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EVALUATION OF BOND BETWEEN BITUMINOUS PAVEMENT LAYERS

[*1]Chakrala Sal Rakesh,
[* 2] Dr. Balakrishna Ph.D.
[* 1] PG Student from Department of Civil Engineering, MVR Engineering College,
[2] Head of the department & Associate professor from Civil Engineering. MVR Engineering College, Vijayawada.

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 delimitation. One of the most common distresses due to poor bonding between bituminous layers are 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 I concrete surface and a newly constructed bituminous overlay. Normally, hot bituminous binders, cutback bitumen 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 attack coat laid at the interface between Bituminous Concrete (BC) and Dense Bituminous Macadam (DBMS 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 020 kg/m2, 0.25 k elm' and 0.30 kg/m2made at 25°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 found to be 0.25 kg/m2 as recommended in MORT&H-s specifications.

Keywords:
Interlayer, Bond Strength, Shear Strength, Tack Coat, Performance.

INTRODUCTION

Li 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 pavements layers is a slippage failure. This 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 delimitation. One such result is the formation of cracks in the shape of a crescent as shown in figure 1. 1.

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Figure 1.1: Slippage Crack (http://www.surface-engineering.net)

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Background on Tack Coat

A tack coat is an application of a bituminous emulsion or bituminous binder between an existing bituminous I 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 behinds 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:

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

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

III. 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)

IV. Bituminous emulsion is a mixture of bituminous binder, water and emulsifying agent.

V. The emulsifying agent could be soap, dust or colloidal clays. The microstructures as reported by

VI. Roberts et al. is shown in figure 1.2.

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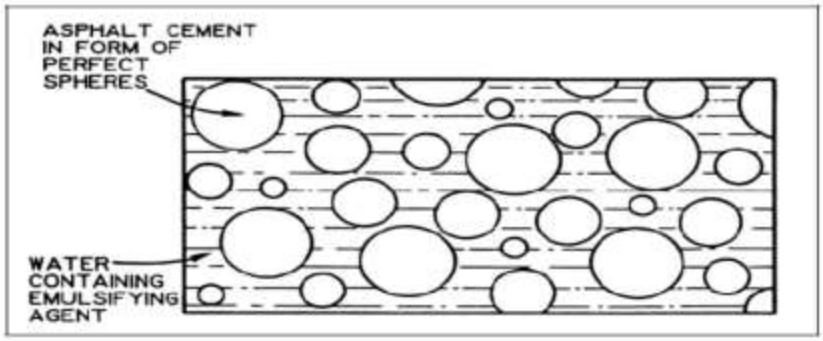

Figure 1.2: Composition of Bituminous Emulsion (Roberts et al., 1996)

Asphalt cement in form of perfect spheres water containing emulsifying agent 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-2.h, SS-1 and SS-1h. The cationic grades include CRS-I, CRS-2, CMS-'), 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 "1-1" 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 (CPS 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.

REVIEW OF LITERATURE

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

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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 TBR analysis of the interface bond strength. Literature on bond strength clearly indicates that shear force is mainly responsible for interface bond failure. Different org, anizations 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);
- Super pave 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;

Shear-Testing Device

Developed at Measphalt Lab Tony Kucharek et al. developed Modified Marshall stability mould at Mcasphalt lab. One of the moulds is fixed at its bottom to a base plate. ‘vhile the other semi circular sleeve can move vertically with minimum friction along the two guiding rods. A load of constant deformation at a rate of 50.8-mmimin is applied on a smooth horizontal stripe located on the top of the shear sleeve adjacent to the interface as shown in figure IX This laboratory study was conducted on double-layered specimens prepared using 16 emulsions applied at 0.05, and 0.15 kg/m2 to evaluate the influence of substrate characteristics. The study concluded that the rougher substrate revealed higher shear strength compared to smoother surface.

Figure 2.8: Shear-Testing device developed at McAsphal Lab (Tony Kucharek et al.)

Important factors affecting the interface bond strength of pavement

Existing literature clearly reveals the important factors affecting the interface bond strength of pavement include rate of displacement, tack coat type, tack coat application rate, testing temperature and normal pressure at the interface.

1 Influence of rate of displacement

The samples tested at greater displacement rates require a greater load to fail because of the visco elastic nature of bituminous binder. Sholar et al. (2003) concluded from the experiments that the core samples tested at greater displacement rate exhibited a higher average failure shear stress (60 psi) compared to the samples tested at 035 in im in (38 psi).

2 Influence of tack coat type

Previous literature clearly indicates the use of hot bituminous binder, cutback bitumen or bituminous emulsions as tack coat materials. The most widely used tack coat material in the world is bitumen emulsion. According to the Unified

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Facilities Guide Specification (UFGS) 02744N, the advantage of the slow-setting grades over the rapid-setting grades is that they can be diluted.

Diluted emulsions are reported to give better results because of the following reasons

(1) Diluted emulsion provides the extra volume required for the tack coat distributor to function at normal speed especially at lower application rates.

(2) Diluted emulsion allows for a more uniform application as it flows easily from the distributor at ambient temperatures. However, for longer setting period of slow setting emulsions compared to rapid setting emulsions, it is not desirable to use slow setting emulsions as a tack coat in relatively cool weather, at night, or when there is a narrow Construction Window.

(3) The International Bitumen Emulsion Federation (IBEF. 1999) conducted a world-wide survey of the use of tack coats. The survey reported that cationic emulsions are the most common bond coat material, with some use of anionic emulsions.

(4) A survey conducted by Paul and Scherocman (1998) in the United States, to gather information on the state of practice with respect to tack coat operations, reported the use of slow-set emulsions by all the respondin2- states.

(5) The most common among them are SS-I, SS-1h, CSS- I, and CSS-lh. Some states like California, Florida, and Vermont used the rapid setting type of emulsions such as RS-1 and RS-2. Florida and Georgia were the only states that used paving grade asphalts (AC-5. AC-20, and AC-30) as tack coats at the time of the survey.

(6) Some states used tack coat materials according to the construction situations. For example, Florida DOT used either a rapid setting emulsion RS-1 or RS-2 during day time, whereas the use of a viscosity-grade asphalt binder (AC-5) was specified for night time construction. Cross and Shrestha (2004) conducted a phone survey in 13 mid-western and western U.S. states indicated that slow-setting emulsions are the primary materials for tack coat, except for California, where the AR-4000 was the most Widely adopted as the tack coat material followed by either SS-1 or CSS-1. The only agency to report the used of cutback asphalt as a tack coat material on an occasional basis was Kansas DOT .New Mexico DOT and Texas DOT reported that performance-grade (PG) binders were occasionally used as tack coat materials.

3 Influence of tack coat application rate

An excessive tack coats may promote shear slippage at the interface while too little may result in de-bonding problems. Therefore, it is important to estimate the optimum amount of tack coat that will produce the best performance. To achieve a proper interface bond, pavement surfaces with different. Conditions (e.g., new, old, or milled) require different tack application rates. Generally, slow-setting grade emulsions require higher application rates than rapid-setting grade emulsions, and rapid-setting grade emulsions require higher application rates than paving grade asphalt binders. Furthermore, dense and gap-graded HMA overlays require less tack coat than open-graded overlays. An international survey, conducted by the International Bitumen Emulsion Federation (1999) indicated that the residual asphalt content varied from 0.026 to 0.089 gallyd2 for tack coats applied on conventional asphalt surfaces. In United States, the survey conducted by Paul and Scherocman (1998), reported that the residual application rates of the emulsions varied between 0.01 and 0.06 gallyd2, depending on the type of surface for application.

Cross and Shrestha (2004) found from their phone survey that application rates varied from 0.03 gallyd2 to 0.15 gaVyd2. The residual asphalt contents, as specified in The Hot-Mix Asphalt Paving Handbook (2000) should range from 0.04 to 0.06 gallyd2. As compare to open-textured surfaces, the requirement of tack coat is less for tight or dense. Also bleeding or flushed surfaces require less tack coat than surfaces that are dry and aged. The requirement of residual asphalt is even more for a milled surface because of the increased specific surface area, as much as 0.08 galiyd2. The requirement is only half as much residual asphalt typically for new HMA layers, 0.02 gallyd^2.

The Asphalt Institute specified the application rate of tack coats ranged from 0.05 to 0.15 gallyd2 for an emulsion diluted with water at a ratio of Lavin recommended application rates of 0.044 gallyd2 for tack coats applied between new HMA layers. He further suggested that milled pavements may require application rates of 0.22 gallyd2 or more due to a larger surface area caused by grooving.

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Mohammad et al. (2002) recommended an optimum residual rate of 0.02 gallyd2 by conductinginterface shear strength using the Simple Shear Test on one type of HMA pavement. As per the section Proper Tack Coat Application (2001)" of the Technical Bulletin published by the Flexible Pavements of Ohio, the recommended typical tack coal application rates for various pavement types using a slow-setting asphalt emulsions (SS], SS 1-h} are shown in table 2.1.

Table 2.1: Recommended tack coat application rates in Ohio

Pavement Condition	Application Rate (gaVyd2)		
	Residual	Undiluted	Diluted (I:I)
New HMA	0.03-0.04	0.05-0.07	0.10-0.13
Oxidized HMA	0.04-0.06	0.07-0.10	0.13-0.20
Milled Surface (HIVIA)	0.06-0.08	0.10-0.13	0.20-0.27
Milled Surface (PCC)	0.06-0.08	0.10-0.13	0.10-0.27
Portland Cement Concrete	0.04-0.06	0.07-0.10	0.13-0.20

According to the tack coat guidelines of the Construction Procedure Bulletin (2003) of California Department of Transportation, the recommended application rates for different types of tack coats and pavement conditions, which are used in the state of California asshown in table 2.2.

Table 2.2: Recommended Tack Coat Application Rates Used in California

Type of Overlay	Type of Surface	Slow Setting (gallyd2)	Rapid Setting (gallyd2)	Paving Asphalt (gallyd2)
HMA	Dense, Tight Surface (e.g., between lifts)	0.044-0.077	0.022-0.044	0.011-0.022
	Open Textured or Dry, Aged Surface (e.g., milked surface)	0.077-0.199	0.044-0.088	0.022-0.055
Open Graded HMA	Dense, Tight Surface (e.g., between lifts)	0.055-0.110	0.022-0.055	0.011-0.033
	Open Textured or Dry, Aged Surface (e.g., milled surface)	0.110-0.243	0.055-0.121	0.033-0.066

4 Influence of testing temperature

It was found from the analysis of the laboratory studies conducted by various Researchers and Highway agencies that the testing temperature had the most significant impact on the bond strength. As test temperature increases layer bond strength decreases due to reduced stiffness of tack coat material. The study conducted by West et al.(2005), concluded that, the average bond strength values were 2.3 times greater at 1{}° C compared to 25° C; while the average bond strength values were 1/6 times lesser at 60° C compared to 25° C.

5 Influence of normal pressure

Most of laboratory studies that varied the normal pressure applied to a sample have all concluded that as normal pressure increases layer bond strength increases especially at higher temperature. At higher temperatures, the effect of internal friction on bond strengths were more than the tack coat materials and application rates, and the internal friction is dependent on normal load and surface texture. At intermediate and low temperatures, bond strength was not very sensitive to the normal pressure levels.

Summary of Findings

Different organizations and different researchers as mentioned in the preceding paragraphs have developed and studied on various devices and determined the bond strengths of the interlayer of the bituminous pavement. While some have used complicated devices, it has been decided to go for simpler devices by fabricating simpler setups and using the same in existing Marshall Stability Apparatus then saving the time and cost aspects.

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EXPERIMENTAL INVESTIGATIONS

It describes the experimental IkA orks carried out in this present investigation. It has been divided into two pails.
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

1 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.

1.1 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.

1.2 Fine Aggregates

Fine aggregates, consisting of stone crusher dusts were collected from a local crusher with fractions passing 435 mm and retained on 0.075 mm IS sieve. Its specific gravity was found to be 162.

1.3 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 (ram)	Percent Passing
37.5	100
26.5	95
19.0	S3
13.2	68
4.75	46
2.36	35
0.300	14
0.075	5

Table 3.2: Adopted aggregate gradation for BC

Property	a aclirlil
Nominal Aggregate Size (mm)	I 3
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
OA 50	16
0.075	7

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Table 3.3: Physical properties of coarse aggregates

Property	Test Method	Test Result
Aggregate Impact Value (%)	rt IS: 2386 (Pa-IV)	14.28
Aggregate Crushing Value (%)	IS: 2386 (Part-IV)	13.02
Los Angeles Abrasion Value (%)	IS: 2386 (Part-TV) 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

4.2 **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˚C. 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˚C.

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

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	
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	

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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.

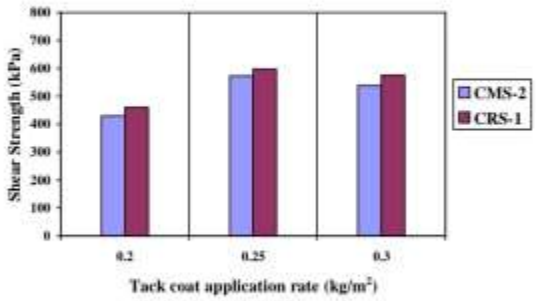

Figure 4.1: Plot of Shear Strength v/s Tack Coat application rates for 100 mm diameter specimens using Shear testing model no. 1.

4.3 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˚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˚C

Table 4.2 Results of the shear strength of 150 mm diameter specimens using Shear testing model no. 2 at 25°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	
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	

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4.4 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°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°C

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

Tack Coat Type	Application rate (kg/m^2)	Load (kN)	Shear Strength (kPa)	Average Shear Strength (kPa)
CMS-2	0.20	9.193	520.216	537.004
CMS-2	0.20	9.786	553.773	
CMS-2	0.20	9.490	537.023	
CMS-2	0.25	11.560	654.161	676.607
CMS-2	0.25	12.450	704.524	
CMS-2	0.25	11.860	671.137	
CMS-2	0.30	11.414	645.899	634.732
CMS-2	0.30	10.970	620.774	
CMS-2	0.30	11.266	637.524	
CRS-1	0.20	9.786	553.773	570.523
CRS-1	0.20	10.082	570.523	
CRS-1	0.20	10.378	587.273	
CRS-1	0.25	12.450	704.524	704.430
CRS-1	0.25	12.150	687.548	
CRS-1	0.25	12.745	721.218	
CRS-1	0.30	11.710	662.649	668.195
CRS-1	0.30	11.857	670.967	
CRS-1	0.30	11.857	670.967	

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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.

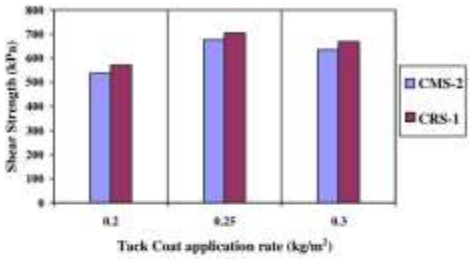

Figure 4.3: Plot of Shear Strength v/s Tack Coat application rates for 150 mm diameter specimens using Shear testing model no. 3.

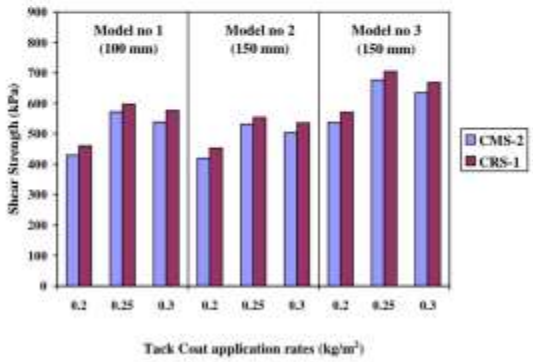

Figure 4.4: Comparison of Shear Strength v/s Application rates for the three models.

Analyzing the results graphically as shown in figure 4.4, it can be concluded that specimen with CRS-1 as tack coat exhibited higher shear strength values compared to CMS-2 as tack coat at all application rates varying at 0.20 k g/m^2, 0.25 kg/m^2 and 0.30 kg/m^2 for all three types of shear testing devices. Also the optimum application rate was found to be 0.25 kg/ml for the all three models.

4.5 Overall Performance of tack coat

The average shear strength of the specimens with both types of emulsions, namely CMS-2 and CRS-1 as tack coat at application rates varying at 0.20 k g/m^2, 0.25 k g/m^2 and 0.30 kg/m^2 considering all three models together, are calculated as shown in tables 4.4 and 4.5.

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Table 4.4: Results of the average shear strength using CMS-2 as tack coat for all three models at 25°C

Model No	Rate of Application (kg/m²)	Specimen no	Shear Strength (kPa)	Average Shear Strength (kPa)
1	0.20	1	411.001	
	0.20	2	429.590	
	0.20	3	448.179	
2	0.20	1	419.715	
	0.20	2	402.739	462.059
	0.20	3	436.296	
3	0.20	1	520.216	
	0.20	2	553.773	
	0.20	3	537.023	
1	0.25	1	559.842	
	0.25	2	559.842	
	0.25	3	597.148	
2	0.25	1	520.216	
	0.25	2	537.023	593.435
	0.25	3	537.023	
3	0.25	1	654.161	
	0.25	2	704.524	
	0.25	3	671.137	
1	0.30	1	513.369	
	0.30	2	541.253	
	0.30	3	559.842	
2	0.30	1	520.216	
	0.30	2	503.409	558.772
	0.30	3	486.659	
3	0.30	1	645.899	
	0.30	2	620.774	
	0.30	3	637.524	

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Table 4.5: Results of the average shear strength using CRS-1 as tack coat for all three models at 25°C

Model No	Rate of Application (kg/m²)	Specimen no	Shear Strength (kPa)	Average Shear Strength (kPa)
1	0.20	1	485.358	494.740
	0.20	2	466.896	
	0.20	3	429.590	
2	0.20	1	453.102	
	0.20	2	436.296	
	0.20	3	469.853	
3	0.20	1	553.773	
	0.20	2	570.523	
	0.20	3	587.273	
1	0.25	1	578.431	618.424
	0.25	2	597.148	
	0.25	3	615.737	
2	0.25	1	537.023	
	0.25	2	570.410	
	0.25	3	553.773	
3	0.25	1	704.524	
	0.25	2	687.548	
	0.25	3	721.218	
1	0.30	1	578.431	592.921
	0.30	2	559.842	
	0.30	3	587.853	
2	0.30	1	545.398	
	0.30	2	528.591	
	0.30	3	531.590	
3	0.30	1	662.649	
	0.30	2	670.967	
	0.30	3	670.967	

The average maximum shear strength was observed on specimens with CRS-1 as tack coat at an application rate of 0.25 kg/m2 while the specimens with CMS-2 at an application rate of 0.20 kg1m2 showed the average minimum shear strength as shown in figure 4.5. Using CMS- 2 as tack coat the average shear strength values were obtained as 462.059, 593.435 and 558.772 kPa at application rates of 0.20 kg/m2, 0.25 kg/m2 and 0.30 kg/m2 respectively. Similarly using CRS-1 as tack coat at application rates of 0.20 kg/m2, 0.25 kg1m2 and 0.30 kg/m2 the average shear strength values obtained were 494.740, 618.424 and 592.921 kPa respectively.

Conclusions and Recommendations

summarizes the findings of the laboratory study to evaluate the bond strength between pavement layers. The scopes for the future research work are also recommended here.

Conclusions

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 no1, laboratory tests were conducted on 100 mm diameter cylindrical specimens at a temperature of 25° C by applying a shear force of constant deformation rate of 50.8 mm im in. 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 kigini2, 0.25 kg/m2 and 0.30 kg/m2.

The following are specific observations drawn from the test results.

- The test results concluded the application rate of 0.25 kg/m2 as the optimum one for all the tack coats.
- Generally, CRS-1 as tack coat provided the highest shear strength at all application rates, 0.20 kgina2, 0.25 kg/m2 and 0.30 kk-r/m2 as compared to CMS-2.
- The shear strength values obtained from shear testing model no. 3 were higher than those obtained from model no.1 and 2 for all types of tack coat at all application rates. This might be due to eccentricity as the shear load was applied near the interface therefore; the shear strength values obtained were lower than those obtained from model no. 3 where a concentric shear load was applied.

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- Considering all models together, average shear strength values were found to be as 462.059, 593.435 and 558.772 kPa using CMS-2 as tack coat at application rates of 0.20 kg/m2, 0.25 kg/m' and 0.30 kg/m2 respectively while using CRS-1 as tack coat at application rates of 0.20 kgina2, 0.25 kg/m2 and 0.30 kg/m2 the average shear strength values obtained were 494.740, 618.424 and 592.921 kPa respectively.

Future research recommendations

The following recommendations are provided as a part of future work based on the observations drawn from this study.

- It is recommended to compare the results obtained from the laboratory specimens with the results obtained from field core specimens. This will assist in getting a correlation between the laboratory test results and the field observations.
- Further research is recommended to examine the variation of interface bond strength at varying tack coat material types, temperatures and normal pressure.
- Theoretical models are to be developed to validate the experimental results and decide the best model to be adopted.

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