QUANTIFYING THE SHEAR STRENGTH AT THE ASPHALT INTERFACE

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ABSCTRACT

The state of adhesion at the interface between two asphalt layers has significant influence on the stress distribution across pavement layers under traffic loads. It is generally believed that the pavement stress distribution is highly influenced by the adhesion conditions at the interface. This means that poor adhesion between layers will have adverse affects on the structural strength of the asphalt layers leading to premature fatigue failure. To increase bonding between layers, asphalt tack coats are applied prior to overlay. In spite of their wide application, the opinions among pavement engineers differ regarding the effectiveness of tack coat in enhancing the adhesion between two layers.

The main objective of this research was to design a simple and efficient test protocol for the evaluation of tack coats based on adhesion strength, which could be used for different materials. The University of Waterloo developed a simple shear test by applying three point loading on asphalt briquettes, for evaluating the effectiveness of different types of tack coats available in the market. The cylindrical testing setup enables the use of the cored samples from the field or the samples prepared in the laboratory.

This paper describes testing procedures developed using the Marshall loading frame and presents the results carried out on specimens with and without tack coat interface to evaluate the effectiveness of proposed shear tests. Pure tack coats were also investigated in dynamic mode with the assumption, that materials are characterized within linear viscoelastic region.

INTRODUCTION

Tack coat is typically applied before the hot mix asphalt layer or overlay is placed on the existing old pavement. Previous studies have shown the importance of good bonding between layers for the overall pavement performance (Shahin et al., 1987; Uzan et al., 1978; Ishai and Liveh, 1984). It also plays a vital role for pavement layer moduli backcalculation (Romanoschi and Metcalf 2003; Hakim 2003). Different researches conducted a number of studies with the aim to find optimum application rates (Donovan et. al. 2000; Canestrari et. al. 2005). But there are no simple standard test methods available in North America to evaluate the effectiveness different tack coats available in the market to provide the adhesion required to improve the structural integrity of the composite pavement.

OBJECTIVE

The aim of this study was to design and fabricate a simple testing device for the evaluation of the tack coats and to develop guidelines for application on a routine basis. The ideal design would be to use the standard equipment readily available in laboratories. It became apparent that it would be more practical to conduct tests on cylindrical specimens, either cored from the pavement in the field or prepared in the laboratory. Initial investigation revealed that shear, tension, and torsion tests appear to provide the most promising results. The basic tack coat bonding strength at the interface can be assessed in studying the three failure modes as depicted in **Figure 1**: shear failure, tensile failure and torsion failure.

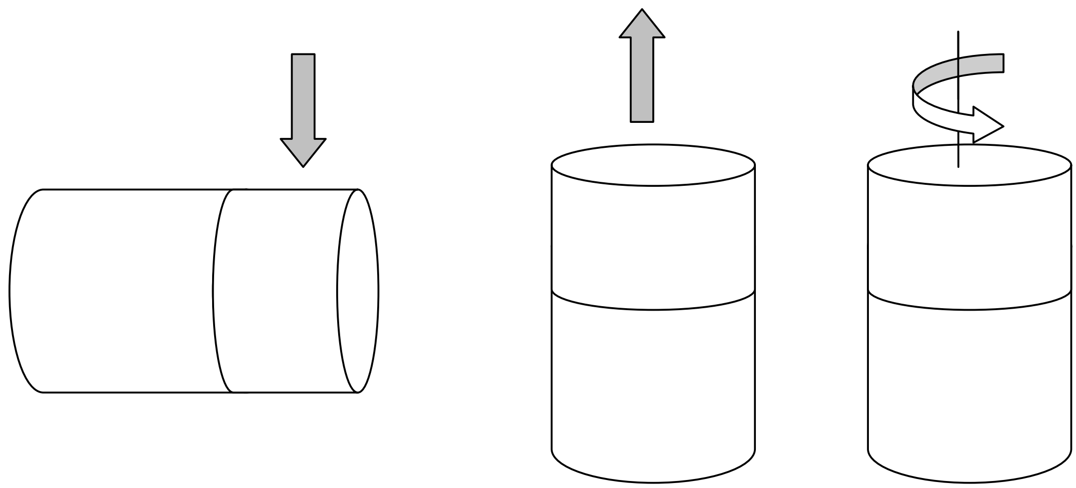

Figure 1. Evaluation of tack bond by different tests

The test results from all these failure modes have their own advantages and disadvantages. For instance results from the tension test may be desirable for assessing the adhesive strength of the tack coat but does not fully simulate the real forces in the pavement structure. In torsion test, the stress in the specimens is not uniformly distributed during loading. Moreover, the design concepts for tension and torsion tests seem to be more difficult to implement using the standard testing equipment in comparison of the shear test. The University of Waterloo research team examined two options for developing a simple shear test.

As a first step, it was decided to develop a test method which could be carried out using the standard equipment readily available in all the laboratories, eg. Marshall Tester. Therefore, the Humboltd HM 3000, owned by the Department of Civil Engineering, was used for initial evaluation. The loading rate of 50.8 mm/min which corresponds to the Marshall Stability test was used. All testing was done at ambient temperature. A considerable amount of time was spent to ensure that the testing equipment and the data acquisition system are suitable for testing tack coat.

First method involves the use of three point loading system, called here as shear tube test, where HMA cylindrical specimens are placed into two metal molds, **Figures 2,3**. This method is based on the procedure developed at the Technical University of Catalonia, where the shear strength of the tack coats is measured (Miro et. al. 2003). The whole system is expected to behave like a three point bending beam except that tack coat is designed to fail due to shear close to one of the supports. In theory, the expected load at the interface is one half of the total vertical load applied on the aluminum mold at the mid point between the supports.

Figure 2. The shear tube test - three point loading

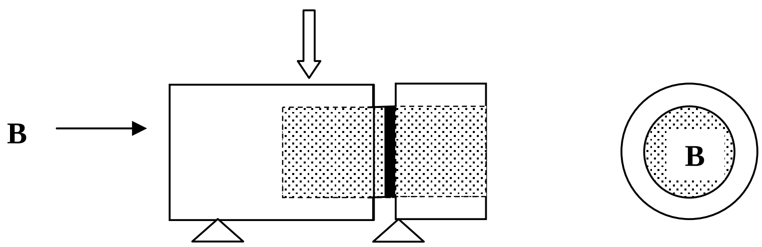

Figure 3. Loading scheme used for the Tube Test

The second design uses the loading block for the evaluation of the Shear Strength as illustrated in **Figures 4,5**. Part of the HMA specimen in the cylindrical mold is directly mounted to the lower platen. A metal holder with a concave surface with approximate radius of specimens is required to withstand the load applied by the platen.

Figure 4. Shear Strength Test - modified method

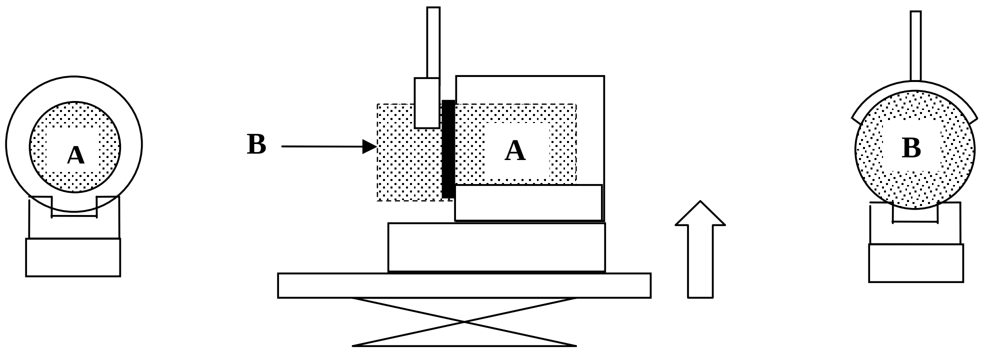

Figure 5. Loading scheme for the Shear Strength Test

EXPERIMENTAL

Both cored samples and laboratory prepared samples were used for testing. Standard Superpave 19.5 mix with the asphalt PG 64-28 was examined. Specimens of four types: with two tack coats (TC_1,2), lacking tack and with no interface were compared.

The basic properties of tack coats are listed in **Table 1.** In order to fully characterize tack coat materials, including shear relaxation modulus G(t), properties of TC_1,2 must be evaluated in dynamic shear rheometer (DSR). For this study, Bohlin controlled strain apparatus was used. Dynamic frequency sweep tests were conducted at temperatures ranging from 20 to 60 ^oC and frequencies (0.1 – 10Hz).

Table 1. Properties of examined tack coat

TC_1	Residue (distillation by mass %)	32.3	Min. 27.5
	Penetration of residue (at 25^o C, 100g , 0.1mm)	120	Min. 100
TC_2	Residue (distillation by mass %)	28	Min. 27.5
	Penetration of residue (at 25^o C, 100g , 0.1mm)	110	Min. 100

The HMA specimens prepared in the laboratory consist of two layers, with the tack coat at the interface. Samples preparation was done in several steps. First, hot mix was compacted in Superpave gyratory compactor at 120 gyrations, with the average height of 70 mm. After cooling the tack coat material was manually applied by brush at the application rate of 0.35 kg/m^2 and let it rest for 24 hours at ambient temperature. Samples with the tack coat were placed in to the gyratory molds with the loose mix on top and compacted at the same number of gyration. Specimens were ready to test within six hours after the compaction.

The target diameter for the specimens was set up to 150 mm. This was relatively easy to achieve with the laboratory samples, however, the dimensions of the field samples depends on the size of coring equipment and were not the same as the size of designed rings/tubes. The significant variation in diameters was observed in these samples with the minimum of 145 mm. Therefore, additional layers of pads had to be used to fill a gap between the mold and the specimens.

RESULTS AND DISCUSSIONS

The shear Tube Test, when loading, exhibited lateral tension at the bottom of the tube / sample as shown in **Figure 6**. Even though the support was only 5 mm to the edge of the mold interface, it was observed that the failure was caused by both the lateral displacement as well as the shear displacement. In this study, the emphasis is given on pure shear; therefore data from the tube test are not further discussed.

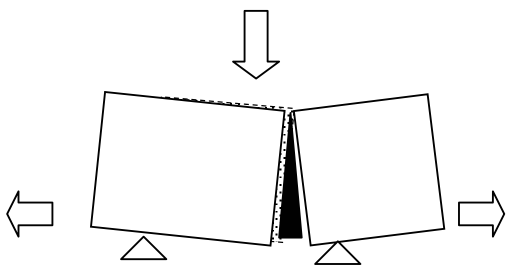

Figure 6. Resultant forces during the Tube Test (magnified)

To address this problem the Shear Strength Test design was modified and fabricated in a way ensures shear mode failure of tack coat, **Figures 4,5**. This was achieved by firmly securing the one-half of the mold to the base of the testing frame and replacing the other-half with a loading head specifically designed to fit the top cylindrical surface of the exposed specimen. A metal holder with a concave surface with approximate radius of specimens is required to withstand the load applied by the platen, **Figure 4**. Such a set up was found to be suitable for a simple shear test without causing any lateral displacement at the bottom of the specimen. The testing showed that the sample moved in the direction of the applied load indicating shear failure.

The constant rate was used to find the maximal strength of the specimen at the interface. The load was applied until the shear failure occurs, usually within the 10 mm of a vertical displacement. Resultant force in kN versus time was recorded and converted to Shear strength in kPa.

Table 2. Maximal load of different gyratory specimen's types

Specimen type	Rate	Bottom layer height	Diameter	Surface	Max. Load (kN)	Max. Stress (kPa)

	(kg/m²)	(mm)	(mm)	(m²)	Load	Average	Stress	Average
TC_1	0.35	74.4	149.5	0.0175	16.5	17.0	943.5	967.8
	0.35	70.0	149.5	0.0175	17.3		986.7	
	0.35	67.9	149.6	0.0176	17.2		981.7	
	0.35	70.2	149.8	0.0176	16.9		959.4	
TC_2	0.35	69.9	149.9	0.0176	19.1	17.6	1082.3	998.1
	0.35	68.9	150.0	0.0177	17.7		1003.3	
	0.35	67.9	149.5	0.0176	17.3		986.8	
	0.35	71.0	149.8	0.0176	16.2		919.9	
no tack	---	71.0	149.9	0.0176	16.6	17.1	940.1	966.9
	---	70.7	149.7	0.0176	19.0		1078.0	
	---	71.5	149.4	0.0175	16.6		947.2	
	---	68.4	150.5	0.0178	16.1		902.4	
no interface	---	90.7	149.9	0.0176	14.6	22.8	830.0	1298.4
	---	85.2	149.6	0.0176	24.6		1399.8	
	---	86.2	149.9	0.0176	24.2		1370.5	
	---	108.6	149.6	0.0176	22.0		1252.4	
	---	129.0	149.6	0.0176	26.2		1491.6	
	---	124.7	149.8	0.0176	25.5		1445.7	

Table 2 shows the maximum shear stress of two tack coats tested using the modified shear strength test. TC_2 gives slightly higher value (3 percent) than the value obtained for the samples tested without tack coat implying that TC_2 provides slight improvement in bonding strength between two layers. It should be noted that the average bonding stress (966.9 kPa) between specimens without tack coat is about 25 percent lower than the shear stress of the specimens without the interface. The application of the TC_2 appears to have increased the bonding strength by about 3 percent. The impact of this increase in bond strength on fatigue performance will be investigated in Phase 2 of this study. From the limited test results, it appears that TC_1 has no effect in improving the bonding strength of the interface layer. Further tests were carried out as discussed below to further characterize the tack coat materials (TC_1 and TC_2).

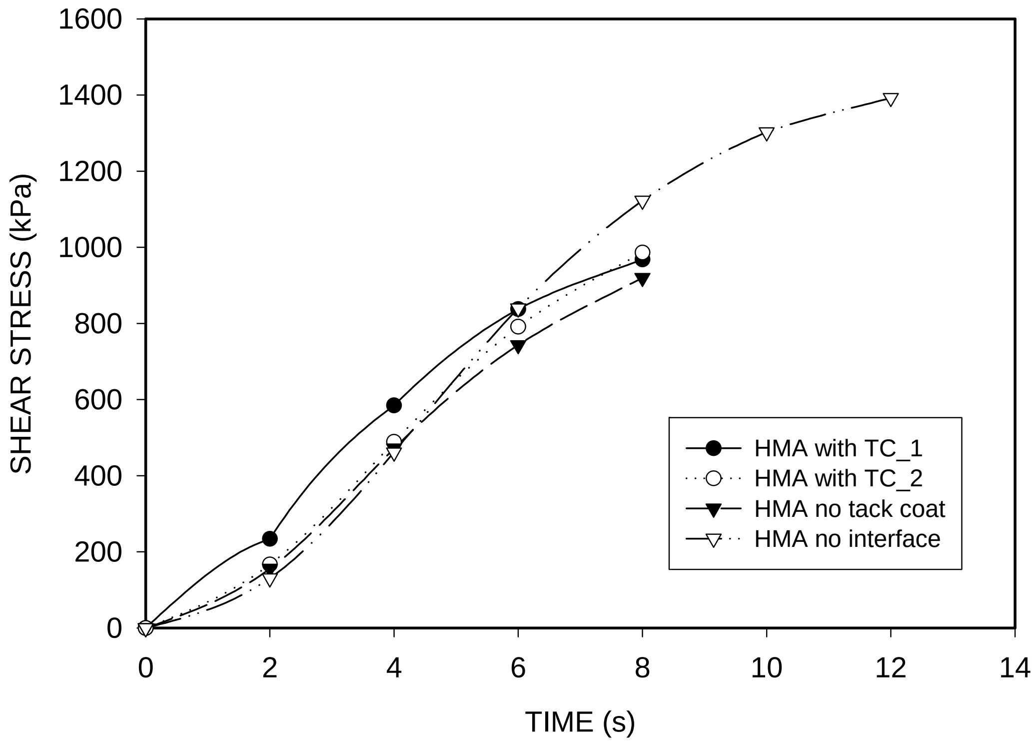

Figure 7. Average shear stress at HMA specimens

Even though the HMA specimens were tested in static mode at one temperature, it may be interesting to characterize pure tack coats by the shear relaxation modulus G(t) (Dealy,1994). Theoretically, this is the only function required for the calculation of the stress, for linear viscoelastic material. It is difficult to measure the complex modulus directly, but it can be extracted from the stress-strain data using the loss G'(ω) and storage G"(ω) moduli. Dynamic mechanical data contain all the information need it for the calculation of discrete relaxation and retardation spectra. At first, the dynamic data at different temperatures were shifted horizontally in order to create master curves (Brodnyan et. al. 1960; Dobson, 1969; Jongepier and Kuilman, 1969). Horizontal shift log a_T was applied to each data set except the reference temperature and Williams-Landel-Ferry (WLF) equation (Ferry, 1980) was used to match shift factors over the temperature range. Results are listed in **Table 3**. It is easy to measure dynamic moduli of tack coats in DSR and convert these data from frequency domain in to the time domain using TTS principle and discrete spectra. The advantage of G(t) is that it is easy interpret results over the time window at given temperature.

Table 3. WLF constants of horizontal fit

		T_o (^{o}K)	C_1	C_2
a_T WLF	**TC_1**	293.08	10.67	86.12
	TC_2	292.71	12.98	105.11

In accordance to established theory (Baumgatertel and Winter, 1989), there are commercial software (Baumgaertel at el., 1990, Rowe and Sharrock, 2000) available to calculate the relaxation and retardation spectra based on master curve listed in **Table 4**. From these, the linear relaxation moduli for TC_1,2 were calculated at the reference temperature T=24^o C, **Figure 8**. It can be seen from **Figure 3** that TC_2 slightly show higher stiffness than stiffness observed for TC_1. This trend quite consistent with the trend observed form the data given in **Table 2**. It appears that shear relaxation modulus test on the tack coats seems to have the potential to evaluate different tack coats. However, no conclusions can be reached because of limited samples. Further tests using several samples will be conducted to explore the potential use of these tests described above.

Table 4. Relaxation and retardation spectra parameters of tack coats

	G (Pa)	Lambda (s)	j (1/Pa)	LAMBDA (s)
TC_1	4.295e+006 8.731e+004 3.498e+003	3.255e-001 1.169e+001 1.983e+002	1.911e-006 1.334e-005	6.845e+000 1.553e+002
TC_2	8.289e+007 1.359e+006 1.709e+005 2.479e+004 2.233e+003	1.516e-002 1.676e+000 1.171e+001 9.203e+001 5.747e+002	2.943e-007 6.105e-007 3.057e-006 7.799e-006	5.697e-001 7.765e+000 6.623e+001 4.984e+002

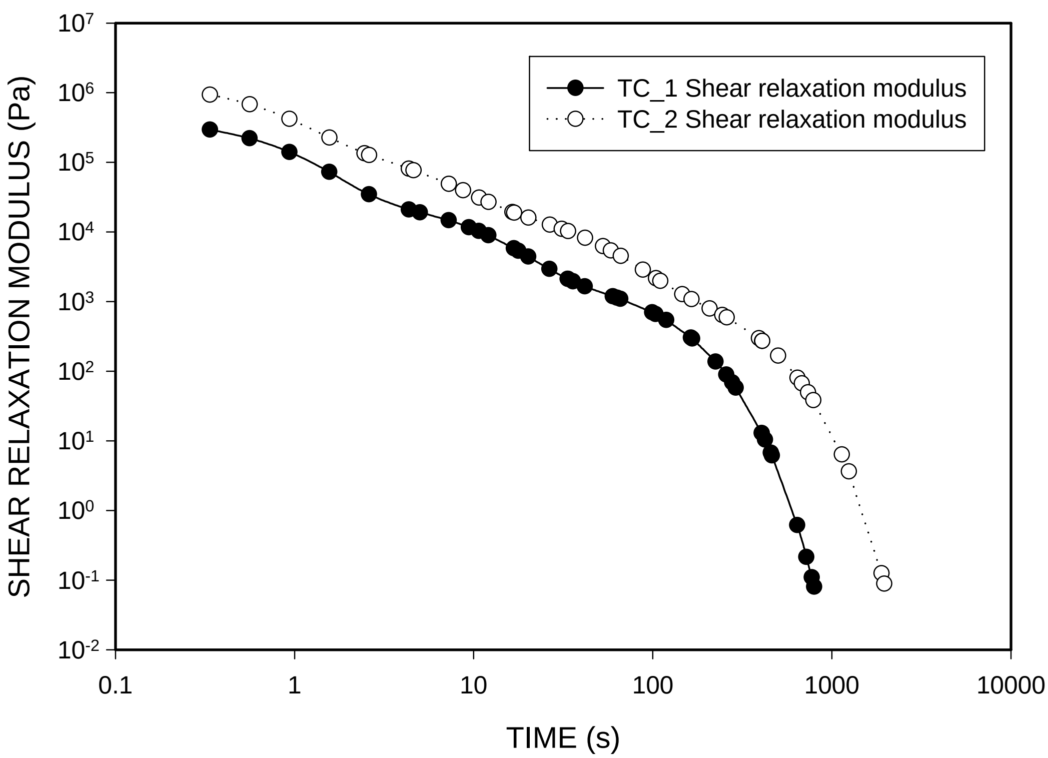

Figure 8. Shear relaxation modulus calculated for tack coats at 24^{o}C.

CONCLUSIONS

The tack coats were evaluated using two types of tests: shear test using Marshall testing apparatus and shear relaxation modulus test using DSR. Both tests are simple to do. There appears to be some correlation between the two tests. The shear testing using Marshall apparatus shows that TC_2 can improve the bond strength by 3%. However, more tests are required to draw any conclusions. The impact of this increase in bond strength on fatigue life needs to be evaluated.

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