Effect of Tack Coat Setting Time on Bituminous Paving Layer Bond Strength

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Abstract:

The structural strength of the pavement is negatively impacted by poor adhesion between two succeeding bituminous layers, which also leads to numerous instances of early pavement breakdown. When installing another bituminous layer on top of an existing or freshly created bituminous surface, it is customary to add a tack coat to increase adherence. This study's major goal is to investigate the impact of tack coat material setting time on the binding strength of a mixture of bituminous layers. Study has also been done on how test temperature, application rate, and tack coat type affect interlayer bond strength (ILBS). The tack coat for a typical bituminous layer combination has been chosen from two types of bituminous emulsions (CRS 1 and CMS 2) and two types of bituminous binders (VG 10 and VG 30). The impact of the gap in time between the two succeeding bituminous layers when no tack coat is applied has also been researched. The interlayer bond strength testing device, a specially made attachment, has been employed by being mounted to the loading frame of a Marshall testing device. It has been found that the ILBS relies on the tack coat type, application rate, test temperature, and setting time. In the bituminous layer combination under consideration, CMS 2 provides the highest ILBS with the lowest quantity needs out of the four tack coat materials. Without a tack coat, the maximum ILBS is seen; however, the higher layer must be set and compacted right after the lower layer.

Keywords: Interlayer bond strength, emulsion, interlayer bond strength testing device, Marshall testing apparatus.

1. Introduction

Flexible pavements are often built of multiple-layer bituminous courses for high traffic roadways. A new bituminous layer is frequently spread over an older one in rehabilitation scenarios as well. The two bituminous layers are often joined together using a low viscosity bituminous substance, typically in the form of an emulsion. Leaving aside numerous other related issues, the effectiveness of such bituminous composite layers largely depends on good bonding between the two layers. The performance of composite structures can be affected in many ways by the bituminous pavement's early and unexpected breakdown due to adequate adhesion that permits lateral motions [Partl et al. 2012]. The horizontal and vertical loads that the vehicle load transfers to each underlying bituminous layer cause dynamic normal and tangential stresses in the pavement interfaces, and as a result, the interface between the layers is essential to the pavement's integrity [Wheat, 2007]. Poor bonding between the pavement layers has been observed to be a factor in a number of serious pavement overlay distresses. Slip-page failure (figure 1), one of the most frequent types of premature distress, is when the pavement layers start to slide on top of one another, typically with the top layer separating from the lower layer [Patel, 2010].

Figure 1. Slippage failure [Patel, 2010]

The two layers are said to start to separate when there is insufficient bonding and sufficient horizontal force, and this failure is most frequently observed in sensitive areas like where traffic is accelerating or decelerating, at traffic signals, and on horizontal curves [West et al., 2005]. Tack coatings are often applied on the existing bituminous surface before the application of another bituminous layer to guarantee appropriate bonding between two bituminous layers. A tack coat is a thin coating of low viscosity bituminous binder, typically bitumen emulsion, applied in order to form a strong adhesive bond between two bituminous layers that are applied successively without separating. he interface bonding is affected by several factors; includ- ing tack coat (type, application rate, curing time, ap- plication temperature and bitumen residue content), pavement surface characteristics (bitumen content, ag- gregate type and gradation, and surface texture), and environmental conditions [Mohammad et al., 2009, Miro et al., 2006 and Al-Qadi et al., 2012]. If the quan- tity of tack coat applied is either too much or too little, there can be unfavorable effects on the interface bond strength [Patel, 2010]. In India, as per MORTH (2013), cationic rapid setting emulsion (CRS 1) and low viscos- ity bitumen VG 10 grade have been recommended to be applied at specified rates. When a tack coat is used, besides other factors, its setting time i.e. the time inter- val between application of tack coat material and new layer, is of paramount importance in achievement of the bond strength. Hence an attempt has been made in this study to explore the influence of setting times of tack coat materials on bond strength at the interlayer of two commonly used bituminous layer combinations duly taking into consideration the tack coat type, application rate and test temperatures. For this, a special type of a fabricated attachment has been used in the loading frame of the Marshall testing apparatus. In this study, the bituminous mixes commonly used in India namely, dense bituminous macadam (DBM) and bituminous concrete (BC) and considered at lower and upper layers respectively, have been used. Similarly commonly used tack coat materials such as cationic rapid setting emul- sion (CRS 1) and VG 10 bitumen have been tried. Fur- ther, commonly available bituminous materials such as cationic medium setting emulsion (CMS 2) and VG 30 grade bitumen have also been used in this study to ex- plore the possibility of their uses as tack coat material.

2. Experimental Methodology and Materials

Fabrication of Special Attachment to Determine Interlayer Bond Strength

A number of methods have been suggested to evalu- ate the bond strength between two bituminous paving layers in the laboratory applicable mostly for the field core samples. In the present study, a simple attachment has been fabricated in similar line with that used in the shearing apparatus at McAsphalt Lab, USA. [Kucha- rek et al. 2011]. The specimens can be tested by easily fitting this fabricated attachment to the Marshall testing apparatus in the laboratory. This attachment specially designed for 101.5 mm (4 in) diameter samples basically composes of two parts (figure 2 and 3). The rear part comprises of two split semi-circular plates of same diameter (60 mm in length) which can clamp the lower part of the specimen rigidly (101.5 mm dia and 100 mm height). The specimen is therefore, appropriately aligned and supported rigidly into the two vertical rods at the backside. Similarly, the other part is in the form of one semi-circular part of same diameter (40 mm in length) which properly encloses the upper part of the sample and load is applied through this part at its middle through a horizontal square bar welded to the front circular plate. This upper part (40 mm) is so arranged as to move freely on loading with minimum friction along two vertical guiding rods fixed onto the base plate. For example, the specimen is composite in nature, with lower part and upper part, both of same dia, but of heights of 60 mm and 40 mm respectively with a layer of tack coat material bonding to the two parts. The vertical load is transferred to the upper part of the specimen, which remains at the front side, for the shearing of the specimens at the bonding layer at a constant rate of 50.8 mm/min (2 in/min).

Figure 2. General photographic view of testing arrangement, with fabricated Inter-layer Bond Strength Testing Device

Figure 3. Close up photographic view of fabricated Inter-layer Bond Strength Testing Device

Evaluation of Interlayer Bond Strength (ILBS)

The fabricated arrangement (figure 2 and 3) has been so made that the load applied on the top of the upper part of the specimen causes smooth shearing of the upper part from the lower part, the latter being rigidly fixed by the semicircular clamps and the vertical rods at the back side. It has been assumed that the shearing takes place in the vertical plane along the predefined interlayer, in which the tack coat is applied. The interlayer bond strength (ILBS in kPa) between two successive bituminous paving layers has been estimated by conducting such experiments on cylindrical composite specimens prepared in the laboratory usingthe following expression [West et al., 2005].

$$ILBS = \frac{F_{max}}{A} \qquad (1)$$

Where

F_{max}: Maximum load required to cause shearing of the upper part of the specimen from the fixed lower part (kN)

A: Cross sectional area of specimen (m^2)

Materials Used

In India, the surface course in a flexible pavement normally comprises of various types of bituminous layers. The most common type of surface course used in important highways in India, comprises mostly of a bituminous concrete (BC) layer over a dense bituminous macadam (DBM) layer (DBM-BC combination). Keeping this mind, in the present laboratory study the cylindrical composite specimens used for determination of interlayer bond strength comprise of bituminous layers with a total height of about 100 mm, with lower layer made of DBM mix compacted to a thickness of 60 mm and upper one made of BC mix of 40 mm thickness. For preparation of the specimens for testing, aggregates collected from a local quarry have been used as per gradations specified by the Ministry of Road Transport and Highways (MORTH, 2013) respectively, for the 26.5 mm nominal maximum aggregate size (NMAS) for DBM layer and 13.2 mm NMAS for BC layer. The specific gravity of the aggregates used was 2.80. The physical properties of aggregates as tested in the laboratory (Table 1). Portland slag cement also procured from the local market, which passes 0.075 mm IS sieve, was used as filler in the bituminous mixes. Its specific gravity was found to be 3.0. In this study, for binding the two different bituminous layers, low viscosity binders recommended by MORTH (2013) namely; cationic rapid setting emulsion (CRS 1) and bitumen VG 10 have been used as tack coat. Further, two other materials, namely cationic medium setting emulsion (CMS 2) and VG 30 bitumen have also been tried to explore their use as a bonding material between two bituminous layers. An attempt has also been made to observe the interlayer bond strength when there is no tack coat is used. As the effectiveness of bond depends on the setting time of the emulsion used and also of time elapsed after application of VG 10 and VG 30 grade of bitumen, these four types of tack coat materials have been applied at different rates and different setting times. For without tack coat applied case, the time interval between completion of compaction of lower layer and spreading of materials for upper layer has been considered. The physical properties of the two types of emulsions and two types of viscosity grade bitumens procured from a local government depot and used in this study as tack coat are given (Table 2 and 3). It is to be noted that the same VG 30 bitumen, has also been used for preparation of each type of bituminous mix considered in the preparation of composite specimens.

Table.1 Physical properties of aggregates

Property	Test Method	Test Results
(%) Aggregate Impact Value	(IS: 2386 (Part-IV	14
Aggregate Crushing Value (%)	(IS: 2386 (Part-IV	13
Los Angeles Abrasion Value (%)	(IS: 2386 (Part-IV	18
(%) Flakiness Index	(IS: 2386 (Part-I	19
(%) Elongation Index		21
(%) Water Absorption	(IS: 2386 (Part-III	0.13

Table.2 Physical properties of emulsions used as Tack Coat

Property	Test Method	Emulsion Type	Test Results
Saybolt (Furol) Viscosity at (50^{0}C (seconds	ASTM D 7496	CRS-1	37
		CMS-2	114
(Residue (by evaporation (%)	ASTM D 6934	CRS-1	61
		CMS-2	68
Residue penetration of (emulsion at 25^{0}C (0.1 mm	IS: 1203-1978	CRS-1	87
		CMS-2	107

Table.3 Physical properties of VG 10 and VG 30 bitumen used as a Tack Coat and in layer mix properties

Property	Test Method	Test Results	
		VG 10	VG 30
Penetration at (25°C (0.1 mm	IS: 1203-1978	95	67
Softening Point ((R&B) (°C	IS: 1205-1978	42	48
Absolute viscosi-(ty at 60°C (poise	IS: 73-1992	840	2505
Kinematic viscos-(ity at 135°C (cSt		280	405

2.4 Preparation of Specimens and Testing

The Marshall test procedure is a very simple and reasonable procedure and hence is widely adopted for the design of bituminous mixtures. In this study, the loading frame of the Marshall test apparatus is used to fix a simple fabricated attachment for the determination of interlayer bond strength between two bituminous paving layers of a composite specimen. Therefore, Marshall procedure has been followed to prepare the composite specimen containing two different mixes. However to suit the present requirement of the study minor exceptions have been made with respect to the normal Marshall procedure. The overall layer dimensions of the laboratory composite specimen are usual 101.5 mm internal diameter but about 100 mm height. Hence modified Marshall moulds each of 101.5 mm internal diameter and total height of 105 mm are specially fabricated. In the first stage, the sample for the lower part made of DBM layer is prepared in this fabricated mould for a height of about 60 mm in the laboratory according to the normal Marshall procedure specified in ASTM D1559.

The specimen, however, is kept in the same mould for a minimum period of 24 hours, a specified tack coat material is applied at a given application rate with the help of a fine soft brush on the top of the DBM layer in the mould. The varying rate of application of tack coat was chosen considering the MORTH (2007) guidelines. The type, amount and setting time of the tack coat are important factors for achieving the appropriate interlayer bond strength. For emulsion, the setting time is estimated by visual observation only. The breaking of emulsion responsible for proper setting depends on many factors such as type of surface, temperature and amount of emulsion. After a given time of application of tack coat material the required respective quantity of hot BC mix is placed over the already prepared DBM layer inside the mould and compacted as per normal procedure only on one side.

For some specimens prepared without any tack coat, the top BC layer placed immediately or at a given time after the preparation of the lower DBM layer was compacted. For observing the variation in bond strength of the composite specimen when no tack coat materials have been used, the compaction time between two layers has been varied. As the upper layer is made of a compacted height of about 40 mm and as the whole specimen cannot be compacted from both ends, Marshall blows were given only on the top. It has been observed that their densities are almost same as that of normal Marshall mixes with similar compositions. As the composite specimen attains normal room temperature, the specimen is extracted and is ready for testing and evaluation of interlayer bond strength.

The specimens thus prepared were tested at four different temperatures namely 25^0, 30^0, 35^0 and 40^{0}C which are mostly prevalent in India for the most part of the year. For this the composite specimens are conditioned for two hours at a specified temperature in the oven before testing. The lower portion of the specimen is carefully placed inside the two semicircular clamping plates rigidly bolted and fixed such that the upper portion overhangs towards the operator. The top BC part of the specimen is loaded through another simple arrangement (figure 3). In this arrangement, a horizontal beam with a semicircular plate just covers the half of the specimen, with the beam smoothly guided vertically through two vertical roads. The load is applied to this front part, so that there is a shearing through the predefined bond layer. The load at the time of detachment of the upper part from the lower part is noted from the proving ring and is used for calculation of the interlayer bond strength.

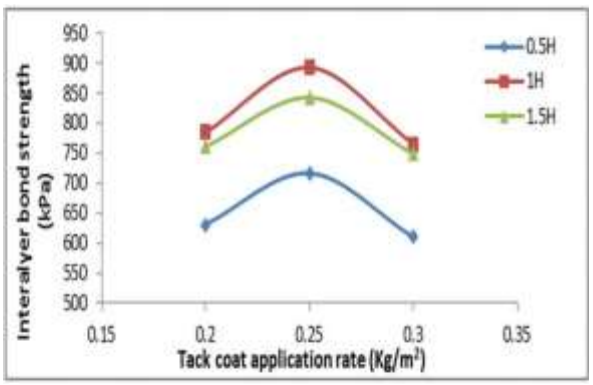

Figure 4. Variation of ILBS with application rate for CRS 1 as tack coat at 25ºC

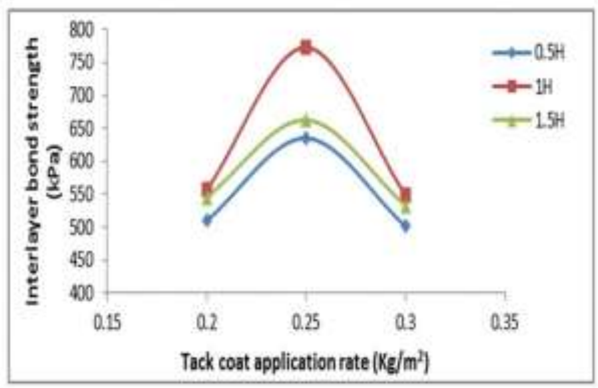

Figure 5. Variation of ILBS with application rate for CRS 1 as tack coat at 30ºC

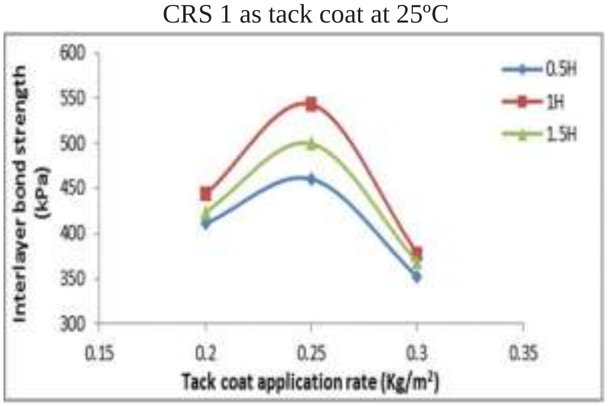

Figure 6. Variation of ILBS with application rate for CRS 1 as tack coat at 35ºC

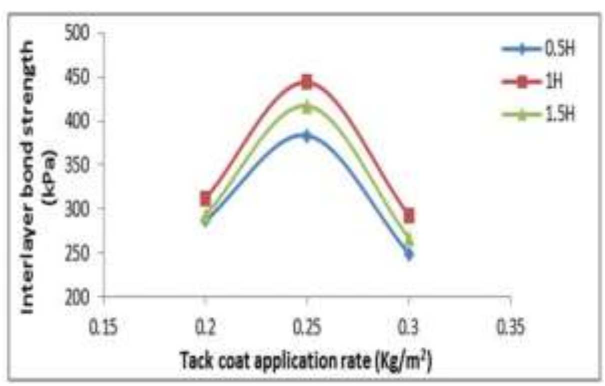

Figure7. Variation of ILBS with application rate for CRS

1 as tack coat at 40ºC

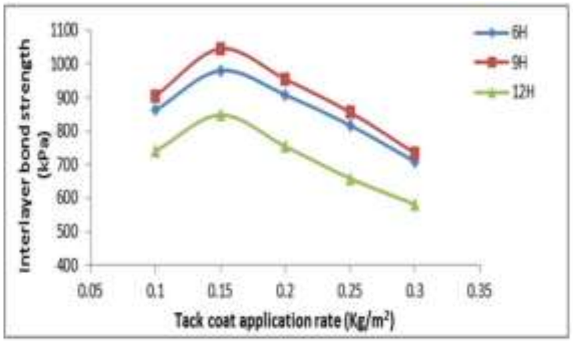

Figure 8. Variation of ILBS with application rate for CMS 2 as tack coat at 25ºC

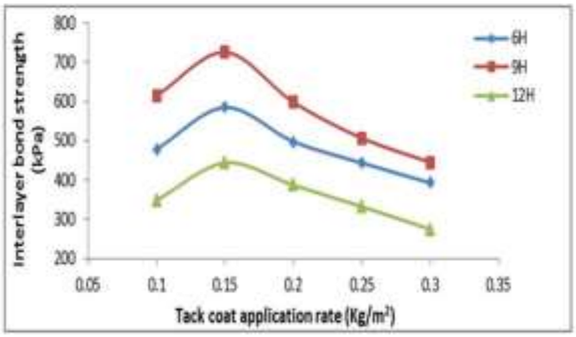

Figure10. Variation of ILBS with application rate for CMS 2 as tack coat at 35ºC

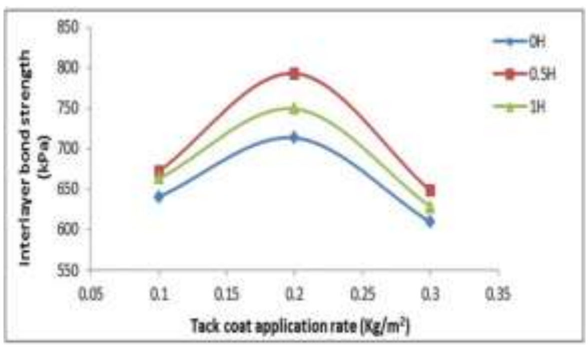

Figure 12. Variation of ILBS with application rate for VG 10 as tack coat at 25ºC

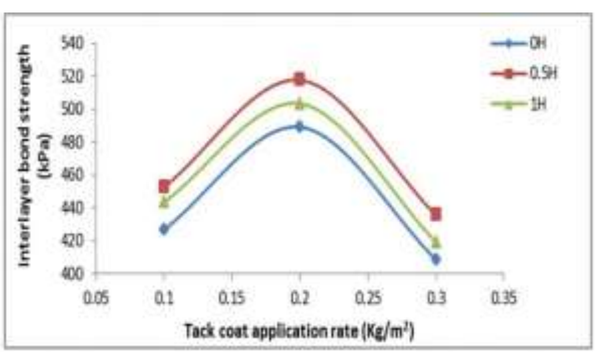

Figure 14 Variation of ILBS with application rate for VG 10 as tack coat at 35ºC

Figure 9. Variation of ILBS with application rate for CMS 2 as tack coat at 30ºC

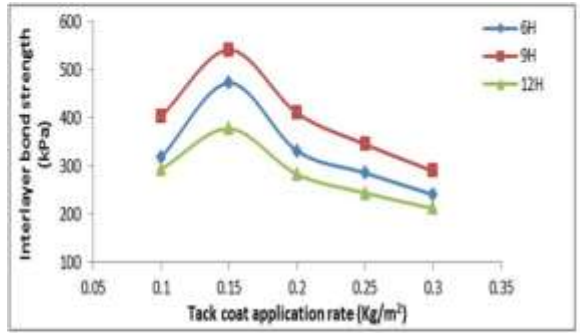

Figure11. Variation of ILBS with application rate for CMS 2 as tack coat at 40ºC

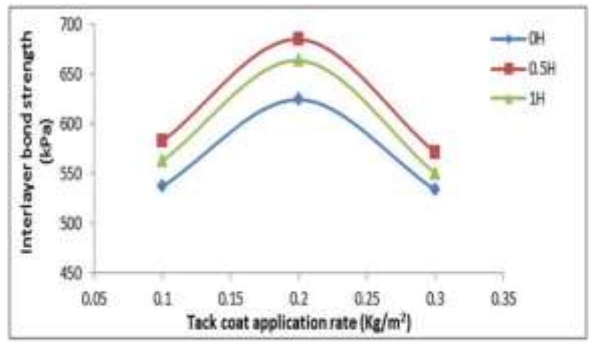

Figure 13. Variation of ILBS with application rate for VG 10 as tack coat at 300C

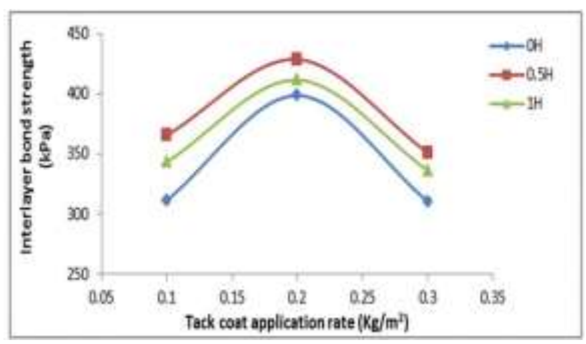

Figure 15 Variation of ILBS with application rate for VG 10 as tack coat at 40ºC

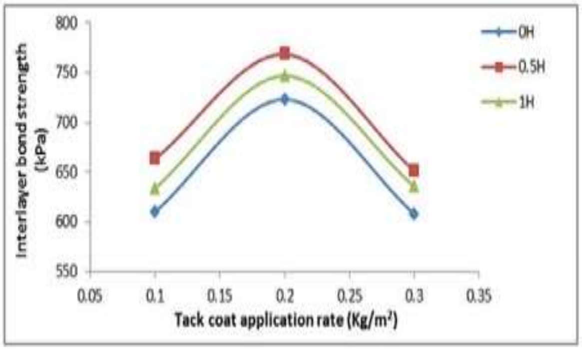

Figure 16 Variation of ILBS with application rate for VG 30 as tack coat at 25ºC

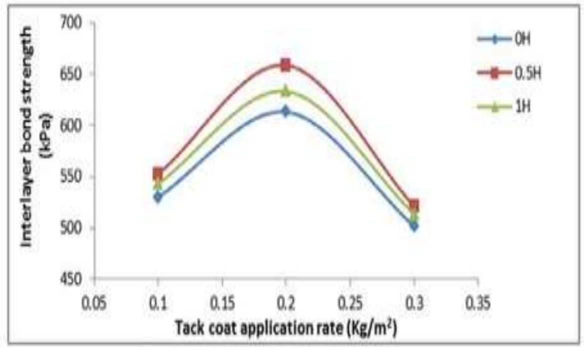

Figure 17 Variation of ILBS with application rate for VG 30 as tack coat at 30ºC

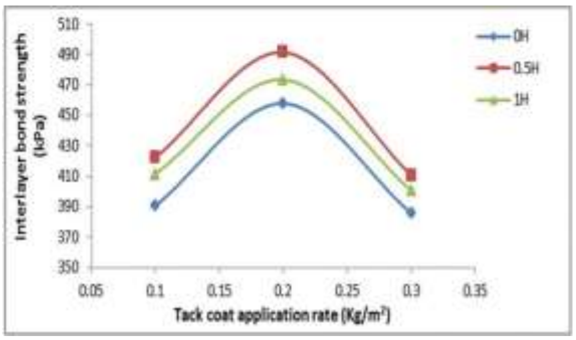

Figure 18 Variation of ILBS with application rate for VG 30 as tack coat at 35ºC

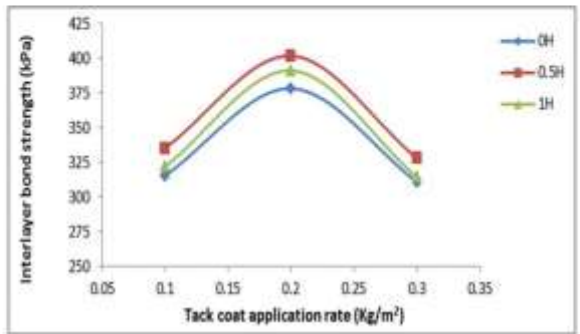

Figure 19 Variation of ILBS with application rate for VG 30 as tack coat at 40ºC

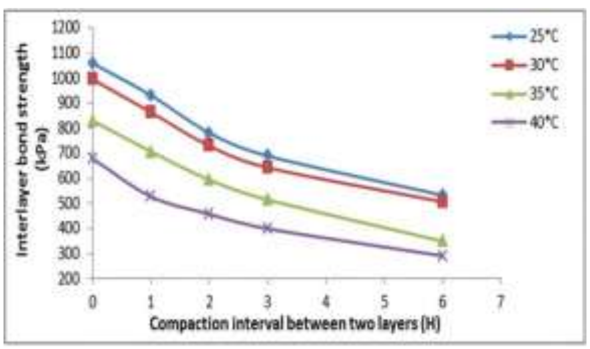

Figure 20 Variation of ILBS with compaction interval between two layers without any tack coat

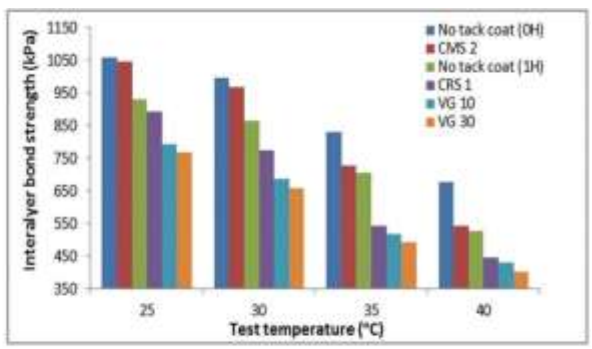

Figure 21 Variation of Maximum ILBS for different tack coat materials

3. Results and Discussions

The results of interlayer bond strength observed for DBM-BC combinations of composite bituminous specimens under varying conditions such are types of a tack coat material, setting time of tack coat materials, application rate and test temperatures have been presented (figures. 4 to 20). These laboratory prepared specimens have also been tested at four different test temperatures. For each type of tack coat materials, three varying setting times have also been considered. The variations of ILBS at different test temperatures for different tack coat materials at their optimum dosages in the form of a bar chart (figure. 21).

It is observed that as expected the ILBS decreases with increase in test temperature irrespective of type of tack coat material. For any tack coat material and any test temperature, the bond strength increases for tack coat quantity up to a certain value, after which the same decreases. i.e. there is an optimum tack coat application rate. The optimum application rates are found to be 0.25, 0.15 and 0.2 Kg/m² respectively, for tack coat materials CRS 1 emulsion, CMS 2 emulsion and both VG 10 and VG 30 bitumens. Considering this, CMS 2 emulsion is observed to offer advantages of maximum bond and minimum quantity requirement as compared to other taken as tack coat materials. It is also seen that maximum ILBS results when CMS 2 is used followed by CRS 1, VG 10 and VG 30 bitumen at any test temperatures. This might be due to the fact that the low viscosity of the material provides the required thickness of the binding layer causing better bonding. However the top BC layer is to be laid after 9 hrs of applying tack coat. The maximum interlayer bond strength observed for above all contemplation at 25^0C for DBM-BC combination of the bituminous layer. The influence of where no tack coat is used between successive DBM and BC layers, maximum bond strength can be achieved if the BC layer is immediately spread and compacted over the DBM layer compaction (figure 20). The bond strength is observed to decrease as time interval of compaction between two layers increased. There may be same difficulties during construction and after construction. For bond strength point of view, non-use of tack coat and immediately laying of top layer gives best results of bond strength.

A summary of observations of bond strength for different tack coat materials shows that when no tack coat is applied and upper layer is laid immediately after the lower layer, maximum bond between the two layers is achieved (figure 21). This is because in hot mx conditions, the upper layer fits appropriately with the lower layer providing good interface in aggregate structure at the interlayer. Successive laying is however discouraged, as normally the top layer is laid after leaving the bottom layer to traffic to allow any passive unevenness on the pavement surface. If tack coat is used, as per the observations CMS 2 emulsion at a low ratio of 0.15 Kg/m^2 provided not only the economic benefit but also given the maximum interlayer bond strength.

4. Conclusions

An attempt has been made in this experimental study to determine the interlayer bond strength in the laboratory for commonly used emulsions such as CRS 1 emulsion and VG 10 bitumen normally used as a tack coat material in India between two successive bituminous paving layers. Two other similar materials such as CMS 2 emulsion and VG 30 bitumen have also been tried. An attempt has also been made to explore the bond strength when no tack coat is applied and the top layer is laid and compacted directly on the bottom bituminous layer at varying time intervals after the completion of bottom layer. For this, laboratory prepared composite samples for DBM-BC layer combinations have been used. A special attachment has been fabricated, which can be fit to the loading frame of the Marshall test apparatus. The specimens have been tested at four different prevailing test temperatures, namely 25^0, 30^0, 35^0 and 40^0C, which are very much prevalent in India. Variations in setting time for different tack coat material type, application rate, setting time and test temperature for the DBM-BC composite specimens have been made to study the effect of setting time on the interlayer bond strength for different tack coat conditions. The following conclusions are drawn from the results of the tests conducted.

* It is observed that for CRS 1and CMS-2, maximum interlayer bond strength results at 0.25 Kg/m^2 and 0.15 Kg/m^2 respectively application rate in all test temperature conditions used. These optimum application rates are also found for all setting times considered for both types of emulsions.

* In the cationic medium setting type of emulsion used as tack coat, the maximum ILBS is observed when setting time is at 9 hours and the same for cationic rapid setting type of emulsion, is observed for setting of at 1 hour.

* When VG 10 and conventional VG 30 bitumens are used as tack coat, the maximum interlayer bond strength is observed at 0.2 Kg/m^2 application rate with setting time of 0.5 hour in all test temperatures.

* When no tack coat is used, maximum bond strength is achieved when the upper layer is laid and compacted immediately after the completion of the compaction of the lower layer. As this duration increases, the interlayer bond strength decreases.

* For all types of tack coat materials considered for the bond strength in generally decreases with increase in temperature.

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