Pavement Valuation of Bond Between Bituminous Pavement Layers

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Abstract - The interlayer bonding between the pavement layers in modern multi-layered flexible pavements is crucial for ensuring long-term performance. Poor bonding can lead to significant pavement distresses, such as premature fatigue, top-down cracking, potholes, and surface delamination. One common issue caused by inadequate bonding is slippage failure, especially in areas with frequent heavy vehicle acceleration, deceleration, or turning. Tack coats, typically made from bituminous emulsions or binders, are applied between pavement layers to enhance bonding. This study focuses on evaluating the bond strength at the interface between pavement layers using laboratory testing. Special attachments were fabricated for the Marshall Loading Frame to measure the bond performance between Bituminous Concrete (BC) and Dense Bituminous Macadam (DBM) layers. The tests involved 100 mm and 150 mm diameter specimens using two common emulsions, CMS-2 and CRS-1, applied at varying rates (0.20 kg/m², 0.25 kg/m², and 0.30 kg/m²) at a temperature of 25°C. The results indicate that CRS-1 provides superior interface bond strength compared to CMS-2. The optimal application rate for both emulsions was found to be 0.25 kg/m², aligning with MORT&H specifications.

Keywords: Pavement Interlayer, Bond Strength, Tack Coat, Shear Strength, Bituminous Pavement, Tack Coat Performance, Pavement Layers, CRS-1, CMS-2, MORT&H Specifications.

1.Introduction

Flexible pavements, designed to handle high traffic loads, are typically constructed in multiple layers to distribute stress efficiently across the pavement structure. The bonding between these layers plays a critical role in ensuring that the pavement functions as a unified structure, which significantly impacts its long-term performance. Proper interlayer bonding minimizes structural damage by evenly distributing applied stresses, leading to better overall durability. However, inadequate bonding can result in various pavement distresses, with slippage failure being one of the most common. Slippage failure often occurs in areas where heavy vehicles frequently turn, accelerate, or decelerate, subjecting the pavement to both horizontal and vertical stresses. This leads to dynamic normal and tangential stresses, causing the layers to separate if the bonding is insufficient. Inadequate bonding strength can also result in issues like potholes, top-down cracking, early fatigue, and surface layer delamination, typically manifested by crescent-shaped fractures.To prevent these issues, a tack coat is applied between the layers of bituminous pavement to ensure strong bonding. A tack coat, often made of bituminous emulsion or hot bituminous binder, acts as a bonding agent between the new and existing pavement layers. Bituminous emulsions are increasingly favored as tack coat materials over cutback asphalt and hot bituminous binders due to their environmental benefits, safety, and ease of application. Bituminous emulsions are water-based, pollution-free, and can be applied at lower temperatures, reducing health risks and making them safer for workers. Proper application of tack coats is essential for ensuring the pavement layers act as a cohesive unit, ultimately improving the overall performance and longevity of the pavement structure.

2. Objectives:

The primary objective of this study is to fabricate simple testing devices to evaluate the bond strength of tack coats at the interface between bituminous pavement layers in a laboratory setting. This will be achieved by performing several laboratory tests with different tack coat application rates. The ideal design will be a standard setup that produces consistent results comparable to other studies. A secondary goal of this study is to provide valuable information for selecting the best type of tack coat materials and determining the optimum application rate.

2.Experimental investigations:

2.1Materials Used

Aggregates used in bituminous pavement construction were sourced and tested according to the "Manual for Construction and Supervision of Bituminous Works" (MORT&H, 2001). Coarse aggregates, consisting of stone chips smaller than 4.75 mm, were locally sourced, and their physical properties were determined through standard tests. Fine aggregates, comprising stone crusher dust passing the 4.75 mm sieve and retained on the 0.075 mm sieve, had a specific gravity of 2.62. Portland slag cement (Grade 43), used as filler material and passing the 0.075 mm sieve, had a specific gravity of 3.0. These materials were used in preparing Bituminous Concrete (BC) and Dense Bituminous Macadam (DBM) samples.

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

Table 1: Physical properties of coarse aggregates

The results of various aggregate tests reveal key insights into their suitability for construction. The Aggregate Impact Value (AIV) of 14.28% indicates good resistance to impact, while the Aggregate Crushing Value (ACV) of 13.02% signifies high strength. A Los Angeles Abrasion Value of 18% shows good wear resistance, suitable for high-traffic surfaces. The Flakiness Index of 18.83% and Elongation Index of 21.50% suggest acceptable particle shape. The Specific Gravity of 2.75 indicates typical density, and a low Water Absorption of 0.13% highlights the aggregate's durability, essential for long-term infrastructure performance.

Property IS: 1203-1978 67.7 Softening Point	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 D4402	**200**

Table 2: Physical properties of VG 30 bitumen binder

physical properties of VG 30 bitumen binder, tested for road construction suitability, reveal its adaptability in hot climates. With a penetration value of 67.7 at 25°C (IS: 1203-1978), VG 30 exhibits moderate consistency, suitable for various traffic and weather conditions. Its softening point of 48.5°C (IS: 1205-1978) indicates resilience to high temperatures, crucial for pavement stability. Additionally, the binder's viscosity at 160°C, measured at 200 cP (ASTM D4402), ensures proper fluidity during hot mix asphalt preparation, while maintaining durability under traffic loads and operational stresses.

2.2 Preparation of Samples

The mixes were made in compliance with ASTM D1559's Marshall process. The standard laboratory specimens used to measure interface bond strength had a diameter of 100 mm and a height of 150 mm. Every specimen had two layers with an interface tack coat applied. Specimen diameters of 100 mm and 150 mm, as well as the application rates of 0.20 kg/m², 0.25 kg/m², and 0.30 kg/m² for two standard emulsions, CMS-2 and CRS-1, as tack coatings, were the test variables. Bituminous concrete

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(BC) with a VG 30 binder was the top layer, and dense bituminous macadam (DBM) with a VG 30 binder made up the bottom layer. The loose mix was first compressed with 75 blows with a Marshall Hammer to prepare the bottom layer, and it was then allowed to cool to room temperature.

Then, by multiplying the tack coat application rate by the specimen's surface area, the amount of tack coat to be applied to the specimen's surface was determined.

Figure 3.1.2: Photographs of the Shear-Testing model no. 1.

3. RESULTS AND DISCUSSION

Tack Coat Type	Application rate (kg/m2)	Load (kg)	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	

Table.3 Results of the shear strength of 100 mm diameter specimens using Shear testing model no. 1 at 250C

The data provides detailed information about the performance of two types of tack coats, CMS-2 and CRS-1, applied at different rates (0.20 kg/m², 0.25 kg/m², and 0.30 kg/m²). The primary focus is on the application rate, load-bearing capacity, and shear strength of the tack coats, with an emphasis on understanding how these factors impact the shear strength, which is critical for ensuring the bond between pavement layers.

CMS-2 Tack Coat:

For CMS-2 applied at an application rate of 0.20 kg/m², the corresponding loads and shear strengths vary. Three test results show loads of 3.228 kg, 3.374 kg, and 3.52 kg, with corresponding shear strengths of 411.001 kPa, 429.590 kPa, and 448.179 kPa. The average shear strength** for this application rate is calculated as 429.590 kPa, indicating a moderate bonding capability at this lower rate

When the application rate is increased to 0.25 kg/m², the loads increase, with values of 4.397 kg for two tests and 4.690 kg for the third. The corresponding shear strengths improve significantly, with values of 559.842 kPa, 559.842 kPa, and 597.148 kPa. The average shear strength at this rate is 572.277 kPa, reflecting a stronger bond with the increased tack coat quantity.

Tack CoatType	Application rate (kg/m^2)	Load (kg)	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	

Table.4 Results of the shear strength of 150 mm diameter specimens using Shear testing model no. 3 at 250C

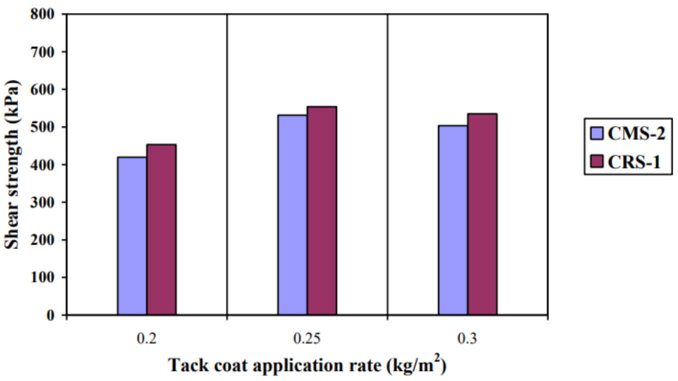

Fig.Plot of Shear Strength v/s Tack Coat application rates for 150 mm diameter

Model No	Rate of Application (kg/m2)	Specimen no	Shear Strength (kPa)
1	0.20	1	485.358
	0.20	2	466.896
	0.20	3	429.590
2	0.20	1	453.102
	0.20	2	453.102
	0.20	3	469.853
	0.20	1	553.773
3	0.20	2	570.523
	0.20	3	587.273
1	0.25	1	578.431
	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
	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

Table.5 Results of the average shear strength using CRS-1 as tack coat for all three models at 250C

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 kg/m2 , 0.25 kg/m2 and 0.30 kg/m2 for all three types of shear testing devices. Also the optimum application rate was found to be 0.25 kg/m2 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 kg/m2 , 0.25 kg/m2 and 0.30 kg/m2 considering all three models together, are calculated as shown in tables 4.4 and 4.5Specimens that applied CRS-1 at a rate of 0.25 kg/m² as the tack coat had the greatest average maximum shear strength. On the other hand, specimens with CMS-2 at an application rate of 0.20 kg/m² exhibited the lowest average shear strength (Figure 4.5).

Taking into account all three models combined, the average shear strength of the specimens with both types of emulsions, CMS-2 and CRS-1, as tack coatings at application rates of 0.20 kg/m², 0.25 kg/m², and 0.30 kg/m²The average shear strength values for specimens with CMS-2 as the tack coat were - 462.059 kPa at an application rate of 0.20 kg/m², - 593.435 kPa at an application rate of 0.25 kg/m², and - 558.772 kPa at an application rate of 0.30 kg/m²

Also, the optimum application rate was found to be 0.25 kg/m2 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 kg/m2 , 0.25 kg/m2 and 0.30 kg/m2 considering all three models together, are calculated as shown in tables 4.4 and 4.5

The average shear strength values for specimens with CRS-1 as the tack coat were - 494.740 kPa at an application rate of 0.20 kg/m² - 618.424 kPa at an application rate of 0.25 kg/m² - 592.921 kPa at this rate. The shear strength results of specimens tested using three different models, with varying application rates, reveal distinct performance variations in terms of bonding strength. Three tack coat application rates—0.20 kg/m², 0.25 kg/m², and 0.30 kg/m²—were tested across three specimens for each model.

For Model No. 1 at 0.20 kg/m², the shear strength ranged from 429.590 kPa to 485.358 kPa, with an average shear strength of 494.740 kPa. At the same application rate, Model No. 2 exhibited slightly lower performance, with values ranging from 453.102 kPa to 469.853 kPa. However, Model No. 3 significantly outperformed the other models, with an average shear strength of 570.523 kPa.At the 0.25 kg/m² application rate, the shear strength for Model No. 1 ranged from 578.431 kPa to 615.737 kPa, with an average of 618.424 kPa, showing improved bonding compared to the 0.20 kg/m² rate. Model No. 2 also displayed an increase in shear strength, but Model

No. 3 again outperformed the others, reaching an average shear strength of 704.524 kPa.For the 0.30 kg/m² application rate, Model No. 1 recorded an average of 592.921 kPa, while Model No. 2's shear strength ranged from 528.591 kPa to 545.398 kPa. Model No. 3, as with the other rates, achieved the highest values, with an average shear strength of 668.195 kPa.Overall, Model No. 3 consistently provided higher shear strength values across all application rates, particularly at 0.25 kg/m².The shear strength results of three models at various tack coat application rates (0.20, 0.25, and 0.30 kg/m²) indicate distinct performance trends. At 0.20 kg/m², Model No. 3 had the highest average shear strength of 537.004 kPa, while Model No. 1 and Model No. 2 averaged 462.059 kPa and 419.583 kPa, respectively.

At 0.25 kg/m², shear strength increased across all models. Model No. 3 outperformed the others with an average of 676.607 kPa, reaching a maximum of 704.524 kPa. Model No. 1 averaged 593.435 kPa, and Model No. 2 followed with 531.421 kPa.

At the highest application rate of 0.30 kg/m², Model No. 3 again led with an average of 634.732 kPa, compared to Model No. 1's 558.772 kPa and Model No. 2's 503.428 kPa.

Overall, Model No. 3 consistently demonstrated the highest shear strength, with the optimal bonding observed at 0.25 kg/m², highlighting its suitability for ensuring maximum bonding strength in pavement applications.

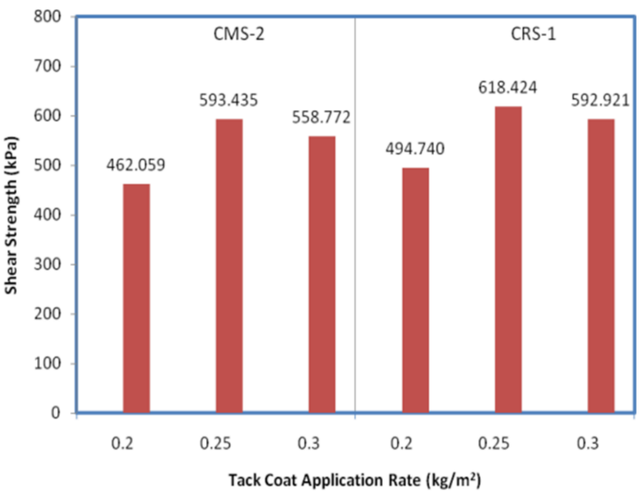

Fig 4.5: Average Shear Strength v/s Application rates for the three models

4. Conclusions and recommendations

The test findings indicated that an application rate of 0.25 kg/m² is ideal for all tack coatings. In terms of shear strength, CRS-1 outperformed CMS-2 at all application rates (0.20, 0.25, and 0.30 kg/m²).

For all types of tack coats and at all application rates, the shear strength values obtained from shear testing in model no. 3 were higher than those from models no. 1 and 2. Since the shear force in models 1 and 2 was applied close to the interface, their shear strength values were lower than in model 3, where a concentric shear load was applied. This discrepancy might be due to eccentricity.

When considering all models, the average shear strength values using CMS-2 as the tack coat at application rates of 0.20 kg/m², 0.25 kg/m², and 0.30 kg/m² were 462.059 kPa, 593.435 kPa, and 558.772 kPa, respectively. Using CRS-1 as the tack coat, the application rates of 0.20 kg/m², 0.25 kg/m², and 0.30 kg/m² yielded average shear strength values of 494.740 kPa, 618.424 kPa, and 592.921 kPa, respectively.

5.1 Future research recommendations

The following recommendations are provided for future work based on the observations drawn from this study:

- A comparison between the findings from field core specimens and laboratory specimens is advised. This comparison will help establish a relationship between field observations and laboratory test results.
- The variation in interface bond strength with different tack coat materials, temperatures, and normal pressures should be further investigated.
- To validate the experimental data and determine the most appropriate model, theoretical models should be developed.

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