1.39	1.2	0.14	0.12
	1.01		0.10	
AC10 (40/60)/SAMI D	0.98	1.08	0.10	0.11
	1.17		0.12	
AC10 (40/60)/SAMI A)	>6.53	>6.07	>0.64	>0.59
	>5.60		>0.55	
AC10 (40/60)/SAMI B)	>5.52	>5.51	>0.54	>0.54
	>5.49		>0.54	
AC10 (40/60)/Sand asphalt	2.86	2.89	0.29	0.29
	2.92		0.29	
AC10 (40/60)/AC10(10/20)	3.68	3.62	0.36	0.36
	3.55		0.36	

Figure 3 shows that the tensile strength of all the interfaces tested decreased with increasing temperature, indicating stronger bond at lower temperature than higher temperature. This was probably due to the reduction in the stiffness of the overlay and the SAMI as temperature increases (see Table 4). A typical failed interface is shown in Figure 4.

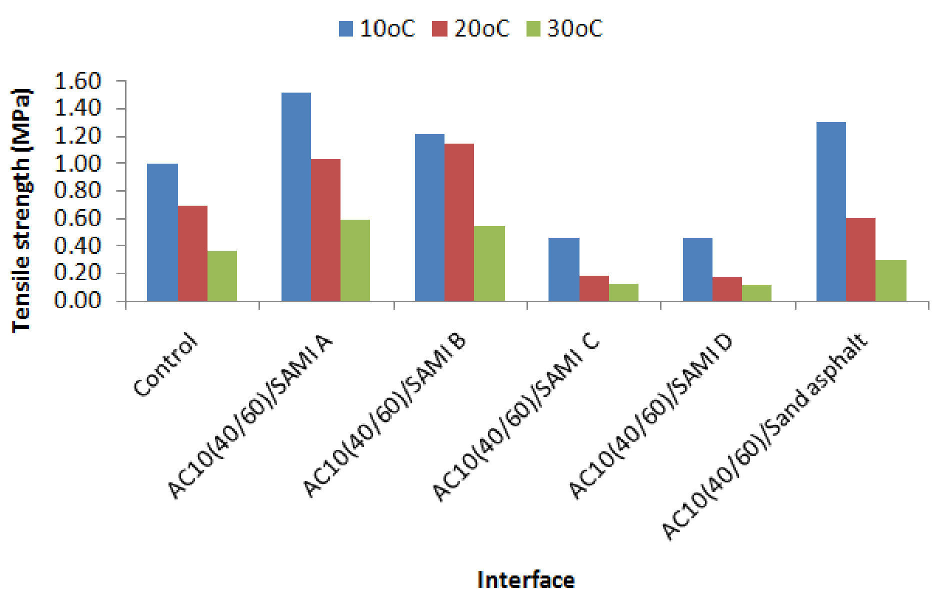

Fig. 3: Pull of test results at 10°C, 20°C, 30°C.

Fig. 4: A typical failed interface after test.

Conclusions:

This study reviews the various methods of evaluating the overlay-interlayer interface properties. The pull-off test was used to determine the tensile strength of the overlay-SAMI interface. It was found in the pull-off test that the overlay-SAMI A and overlay SAMI B interfaces had greater tensile strengths than the control and overlay-sand asphalt, overlay-SAMI C and overlay-SAMI D interfaces at 10^oC, 20^oC and 30^oC. Also, the overlay-sand asphalt, overlay-SAMI C and overlay-SAMI D interfaces had weaker tensile strength than the control at 10^oC, 20^oC and 30^oC. The overlay-SAMI C interface had a slight stronger bond than the overlay-SAMI D interface at 20^oC and 30^oC, while they have the same strength at 10^oC. The study shows that the introduction of the SAMIs influences the interface bond. It results in decrease of the interface tensile strength except in samples with SAMI A and B.

The interface tensile strength decreases with increasing temperature. This shows that the interface properties are influenced by temperature and materials in contact. The effects of the interface properties on the resistance of SAMI to propagation of reflective cracks on overlay would be investigated in future study.

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