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Advanced Characterisation Methods for Interface Shear Resistance for Airport Overlays

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Abstract It is recognised that the adequacy of bond between an asphalt surface layer and the underlying pavement material is fundamental to good pavement performance. This is even more important in airport pavements where shear forces imparted by braking and turning aircraft are high. Various measures of interface shear resistance are available to characterise the bond of asphalt surface layers. Advanced test methods were developed to measure the shear resistance of the interface between asphalt layers. These methods include monotonic testing in direct shear as well as repeated load testing in inclined shear modes.

Keywords Shear stress, Interface shear resistance, Interface shear fatigue.

1 Introduction

Interface shear resistance is a measure of the bond between two layers under shear loading. In the context of asphalt surface layers, it is a measure of the durability and adequacy of the interface between the surface layer and the underlying pavement. Bond is a non-specific term that broadly considers adhesion between the layers as well as interlayer friction and mechanical interlocking of the two layers due to aggregate embedment. Interface shear resistance provides a holistic measure of the risk of loss of bond leading to delamination under certain shear loading conditions. Where the interface shear resistance is exceeded or fatigued by the imposed shear stresses induced, debonding can occur (Mohammad et al. 2009).

The aim of this research was to develop advanced methods of laboratory characterisation of asphalt surface layer interfaces, specifically for airport pavement surfaces. The development of methods for monotonic and repeated load assessment of interfaces is described as well as protocols for the analysis of the results. The test protocols have been validated elsewhere (White & Gabrawy 2016).

2 Background

Achieving adequate and durable interfaces during asphalt surface construction is critical to achieving good pavement performance. Various researchers have demonstrated the impact of poor interface condition on pavement distress and service life (White 2015a). This is particularly important for aircraft pavements, where a typical aircraft performing a typical landing at a typical airport has been shown to induce shear stress around double those induced by a heavy braking truck (White 2015b).

Unlike vertical stresses, shear stresses do not peak at the surface. Uzan et al. (1978) stated that shear stress peaks at around the mid-depth of the surface layer. Su et al. (2008) showed the shear stress peaking at around 60 mm below the surface. The depth of peak shear stress has also been shown to be independent of the tyre pressure and wheel load (Su et al. 2008). White (2015b) found all practical surface interfaces to be located within a zone of near-peak shear stress.

Laboratory testing of asphalt layer interfaces can be performed on cores recovered from the field or on samples manufactured in the laboratory. Field testing of interface shear strength is not common. Due to its increased reliability and popularity, laboratory testing of cores recovered from the field has been focused on. There are a range of test methods and modes available for laboratory testing of interfaces. These can be either monotonic or repeated load in nature.

Interface resistance to shear can be measured by its strength, modulus/stiffness or work/energy. The three concepts are demonstrated using a typical shear load-displacement plot from a direct shear test in Figure 1. Monotonic strength is the easiest of these to measure and is the most intuitively interpretable. As a result, many researchers have compared interface shear resistance based on Interface Shear Strength (ISS) which can be calculated from Equation 1.

Interface Shear Modulus (ISM) is the non-scalar equivalent of interface shear stiffness. Various researchers have used Goodman's Constitutive Law as expressed in Equation 2 (White 2015a). Equation 2 effectively represents the gradient of the stress/strain plot. Where stiffness is used in place of modulus, this becomes the load/displacement plot and Goodman's Law becomes Hooke's Law.

Interface Shear Work (ISW) is the area under the load-displacement plot up to a specific amount of shear deformation, as expressed in Equation 3 and shown in Figure 1 as the shaded portion under the graph. The non-scalar equivalent would be the interface shear energy. Santagata et al. (2009) used the energy to the peak stress to calculate an equivalent shear strain.

$$ISS = L_P / A \tag{1}$$

$$ISM = \Delta L / \Delta d \tag{2}$$

$$ISW = \sum(L \times \Delta d) \tag{3}$$

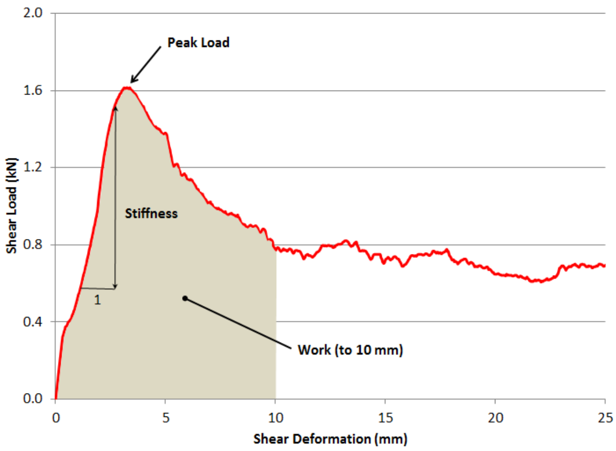

Fig. 1 Example load versus displacement plot and shear resistance indicators.

The test methods and protocols are generally grouped into three main loading mechanisms; axial tension, torsional shear and direct shear. Axial tension tests measure the degree of adhesion between the two layers. Direct tension testing of interfaces is more suited to studies that are interested in comparison of the adhesion between layers. Torsional testing is less frequently reported. Although not reflective of the actual loading scenario in the field, torsion tests are capable of inducing pure radial and tangential shear forces across the interface (Goodman et al. 2002). However, the shear forces vary from zero at the centre to maximal at the circumference of the sample (Diakhate et al. 2007).

Direct shear tests offer a more comprehensive assessment of the full interface strength likely to be achieved in the field with adhesion, friction and interlock all contributing to the resulting interface shear strength. The load is also applied in a more representative manner and direction to that expected in the field. Field cores and laboratory prepared samples can both be readily tested and a number of test methods can accommodate both round and square samples (Santagata et al. 2009). Square samples offer more reliable and uniform contact with the load platen. The most common arrangements for the direct shear test are the shear box test the shear tube test.

It is well established that interface characteristics are influenced by surface condition and preparation, temperature, tack coat material, tack coat curing time and tack coat application rate (Tashman et al. 2008). To this list Mejia et al. (2008) added the rate of loading while Kruntcheva et al. (2006) included traffic loading to the list of important factors. These findings are not inconsistent with those reported by Uzan et al. (1978). Numerous investigations have considered the influence of one or more parameters on the various measures of interface shear resistance using various test modes. Some parameters have been found to be more important than others and not all findings appear consistent if considered in isolation, but generally make more sense when considered in context.

3 Developed Test Methods

Two test methods were developed to characterise the interface between asphalt overlays, specifically for airport runways. Two tests were developed, one for the measurement of the monotonic characteristics, and the second, a repeated load test intended to measure the fatigue properties. The aim was to characterise the performance of interfaces constructed in the field during resurfacing using current and potential future construction methods. The test methods developed were designed for cores recovered from the field, rather than laboratory manufactured.

3.1 Monotonic Test Method

The Direct Shear (DS) test method was designed to measure the monotonic characteristics of the interface between the surface and the underlying layer. A shear box style test was selected over a shear tube test. Up to six prismatic samples are cut from each single 240 mm diameter core and tested at various normal stresses. Square samples are not commonly used for direct shear strength testing but were selected to avoid any point-loading associated with imperfectly matching circular sections. The samples are nominal 50 mm by 50 mm interface dimensions and nominally 100 mm thick, with the interface at the mid-point.

The applied normal stresses can range from approximately 20 kPa to 700 kPa, in order to generate Mohr-Coulomb type envelopes. These normal stresses were selected as being indicative of the range of stresses experienced by an interface as an aircraft passes and can be adjusted for the specific investigation requirements.

Direct shear testing is performed on samples conditioned to a temperature representing the mean summer pavement temperature approximately 50 mm below the asphalt surface. For Australia, 55°C is recommended. The samples are sheared at a constant rate of 50 mm per minute to be consistent with the rate used by other researchers. Both the test temperature and strain rate can be adjusted. During the DS test, temperature, deformation, normal force and shear force are all recorded every 0.1 seconds throughout the deformation.

For each sample the ISS, ISM and ISW can be calculated. The ISS is calculated using the remaining interface contact area at the time of the peak shear load. The ISM is calculated between 25% and 75% of the peak shear force. The ISW is calculated as the area under the load-displacement graph over the first 10 mm.

Linear regressions are subsequently performed on the ISS, ISM and ISW results for each core. For the ISS, the y-intercept of the linear relationship represents the interface cohesion, which is provided by the adhesion between the layers resulting from the tack coat. The slope of the regression provides the interface friction angle. Equivalent parameters (intercept and gradient angle) are also calculated for ISM and ISW across the samples tested at different confining stress for each core sample.

3.2 Repeated Load Test Method

The Inclined Repeated Interface Shear (IRIS) test was designed to imitate the cyclic shear stresses expected to occur in an asphalt surface layer in the field during aircraft braking. To induce a shear stress across the interface, the interface is orientated at 45° to the vertical at the mid-height of the sample. Two 75 mm diameter cores are cut from a 240 mm diameter core on a 45° angle to the vertical.

In many cases, the samples are not sufficiently tall to allow the tops to be trimmed at the required sample height. An epoxy of approximately matching stiffness is provided between coring and final trimming to create cylindrical samples. Samples are measured and pre-conditioned to a temperature consistent with the DS testing. The samples are subject to cyclic compression loading, which can be adjusted but is recommended as:

- Load rate/frequency. 0.1 seconds haversine loading.
- Rest time. 0.9 seconds.
- Confining stress. 138 kPa.
- Cyclic axial (deviatory) stress. 828 kPa.

Each sample is tested under a sub-maximal cyclic load until 20,000 cycles or deformation exceeds 100,000 μɛ. The sample deformation is logged against load cycles. Following completion of the test, the cores are inspected.

Test temperature, confining pressure, vertical load and axial strain are logged every 0.1 seconds during the cyclic loading. Axial strain and strain rate are calculated. The strain after 450 and 2,000 cycles is reported as well as the number of cycles at which tertiary asphalt flow commenced. The deformation after 20,000 cycles or the number of cycles to 100,000 μɛ is also recorded, depending what occurs first and triggers termination of the test.

4 Conclusions

Interfaces between asphalt surface layers and the underlying pavement are located 50-60 mm from the pavement surface. This coincides with the zone of near-peak shear stress under braking aircraft tyres. As a result of more aggressive aircraft developments, shear stress failures of interfaces are expected to increase in the future. Advanced methods of testing interface shear resistance under monotonic and repeated loading is essential to enabling research to better understand the factors that affect interface shear resistance. The methods developed have been verified by others via pilot testing of a number of typical asphalt surfaces. The test methods can now be utilised to measure the impact of different tack coats materials, application rates and interface construction methods of the interface resistance.

5 References

Diakhate, M, Petit, C, Millien, A, Phelipot-Mardele, A ,Pouteau, B & Goacolou, H 2007, 'Comparison of direct shear and torque tests for determining viscoelastic shear behavior of tack coats', *Proceedings Advanced Characterisation of Pavement and Soil Engineering Materials*, Athens, Greece, 20-22 June, Taylor and Francis, pp. 281-290.

Goodman, S, Bekheet, W, Hassan, Y, & Abd El Halim, AO 2002, 'Rapid in-situ shear testing of asphalt pavements for runway construction quality control and assurance, *Proceedings 2002 FAA Airport Technology Transfer Conference*, Atlantic City, USA, May.

Kruntcheva, MR, Collop, AC & Thom, NH 2006, 'Effect of bond condition on flexible pavement performance', *Journal of Materials in Civil Engineering*, vol. 18, no. 3, pp. 467-471.

Mejia, D, Celaya, M, Iyer, S, Rao, C, Shokouhi, P & Nazarian, S 2008, *A Work Plan toward Evaluation of Technologies to Assess Presence and Extent of Delamination of HMA Airfield Pavements*, Research Project 06-04, Centre of Transportation Infrastructure Systems, El Paso, USA, June.

Mohammad, LN, Bae, A, Elseifi, MA, Button, J & Scherocman, JA 2009, 'Interface shear strength characterisation of emulsified tack coats', *Proceedings Asphalt Pavement Technology*, Minneapolis, USA, 15-18 March, Association of Asphalt Pavement Technologists, vol. 78, pp. 250-277.

Santagata, FA, Ferrotti, G, Partl, MN & Canestrari, F 2009, 'Statistical investigation of two different interlayer shear test methods', *Materials and Structures*, vol. 42, pp. 705-714.

Su, K, Sun, L, Hachiya, A & Maekawa, R 2008, 'Analysis of shear stresses in asphalt pavements under actual measured tire – pavement contact pressure', *Proceedings 6th International Conference on Road and Airfield Pavement Technology*, Sapporo, Japan, 20-23 July, Pavement Engineering Society (Singapore), pp. 11-18.

Tashman, L, Nam, K, Papagiannakis, T, Willoughby, K, Pierce, L & Baker, T 2008, 'Evaluation of construction practices that influence the bond strength at the interface between pavement layers', *Journal of Performance of Constructed Facilities*, vol. 22, no. 3, pp. 154-161.

Uzan, J, Livneh, M, & Eshed Y 1978, 'Investigation of adhesion properties between asphaltic-concrete layers', *Journal of the Association of Asphalt Paving Technologists*, vol. 47, pp. 495-521.

White, G 2015a, 'Asphalt overlay bond strength', *Proceedings Airport Pavement and Lighting Forum*, Sydney, NSW, Australia, 30 April – 1 May 2015, Australian Airports Association.

White, G 2015b, 'Shear stresses in an asphalt surface under various aircraft braking conditions', *International Journal of Pavement Engineering*, under review.

White, G & Gabrawy, T 2016, 'Airport asphalt surface interface shear resistance', *International Journal of Pavement Engineering and Asphalt Technology*, vol. 17, no. 1.