Studying the Effect of Different Tack Coat Materials on Interface Bond Strength of Flexible Pavement Overlay

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Abstract

Asphalt pavement is a complex structure usually consists of surface, the base and subbase courses on a subgrade. A complete bond between layers will made the pavement work as a single composite structure. A slippage is the one most common distress due to poor bonding among pavement layers which decrease the life of overlay pavement structure. This research is a try to estimate bond strength at the interface among pavement layers by performing laboratory tests. FDOT test method use to evaluate the bond between bituminous layers, to carry these objective cylinder specimens with 101.6 mm diameter need set using normal Marshall Process firstly for the fundamental layer, follow in application of tack coat and lastly overlay with the upper layer in the similar mold in a fitting manner. After the samples tested it is detected interface bond strength depend on tack coat type and rate .The optimal quantity of tack coat has been establish 0.25l/m^2 for Css-1 and Anionic, 0.4 l/m^2 for Rc-70.

Keywords: tackcoat, interlayer, bond strength, shear strength and FDOT.

1. Introduction

The flexible pavement was usually constructed then designed in numerous layers for operative stresses distribution through pavement layer below dense road traffic weight. The interlayer bonding of multi-layered roadway system plays a significant role to achieve long term performance of pavement **[7].** Suitable bond between the layers should be ensured so that multiple layers do as a monolithic structure. To attain good bond strength, a tack coat is typically sprayed in among the bituminous pavement layer. As a result, the applied stresses are evenly distributed in the pavement system and subsequently, reduce structural damage to the pavements **[7]**.

Emulsified asphalt is gradually used as an alternative of cut back asphalt or hot asphalt cement for the reason that of their lesser temperature application and environmental concern connected to the volatile mechanisms. Type of agent emulsifying use in asphalt emulsion should conclude whether the emulsion cationic, or anionic. Cationic emulsions made up from droplets that carry a positive charge; anionic taking negatively charge droplets. Likewise emulsified graded as per their setting rate; which specifies how rapidly the H2O evaporate from emulsion such are slow setting [SS], medium setting [MS] and rapid setting [RS]. The main change between cationic and anionic is that the cationic emulsions evaporate H2O faster than the anionic emulsion **[8].** The grades of anionic are (RS-1), (MS-1), (MS-2h), (SS-1). The cationic grades named as (CRS-1), (CMS-2h), (CSS-1), and (CSS-1h). The nonappearance of letter C in an emulsion means an anionic one and obverse. The letter "h" attitudes for hard grade asphalt binder [low penetration] and the number "1" and "2" specifies low and high viscosity correspondingly **[8]**

Most of pavement strategy and evaluation methods assume that nearby pavement layers are fully bonded together and no movement were developed among them **[11].** The bond between films is very significant to ensure that this layers work together as a compound structure to resist traffic and environmental (e.g. induced temperature) loadings. To accomplish that condition; a thin film of asphalt bond coat (or tack coat) is typically applied at the interfaces. On the other hand, full bonding is not continuously reached and a number of pavement failures related to lowest bond condition must been reported **[3] [11]**. Because full bonding is not always achieved, a theoretical evaluation to investigate the influence of interlayer bond state on pavement performance is necessary.

Use a direct shear test method to test with (60-70) penetration asphalt binder such as a tack coat at 5 diverse application rates. The test was conducted in different temperature two temperature use (77) and (131) F (25 and 55°C). The tack coat was applied on the lowest layer and 3cm (1.8inch) of mix compacted on top; the direct shear device was established considering the specimen dimensions with a constant movement rate of 2.5 mm/min (0.098 in/min). The shear strength were evaluated at five changed normal loading pressures of 0.05, 0.5, 1.0, 2.5 and 5 Kg/cm^2. The shear strength increased as soon as the test temperature drops and the normal pressure increases. The observed optimal tack coats application rate for this studied was 1.0 Kg/m^2 at 25°C.**[13]**

In Delft University of Technology Molenaar et al. (1986) [6] used a shear test scheme to determine the tack coat shear resistance at the interface of the asphalt layers. The device was fixed on a standard Marshall Stability loading press for a load applied at a rate of 0.85 mm/Sec. This device held bottom part of the compacted cylindrical specimen and shear load was applied perpendicular to the alliance of the specimens of the upper layer. **[6]**

Established a simple direct shear test method to measure the shear strength for the field cores at their interface. The test was done at 25℃(77F), with a rate of loading was constant at 50.8 mm/min (2in/min). The field cores were gotten from test section with no tack, and with 0.091, 0.266 and 0.362 l/m^2 (0.02, 0.06, 0.08gal/yd^2) tack coat application rate.**[9]**

Assessed the strength bond of tack coat used in the interface of the bituminous paving layer by via the Superpave shear tester, which involves of a shear box set up for 150 mm (6 inch) diameter specimens. The samples were compacted up to 50 mm and tack coat applied in 5 different application rates (0.0 to 0.9 L/m^2), the specimens were allowable to cure and second lift is placed on top and compacted; the tack coat bond strength estimated with 2 PG bitumen binders (PG 64-2P and PG 76-22M) and 4 emulsified asphalts (CRS-2P, CSS-1, SS-1 and SS-1h). The test was conducted on two trial temperatures 25 and 55℃ (77 and 131F). They observed CRS-2P emulsion as the best performer and 25℃ (77F) test temperature gives five times more shear strength then 55℃(131F). **[5]**

2. Objective and Scope

The objective of this study was to explore the factors that impact the adhesive bond providing by the tack coats at the interface among pavement layers; in order to facilitate the construction of roads with more guarantee of achieving the design requirements. In this research studying the effect of the following factors on the bond strength Asphaltic pavement layers:

1. The types of tack coat materials, 3 types of tack coat (Anionic, Css-1 and Rc-70) will be used.
2. Application rates of tack coat materials (0.15 ,0.25 and 0.35 for Anionic and Css-1) and (0.3,0.4 and 0.5 for Rc-70)
3. Adopting FDOT direct shear test for measuring bond strength between asphalt pavement layers.(**Florida method of test,2014**)

3. Material used in the experimental work

Materials were estimated conferring to the repetitive type of tests from the ASTM standard specifications and compared with the SCRB (2003) **[4]** specification requirements**.**

3.1Asphalt Cement

Single type of asphalt cement (40-50) penetration graded is used in this work. It is gained from [Dourah Refinery], south-west of Baghdad. Tests conducted on asphalt cement check that, its properties comply with the specifications of State Corporation for Roads and Bridges **[4]**; the physical properties of the asphalt cement are presented in **Table. 1**.

Table. 1 The Physical Properties of Asphalt Cement

Property	Test Condition	Unit	ASTM Designation No.	Penetration Grade (40-50)	SCRB Specification 2003
Penetration	25 °C, 100 gm , 5sec	1/10 mm	D-5	44	40-50
Viscosity	135 165°C	Pas.sec	D-4402	0.525 0.137	----
Softening point	Ring &Ball	(°C)	D-36	49	----
Ductility	25 °C, 5cm/min	cm	ASTM D-113	120	+100
Specific Gravity	25°C	-----	ASTM D-70	1.05	-----
Flash Point	Cleveland open Cup	(°C)	D-92	280	>232
After Thin Film Oven Test ASTM D 1754					
Penetration of Residue	25 C̊, 100 gm, 5sec	1/10 mm	D-5	30	>55%
Ductility of Residue	25 °C, 5cm/min	cm	D-113	84	>25%

3.2 Aggregate

The crushed quartz aggregates basis which is used to fix the specimens is Al-Nibaie quarry which is usually used in local asphalt paving. The outcomes of physical properties and chemical properties are presented in **Tables. 2 and 3** respectively .

Table. 2 Physical Properties of Selected Aggregate

Laboratory Test	Coarse Aggregate	Fine Aggregate	ASTM Specification
Bulk Specific Gravity (ASTM C-127 and C128)	2.61	2.631	….
Apparent Specific Gravity (ASTM C127 and C128)	2.641	2.6802	….
Percent Water Absorption (ASTM C-127 and C128)	0.423	0.57	…
Percent Wear(Loss Angeles Abrasion) (ASTM C-131)	19.3%	----	35-45% Max.
Percent Sand equivalent D2419	-----	52	Min 45%
Angularity for Coarse aggregate ASTM D5821	97%	----	Min 95%
Percent flat and elongated particles D4791	Flat	2%	Max 10%
	Elongation	5%	

Table. 3 Chemical Properties of Selected Aggregate*

Chemical Compound	Content,%
Silica, Sio2	83.53
Lime ,Cao	4.33
Magnesia, MgO	0.76
Sulfuric Anhydride,SO3	2.8
Alumina,Al2O3	0.50
Ferric Oxide, Fe2O3	0.63
Loss on Ignition	6.5
Total	99.05
Mineral Composition	
Quartz	81.3
Calcite	10.02

* Tests are carried out in cooperation with National Center for Construction and Laboratories.

3.3 Tack Coat Type

3.3.1 Emulsified asphalt

Emulsified asphalts are created by breaking asphalt cement, typically of 100 to 250 penetration range; into miniature particles and dispersing them in water with emulsifier. These minute elements have like-electrical charges and so do not coalesce. They stay in suspension in the liquid stage as long as the water does not vaporize or the emulsifier does not break. Emulsified asphalts hence involve of asphalt, which makes up about 55 to 70 percent by weight, water, and an emulsifying agent, this in some cases too may contain a stabilizer. Emulsions are categorized by their ionic charge. Emulsions cationic begin with a "C." If there is no C, the emulsion is usually an anionic. The charge is essential when designing an emulsion for compatibility with definite aggregates **[8].** Two type of asphalt emulsion used in this study. The next physical tests for asphalt emulsion were used in present study **Table.4, Table.5** and **Plate.1:**

Table. 4 Physical Properties of Anionic Asphalt Emulsion according to ASTM

TEST	ASTM Designation D244	Test Result	ASTM SPECIFICATION MIN.	Max.
Particle Charge Test	D244	Negative	Negative	
Viscosity Saybolt Furol at 25 °C(77)F	D244	24	20	100
Residue by Evaporation	D6933	59.4	50	70
Settlement Test 5day%	D6933	0.9	0	1
1Day storage Stability test %	D2397	0.4	0	1
Test on Residue				
Penetration	D5	121	100	250
Ductility 25 °C 77F cm/min	D113	41	……	……
Density (gm./liter)	D 6937	1014		

Table. 5 Physical Properties of Asphalt Emulsion Cationic Slow Setting Low Viscosity (Css-1).

Test	ASTM Designation	Test Result	ASTM Specification	
			Min.	Max.
Particle Charge	D244	positive	positive	
Viscosity,Saybolt Furol at 25°C	D244	26	20	100
Residue by Distillation, %.	D6997	55.3	57	……
Residue By Evaporation	D6934	54.9	50	70

Sieve Test,%	D6933	0.02	……	0.10
Cement mixing test, %	D6935	0.732	……	2.0
Settlement Test,5day,%	D6930	0.1	0	1
1 Day Storage stability test, %	D6930	0.04	0	1
Tests on Residue				
Penetration,25°C (77°F), 100 g, 5 s	D5	133	100	250
Ductility, 25°C (77°F), 5cm/min,	D113	185	40	……
Density (gm./liter)	D 6937	994	……	……

Plate.1: illustrated the physical test for emulsion (Penetration and Saybolt Furol viscosity)

3.3.2 Cut back Asphalt (Rc-70)

Cutback asphalts consist mainly of asphalt cement and a solvent. The speediness at which they cure is connected to the volatility of the solvent (diluent) used. Cutback made with greatly volatile solvents will treatment faster as the solvent Will evaporate more quickly. In opposition, cutbacks made with less volatile solvents will cure slower as the solvent will evaporate slower. There are three types (SC, MC and RC) cutback asphalts; which designate the rate at which the solvent evaporates **[12]**. **Table.6** shows the physical properties of cutback asphalt.

Table. 6 Physical Properties of Cutback Asphalt Rc-70*

Properties	ASTM Designation	*Cutback* Asphalt*	Specification Limits	
			Min.	Max.
Density (gm./liter)	D 2028 D3142	1080	….	….
Water concentration (%)	D 95	10%	….	0.2%
Residual from evaporation	D 2028	85%	55%	….
Viscosity	D 2170	80	70	95

* Tests are carried out in cooperation with National Center for Construction and Laboratories.

3.3.4 Mineral Filler

Unique type of mineral filler which is Portland cement is used. The biochemical compositions and physical properties are shown in **Table.7**.

Table.7 Physical Properties and Chemical Compositions of Portland cement filler*

Chemical Compound	Content,%
SiO_2	20.5
$AL_2\, O_2$	3.9
$Fe_2\, O_3$	4.41
CaO	36.5
MgO	2.72
SO_3	3.43
Mass loss of heating	2.51
Lime saturation factor	0.92
Physical properties	
% Passing Sieve No.200 (0.075 mm)	96
Apparent Specific Gravity	3.1
Specific Surface Area (m2/kg)	312.5

* Tests are carried out in cooperation with National Center for Construction and Laboratories.

4.Experimental Testing

The design of asphalt mix according to superpave gyratory compactor is included mixing the materials (aggregate, asphalt binder and mineral filler), later making sure it is in agreement with specifications, then preparation the specimen to the compaction procedures in the Superpave gyratory compactor (SGC) according to AASHTO T 312. The design bitumen binder content is recognized at 4.0% air voids as demonstrate in **Fig.1.**The optimum asphalt content was found to be (4.9%) by the total weight of mixture. **Plate. 2** show the steps of preparation samples of the Superpave gyratory compactor. **Table.8** and **Table.9** Result of different specific gravity and initial Asphalt content and mixture volumetric requirement respectively.

Table.8 Result of Different Specific Gravity and Initial Asphalt Content

Blend	% G_{mm} @N_{ini}	%G_{mm} @N_{des}	% G_{mm} @ N_{max}	Va %	VFA estimation	VMA Estim.	Asphalt binder estim.
1	86.6	95	96.35	5	75.46	16.5	5.3
2	86.15	95.5	97	4.5	71.8	14.2	5
3	86.8	96.4	97.8	3.6	73.4	15	4.74

Table.9 Mixture volumetric requirement

Blend	Specific bulk gravity, (Gmb)	Specific apparent gravity, (Gma)	Effective specific gravity,(Gse)	Initial asphalt content (Pi) %
1	2.63	2.668	2.661	4.9
2	2.637	2.677	2.669	4.9
3	2.645	2.686	2.678	4.9

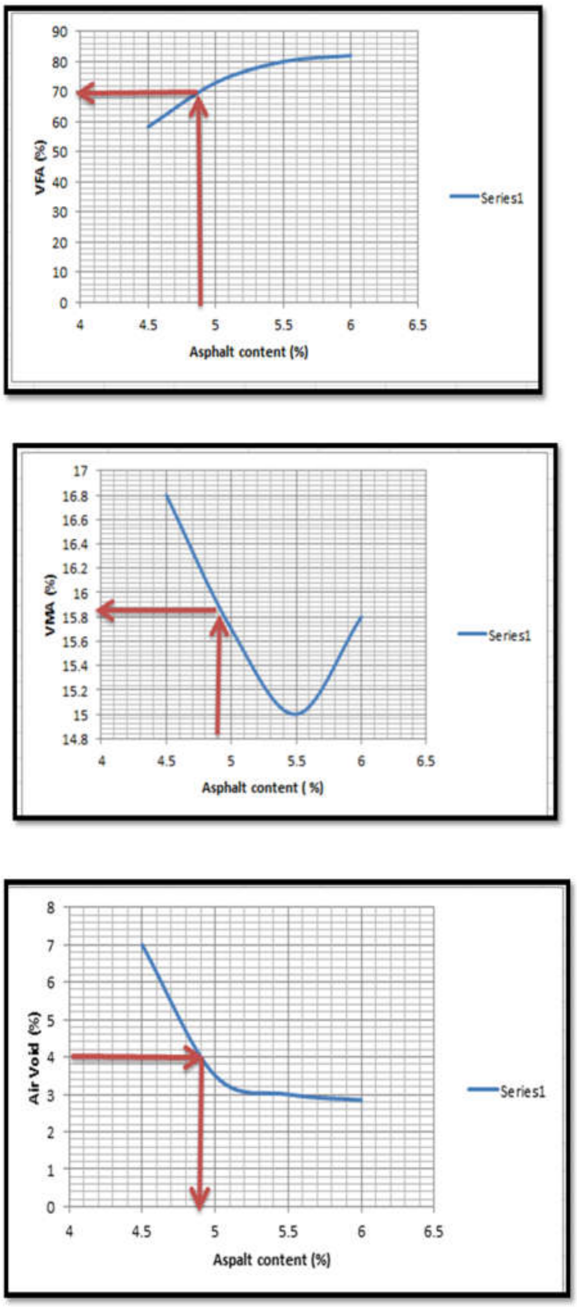

Fig. 1 Relation of air void, VMA% and VFA% versus asphalt content %

Plate.2 Superpave GyratoryCompactor Samples preparation

5. FDOT Direct Shear Test

5.1 Manufacturing of Interlayer Bond Strength Tester

The mold for testing the bond strength shall be designed it can be used with the corresponding loading machine (hydraulic testing machine that can provide a vertical movement of 2.0 in. /min). This mold with 10.15cm (4in.) diameter, length 20cm, width 11.5cm, thickness 3cm, and height19cm.The gapis1/4 in. is illustrated in **Fig.2**, **plate. 3** Cross-sectional and profile views. **[14]**

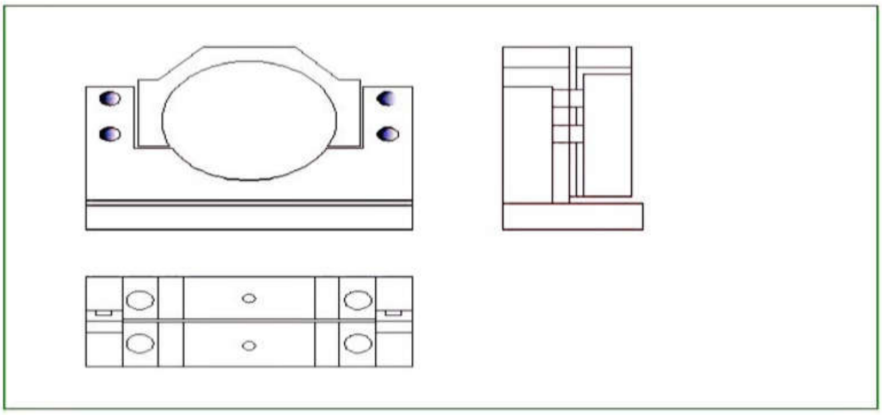

Fig2. 3-D Illustration of the Interlayer Bond Strength Tester

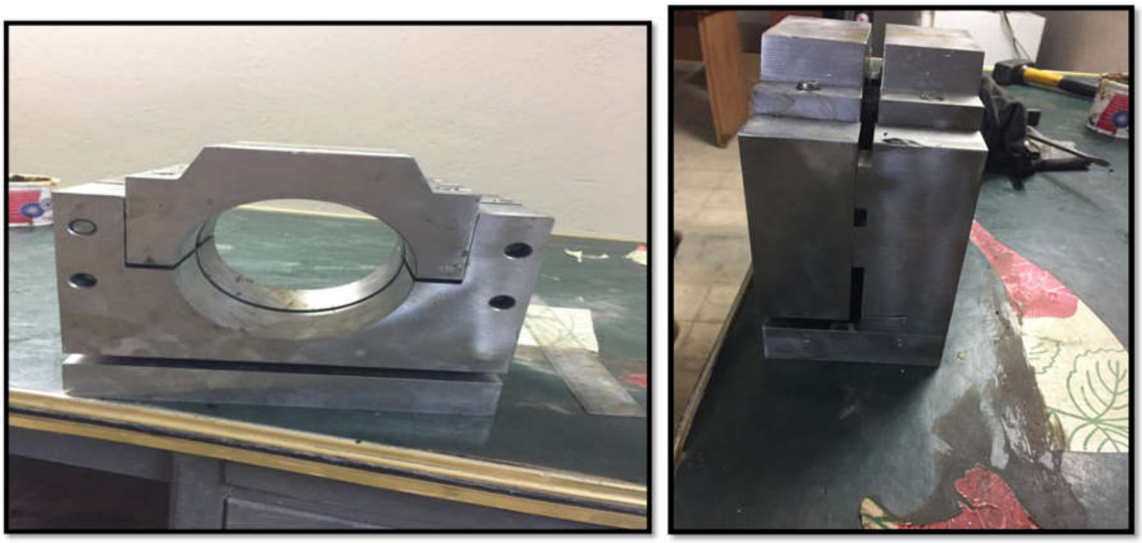

Plate.3 Cross-sectional of manufacturing mold

5.2 Specimen Preparation

The test factorial for this study included one mix type, 3 tack coat types, and three temperatures. A total of 55 specimens were necessary for testing to study the effect of tack coat types and temperature on bonding strength. A testing specimen involved of two layers, upper and lowest, with a tack coat at the interface of these layers. The diameter of each specimen was 101.6 mm (4 in.). The loose mix is set at optimum asphalt content 4.9% and 12.5 mm nominal maximum aggregate size then left in oven for 2 hr aging at 135℃ according to superpave specification. To facilitate using of manufacturing mold ,adopt a

Marshall mold dimension with the highest number of blows (75 blow) to compact the upper layer .This is conducted to simulate an HMA overlay of an in-place HMA pavement. The specimens have been prepared using normal Marshall Procedure first for the underlying layer, followed by application of tack coat and finally overlaying with the top layer in the same mould in an appropriate manner. **Plate.4** Specimen Preparation

Plate.4 Specimen Preparation

5.3 The test Procedure

According to constant loading rate (50.8mm/min) of Marshall Apparatus, the interface bonding strength will be tested under this rate.The interface bonding strength was estimated by measuring the shear strength of the test samples at the interface. A simple shear test was conducted with the FDOT to determine interface bond strength. A shearing load was applied at a constant rate of 2 in/min (50.8mm/min) on the specimen until failure. The specimen is left in water path or a chamber for (2hr±15min) at testing temperature (15˚C, 30˚C and 45˚C) this temperature adopted according to many literature research to allow uniform distribution of temperature within the specimen .The sample is placed in the mold so that the direction of load on the specimen is parallel to the shear direction, the load applied on movable part of the mold until specimen failure this shown in **plate.5.**

Plate. 5 the procedure for test FDOT

The interface bond shear strength was calculated by [2]

$$\textbf{IBS} = \frac{P}{\frac{\pi D^2}{4}}$$

IBS = interlayer bond strength (psi)

P = Max. Load applied to specimen (lb.)

D = diameter of test specimen (in.)

6. Test result analysis and discussion

The results of various tests conducted to evaluate the interlayer bond strength in various types of combinations are presented below in **Table.10**:

Table.10 the results of various tests conducted to evaluate the interlayer bond strength

Type of Tack Coat	Set Time	Application rate (l/m^2) of tack coat materials	Interface Bond strength at different test temperature (psi)		
			15°C	**30°C**	**45°C**
CSS-1	2 Hour	0.15	157.75	34.9	10.18
		0.25	349.36	52.47	14.23
		0.35	121.6	50.53	12.1
	4 Hour	0.15	173.54	33	11.6
		0.25	208.63	55.8	12.81
		0.35	191.26	50.88	10.63
Anionic	2 Hour	0.15	114.1	43.52	9.65
		0.25	136.87	51.41	13.5
		0.35	121.07	48.8	11.05
	4 Hour	0.15	155.8	56.85	10.53
		0.25	192.66	65.27	15.27
		0.35	175.3	39.48	11.93
Rc-70	2 Hour	0.3	135.11	54.39	7.36
		0.4	168.45	72.99	10.9
		0.5	116.7	47.2	7.72
	4 Hour	0.3	130.2	52.29	6.32
		0.4	186	68.1	8.4
		0.5	173.36	53	4.9
Without tack coat			159.5	113.7	12.1

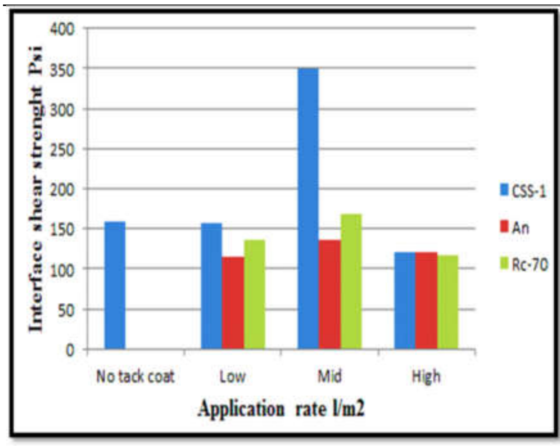

Fig.2 Interface bond strength (Psi) at 15°C when setting time 2 hour

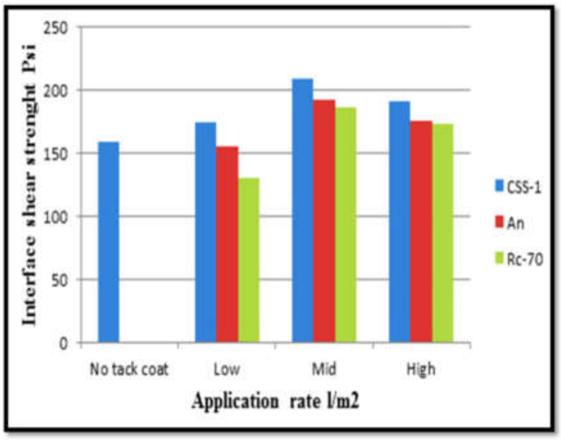

Fig.3 Interface bond strength (Psi) at 15°C when setting time 4 hour

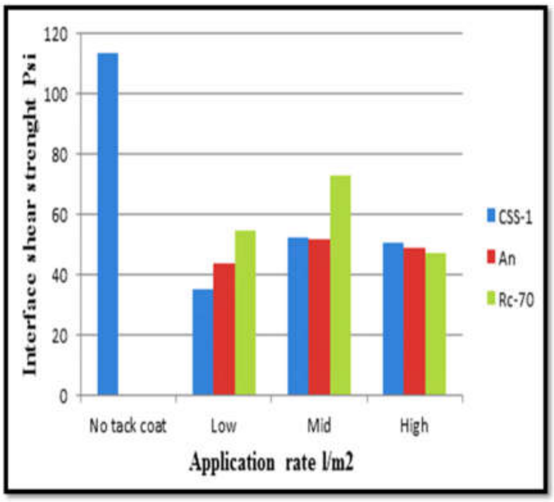

Fig.4 Interface bond strength (Psi) at 30°C when setting time 2 hour

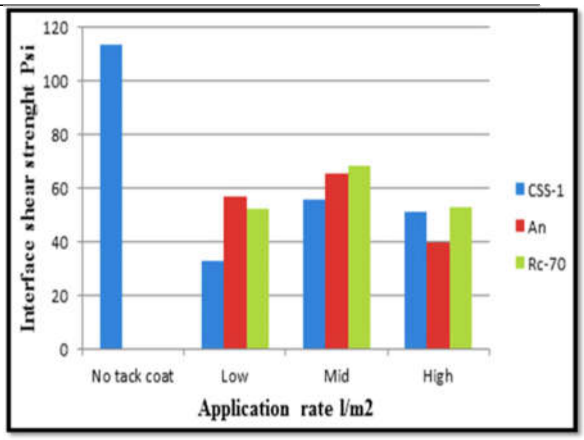

Fig.5 Interface bond strength (Psi) at 30°C when setting time 4 hour

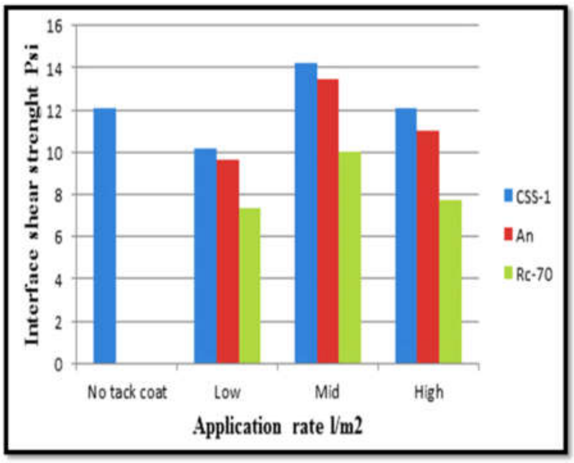

Fig.6 Interface bond strength (Psi) at 45°C when setting time 2 hour

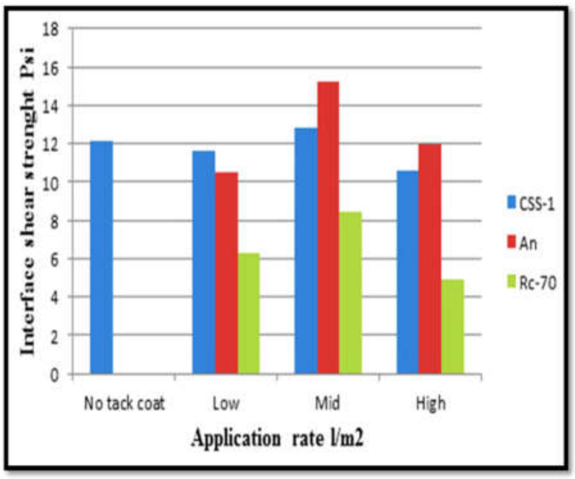

Fig.7 Interface bond strength (Psi) at 45°C when setting time 4 hour

From all above figures presented the Css-1type of tack coat have the maximum interface bond strength at 15°C at 0.25l/m^2 application rate when setting time 2 hour. The Anionic type of tack coat has the maximum interface bond strength at 45°C at 0.25l/m^2 application rate at 4 hour setting. The cut back Rc-70 type of tack coat has the maximum interface bond strength at 30°C at 0.4l/m^2application rate.

The 15°C give the maximum interface bond strenght among all other test temperature.

The effect of setting time has little effect and differs from temperature to temperature. The majority of states had no specification for maximum set time.[13]

The best performing tack coat material is Cationic slow setting low viscosity (Css-1) will give high interface bond strength at 15,45°C with 0.25 l/m^2.The best application rate is 0.25l/m^2 for Css-1,Anionic and 0.4 for Rc-70 tack coat type.

The interface bond strength greatly affected by temperature and decrease with increase temperature that is due to reducing in tack coat materials viscosity with increase temperature. It well known that asphalt behave as a viscous in high temperature and elastic at low temperature.

The interface bond strength affected by application rate. In this study the interface bond strength increase with increase application rate until mid application rate then decrease at high application, that is due to appear slippage between the two layers due to the lubrication effect, which leads to a decrease in the bond strength at the interface. we can concluded the use of high application rate doesn't lead to high interface bond strength.

The specimen without tack coat has the maximum interface bond strength at 30°C .

7.Summary and Conclusions

The following are specific observations drawn from the test results:

- The maximum interface bond strength for Css-1 type and anionic at 0.25 l/m^2 application rate at all temperature test and setting time.
- The Css-1 tack coat type provided highest bond strength at all application rate 0.15 l/m^2, 0.25 l/m^2, 0.35 l/m^2 when temperature 15 °C at 2, 4 hour setting time compared to anionic and Rc-70.
- For the situation of interface layers without tack coat will give high bond strength at 30°C.
- The temperature has a significant effect on interface bond

strength and decrease with increasing of temperature due to decreasing the emulsion viscosity with increasing of temperature.

- The optimum rate for emulsion (Css-1 and Anionic) is 0.25 l/m^2 and for Rc-70 is 0.4 l/m^2.

- At a test temperature 15℃, all types of tack coat used have been found maximum interlayer bond strength value as compared to other test temperatures.

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دراسة تأثير الانواع المختلفة من المواد اللاصقة على منطقة الربط بين طبقات التبليط الاسفلتي المرن

أ.م.د. حسن حمودي جوني
تهاني جلال طعيمة

الخلاصة

التبليط الاسفلتي هو منشا يتكون من الطبقة السطحية وطبقة الاساس وطبقة ما تحت الاساس ومستند على طبقة التربة التحتية.
الترابط الكامل بين الطبقات يجعل التبليط يعمل كمنشأ واحد مركب. الانزلاق هو اكثر انواع الفشل الناتج من ضعف الربط بين بين طبقات التبليط الذي يؤدي الى تقليل عمر التبليط .الطبقة اللاصقة هي تطبيق مستحلب اسفلتي بين طبقة السطحية الموجودة وطبقة اسفلتية جديدة وتستخدم لزيادة التلاصق بين طبقتين هذه الدراسة هي محاولة لتحليل قوة الربط في منطقة التداخل بين طبقات التبليط عن طريق الفحوصات المختبرية ,طريقةفحص قسم فلوريدا لدراسات النقل استخدمت لتحليل الربط بين طبقات التبليط لعمل هذا المشروع نستخدم نماذج اسطوانية قطرها 100 ملم تحضر بأستخدام خطوات مارشال الاعتيادية بالنسبة للطبقة الاولى يتبعها تطبيق المادة اللاصقة بعد ذلك توضع الطبقة الاعلى بنفس اسلوب مارشال .ثلاثة انواع من الطبقة اللاصقة استخدمت.بعد ذلك النماذج تفحص ووجد ان قوة الربط بين الطبقات تعتمد على درجة الحرارة وتقل بزيادة درجة الحرارة وكذلك تعتمد على كمية ونوع المادة اللاصقة.
النسبة المثالية للطبقة اللاصقة بالنسبة الى المستحلب الاسفلتيالموجب الشحنة هي 0.25 لتر /متر مربع وبالنسبة للمستحلب الاسفلتي السالب الشحنة هي 0.25 لتر /متر مربع وبانسبة لسائلا للأسفلت المعالجة سريع هي 0.4 لتر/متر مربع

الكلمات المفتاحية: الطبقة اللاصقة،التداخل,قوة الربط, مقاومة القص وقسم الفلوريدا لدراسات النقل.