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RESEARCH ARTICLE

Influence of Surface Texture on Interface Bond Shear Strength of Asphalt Concrete

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Abstract

The bonding strength provided by the tack coat between asphalt concrete layers at the interface is considered as an essential issue in the performance of the flexible pavement throughout its service life. However, the surface texture of the pavement surface exhibits another essential issue in the bond strength. In this investigation, three layers of asphalt concrete (base, binder and wearing) courses with (25, 19, and 12.5) mm of nominal maximum size of aggregates have been prepared using roller compactor. Rapid curing cutback RC-70 and cationic medium setting emulsion CMS have been implemented as tack coats with three application rates. The slab specimens were subjected to mean texture depth determination using sand patch method. Core specimens of 102 mm diameter were obtained from the prepared slab samples and subjected to interface bond strength test with the aid of a special manufactured mold. Test results were analyzed and compared. It was concluded that when RC-70 tack coat was implemented, asphalt concrete binder course laid on base course exhibited the highest shear strength of 1600 kPa at an application rate of 0.33 liter/m² when compared to other application rates. Asphalt concrete wearing course laid on binder course exhibited the highest shear strength of 1515 kPa at an application rate of 0.15 liter/m² when compared to other application rates. When CMS tack coat was implemented, asphalt concrete binder course laid on base course exhibited the highest shear strength of 1620 kPa at an application rate of 0.23 liter/m² when compared to other application rates. Finally, the asphalt concrete wearing course laid on binder course exhibited the highest shear strength of 2272 kPa at an application rate of 0.23 liter/m² when compared to other application rates.

Keywords: Cutback, Emulsion, Tack coat, Asphalt concrete, Interface bond, Texture

1.Introduction

The Flexible pavement consists of interconnected layers of asphalt concrete mixtures. Bonding between the layers is an essential parameter in the long-term serviceability of the pavement. The interface bonding of layers is subjected to dynamic loading coming from wheel load repetitions as reported by Szydlo and Malicki,[1]. An attempt has been made by Panda et al.,[2] to develop a simple testing arrangement to be used in the laboratory to determine the interlayer bond shear strength. It was stated that the boundary between the consecutive asphaltic layers is the layer interface while the pavement stress distribution is highly influenced by the adhesion conditions at this interface. Poor adhesion between pavement layers causes adverse effects on the structural strength of the pavement system. Slippage and delamination failures could occur, thus defeating the safety and construction objectives. It is concluded that Cationic rapid setting (CRS-1) emulsion applied at 0.25 Kg/m² offers the best results of interlayer bond strength. Ghaly et al.,[3] evaluated the practice followed of using tack coat through controlled laboratory simple shear

tests and determined the optimum tack coat application rate. The influences of tack coat types, application rates, viscosity and temperatures on the interface shear strength were assessed. It was concluded that modified asphalt emulsion has the highest interface bond strength. It was also found that applying low viscosity tack coat emulsion at two layers is more effective than a tack coat emulsion with high viscosity one-layer coat. Andrea and Tozzo,[4] analyzed the shear behavior of double-layer specimens with the same features tested in different state of stress but at the same deformation rate. The tests were performed on two devices, designed to reproduce the most common stress/deformation relationship and modified to allow the comparison of the results. The maximum shear stress and the corresponding normal stress were evaluated by the tests. It was concluded that there is a relationship between these parameters and the specimens' features. Zhang, [5] focused on how the interlayer shear strength varied when relevant influential factors are changed. Results indicate that the interlayer shear strength increased with the decreased test temperature, increased traffic load, and increased test confinement pressure. Chen and Huang, [6] evaluated the interlayer shear strength by different gradation combinations. The direct shear

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test was used to measure the bond properties provided by tack coat, whereas the surface characteristics were measured by traditional techniques. Variables included surface type, curing time, curing temperature, emulsion type, and application rate. It was concluded that the interface between the dense-graded asphalt mixtures resulted in higher peak shear strength than that between the open- and gap-graded mixtures. It was concluded that an increase in mean texture depth and film thickness led to a decrease in the peak shear strength. The surface characteristics were shown to play a key role in interlayer bonding. Zulkifili and Sutanto,[7] investigated the influence of bond on the performance of Malaysian roads. The pavement structure of Malaysian road was analyzed using a layered linear elastic program, considering different states of the bond at the interfaces of the pavement layers and a static horizontal load. The results indicate that the condition of the bond between the wearing and binder course can reduce the life of the pavement by up to 64%. On the other hand, the results also indicate that the condition of the bond between the binder and road base course, which was made up from asphaltic materials can reduce the life of the pavement by up to 68%. Jaskula and Rys, [8] stated that the quality of interlayer bonding at the interfaces between the asphalt layers in flexible pavements affects the overall pavement performance. It was reported that Lack of interlayer bonding between asphalt layers can cause pavement's premature failures such as rutting, slippage of the wearing course, cracking or simply a reduction in the calculated fatigue life of the pavement structure. It was found out that low quality of tack coat as well as the same aggregate gradation in the bonded asphalt mixtures were the main reasons behind the weak quality of interlayer bonding. Coleri et al., [9] reported that the adhesive bond between two asphalt concrete layers helps the pavement system to behave as a monolithic structure and improves the structural integrity. The failure of this bond result in a significant reduction in the shear strength resistance of the pavement structure and make the system more vulnerable to many distress types, such as cracking, and potholes.

The aim of the present investigation is to assess the influence of surface texture and two types of tack coat on the interface bond shear strength of asphalt concrete.

2. Materials and Methods

2.1. Asphalt Cement

The asphalt cement used in this study is brought from AL Dura refinery, south of Baghdad. Penetration graded binder 40-50 is used. The physical properties of the binder are presented in Table 1. Test results conforms well with State Commission for Roads and Bridges SCRB,[11] requirements. Testing procedures were conducted according to American society for testing and materials ASTM, [10] and American Association of State Highway and Transportation Officials AASHTO, [12].

2.2 Cut Back Asphalt

Cut back is petroleum residuum (asphalt) which has been blended with petroleum distillates. In this study, tack coats RC70 which is widely used in Iraq, is implemented. Such cut back is prepared by mixing one gasoline ratio into two ratios of asphalt cement (85 -100) measured in volume. The physical properties of the RC-70 are presented in Table 2. Three application rates of (0.15, 0.33, 0.5) liter/m² have been implemented which are within the limitations of SCRB, [11]. The application rates implemented were based on visual inspection.

Table 1. Physical Properties of Asphalt Cement

Test	Test Condition	ASTM, [10] Designation	Units	SCRB, [11] Specification	Test Result
Penetration	100gm, 25C°, 5 sec (1/10mm)	D-5	1/10mm	40-50	46.5
Specific Gravity	@ 25 °C	D-70	gm/cm ³	-----	1.05
Flash point	Cleveland open cup	D-92	°C	>232	285
Ductility	25 °C, 5cm / min	D-113	cm	>100	>150
Softening point	Ring and ball	D-36	°C	-----	48
Kinematic viscosity	@135°C	D2170	C. Stoke	-----	230
Residue after thin film oven test					
Penetration of residue	100gm, 25°C, 5 sec (1/10mm)	D 5	1/10mm	40 – 50	36.5
Ductility of residue	25 °C, 5cm / min	D113	cm	>55	145
Loss in weight	5 hours at 163 C°, 50 gm	D 1754	%	<0.75	0.13

Table 2. Physical Properties of RC-70 Cut Back

Test	ASTM, [10] Designation	Cut Back Asphalt	Specification Limits ASTM, [10]	
			Minimum	Maximum
Density (gm/liter)	D2028, D3142	995	---	---
Water concentration (%)	D95	0.1%	---	0.2%
Residual by Evaporation (%)	D2028	90%	55%	---
Kinematic viscosity (C. Stoke)	D2170	75	70	95

2.3. Cationic Emulsion

Medium setting cationic emulsion has been implemented as tack coat. This classification is based on the rate of breaking of the emulsion ; that is , the rate at which the dispersed asphalt particles can be made to recombine to form a continuous film of asphalt cement. The physical properties of emulsion are illustrated in Table 3. Three application rates of (0.1, 0.23, 0.35) liter/m² have been implemented which are within the limitations of SCRB,[11]. The application rates implemented were based on visual inspection.

Table 3. Physical Properties of Emulsion

Property	ASTM, [10] Designation	Test Result	Limits
Emulsion type	D2397	Cationic (CMS)	Medium setting
Residue by evaporation %	D6934	54	Min 40
Specific gravity, gm/cm ³	D70	1.04	-----
Penetration (mm)	D5	219	100 - 250
Ductility(cm)	D113	46	Min 40
Viscosity, Saybolt - Furol viscometer @ 50 °C – AASHTO, [12]	AASHTO M208	348	110 - 990
Solubility in Trichloroethylene (%)	D2042	97.7	Min 97.5
Emulsified asphalt / job aggregate coating practice	D244	Fair	Good

2.4. Aggregate Properties

The coarse aggregates (combination of crushed and uncrushed) for base layer and (crushed) for binder and wearing course layers are obtained from AL-Nibae quarry. Coarse aggregates consist of hard, strong, and durable pieces, free of coherent coatings. The size of coarse aggregate range between (25 mm) and retained on sieve No. 4 (4.75mm) according to SCRB [11] specification. The physical properties of the coarse and fine aggregate are shown in Table 4.

Table 4. Physical Properties of Aggregates

Property according to ASTM, [10]	Coarse Aggregate	Fine Aggregate	SCRB, [11] Limits
Bulk Specific Gravity(ASTM C-127 and C128)	2.61	2.632	-----
Apparent Specific Gravity (ASTM C127and C128)	2.657	2.693	-----
Percent Water Absorption (ASTM C-127 and C128)	0.443	0.526	5 % Max.
Percent Wear (Loss Angeles Abrasion)(ASTM C-131)	18.6	-----	35 - 45
Percent Sand equivalent D2419	-----	55	45 min
Angularity for coarse aggregate ASTM D5821	96%	-----	90 min
Percent flat and elongated particles D4791	Flat Elongation	3% 5%	<10% 5 - 1

2.5. Mineral Filler

Portland cement was used as a mineral filler. It is thoroughly dry and free from lumps or aggregation of fine particles. The chemical compositions and physical properties shown in Tables 5 and 6, respectively are supplied by the manufacturer.

Table 5. Chemical Compositions of Portland Cement

Chemical compound	Content%
SiO ₂	21.49
Al ₂ O ₃	3.78
Fe ₂ O ₃	3.36
CaO	62.52
MgO	1.57
SO ₃	5.65
Mass loss of heating	2.34
Lime saturation factor	0.93

Table 6. Physical Properties of Portland Cement

Property	Test Result
% passing Sieve No.200(0.075mm)	97
Specific Gravity, gm/cm ³	3.14
Specific Surface Area (m ² /kg)	310.5

2.6. Combined Gradation of Asphalt Concrete

The coarse and fine aggregates used in this study were sieved and recombined in the proper proportions to meet the Base, binder, and Surface course gradations. Figure 1 exhibit the aggregates gradations used to prepare mixtures for wearing, binder and, base courses respectively as per (SCRB, [11].

Figure 1. The Aggregate Gradation According to SCRB,[11]

3. Testing Methods

3.1. Preparation of Asphalt Concrete Mixtures

The aggregates were dried in an oven to a constant weight at 110 °C, then sieved to different sizes, and stored separately. Coarse and fine aggregates were combined with mineral filler to meet the specified gradation of asphalt concrete layers as per SCRB, [11] specifications. The combined aggregate mixture was heated to 150 °C before mixing with asphalt cement. The asphalt cement was heated to the same temperature of 150°C, then it was added to the heated aggregate to achieve the desired amount and mixed thoroughly using a mechanical mixer for two minutes until all aggregate particles were coated with thin film of asphalt cement. Marshall Size specimens were prepared in accordance with ASTM D1559,[10] using 75 blows of Marshall hammer on each face of the specimen for binder and wearing course mixtures. However, 50 blows of Marshall hammer on each face of the specimen for the base course mixture was used. Specimens were tested for Marshall and volumetric properties, and the optimum asphalt content for each mixture was obtained. Table 7 shows the Marshall properties of the investigated mixtures.

3.2. Preparation of Asphalt Concrete Slab Samples and Core Specimens

Two types of asphalt concrete slab specimens of (400 mm by 300 mm) were prepared using the roller compactor. The first type consists of base course of 80 mm thickness overlaid with binder course of 40 mm. the second type consists of binder course of 60 mm overlaid with wearing course of 40 mm. Pneumatic Roller Compactor B3602-DYNA, Ver 1.14, was implemented to prepare slab samples.

Table 7. Marshall Properties of Asphalt Concrete

Layer	Wearing	Binder	Base
Marshall Stability kN	10.1	9.8	8.8
Unit weight	2.354	2.346	2.325
Air voids %	4.15	4.2	4.4
Flow mm	3.5	3.5	3.4
VMA %	15	14.6	13.7
VFA %	72	71	69
Optimum asphalt content %	5	4.7	4.3

Roller compaction was adopted as per EN12697-33,[13] with a static load starting from 2.4 kN for 10 cycles. The load was increased each 10 cycles to reach 9.1 kN for a total of 33 cycles to meet the target density of the layer at optimum asphalt content. The compaction temperature was maintained at 135 °C. Figure 2 shows the roller compactor implemented.

Figure 2. The Roller Compactor Implemented

After the base course slab of the first type or the binder course of the second type were compacted, the slabs were left for 24 hours to cool at laboratory environment. Then the compacted slabs for each type were subjected to tack coat application at the specified application rate and tack coat type. Samples were left for 120 minutes to cure the tack coat, then overlaid by binder or wearing course mixtures and subjected to the roller compaction to the target density as explained above. Slab samples were left for 24 hours at the laboratory environment to cool. Slab samples were subjected to mean texture depth determination with the aid of sand patch method as per ASTM,[10]. Afterward, six core specimens of 110 mm diameter were cut by the diamond saw to the full depth of the slab which consists of two courses of asphalt concrete. The total number of slab samples prepared was 12 while, the total number of core specimens was 72. Figure 3 exhibits part of the prepared slab samples, while Figure 4 shows part of the obtained core specimens.

Figure 3. Part of the Prepared Slab Samples

3.3. Determination of Mean Texture Depth Using Sand Patch Method:

Determination of mean texture depth is macrotexture quantification of a pavement surface expressed in mm. The test was conducted for each asphalt concrete layer as per (ASTM-D965, 2013).

Figure 4. Part of the Core Specimens Obtained

Figure 5 demonstrates the mean texture depth determination. It was found that the average mean texture depth MTD of base course layer is 0.26 mm, while the binder and surface course mixtures exhibit (0.22 and 0.11) mm respectively.

Figure 5. Texture Depth Using Sand Patch

3.4. Interface Bond Shear Strength Test

Shear test device consist of testing mold which was designed and manufactured at local market was implemented to evaluate interface shear strength. The test involves the application of a direct shear load and the resulting shear displacement during the test was monitored. The mold and the asphalt concrete specimen are placed in an environmental chamber capable of controlling the temperature to within $20 \pm 0.5^\circ\text{C}$. The test mechanism is such that one layer is held stationary in the mold while the other layer is loaded with a specific shear displacement rate. The specimens that were used in this study had a diameter of 101 mm and variable length of (100-120) mm based on testing combination of pavement layers. Testing was conducted at 20°C at a constant loading rate of 5 mm/min. The test setup and testing mold are shown in Figure 6. The interface bond shear strength is calculated by dividing the maximum load sustained by the specimen before failure by the cross-sectional area of the specimen. Similar testing mold and procedure was reported by Andreaa and, Tozzoa,[4]; Zhang,[5]; Leng et al.,[14]; Biglari et al., [15]; and Mirsayar et al., [16].

Figure 6. Interface Bond Shear Strength Testing Apparatus

3.5. Non-destructive Testing Through the Layers Interface

The portable ultrasonic non-destructive digital indicating tester (Pundit) was implemented in this study. The device generates and receives ultrasonic waves and has a digital display of the results, and it can be used with piezo electric transducers over a frequency range from 20 to 500 kHz. A frequency of 54 kHz and accuracy of 0.1 were implemented through this study to measure the ultrasonic pulse velocity of the specimens. The direct transmission arrangement was used in this study. The pulser and receiver were placed on opposite specimen parallel surfaces according to ASTM C597,[10]. The pulse transit path length of two asphalt concrete layers was measured accurately, and the time of its travelling was recorded. The distance between the transducers, which was equal to the thickness of the core

specimen, was divided by the time measured to calculate the ultrasonic pulse waves velocity. Similar testing procedure was reported by Sarsam and Kadium.[17]. The dynamic modulus was calculated based on the pulse velocity using the mathematical model 1., [18-20].

$$E = V_c^2 D / G \quad \text{-----}(1)$$

Where:

E = Dynamic Modulus (psf)

V_c = Ultrasonic Pulse Velocity (ft/sec)

D = Unit weight of the sample (lb/ft³)

G = Acceleration due to gravity (ft/sec²)

4. Results and Discussion

4.1. Influence of Mean Texture Depth on Application Rate of Tack Coat

It was observed that the base course exhibited the coarser texture of 0.26 mm, while the binder and wearing courses showed finer textures of (0.22 and 0.11) mm respectively. This could be attributed to the various nominal maximum size of aggregates of (25, 19, and 12.5) mm for base, binder and wearing courses respectively as well as the various asphalt content of (5%, 4.7% and 4.3%) for base, binder and wearing courses, respectively. On the other hand, the rate of application of cutback could vary significantly based on the texture. The coarse texture of base course requires rate of application of 0.33 liter/m² of cutback asphalt as an optimized requirement while the binder course requires 0.15 liter/m² of cutback asphalt as an optimized requirement. When cationic emulsion is implemented as tack coat, the base course requires rate of application of 0.23 liter/m² of emulsion asphalt as an optimized requirement while the binder course requires 0.23 liter/m² of emulsion asphalt as an optimized requirement. Similar findings were reported by Shafabakhsh and Ahmadi,[21].

4.2. Influence of Surface Texture on IBSS (Interface Bond Shear Strength)

The IBSS may vary between two layers, depending on the type and the texture of the bottom layer sample as reported by Huang et al.,[22]. Increasing the coarseness of texture can result in increased interface bond shear strength. Figure 7. demonstrates the influence of application rate and tack coat type on the interface bond shear strength. It can be observed that for RC-70 cutback, the asphalt concrete binder course laid on base course exhibited the highest shear strength of 1600 kPa at an application rate of 0.33 liter/m² when compared to other application rates. When the application rate increases, the shear strength decreases. This could be attributed to the excess asphalt film with more lubrication ability which reduces the required friction and particles interlock.

Figure 7. Influence of Application Rate and Tack Coat Type on IBSS.

However, the asphalt concrete wearing course laid on binder course exhibited the highest shear strength of 1515 kPa at an application rate

of 0.15 liter/m² when compared to other application rates. On the other hand, when cationic emulsion was implemented as tack coat, the asphalt concrete binder course laid on base course exhibited the highest shear strength of 1620 kPa at an application rate of 0.23 liter/m² when compared to other application rates. However, the asphalt concrete wearing course laid on binder course exhibited the highest shear strength of 2272 kPa at an application rate of 0.23 liter/m² when compared to other application rates. Table 8. shows the details of the impact of surface texture on IBSS. It can be observed that in general, both RC-70 and CMS tack coat exhibited higher IBSS with coarse surface texture as compared to the case of fine surface texture regardless of the application rate adopted. On the other hand, RC-70 tack coat exhibit higher IBSS for fine surface texture as compared to CMS tack coat.

Table 8. Summary of determined IBSS and relationship with surface texture.

Tack Coat	Application rate l/m ²	Interface shear strength (kPa) binder /base	Texture (mm)	Interface shear strength (kPa) wearing /binder	Texture (mm)
CMS	0.1	1262.7		1367.9	
	0.23	1620.5		1272.8	
	0.35	1599.4	0.22 /	1304.7	0.11 /
RC-70	0.15	1473.2	0.26	1515.2	0.22
	0.33	1599.4		1388.9	
	0.5	1473.2		1388.9	

4.3. Influence of Tack Coat Type and Application Rate on Ultrasonic Pulse Velocity

Figure 8 summarizes the influence of tack coat on the pulse velocity. Mild variation in pulse velocity could be detected on fine surface texture when emulsion was implemented as compared to the coarse texture. However, no significant variation in pulse velocity could be observed for coarse texture regardless of the application rate. On the other hand, when cutback was implemented as tack coat, significant variation in pulse velocity was detected among tack coat type and application rate. Generally, the impact of tack coat type on ultrasonic pulse velocity was minimal.

Figure 8. Influence of Tack Coat Type and Application Rate on Ultrasonic Pulse Velocity

Figure 9. Influence of Tack Coat Type and Application Rate on Dynamic Modulus

Figure 9. exhibit the influence of Tack Coat Type and Application Rate on Dynamic Modulus of asphalt concrete. A significant variation in dynamic modulus could be observed at the (binder/base) interface when CMS or RC-70 tack coat were implemented. This may be attributed to better dispersion of the tack coat in the coarse texture. On the other hand, the (wearing/binder) interface exhibit lower dynamic modulus than that of coarse texture regardless of the tack coat type or application rate.

5. Conclusions

Based on the limitations of materials and testing program, the following conclusions may be drawn.

- The coarse texture of base course requires rate of application of 0.33 liter/m² of cutback asphalt (RC-70 as an optimized requirement while the binder course requires 0.15 liter/m² of cutback asphalt as an optimized requirement.
- The base course requires rate of application of 0.23 liter/m² of emulsion asphalt (CMS) as an optimized requirement while the binder course requires 0.23 liter/m² of emulsion asphalt as an optimized requirement.
- When RC-70 tack coat was implemented, Asphalt concrete binder course laid on base course exhibit the highest shear strength of 1600 kPa at an application rate of 0.33 liter/m² when compared to other application rates. Asphalt concrete wearing course laid on binder course exhibit the highest shear strength of 1515 kPa at an application rate of 0.15 liter/m² when compared to other application rates.

- When CMS tack coat was implemented, asphalt concrete binder course laid on base course exhibit the highest shear strength of 1620 kPa at an application rate of 0.23 liter/m² when compared to other application rates. However, the asphalt concrete wearing course laid on binder course exhibit the highest shear strength of 2272 kPa at an application rate of 0.23 liter/m² when compared to other application rates.
- In general, both RC-70 and CMS tack coat exhibit higher IBSS with coarse surface texture as compared to the case of fine surface texture regardless of the application rate adopted. On the other hand, RC-70 tack coat exhibit higher IBSS for fine surface texture as compared to CMS tack coat.
- Significant variation in pulse velocity could be detected on fine surface texture as compared to the coarse texture regardless of the application rate or tack coat type. On the other hand, the variation in pulse velocity was not significant among tack coat type.
- A significant variation in dynamic modulus could be observed at the (binder/base) interface when CMS or RC-70 tack coat were implemented. The (wearing/binder) interface exhibit lower dynamic modulus than that of coarse texture regardless of the tack coat type or application rate.

Declaration of Conflict of Interests

The authors declare that there is no conflict of interest.

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