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Laboratory study to investigate the performance of Tack Coat between bituminous layers

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Abstract: *The vehicle ownership rate has been escalating round the world and to accommodate this increasing traffic load the modern trend of designing multi-layered bituminous pavement comes into play. Insufficient pavement interface bonding may lead to major pavement overlay distresses and eventually reduces the pavement service life. A tack coat is usually sprayed in between the bituminous pavement layers for effective stress distribution across pavement layer under heavy traffic loads. This paper presents the experimental results obtained through laboratory and field studies to recommend the effective tack coat materials and optimum application rate. A simple interface direct shear test was performed on 150 mm diameter cylindrical laboratory prepared specimens using two conventionally used tack coat materials in India namely, CMS-2 and CRS-1 sprayed at the interface between Bituminous Concrete (BC) and Dense Bituminous Macadam (DBM) at application rates varying at 0.20 kg/m^2, 0.25 kg/m^2 and 0.30 kg/m^2.The test results indicated 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/m^2 as recommended in MORT&H's specifications. Also the test results obtained from the laboratory prepared specimens were compared with the results obtained from field cored specimens and found higher shear strength value of laboratory prepared specimens compared to field core specimens.*

Keywords: *interface; bond strength; tack coat; emulsion; field core*

I. Introduction

The interface bonding between the layers is vital to the pavement integrity as the stresses generated from the heavy traffic loads need to be evenly distributed to each underlying bituminous layer to reduce the structural damage to pavements. Major pavement overlay distresses that have been linked to the poor interface bonding between pavement layers include slippage failure, premature fatigue, top down cracking, potholes and surface layer delamination [1-3]. One such result is the formation of cracks in the shape of a crescent as shown in Figure 1.1.

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

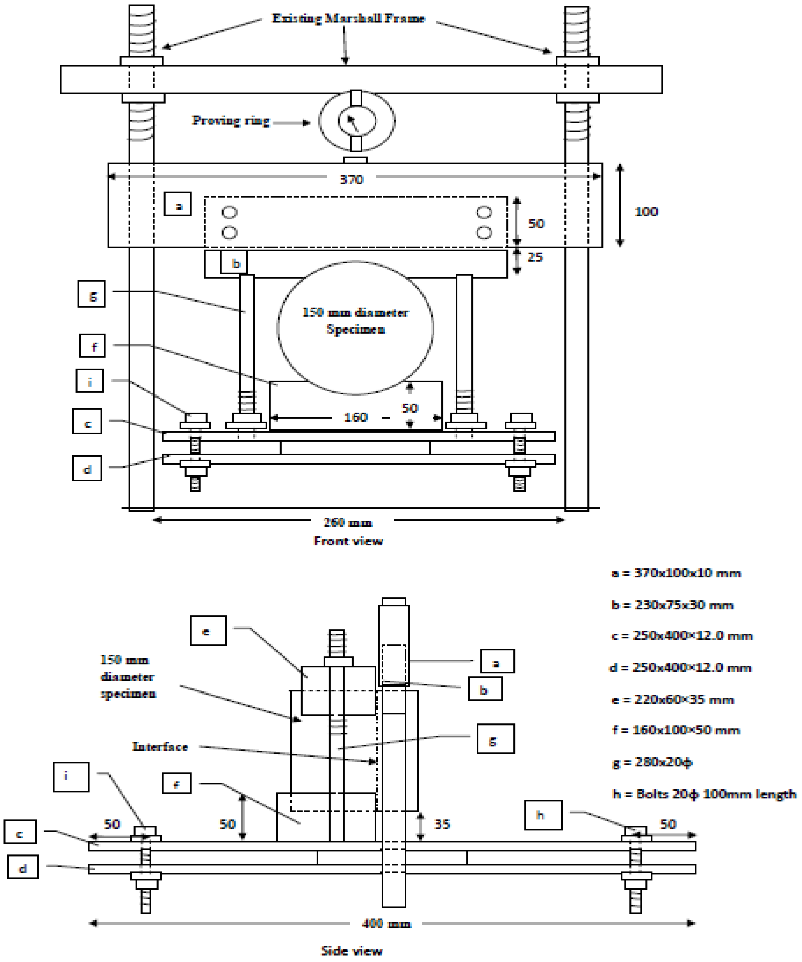
A tack coat is applied at the interface between the bituminous layers which acts as an adhesive or glue so that combined pavement layers perform as a monolithic structure rather than individual sections. Although hot bituminous binder, cutback bitumen or bituminous emulsions are commonly used as a tack coat materials, the use of bituminous emulsions as a tack coat material is escalating instead of cutback asphalt or hot bituminous binder because of their lower application temperature and environmental concerns related to the volatile components [4, 5].

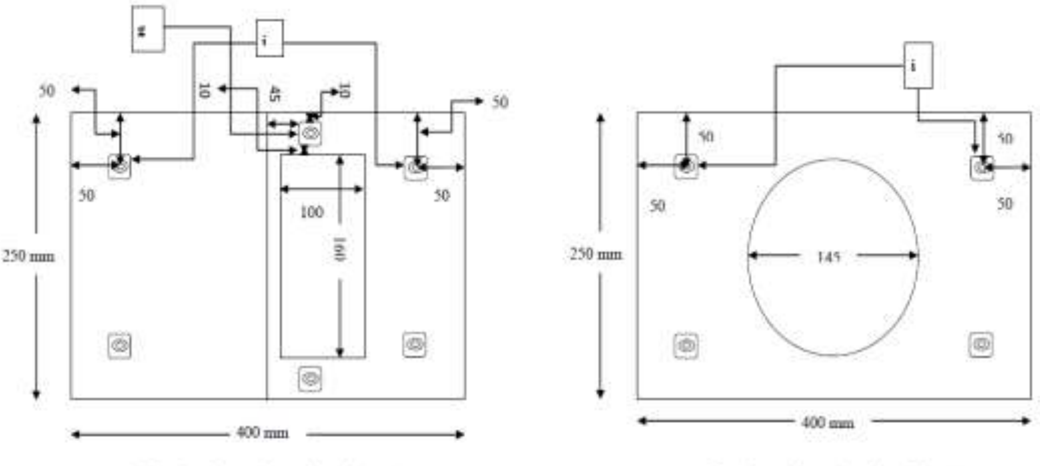
Literature on bond strength clearly reveals that shear force is mainly responsible for interface bond failure. That is why most of the research studies on the interface bond strength deal with tack coat direct shear tests. The most popular approach has been to employ a vertical shear force on a 150 mm double layered cylindrical specimen along the interface at a constant deformation rate of 50.8 mm/min until complete separation of the specimen [6-9]. While Santagata et.al.[10] designed a device known as Ancona Shear Testing Research and Analysis (ASTRA) where a horizontal load was applied along the interface of double-layered cylindrical specimens of 100 mm diameter at a constant displacement rate of 2.5 mm/min until failure; in the meantime, a constant normal load was applied on top of the specimen.

This paper aims primarily to fabricate a simple shear testing setup to save the time and cost aspects and then using the same in existing Marshall Stability Apparatus for evaluating the interlayer bond strength between bituminous layers by performing laboratory tests. A secondary goal of this paper is to provide helpful information for the selection of the best type of tack coat materials and optimum application rate.

II. Fabrication of Laboratory Device

In this study, a shear testing device known as Layer-Parallel Direct Shear (LPDS) developed by the Swiss Federal Laboratories for Material Testing and Research was fabricated for analyzing the interface shear strength. This device was so fabricated that it could be easily fitted into Marshall loading frame. 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 device are shown in Figure 2.1.





Top view of upper base plate (12 mm)

Top view of lower base plate (12 mm)

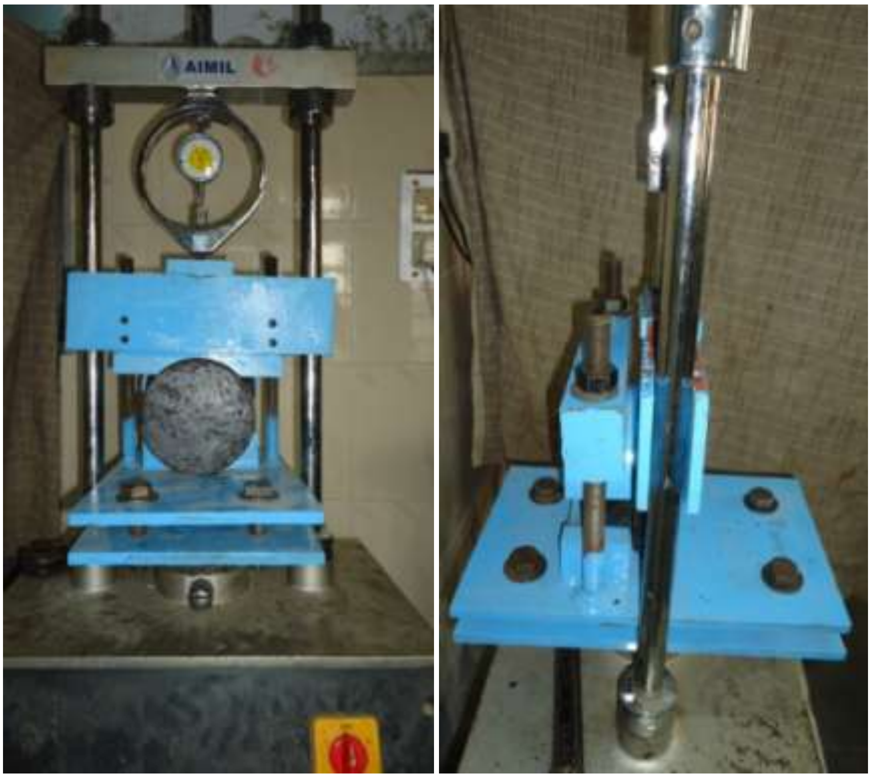


Figure 2.1: Schematic diagram and photographic view of the Shear-Testing Device.

III. Experimental Investigations

3.1 Materials Used

3.1.1 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 [11]. 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 3.1.**

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. 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: 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

3.1.2 Binder

One 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 the binder. The physical properties thus obtained are summarized in **Table 3.2.**

Table 3.2: 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

3.1.3 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 3.3.**

Table 3.3: 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
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

3.2 Specimen Preparation

3.2.1 Laboratory Prepared Specimens

The laboratory specimens were prepared using CMS-2 and CRS-1 as a tack coat according to the Marshall procedure specified in ASTM D1559. The test specimens were composed of two layers with a diameter of 150 mm and a total height of 100 mm. The bottom layer consisted of a Dense Bituminous Macadam (DBM) with a viscosity grade VG 30 binder, the top layer was a Bituminous Concrete (BC) with a viscosity grade VG 30 binder. For the preparation of bottom layer first the loose mix was compacted by giving 75 blows using Modified Marshall Hammer and then it was allowed to cool down at room temperature. The tack coat material was sprayed onto one face of the specimen at application rates varying at 0.20, 0.25 and 0.30 kg/m^2 as per MORT&H's specification and let it cured until setting completed. The top layer was compacted by placing the bottom layer in a compaction mould and compacting the loose mix on top of the tack-coated bottom layer by giving the same no of blows. Then the prepared specimens were allowed to cure at 25^0C before testing.

3.2.2 Field Prepared Specimens

The field core specimens were extracted from two test sections of an ongoing State Highway Project, located in Odisha, India for field validation of the shear testing device. The core specimens consisted of a 40 mm thick Bituminous Concrete (BC) layer on the top of a 75 mm thick Dense Bituminous Macadam (DBM) layer. The first test section was prepared by spraying CRS-1 as a tack coat at an application rate of 0.20 kg/m^2 while the second section was prepared by spraying the same at an application rate of 0.25 kg/m^2. The cored specimens were allowed to dry inside an oven at 40^0C for a minimum of 24 hours due to the use of water as a lubricant during coring process. The samples were then placed inside a conditioning chamber at 25°C for a minimum of four hours before testing.

IV. Analysis of Test Results and Discussions

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)

Laboratory tests were conducted on both laboratory specimens and field cored specimens at a testing temperature of 25^0C. Figure 4.1 shows the variations in the average shear strength value with the tack coat application rate for both CMS-2 and CRS-1 as tack coat material.

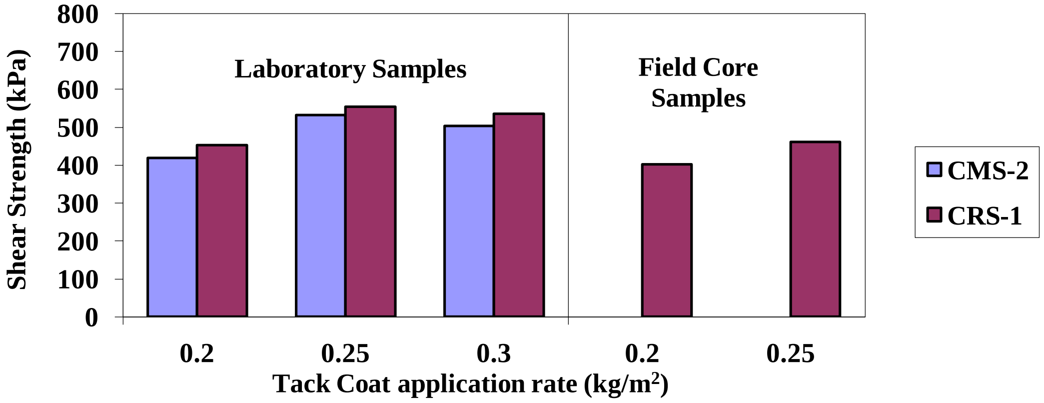


Figure 4.1: Plot of Shear Strength v/s Tack Coat types.

4.1 Optimum application rate

The test results shown in Figure 4.1 indicated that the average shear strength increased with an increase in application rate within an application rate of 0.25 kg/m^2 for both CMS-2 and CRS-1 as tack coat. However, the effect of the increase in application rate diminished beyond an application rate of 0.25 kg/m^2 since the average shear strength values obtained at an application rate of 0.30 kg/m^2 were slightly lower than that of an application rate of 0.25 kg/m^2.

Table 4.1: Analysis of optimum application rate for tack coat types

Tack Coat Type	Application rate (kg/m^2)	Average Shear Strength (kPa)	Standard Deviation	Coefficient of Variation (%)
CMS-2	0.20	419.583	16.77	4.00
	0.25	531.421	9.70	1.83
	0.30	503.428	16.78	3.33
CRS-1	0.20	453.084	16.78	3.70
	0.25	553.735	16.69	3.01
	0.30	535.193	8.96	1.67

The test results showed high consistency in shear strength values as the calculated Coefficient of variations did not exceed 4.00 % as seen in **Table 4.1**. Hence within the considered rate of application, 0.20, 0.25 and 0.30 kg/m^2, an application rate of 0.25 kg/m^2 was found to be optimum one for both CMS-2 and CRS-1 as tack coat.

4.2 Influence of tack coat type

Two tack coat materials (CMS-2 & CRS-1) were used for the laboratory phase of the study. Analyzing the results graphically as shown in Figure 4.1, the specimen with CRS-1 as a tack coat exhibited higher average shear strength than CMS-2 at application rate varying at 0.20, 0.25 and 0.30 kg/m^2. The obtained results had good repeatability since the calculated Coefficient of variations did not exceed 4.00 % as seen in **Table 4.1**. Therefore it can be concluded that specimen with CRS-1 was the most effective as a tack coat material.

4.3 Comparison with field core specimens

The core specimens were obtained from the field to compare the results obtained from laboratory specimens. It is clearly observed from Figure 4.1 that the average shear strength obtained from the field core specimens was significantly lower compared to laboratory prepared specimens.

V. Conclusions

In this paper a laboratory study was conducted to evaluate the bond strength provided by the tack coat laid at the interface between the Bituminous Concrete (BC) and Dense Bituminous Macadam (DBM). Also cylindrical core specimens were extracted from field to compare the results obtained from field with the results obtained from laboratory specimens. The following conclusions can be drawn from the study.

- Interface bonding is weaker at lower application rate because of the insufficient tack coat available to withstand the heavy shear stress. Also, shear strength decreases when the application rate is beyond the optimum as the excess tack coat material causes slippage at the interface. The test results concluded the application rate of 0.25 kg/m^2 as the optimum one for both types of tack coat.
- The specimens prepared using CRS-1 as a tack coat material exhibited slightly higher bond strength at all application rates compared to CMS-2.
- Laboratory specimens presented significantly higher shear strength compared to field core specimens.

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