Critical review on the bond strength of geosynthetic interlayer systems in asphalt overlays

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ABSTRACT

Asphalt pavements are layered structures designed to carry road traffic loads for a designed time period. The performance of this layered structure depends upon the bond interaction between the layers. Improper design due to the wrong interpretation of factors influencing the performance of pavements results in the development of distresses. The most common rehabilitation technique against these distresses is the placement of overlays. These overlays may suffer from a distress phenomenon called reflective cracking. The propagation of the cracks in the existing pavement onto and through the new overlay results in reflective cracking. Many interlayer systems are introduced to mitigate the effect of reflection cracking, out of which geosynthetic interlayer systems are gaining attention due to its ease of installation and cost effectiveness. The performance of the interlayer system depends upon the bonding with the existing layer as well as with the overlay. This paper focuses to study the different type of bond test methods based on the stresses developed at the interface and to evaluate the factors that influence the bonding due to the presence of the geosynthetic interlayer in the performance of asphaltic pavement.

Keywords: Bond strength, Geosynthetics, Bond failures, Shear bond test, Tensile bond test

1 INTRODUCTION

The life of an asphalt pavement not only depends on the strength and stiffness of its individual layers, but also on the bond strength between them. The interlayer bond is so important factor to ensure the adjacent layers to act monolithically to withstand traffic and environmental loadings. The bonding between the layers is usually done by the application of tack coat (bituminous coat or emulsion) (Roberts et al. 1996).

Since 1970s, a significant number of premature bond failures resulting in slippage and tearing were reported, shortly after the construction of the newly constructed road. The cases of slippage cracking and horizontal permanent deformation of surfacing due to poor interface bond condition at locations were the shearing forces induced by horizontal loads are high, viz. a viz. curve, intersection, upward and downward gradients, frequent breaking zone; or where an asphalt surfacing is laid over a concrete layer (Bognacki et al. 2007; Charmot et al. 2005; Hachiya and Sato 1997; Peattie 1980).

Many design and analysis techniques are developed on the assumption that the adjacent pavement layers are fully bonded and their interfacial horizontal movements are constrained. The poor bond condition will result in the reduction of stiffness and residual life of the pavement structure (Hakim 2002; West et al. 2005). Compaction difficulty, excessive movement under rollers, premature fatigue, top down cracking and surface delamination may also be attributed to insufficient bond between layers of Hot mix asphalt (HMA). Proper estimation of bond strength and its influence in the performance of asphalt layers should be studied for betterment of the life span of the pavement.

This paper focuses to summarise the researchers done to understand the mechanism of debonding in the field. Based on the different modes of failures, different test methods are adopted to evaluate the interface bond strength. Even though large number of test are proposed by the researchers the suitability of each test methods are discussed. The distresses developed in the pavement section can be reduced by the introduction of geosynthetic interlayer systems which will act as tensile member. The factors which influence the bonding strength of the geosynthetic interlayer system should be considered while selecting a paving fabric which in turn controls the overall performance of the pavement.

2 MODES OF BOND FAILURES

Interface bond failures are categorized into three different modes: Shear separation (Mode A), Tensile separation (Mode B), and Mixed shear and tensile separation (Mode C). The terminology do not corresponds to any conventional fracture mechanics modes of failures (Muslich 2010). The separation modes and field condition bond failures are depicted in

Figure 1 and Figure 2.

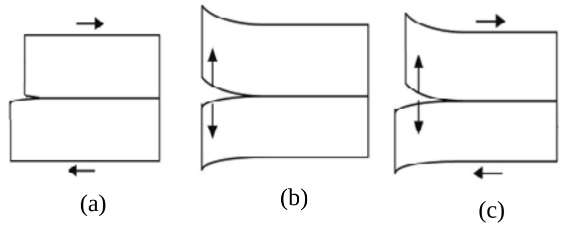

Fig. 1 Modes of bond failures: (a) Shear separation (Mode A) (b) Tensile separation (Mode B) (c) Mixed shear and tensile separation (Mode C)

2.1 Shear Separation (Modes A)

Shear separation occurs in the horizontal and transverse direction generated by traffic or temperature induced shear stresses and most common failure in the field. The locations were the vehicle accelerates, decelerates, brakes, turns and change in gradient creates additional horizontal stresses. The horizontal and transverse stresses developed could be as high as 12% and 20% of the vertical tyre- pavement contact stresses (Muslich 2010; Deer and Maina 2011).

2.2 Tensile separation (Mode B)

The vertical tensile stresses caused by blistering, the phenomenon of expansion of gases caused by trapped moisture or microbial activity at the interface and due to the suction of the tyre between the pavement and the thread block leads to tensile separation (Brown and Darnell 1987; Hironaka and Holland 1987; Raab and Partl 1999). It should be noted that this tensile stresses generated is not reported to create any bond failure in the field conditions (Bernhard et al. 2005).

2.3 Both Shear and Tensile separation (Mode C)

When the interface strength below a thin surface is low, the horizontal loadings are concentrated in the surfacing layer and may cause buckling of the surface in front of the tyre. The bucking generates a vertical stress along with the shear stress induced by the horizontal loading. This phenomenon would be rarely found in a real pavement condition (Muslich 2010).

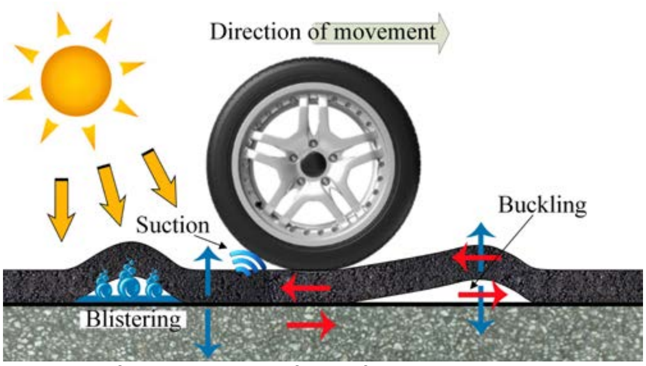

Fig 2. The field mechanism of bond failures

3 INTERFACE BOND TEST METHODS

The degree of bonding at the pavement interface affects the stress distribution within the materials that contribute a layer. Several studies have been conducted to evaluate the effect of the interface condition between the overlay and the existing pavement surface as well as the effect of interlayer system (Elseifi and Al-Qadi 2004). A number of laboratory testing methods utilize various test principle to investigate the adhesive properties at interface based on the modes of failure (Figure 3).

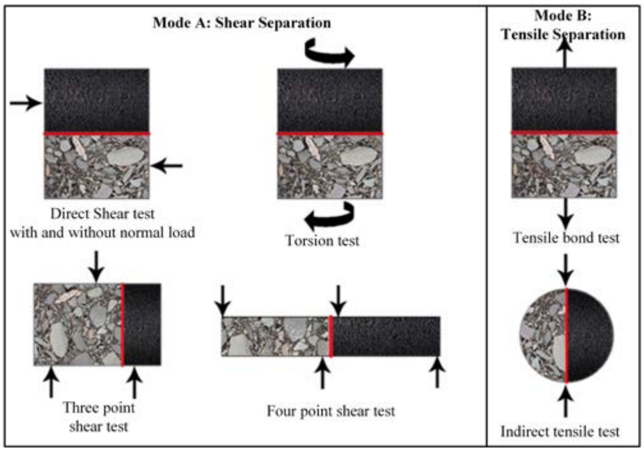

Fig 3. Interface bond test methods

3.1 Mode A: Shear bond test and Torsion test

Most commonly and widely used methods to investigate the bond properties are the direct shear tests with and without normal loads. Both of them are known to suffer from non-uniform shear stress distribution in the interface. Suitability for a detailed research on the effect of normal load and dilatancy can be done with the direct shear test with normal load. The complexity in the application of the normal load makes it unacceptable as a routine test. Meanwhile the direct shear test without normal load, due to its simpler experimental setup, easier sample preparation, fast and precise makes it more suitable for a laboratory based routine test. Moreover several test protocols have included (Germany, Austria and Switzerland) or proposed (UK and USA) the direct shear test without normal load as laboratory-based standard tests (Collop et al. 2004; Raab and Partl 1999; Sholar et al. 2004; Stöckert 2002). The direct shear tests with and without normal loads are outlined in Table 1 and 2.

Considering the point shear tests, three point shear test is quite similar to the direct shear test. It also suffers from the non-uniform shear stress distribution at the interface. The support and loading arrangement demands longer core specimen and a higher capacity of loading mechanism making its less popular compared to that of the direct shear test without normal load (Recasens et al. 2005). In terms of the uniformity of the induced shear stress at the interface, the four point

Table 1. Direct shear bond tests without normal load

.	Description	Test Result	Ref
Leutner device (Lab)	A vertical shear load is applied to a 150 mm diameter cylindrical specimen at a constant rate of 50 mm/min at 21.1° C until failure	Shear load Vs displacement	Collop et al. (2003)
LTRC Direct Shear Test (Lab)	A horizontal shear load is applied to a dual layer 150 mm diameter cylindrical specimen at a constant rate of 225 N/min in a temperature range of -20 to 80°C	Shear stress at Failure	Mohammad et al. (2002)
Florida Direct Shear test (Lab)	A vertical shear load is applied to a dual layer 150 mm diameter cylindrical specimen with a constant strain rate of 50 mm/min at 25°C until failure	Shear strength at failure	Sholar et al. (2004)
LPDS test (Lab)	A vertical shear load is applied to a cylindrical composite specimen of 100 mm diameter with strain control mode at constant rate	Shear strength	Raab and Partl (2004)
Dynamic Interaction Test (Lab)	A sinusoidal shear force is applied to dual-layered cylindrical composite specimen at particular temperature and given load frequency	Interlayer reaction complex modulus KI	Mohammad (2012)
HasDell EBSTTM (Lab)	A shear force is applied along the interface of a cylindrical (150 mm dia) or to a square composite specimen until failure	Bond shear strength	Mohammad et al. (2009)
Double shear testing (Lab)	Three layers of 305×305×50 mm pieces each and vertical load is applied to the centre piece at a rate of 5 mm/min at 15°C	Shear strength	Zamora-Barraza et al. (2010)
MCS device (Lab)	A vertical dynamic shear load is applied to a three layered specimens with the dimension 70×100×30 mm with a sinusoidal displacement of 1 Hz at temperature of 5°C	Shear force time and deformation	Diakhate et al. (2006)

shear bond test seems to be pre-eminent for a detail research because it renders a uniform shear stress distribution and eradicate the bending at the interface. However, the complexity in the preparation in the sample and the experimental test setup, the four point bending test is not considered suitable for routine test (De Bondt 1999; Erkens 2002).

Application of torque manually or mechanical over a core specimen or insitu causing shear failure to the interface is done in torque bond test. Studies show that issues related to shear failure within the asphalt layer and the scattering results made the torque bond test less accurate than the other tests that utilize the shear separation principle. Furthermore, because it typically requires gluing of specimen (or gripping if a clamping mechanism is used) the torque bond test would be less suitable for laboratory based routine testing of bond.

3.2 Mode B: Tensile bond test and Indirect tensile test

The tensile bond properties can be determined by tensile bond test and indirect tensile test. The studies show that tensile bond test and indirect tensile test are unrealistic compared to the real field interface loading condition. Moreover both the test method have the limitation related to scattering of results, inability to determine the interface tensile strength when the bond strength is higher than that of the asphalt layer and to assess the effect of aggregate interlock. Due to the aforementioned considerations, the test methods are seems not suitable for determining the bond properties of an interface between the pavement layers. The chances for the mode B failure to occur in the real pavement structure is rare (Muslich 2010).

4 FACTORS INFLUENCING THE BONDING OF GEOSYNTHETIC INTERLAYER SYSTEM

Pavement related problems can be avoided by improving the factors that affect the bonding between the HMA layers. The variety of factors that influence the test results and the performance are the different types of geosynthetics, tack coat type and application rates, test control (stress or strain), the magnitude of the normal loads and the shearing rate (Hakim 2002; Sanders 2001). In the following section, a brief idea regarding the influence tack coat and geosynthetics in the bond strength is explained.

4.1 Tack Coat Characteristics

The performance of geosynthetic interlayer depend upon the selection of proper tack coat material and application rate. Common field problems related to tack coat application depends upon the proper temperature control, clogged or leaking spray bars and nozzles, application of too much or too little material and non-uniform distribution.

4.1.1. Type of tack coat

The most widely used tack coat material in the world is emulsified asphalt or asphalt emulsion. Emulsified asphalt is not normally recommended as tack coat for geosynthetics. Although emulsified asphalts have been successfully used as tack for fabrics, they develop bond strength more slowly than asphalt cement, and debonding on windy days has been reported. Cutbacks asphalts should never be used for fabric tack, because the solvent can remain for extended periods and weaken the polymer in the geosynthetics. Type of tack usually recommended is the hot asphalt cement (not Table 2.

Direct shear bond tests with normal load

Apparatus (Lab/Insitu)	Description	Test Result	Ref
NCAT Shear Test (Lab)	A vertical shear load is applied to cylindrical specimen of 150 mm at a constant deformation rate of 50 mm/min. Normal load from 0 to 550 kPa can be applied. The test can be carried at 10°C, 25°C, 60°C	Maximum shear stress	Wheat (2007)
Romanoshi device	A vertical shear force is applied to a cylindrical specimen of 95 mm at a constant deformation rate of 12 mm/mm with a normal load ranging from 0 to 550 kPa. The working temperature may vary from 15°C, 25°C, 35°C.	Maximum shear stress	Raab et al. (2009)
Al Qadi device	A vertical shear load is applied along with a normal load at a deformation rate of 12mm/min. The temperature varies 10°C, 20°C, 30°C.	Maximum shear force	Raab et al. (2009)
Asher device	A sinusoidal vertical shear load with amplitudes of 0.005 to 0.1 mm and frequency of 1-15 Hz with a normal force of 0-1.11 N/mm^2. The temperature range varies from -10°C to 30°C	Relative deformation between layers/ shear stress between layers in m^3/N	Raab et al. (2009)
Romansohi dynamic device	A vertical load 10% of max load, frequency of 5 Hz, total period of 0.2 s, length of pulse of 0.05s (simulating a vehicle pass of 50 km/h) is applied to a 100 mm cylindrical sample whose horizontal axis is at 25.5° with the vertical axis	The no of cycles corresponding to 6 mm of permanent shear displacement	Raab et al. (2009)
Shear box	A sinusoidal shear stress with frequency of 2 Hz, vertical load 200 kN/m^2 is applied to a prismatic specimen of 320×200 mm. While vertical stress was kept constant, shear stress was increased in 5 levels until the specimen fails; if not a static test was performed at a constant deformation rate of 1.5 mm/min	Dynamic shear stress and relative displacement diagram	Raab et al. (2009)
ASTRA device	Rectangular (100 × 100 mm) or cylindrical (95 - 99 mm) specimen were sheared at a deformation rate of 2.5 mm/min	Shear force at failure	Deysarkar (2004)
SHRP shear test device SST	Cylindrical specimen of 150 mm dia is applied with a constant shear load mode of 222.4 N/min. Application of normal load is also possible	Shear force	Mohammad (2012)

emulsion of the same grade as that determined for the HMA overlay (Button and Lytton 2007).

4.1.2. Tack coat dosage

Asphalt retention is an important property for the application of tack coat dosage. It quantify the amount of tack coat necessary to saturate the fabric and make a good bond. The absorption capacity of geosynthetics varies with type, weigh and thickness of the material. A typical fabric will absorb 0.91 ℓ/m^2. An additional 0.023 ℓ/m^2 of tack coat must be included for bonding to the old and new asphalt concrete (AC) layers unless a freshly oiled leveling course is first installed (Amini 2005). If emulsified asphalt is used as tack, it should not be diluted with water. When emulsion are used, the application rate must be increased to offset the water content of emulsion (Holtz et al. 1998). Applying tack coat too lightly can result in lack of bond while excessively heavy application may introduce a slip plane in the interface (Buchanan and Woods 2004). Bleeding occurs with too much asphalt which can result in overlay slippage. Bleeding also can cause difficulty with installation, as it can result in the geotextile sticking to and being pulled by the tires and tracks of the asphalt trucks and paving vehicles (Button and Lytton 2007; Holtz et al. 1998).

4.1.3. Temperature Control

Temperature of the tack when the geosynthetic is placed can be critical. AC pavement significantly above the specified temperature can resist in the asphalt tack coat being drawn out of the geotextile which can result in shrinkage or even melting of the geotextile. Shrinkage and melting is a concern for a polypropylene geotextile which has a typical melt temperature of 225°C.

The temperature of the asphalt sealant shall be sufficiently to permit uniform spray pattern. For asphalt cements the minimum temperature shall be 145°C. To avoid geotextile damage, the distributor tank temperature shall not exceed 160°C. One must install a geosynthetic while asphalt is still tacky. The geosynthetic may become prematurely saturated if the temperature of application is more than 160°C in a hotter climate resulting in slippage and geosynthetic pick up (Button and Lytton 2007; Holtz et al. 1998).

4.1.4 Emulsion breaking time

Emulsion breaking is the process in which water in the emulsion evaporated. Inadequate emulsion curing can be the difference between the effective and ineffective tack applications, and cure time range from 20 minutes for a broken emulsion to several hours for a dry emulsion. Spray patterns for asphaltic emulsion are improved by heating (Buchanan and Woods 2004). Temperature in the range of 55°C to 70°C are desirable. A temperature of 70°C shall not be exceeded since higher temperature may break the emulsion (Holtz et al. 1998). Also, if dust adheres to tack coat before the next layer is placed it can negatively effect on bond strength between layers. Water on the application surface can have a similar bond reducing effect. Geosynthetic has to be kept soon after the breaking time of the emulsion (Cleveland et al. 2002).

4.2 Geosynthetic Characteristics

4.2.1. Type of Geosynthetics

The bonding strength varies with different types of geosynthetics, categorized as fabric, grid and composite. Studies shows that the introduction of geosynthetic interlayer will usually reduce the interface strength if proper care is not taken compared to the unreinforced one. Depending on interactions between the interlayer and environment, it was found that approximately 50% of the shear stiffness at the interface is lost when a glassgrid was used and up to 80% for steel mesh compared to the unreinforced sample. It is important to note that the application of such absorbing interlayer may lead to negative effects on interlayer bond (Raab and Partl 2004). Table 3 shows the different type geosynthetics mechanism for binding and their bonding strength.

Table 3 Bond strength of different geosynthetics (Tensar 2008)

Interlayer Type	IBS MN/m^2	Mechanism above/below interface
GlasGrid	10	THB/THB
Composite Grid	0.1	THB/Adhesion
Fabric	0.1	Adhesion/Adhesion
Unreinforced	0.1	Adhesion

THB: Through hole bonding

In the case of grid the bonding strength increases just because of the through hole bonding. i.e. the compatibility of aggregate size and grid size which makes the interlocking between grid and the surrounding layers. Meanwhile in other cases the bond strength is due to the adhesion between the aggregate and the geotextile, which does not show much difference with the unreinforced one. The through hole bonding mechanism is more effective compared to adhesion makes the grid to become more popular.

4.2.2. Stiffness Moduli

The stiffness moduli of fabrics are usually less than the moduli of the grid. The fabric can mobilize only limited stress at low strain levels while grids can generate high stress at the same strain levels. As the stiffness moduli increases the bond strength will increase and vice versa. Grid system serves primarily as a reinforcing layer. The stiffness of the grid should be more than the overlay so that it can act as reinforcement.

4.2.3. Mass per unit area and Thickness

The most common paving grade geotextile having the ability to absorb and retain the asphalt tack coat to effectively to form a waterproofing and stress relief interlayer. Generally a needle punched, non-woven material, with mass per unit area of 120 to 200 g/m^2 is recommended. Field evidence indicates that geotextile with greater mass per unit area perform better than the lighter weight geotextiles. As a result a paving fabric need a minimum of 140 g/m^2 as per the AASHTO guidelines (Holtz et al. 1998). Numerical analysis indicates that at some level of mass per unit the bonding of the overlay would be reduced due to shear on the geotextile (Grzybowska and Wojtowicz 2004). Increase in the thickness of fabric is helpful for reducing the reflective cracking phenomenon due to the improvement in the stress absorption capacity. Studies show that increase in the thickness of geosynthetic will reduce the shear capacity due to separation effect resulting in debonding.

5 CONCLUSION

The paper gives an overview on the stresses developed at the interface of the two asphaltic layers in the real field conditions causing debonding. The different types of test methods conducted to stimulate the field conditions and quantifying methods to evaluate the bond strength are discussed in detail. A. comparative study on these test methods based on different research works is done. The interface shear tests are the most commonly used methods to verify the bond strength due to its ease of test methodology and repeatability of the test results. The laboratory shear tests are similar to the real field conditions of debonding and slippage which is mainly caused due to shear forces. The improvement in the life span by reducing the distresses developed over the pavement section can be achieved by introducing geosynthetic material. The tensile action of the geosynthetic material helps in the improvement. The bonding of the geosynthetic material is a major factor which causes the improvement. The factors influencing the bonding of geosynthetic interlayer system is also described.

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