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EVALUATION OF BOND STRENGTH OF INTERLAYERS OF BITUMINOUS PAVEMENT USING CMS-2 AND CRS-1 AS TACK COAT

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Abstract

The interlayer bonding of modern multi-layered pavement system plays an important role to achieve long term performance of a flexible pavement. It has been observed that poor bonding between bituminous pavement layers contributes to major pavement overlay distresses such as premature fatigue, top down cracking, potholes, and surface layer delamination. One of the most common distresses due to poor bonding between bituminous layers is a slippage failure, which usually occurs where heavy vehicles are often accelerating, decelerating, or turning. To enhance the bonding between layers, a tack coat is sprayed in between the bituminous pavement layers. A tack coat is an application of a bituminous emulsion or bituminous binder between an existing bituminous / concrete surface and a newly constructed bituminous overlay. Normally, hot bituminous binders, cutback bitumens or bituminous emulsions are used as tack coat materials.

This study is aimed to evaluate the bond strength at the interface between pavement layers by performing laboratory tests. To carry out this objective, three special attachments are fabricated for use in Marshall Loading Frame for finding the performance of tack coat laid at the interface between Bituminous Concrete (BC) and Dense Bituminous Macadam (DBM) layers in the laboratory. In this study, the results of the specimens prepared with 100 mm and 150 mm diameter specimens using two types of normally used emulsions, namely CMS-2and CRS-1 as tack coat at application rates varying at 0.20 kg/m^2, 0.25 kg/m^2 and 0.30 kg/m^2 made at 25^{0}C temperature are presented. It is observed that CRS-1 as tack coat provides higher interface bond strength value compared to CMS-2. Similarly, irrespective of the types of emulsions used as tack coat, the optimum rate of application is

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found to be 0.25 kg/m^2 as recommended in MORT&H's specifications.

Key Words: Interlayer, bond strength, shear strength, tack coat, performance.

1. INTRODUCTION

1.1 INTRODUCTION

The modern flexible pavement is generally designed and constructed in several layers for effective stress distribution across pavement layers under the heavy traffic loads. The interlayer bonding of the multi-layered pavement system plays an important role to achieve long term performance of pavement. Adequate bond between the layers must be ensured so that multiple layers perform as a monolithic structure. To achieve good bond strength, a tack coat is usually sprayed in between the bituminous pavement layers. As a result, the applied stresses are evenly distributed in the pavement system and subsequently, reduce structural damage to the pavements.

It has been observed that poor bonding between pavement layers contributes to major pavement overlay distresses. One of the most common distresses due to poor bonding between pavement layers is a slippage failure, which usually occurs where heavy vehicles are often accelerating, decelerating, or turning. The vehicle load creates dynamic normal and tangential stresses in the pavement interfaces from horizontal and vertical loads. With the vehicle load being transferred to each underlying bituminous layer, the interface between the layers is vital to the pavements integrity. Slippage failure develops when the pavement layers begin to slide on one another usually with the top layer separating from the lower layer. This is caused by a lack of bond and a high enough horizontal force to cause the two layers to begin to separate. Other pavement problems that have been linked to poor bond strength between pavement layers include premature fatigue, top down cracking, potholes, and surface layer delamination. Some of failures shown in following figures.

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Figure 1.1: Slippage Crack

Figure 1.2: Pothole

Figure 1.3: Surface Layer Delamination

2 LITURATURE REVIEW

Numerous studies have been performed investigating adhesive properties of the interface between layers. These studies have typically developed a unique test method or instrument for analysis of the interface bond strength. Literature on bond strength clearly indicates that shear force is mainly responsible for interface bond failure.

Different organizations and different researchers have used various tests for evaluating the pavement interface bond strength including the following:

- Layer-Parallel Direct Shear (LPDS);
- Ancona Shear Testing Research and Analysis (ASTRA);
- Superpave Shear Tester (SST), which has been recently modified by the Louisiana Transportation Research Center by building a shear mold assembly;
- Leutner test, originally developed in Germany;

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- FDOT Shear Tester;
- LCB shear test;
- Modified Marshall Test developed by the Pennsylvania Department of Transportation
- NCAT bond strength device developed by National Center for Asphalt Technology ;
- Shear-Testing Device developed at Mcasphalt Lab.

An overview of some of these commonly used test procedures is provided in the subsequent sections.

3. EXPERIMENTAL INVESTIGATION

3.1 Materials Used

Aggregates

For preparation of cylindrical samples composed of Dense Bituminous Macadam (DBM) and Bituminous Concrete (BC), aggregates were as per grading of Manual for Construction and Supervisions of Bituminous Works of Ministry of Road Transport and Highways (MORT&H, 2001) as given in Table 3.1 and 3.2 respectively.

Coarse Aggregates

Coarse aggregates consisted of stone chips collected from a local source, up to 4.75 mm IS sieve size. Standard tests were conducted to determine their physical properties as summarized in Table 3.3.

Fine Aggregates

Fine aggregates, consisting of stone crusher dusts were collected from a local crusher with fractions passing 4.75 mm and retained on 0.075 mm IS sieve. Its specific gravity was found to be 2.62.

Filler

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Portland slag cement (Grade 43) collected from local market passing 0.075 mm IS sieve was used as filler material. Its specific gravity was found to be 3.0.

Table 3.1: Adopted aggregate gradation for DBM

Property	Gradi
Nominal Aggregate	25
IS Sieve (mm)	Perce
37.5	100
26.5	95
19.0	83
13.2	68
4.75	46
2.36	35
0.300	14
0.075	5

Table 3.2: Adopted aggregate gradation for BC

Property	Grading
Nominal Aggregate Size	13
IS Sieve (mm)	Percent
19.0	100
13.2	89.5
9.5	79
4.75	62
2.36	50
1.18	41
0.600	32

0.300	23
0.150	16
0.075	7

Table 3.3: Physical properties of coarse aggregates

Property	Test Method	Test Result
Aggregate Impact Value (%)	IS: 2386 (Part-IV)	14.28
Aggregate Crushing Value (%)	IS: 2386 (Part-IV)	13.02
Los Angels Abrasion Value (%)	IS: 2386 (Part-IV)	18
Flakiness Index (%)	IS: 2386 (Part-I)	18.83
Elongation Index (%)		21.50
Specific Gravity	IS: 2386 (Part-III)	2.75
Water Absorption (%)	IS: 2386 (Part-III)	0.13

Figure 3.1: Photographs of the Aggregate Impact Test

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Figure 3.2: Aggregate Crushing test setup

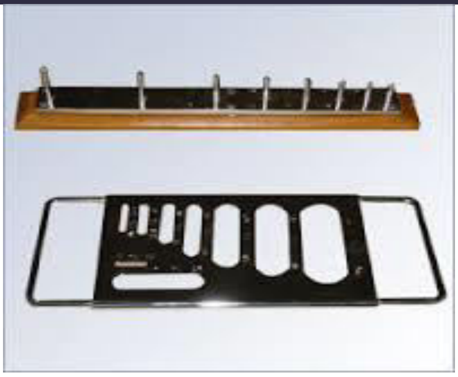

Figure 3.3: Flakiness & Elongation Scales

Figure 3.4: Photographs of the Los Angels Abrasion Test.

Binder

One conventional commonly used bituminous binder, namely VG 30 bitumen collected from local source was used in this investigation to prepare the samples. Conventional tests were performed to determine the important physical properties of these binders. The physical properties thus obtained are summarized in Table 3.4.

Tack Coat Materials

The tack coat materials selected for this study include two emulsions CMS-2 and CRS-1. Standard tests were conducted to determine their physical properties as summarized in Table 3.5.

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Table 3.4: Physical properties of VG 30 bitumen binder

Property	Test Method	Test Result
Penetration at 25°C	IS : 1203-1978	67.7
Softening Point (R&B), °C	IS : 1205-1978	48.5
Viscosity (Brookfield) at 160°C, Cp	ASTM D 4402	200

Figure 3.5: Photographs of the Penetration Test.

Figure 3.6: Softening Point Test.

Table 3.5: Physical properties of Tack Coats

Property	Test	Emulsion	Test
Viscosity by Saybolt Furol viscometer, seconds:	ASTM D	CRS-1	37
		CMS-2	114

Density in g/cm^3	As per Chehab et	CRS-1	0.986
		CMS-2	0.986
Residue by evaporation	ASTM D	CRS-1	61.33
		CMS-2	67.59
Residue Penetration	IS : 1203-	CRS-1	86.7
		CMS-2	106.7
Residue Ductility 27^0 C cm	IS : 1208-	CRS-1	100+
		CMS-2	79

3.2 Preparation of Samples

The mixes were prepared according to the Marshall procedure specified in ASTM D1559. Laboratory specimens prepared to determine interface bond strength were generally 100 mm and 150 mm in diameter and 100 mm in total height. Each specimen consisted of two layers with tack coat applied at the interface. Test variables included 100 mm and 150 mm diameter specimen and two conventional emulsions namely CMS-2 and CRS-1 as tack coats with application rates varying at 0.20 kg/m^2, 0.25 kg/m^2 and 0.30 kg/m^2. The bottom layer consisted of a Dense Bituminous Macadam (DBM) with a VG 30 binder; the top layer was a Bituminous Concrete (BC) with a VG 30 binder. For the preparation of bottom layer, first the loose mix was compacted by giving 75 blows using Marshall Hammer and then it was allowed to cool down at room temperature. Next, the amount of tack to be applied on the specimen surface was calculated by multiplying the tack coat application rate by the surface area of a specimen. The rate of application of tack coat was selected as per MORT&H Specification which is given in the Table 3.6.

Table 3.6: Rate of application of Tack Coat as per MORT&H Specification

Type of Surface	Quantity in kg per m^2 area
Normal bituminous surface	0.20 to 0.25

Dry and hungry bituminous surface	0.25 to 0.30
Granular surface treated with primer	0.25 to 0.30
Granular base (not primed)	0.35 to 0.40
Cement Concrete pavement	0.30 to 0.35

3.3 Fabrication of laboratory test procedure to measure the interface bond strength

For the purpose of testing the shear strength offered by tack coat at the bonded interface, the following three models were fabricated:

- Model no. 1, for testing 100 mm diameter laboratory specimens based on the concept of the Layer-Parallel Direct Shear (LPDS) developed by the Swiss Federal Laboratories for Material Testing and Research.
- Model no. 2, for testing 150 mm diameter laboratory specimens based on the concept of the Layer-Parallel Direct Shear (LPDS) developed by the Swiss Federal Laboratories for Material Testing and Research.
- Model no. 3, for testing 150 mm diameter laboratory specimens based on the concept of the FDOT shear tester developed by the Florida Department of Transportation (FDOT).

3.3.1 Model no. 1

This device could accommodate cylindrical specimens of 100 mm diameter and was so fabricated that the lower part of a specimen could placed on a semicircular u-bearing which was fixed on the top base plate and the specimen could hold firmly with the help of a semicircular clamping. The upper part of the specimen could move freely with minimum friction along the two existing guiding rods of the Marshall apparatus. A load of constant deformation at a rate of 50.8 mm/min was applied on a smooth horizontal stripe located on the top of the shear sleeve adjacent to the interface by means of a yoke, allowing the application of a shear force at the interface. The schematic view and photographic view of the model are shown in figures 3.7.1 and 3.7.2.

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Figure 3.7. Photographs of the Shear-Testing model no. 1

3.3.2 Model no. 2

This device could hold cylindrical specimens of 150 mm diameter and was so fabricated that the bottom layer of the double-layered specimen could place on a semicircular u-bearing which was fixed on the top base plate and the specimen could hold firmly with the help of a semicircular clamping. The upper layer of the specimen could move freely with minimum friction along the two existing guiding rods of the Marshall apparatus. A load of constant deformation at a rate of 50.8-mm/min was applied on a smooth horizontal stripe located on the top of the shear sleeve adjacent to the interface by means of a yoke, allowing the application of a shear force at the interface. The schematic view and photographic view of the model are shown in figures 3.8.1 and 3.8.2.

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Figure 3.8. Photographs of the Shear-Testing model no. 2.

3.3.3 Model no. 3

This device consisted of two circular rings that could accommodate cylindrical specimen of 150 mm diameter and a gap of 5 mm was maintained in between the two rings in order to account for the irregular surface of the cored specimens. One of the rings was fixed at its bottom to a base plate and a concentric shear load was applied at a constant deformation rate of 50.8 mm/min on the top of other ring until failure occurred. The schematic view and photographic view of the model are shown in figures 3.9.1 and 3.9.2.

Figure 3.9. Photographs of the Shear-Testing model no. 3.

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4. RESULT:

This chapter presents results and discussion on the findings of the experimental investigations carried out on the cylindrical laboratory prepared specimens which were tested on special fabricated attachments fitted on the Marshall Loading Frame.

The interface bond strength results obtained from the three shear test models conducted at a temperature of 25^0C on 100 mm and 150 mm diameter specimens with CMS-2 and CRS-1 as tack coats at application rate varying at 0.20 kg/m^2, 0.25 kg/m^2 and 0.30 kg/m^2.

4.1 Shear testing model no. 1

The test was conducted on 100 mm diameter cylindrical specimens with CRS-1 and CMS-2 as tack coats applied at application rate varying at 0.20 kg/m^2, 0.25 kg/m^2 and 0.30 kg/m^2 at a temperature of 25^0C. As seen in table 4.1 and figure 4.1

Table 4.1 Results of the shear strength of 100 mm diameter specimens using Shear testing model no. 1 at 25^0C

Tack Coat Type	Application rate (kg/m^2)	Load (kN)	Shear Strength (kPa)	Average Shear Strength (kPa)
CMS-2	0.20	3.228	411.001	429.590
CMS-2	0.20	3.374	429.590	
CMS-2	0.20	3.52	448.179	
CMS-2	0.25	4.397	559.842	572.277
CMS-2	0.25	4.397	559.842	
CMS-2	0.25	4.690	597.148	
CMS-2	0.30	4.032	513.369	538.155
CMS-2	0.30	4.251	541.253	
CMS-2	0.30	4.397	559.842	
CRS-1	0.20	3.812	485.358	460.615
CRS-1	0.20	3.667	466.896	
CRS-1	0.20	3.374	429.590	
CRS-1	0.25	4.543	578.431	597.106
CRS-1	0.25	4.69	597.148	
CRS-1	0.25	4.836	615.737	

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CRS-1	0.30	4.543	578.431	575.376
CRS-1	0.30	4.397	559.842	
CRS-1	0.30	4.617	587.853	

As shown in figure 4.1, the optimum rate of application was found to be 0.25 kg/m^2 for both CMS-2 and CRS-1 as tack coat.

4.2 Shear testing model no. 2

The test was conducted on 150 mm diameter cylindrical specimens with CRS-1 and CMS-2 as tack coats applied at application rate varying at 0.20 kg/m^2, 0.25 kg/m^2 and 0.30 kg/m^2 at a temperature of 25^{0}C. As seen in table 4.2 and figure 4.2 the specimen with CRS-1 as tack coat exhibited slightly higher shear strength than CMS-2 for all tack coat application rates.

Table 4.2 Results of the shear strength of 150 mm diameter specimens using Shear testing model no. 2 at 25^{0}C

Tack Coat Type	Application rate (kg/m^2)	Load (kN)	Shear Strength (kPa)	Average Shear Strength (kPa)
CMS-2	0.20	7.417	419.715	419.583
CMS-2	0.20	7.117	402.739	
CMS-2	0.20	7.710	436.296	
CMS-2	0.25	9.193	520.216	531.421
CMS-2	0.25	9.490	537.023	
CMS-2	0.25	9.490	537.023	
CMS-2	0.30	9.193	520.216	503.428
CMS-2	0.30	8.896	503.409	
CMS-2	0.30	8.600	486.659	

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CRS-1	0.20	8.007	453.102	453.084
CRS-1	0.20	7.710	436.296	
CRS-1	0.20	8.303	469.853	
CRS-1	0.25	9.490	537.023	553.735
CRS-1	0.25	10.080	570.410	
CRS-1	0.25	9.786	553.773	
CRS-1	0.30	9.638	545.398	535.193
CRS-1	0.30	9.341	528.591	
CRS-1	0.30	9.394	531.590	

As shown in figure 4.2, the optimum rate of application was found to be 0.25 kg/m^2 for both CMS-2 and CRS-1 as tack coat.

4.3 Shear testing model no. 3

The test was conducted on 150 mm diameter cylindrical specimens with CRS-1 and CMS-2 as tack coats applied at application rate varying at 0.20 kg/m^2, 0.25 kg/m^2 and 0.30 kg/m^2 at a temperature of 25^{0}C. As seen in table 4.3 and figure 4.3 the specimen with CRS-1 as tack coat exhibited slightly higher shear strength than CMS-2 at an application rate.

Table 4.3 Results of the shear strength of 150 mm diameter specimens using Shear testing model no. 3 at 25^{0}C

Tack Coat	Applicatio n rate	Load (kN)	Shear Strength	Average Shear
CMS-2	0.2	9.193	520.21	537.004
CMS-2	0.2	9.786	553.77	
CMS-2	0.2	9.490	537.02	
CMS-2	0.2	11.560	654.16	676.607
CMS-2	0.2	12.450	704.52	
CMS-2	0.2	11.860	671.13	
CMS-2	0.3	11.414	645.89	634.732
CMS-2	0.3	10.970	620.77	
CMS-2	0.3	11.266	637.52	
CRS-1	0.2	9.786	553.77	
CRS-1	0.2	10.082	570.52	

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CRS-1	0.2	10.378	587.27	570.523
CRS-1	0.2	12.450	704.52	704.430
CRS-1	0.2	12.150	687.54	
CRS-1	0.2	12.745	721.21	
CRS-1	0.3	11.710	662.64	668.195
CRS-1	0.3	11.857	670.96	
CRS-1	0.3	11.857	670.96	

As shown in figure 4.3, the optimum rate of application was found to be 0.25 kg/m^2 for both CMS-2 and CRS-1 as tack coat.

The comparison of the three model tests are shown graphically in the below figure

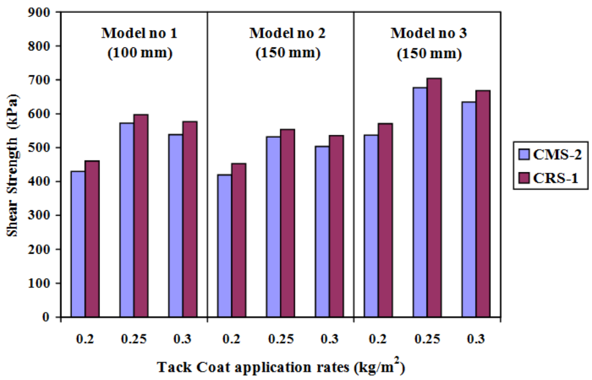

Figure 4.1 Comparison of Shear Strength v/s Application rates for the three models.

5. CONCLUSION

A laboratory study was conducted to evaluate the bond strength between the Bituminous Concrete (BC) and Dense Bituminous Macadam (DBM) layers with tack coat sprayed at the interface. For this purpose three simple shear testing models were fabricated and experiments were conducted using the same in a Marshall Stability Apparatus. For shear testing model no 1, laboratory tests were conducted on 100 mm diameter cylindrical specimens at a Temperature of $25^{0\,C}$ by applying a shear force of constant deformation rate of 50.8 mm/min. While the shear testing model no. 2 and 3 were fabricated to evaluate the bond strength of 150 mm diameter cylindrical specimens. The samples were prepared in laboratory by applying CMS-2 and CRS-1 as tack coat at interface at application rates varying at 0.20 kg/m^2, 0.25 kg/m^2 and 0.30 kg/m^2.

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