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EVALUATION OF BOND BETWEEN BITUMINOUS PAVEMENT LAYERS

Mohd Imran Kumar[1], Er Vikas Garg[2], Er Zubair[3], Dr Pooja Sharma[4]
[1]M Tech Scholar, [2]Assistant Professor (DBU),
[3]Assistant Professor (Swami Vivekanand College), [4]HOD Civil Dept. (DBU)

I. INTRODUCTION

Problem Statement

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. One such result is the formation of cracks in the shape of a crescent

Background on Tack Coat

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. A tack coat is also known as bond coat as it is used to bond one pavement layer to another. A tack coat acts as an adhesive or glue so that combined pavement layers perform as a monolithic structure rather than individual sections. Typically, tack coats are emulsions consisting of bituminous binder particles, which have been dispersed in water with an emulsifying agent. Bituminous particles are kept in suspension in the water by the emulsifying agent and thus bitumen consistency is reduced at ambient temperature from a semi-solid to a liquid form. This liquefied bitumen is easier to distribute at ambient temperatures. When this liquid bitumen is applied on a clean surface, the water evaporates from the emulsion, leaving behind a thin layer of residual bituminous on the pavement surface. When the bituminous binder is used as a tack coat, it requires heating for application (Rahman, 2010). Normally, hot bituminous binder, cutback bitumen or bituminous emulsions are used as tack coat materials. However, the use of bituminous emulsions as a tack coat material is escalating instead of cutback asphalt or hot bituminous binder because of the following advantages:

Bituminous emulsions can be applied at lower application temperatures compared to cutback bitumen or hot bituminous binder.

As bituminous emulsions do not contain harmful volatile chemicals, they are relatively pollution free.

As bituminous emulsions are water based, they have no flashpoint and are not flammable or explosive. Therefore, they are safer to use as they do not pose health risk to workers. (Patel, 2010)

Bituminous emulsion is a mixture of bituminous binder, water and emulsifying agent. The emulsifying agent could be soap, dust or colloidal clays. The microstructures as reported by Roberts et al. is shown in figure 1.2.

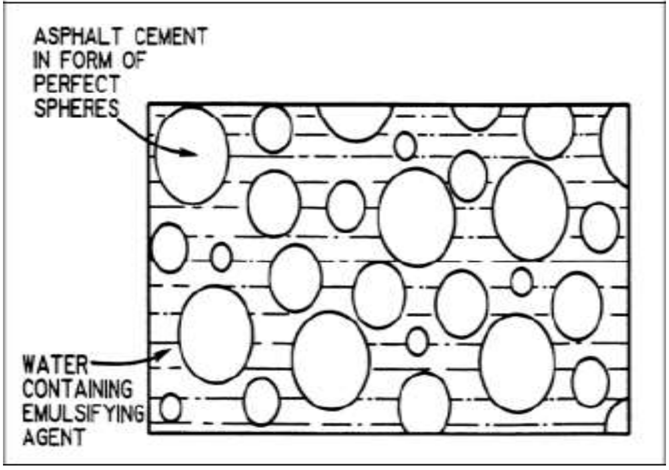


Figure 1.2: Composition of Bituminous Emulsion (Roberts et al., 1996)

Bituminous emulsions, unlike bituminous binder, are liquid at ambient temperatures. The type of emulsifying agent used in the bituminous emulsion will determine whether the emulsion will be anionic, or cationic. Cationic emulsions have bituminous droplets which carry a positive charge. Anionic emulsions have negatively charged bituminous droplets. Base on their setting rate, which indicates how quickly the water separates from the emulsion, both anionic and cationic emulsions are further classified into rapid setting (RS), medium setting (MS), and slow setting (SS). The setting rate is basically controlled by the type and amount of the emulsifying agent. The principal difference between anionic and cationic emulsions is that the cationic emulsion gives up water faster than the anionic emulsion. The anionic grades are: RS-1, RS-2, MS-1, MS-2, MS-2h, SS-1 and SS-1h. The cationic grades include CRS-1, CRS-2, CMS-2, CMS-2 h, CSS-1, and CSS-1h. It should be noted that the absence of letter "C" in an emulsion type denotes an anionic emulsion and vice-versa. The letter "h" stands for hard grade asphalt cement (low penetration) and the numbers "1" and "2" indicates low and high viscosity respectively (Patel, 2010). Cutback bitumen is also liquid bitumen produced by adding petroleum solvents to bituminous binder. Typical petroleum solvent includes gasoline and kerosene. They are used as tack coats because they reduce bitumen viscosity for lower temperature use. The use of cutback bitumen as a tack coat material has declined rapidly over the years due to environmental concerns and the health risk as the solvents evaporate into atmosphere. Cutback bitumen is divided into two classifications Rapid Curing (RC) and Medium Curing (MC) based on the type of solvent used. Rapid curing cutback uses gasoline while medium curing cutback uses kerosene. Hot bituminous binders are obtained from distillation of crude oil. Unlike emulsions, bituminous binder particles do not carry any charge. Any grade of bituminous binder is acceptable as a tack coat material, although it is generally preferable to use the same grade of bituminous binder used in the HMA for tack coat (CPB 03-1, Tack Coat Guidelines).

Research Objective

The primary objective of this study is to fabricate a few simple testing devices for the evaluation of the bond strength offered by the tack coats at the interface between bituminous pavement layers in the laboratory scale by performing several laboratory tests with different tack coat application rates. The ideal design will be that the standard setup which produces consistent results comparable to others. A secondary goal of this study is to provide helpful information for the selection of the best type of tack coat materials and optimum application rate.

II. REVIEW OF LITERATURE

Introduction

In this chapter, extensive literature survey on the various laboratory studies conducted for the evaluation of bond strength between bituminous pavement layers has been discussed.

Tests to Evaluate the Interface Bond Strength of Pavement

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;
- 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 ;

III. EXPERIMENTAL INVESTIGATIONS

Introduction

This chapter describes the experimental works carried out in this present investigation.

This chapter has been divided into two parts. First part deals with the experiments carried out on the materials (aggregates, bitumen, and emulsions), second part deals with the fabrication of the shear testing devices for evaluation of pavement interface bond strength.

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

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	Grading
Nominal Aggregate Size (mm)	25
IS Sieve (mm)	Percent Passing

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 (mm)	13
IS Sieve (mm)	Percent Passing
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

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.

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

Table 3.5: Physical properties of Tack Coats

Property	Test Method	Emulsion Type	Test Results
Viscosity by Saybolt Furol viscometer, seconds: At 50^0 C	ASTM D 6934	CRS-1	37
		CMS-2	114
Density in g/cm^3	As per Chehab et al. (2008)	CRS-1	0.986
		CMS-2	0.986

Residue by evaporation, percent	ASTM D 244	CRS-1	61.33
		CMS-2	67.59
Residue Penetration 25^0 C/100 g/5 sec	IS : 1203-1978	CRS-1	86.7
		CMS-2	106.7
Residue Ductility 27^0 C cm	IS : 1208-1978	CRS-1	100+
		CMS-2	79

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/m2, 0.25 kg/m2 and 0.30 kg/m2. 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.

Shear-Testing Device developed at Mcasphalt Lab.

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

Layer-Parallel Direct Shear (LPDS)

The Swiss Federal Laboratories for Material Testing and Research developed a shear testing device known as Layer-Parallel Direct Shear (LPDS) which is a modified version of equipment developed in Germany by Leutner (1979). The modified LPDS test is used to test the 150 mm diameter cylindrical specimens using Marshall testing as reported by Raab and Partl (2002). The bottom layer of a double-layered specimen is placed on a u-bearing and the upper layer is moved with a constant displacement rate of 50.8 mm/min at a temperature of 20^0C by means of a yoke, allowing the application of a shear force at the interface as shown in figure 2.1. The shear force and the corresponding displacement are continuously recorded to find the maximum load. The nominal shear stress ($\tau_{LPDS)}$) is calculated as follows:

$\tau_{LPDS} = F/A$

$= 4F/ (d^2\pi)$

Where, F = maximal force;

A = nominal cross sectional area; and d = specimen diameter.

The study was conducted to evaluate the influence of compaction (50 and 204 gyrations), surface texture (smooth and rough), moisture, heat and water on the interface shear bond of pavements by using 20 different types of tack coats. The study concluded that higher shear strengths were observed for the specimens with the smooth surface than the specimens with rough surface. The results clearly indicated the negative influence on adhesion due to the presence of moisture and absence of tack coat. The study also reported the improvement of shear adhesion up to 10% for a top-layer compaction at 240 gyrations by using a certain tack coat, while such improvement was not observed for 50 gyrations.

IV. RESULTS AND DISCUSSION

Introduction

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.

The interface shear strength, ISS, was computed as follows:

$ISS = F_{max} / A$

Where,

ISS = Interface Shear Strength (kPa),

F_{max} = Ultimate load applied to specimen (kN), and A = Cross-sectional area of test specimen (m^2)

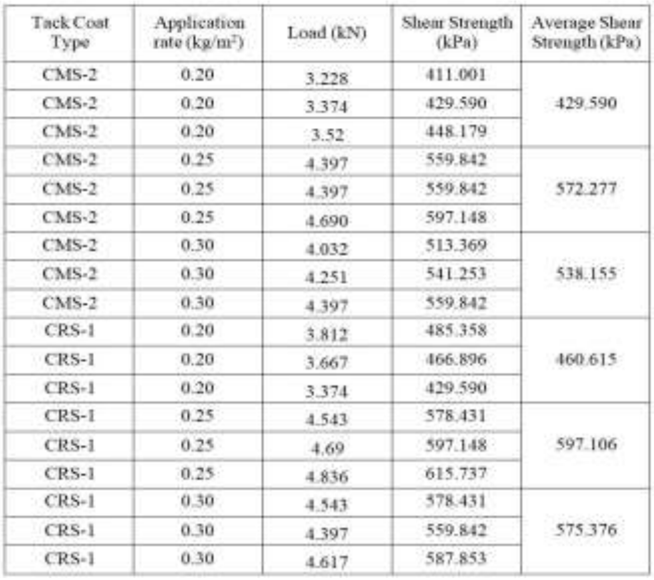
$= \Pi \times R^2$

R = Radius of the specimen (m)

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 the specimen with CRS-1 as tack coat exhibited higher shear strength as compared to CMS-2 for all application rates.

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/m²)	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	
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.

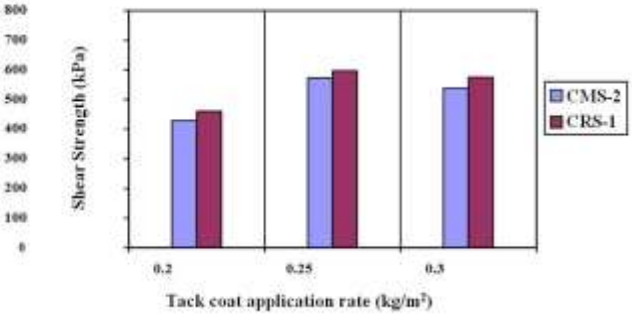


Figure 4.1: Plot of Shear Strength v/s Tack Coat application rates for 100 mm diameter specimens using Shear testing model no. 1.

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