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Temperature Susceptibility at Interface of Asphalt Concrete Layers

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ABSTRACT

The multi layers of asphalt concrete pavement are usually bonded at their interfaces with tack coat. The strength of bonding is related with tack coat type and application rate which influence the pavement durability throughout its service life. This work investigates the influence of testing temperature on the interface shear strength and its temperature susceptibility. Two types of tack coat (cutback RC-70 and emulsion CMS) and three application rates have been implemented in the preparation of two layers slab samples (base overlaid by binder, and binder overlaid by wearing). Asphalt concrete core specimens were obtained from the roller compacted slab samples and tested for interface shear strength at (20 and 40) °C. It was concluded that CMS tack coat application rate of 0.23 liter/m^{2}is suitable from the interface bond shear strength point of view regardless of testing temperature and pavement layer type. On the other hand, RC-70 tack coat application rate of 0.33 liter/m^2 is suitable from the interface bond shear strength point of view at 40° C testing temperature regardless of the pavement layer type. Tack coat CMS exhibit lower temperature susceptibility as compared to tack coat RC-70 regardless of asphalt concrete layer type or application rate.

Keywords: *Interface, Shear bond Strength, Temperature, Tack coat, Asphalt concrete*

INTRODUCTION

Bae et al., [1] investigated tack coat interface shear bond characteristics at various temperatures and to relate tack coat characteristics in the field to rheological test results in the laboratory. The ISS of two emulsified tack coats was evaluated at a temperature ranging from (−10 to 60) °C. Within the evaluated temperature range, the interface shear strength ISS of the tacked interface increased with the decrease in temperature. As reported by Nguyen et al., [2], temperature has a more profound effect on the interface bond strength between asphalt layers; application rate of tack coat has a smaller impact. Investigating the behavior of the interface between two asphalt layers at a range of temperatures between 20 and 60°C and with different application rates of tack coat between 0.0 and 0.9 l/m^2 (non-residual) using a CRS-1 emulsion. These experimental results are then used to establish regression equations that relate bond strength, temperature, and application rate. The effect of temperature, dosage of tack coat and type of tack coat on the shear properties of the interface were studied through laboratory testing. Two types of emulsified asphalt binders were selected as the tack coats. The property was evaluated in three tack coat dosages (0.25 Kg/m^2, 0.5 Kg/m^2 and 0.75 Kg/m^2 based on residual binder) and at four test temperatures (-10, 0, 25 and 50) °C. The results showed that the shear strength at the interface decreases gradually with increasing temperature. The least failure shear displacement of all specimens was observed at the highest temperature of 50 °C. Moreover, the results indicated that the brittleness at low temperatures, the flow ability at intermediate temperatures, and the viscosity at high temperatures of tack binder have the most significant effects on the shear property of the interface of asphalt pavement as revealed by Hu et al., [3]. Zhang, [4] stated that the effectiveness of tack coat in increasing shear strength may be affected by multiple factors, such as tack coat material, test condition, pavement surface condition, and moisture. The interlayer shear strength increased with the decreased test temperature, increased traffic load (within design limit), and increased test confinement pressure. Test temperature is one of the most important factors influencing interlayer shear strength since emulsions and asphalt binders have different characteristics when temperature varies. Increasing the test temperature from (25 to 37.8)°C decreased the failures hear strength by more than half. Very low shear strength was observed at high test temperatures of (48.9 and60)° C. It is possible that at elevated temperatures, the viscosity of asphalt binder reduced, and asphalt binder lowed easier between pavement interlayer, resulting in decreased shear strength as reveled by Sholar et al., [5]. The temperature effect on interlayer shear strength may vary according to the types of interlayer surface. The dense-graded mixtures interface generally have higher shear strength than porous asphalt concrete- stone matrix asphalt interface when tested at (25 and 35) °C. At 50 °C, the porous – stone matrix system has the highest peak strength value among the other systems. Since the textures between the porous-stone matrix interlayer surfaces are rough, it is possible that at lower temperatures (25 and 35) °C, the cohesion between asphalt mixtures dominates. At elevated temperatures (50 °C), the interlocking among aggregates becomes more predominant. This implies that the peak shear strength at high temperatures is more related to the interlayer surface characteristics than that at lower temperatures as reported by Chen and Huang, [6]. Jia-Chong Du, [7] evaluated the bonding shear stress between asphalt pavement layered structures with emulsion and cutback asphalt as tack coat materials. A simple direct shear test device is set up for testing the shear force of the pavement composite interface. The test results show that the shear force decreases with an increase in temperature. It had a maximum value at optimum application rate and the emulsion asphalt used exhibited higher shear force than that of cutback asphalt. Mohammad et al. [8] investigated on the influence of the different emulsions and two asphalt binders as asphalt tack coat materials, and five different tack coat application rates ranging from 0.0 l/m2 to 0.9 l/m^2 at test temperatures of (25 and 55) °C on the shear strength of interfaces between asphalt pavement composite layers. Testing temperature had the most significant impact on bond strength. As the temperature increases, bond strength decreases significantly. Tack coat with low application rates generally provided high bond strength for the fine-graded mixture. However, for the coarse-graded mixture, bond strength does not change much when application rate varies. The two mixture types provided different bond strengths. The influences of tack coat type and application rate on bond strength are different for the fine-graded and coarse-graded mixtures as addressed by West et al., [9].

The aim of this investigation is to assess the influence of implementing two types of tack coat (cutback and emulsion) and (20 and 40) °C testing temperatures and three application rates of tack coat on interface shear strength of asphalt concrete. The temperature susceptibility at the interface is important to be investigated due to its influence on the durability of the shear strength issue between asphalt concrete layers. The influence of cutback type and application rate at warm and hot testing temperatures can address the sustainability of the pavement.

MATERIALS AND METHODS

The materials used in this investigation are locally available while the binder and aggregates are usually used for asphalt pavement construction in Iraq.

Asphalt Cement

The asphalt cement used in this study is brought from AL Dura refinery, south of Baghdad. Penetration graded binder of 40-50 is used. The physical properties of the binder are presented in Table 1. Test results conforms well to state commission for roads and bridges SCRB, [10] requirements. Testing procedures were conducted according to American society for testing and materials ASTM,[11] and American association of state highway and transportation officials AASHTO, [12].

Table 1. Physical Properties of Asphalt Cement

Test	Test condition	ASTM,[11] Designation	Units	SCRB, [10] Specification	Test result
Penetration	100gm, 25C^o , 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, 25C , 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^o,50 gm	D 1754	%	<0.75	0.13

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 RC70 are presented in Table 2. Three application rates of (0.15, 0.33, 0.5) liter/m^2 have been implemented which are within the limitations of state commission for roads and bridges SCRB, [10].

Table 2. Physical Properties of RC-70 Cut Back

Test	ASTM, [11] Designation	Cut Back Asphalt	Specification Limits ASTM, [11]	
			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

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/m^2 have been implemented which are within the limitations of state commission for roads and bridges SCRB, [10].

Table 3.Physical Properties of Emulsion

Property	ASTM, [11] 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

Coarse Aggregate

The coarse aggregates (combination of crushed and uncrushed) for base layer and (crushed) for binder and wearing layers are obtained from AL-Nibaee 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, [10] specification. The physical properties and chemical composition of the coarse aggregate are shown in Table 4.

Fine Aggregate

Two types of fine aggregate are used in this study, crushed and river sand fine aggregate were obtained from AL-Nibaee quarry. The fine aggregate ranges between 4.75mm (No.4) sieve and retained on 0.075mm (NO.200) sieve. It consists of durable, hard, and dry, tough, rough – surfaced and angular grains free of clay, loam or other deleterious substance according to SCRB, [10] specifications. The physical properties and the chemical composition of the fine aggregate are shown in Table 4.

Table 4. Physical Properties of Aggregates

Property	Coarse Aggregate	Fine Aggregate	SCRB, [10] Limitations
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	3%	<10%
	Elongation	5%	5 - 1

Mineral Filler

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

Table 5. Chemical Compositions of Portland Cement Filler

Chemical compound	Content%
SiO_2	21.49
Al_2O_3	3.78
Fe_2O_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 Filler

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

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, [10].

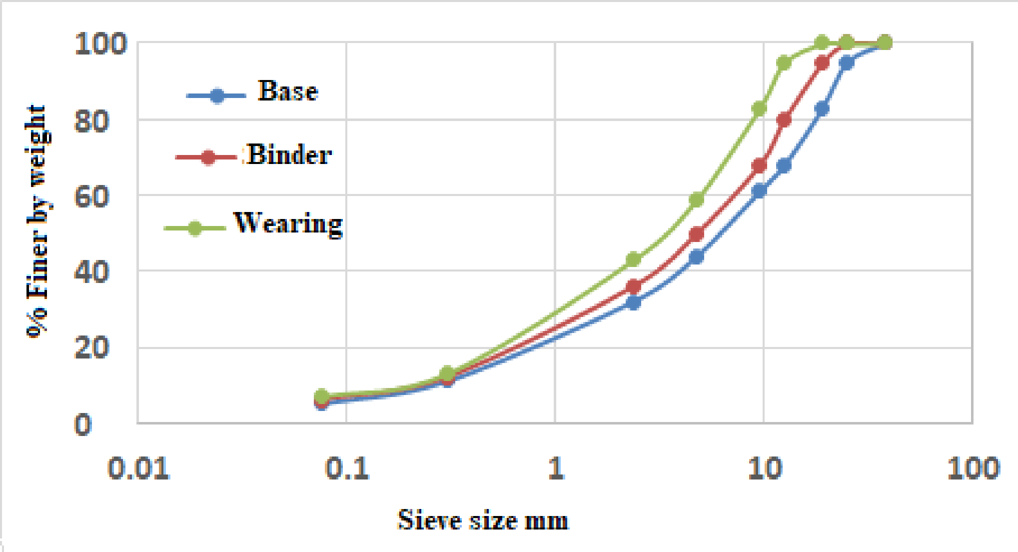

Fig. 1.*The Aggregate Gradation According to SCRB,[10]*

Preparation of Asphalt Concrete Mixtures

The aggregates were dried in an oven to a constant weight at 110 ºC, 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, [10] specifications. The combined aggregate mixture was heated to 150 º C before mixing with asphalt cement. The asphalt cement was heated to the same temperature of 150ºC, then it was added to the heated aggregate to achieve the desired amount and mixed thoroughly using 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, [11] 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 base course mixture was used. Specimens were tested for Marshall and volumetric properties, and the optimum asphalt content for each mixture was obtained.

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. Roller compaction was adopted as per EN12697-33, [13] with a static load start 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 to 135 °C. Figure 2 shows the roller compactor implemented.

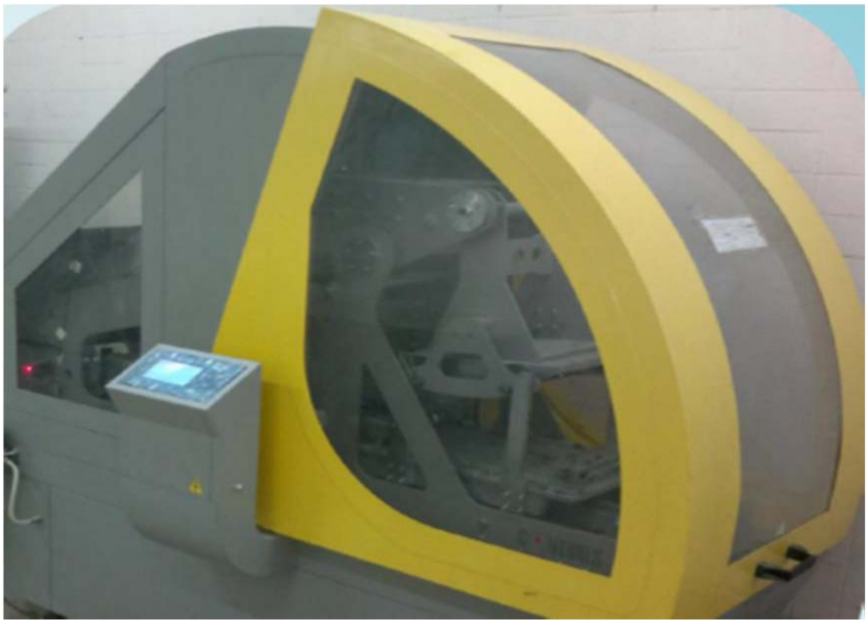

Fig. 2. *The Roller Compactor*

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. Afterword, 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.

Fig. 3. Prepared Slab Samples

Fig. 4. Part of the Core Specimens Obtained

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 ±0.5°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 110 mm and variable length of (100-120) mm based on testing combination of pavement layers. Testing was conducted at (20 and 40)° C at a constant loading rate of 5 mm/min. The test setup and testing mold are shown in Figure 5. 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 Zhang, [14]; Jaskula and Rys, [15]and Biglari et al., [16].

Fig.5. Interface Bond Shear Strength Testing Apparatus

RESULTS AND DISCUSSIONS

Influence of RC-70 Tack Coat application rate on Interface Bond Shear Strength IBSS at 20°C

As demonstrated in Table 7, the RC-70 tack coat was implemented between the base and the binder courses. Implementation of RC-70 tack coat at an application rate of 0.33 l/m^2 exhibit maximum IBSS of 1600 kPa as compared to higher or lower application rates when tested at 20 °C. This may be attributed to the fact that the possible coarse texture of asphalt concrete base course could handle the medium application rate of cutback (0.33 l/m^2). Higher or lower application rate of tack coat than 0.33 l/m^2 exhibit 8% reduction in IBSS.

Table 7. Impact of RC-70 tack coat application rate on IBSS (Binder/Base)

Pavement type	Application rate l/m^2	Interface Bond Shear Strength (kPa)
Base course layer Overlaid with binder course layer	0.15	1473
	0.33	1600
	0.50	1473

Table 8 exhibit the behavior of RC-70 tack coat when implemented between binder and wearing courses. It can be observed that the tack coat at an application rate of 0.15 l/m^2 exhibit maximum IBSS of 1515 kPa as compared to higher application rate when tested at 20 °C. This could be attributed to the smother texture of asphalt concrete binder course which can handle low application rate of cutback. Higher application rate of tack coat than 0.15 l/m^2 exhibit 8.3 % reduction in IBSS.

Table 8. Impact of RC-70 tack coat application rate on IBSS (Wearing/Binder)

Pavement type	Application rate l/m^2	Interface Bond Shear Strength (kPa)
Binder course layer Overlaid with Wearing course layer	0.15	1515
	0.33	1389
	0.50	1389

Influence of CMS Tack Coat application rate on Interface Bond Shear Strength IBSS at 20°C

Table 9 illustrates the behavior of CMS tack coat when implemented between base and binder courses. It can be observed that the tack coat application rate of 0.23 l/m^2 exhibit maximum IBSS of 1620 kPa as compared to higher or lower application rates when tested at 20 °C. This could be attributed to the course texture of asphalt concrete base course which can handle such medium application rate of emulsion. Significant variations in interface bond shear strength can be observed among variation in application rate. Higher or lower application rate of tack coat than 0.23 l/m^2 exhibit (1.3 and 22) % reduction in IBSS.

Table 9. Impact of CMS tack coat application rate on IBSS (Binder/Base)

Pavement type	Application rate l/m^2	Interface Bond Shear Strength (kPa)
Base course layer Overlaid with binder course layer	0.1	1263
	0.23	1620
	0.35	1599

However, Table 10 exhibits the behavior of CMS tack coat when implemented between binders and wearing courses. It can be observed that the tack coat at an application rate of 0.23 l/m^2 exhibit maximum IBSS of 1373 kPa as compared to other application rate when tested at 20 °C. It can be noted that the variation in IBSS is not significant among various application rates.

Table 10. Impact of CMS tack coat application rate on IBSS (Wearing/Binder)

Pavement type	Application rate l/m^2	Interface Bond Shear Strength (kPa)
Binder course layer Overlaid with Wearing course layer	0.1	1368
	0.23	1373
	0.35	1305

Influence of RC-70 Tack Coat application rate on Interface Bond Shear Strength IBSS at 40°C

As demonstrated in Table 11, the RC-70 tack coat was implemented between the base and the binder courses. Implementation of RC-70 tack coat at an application rate of 0.33 l/m^2 exhibit maximum IBSS of 166 kPa as compared to higher or lower application rates when tested at 40 °C.Dramatic reduction in IBSS could be noted due to increment in testing temperature from (20 to 40)°C. IBSS decreases by (93.8, 89.6 and 93.1) % for tack coat application rates of (0.15, 0.33 and 0.50) liter/m^2 respectively. Similar Behavior was reported by Nguyen et al., [2] and Bae et al., [1].

Table 11. Impact of RC-70 Tack Coat Application Rate on IBSS (Binder/Base)

Pavement type	Application rate l/m^2	Interface Bond Shear Strength (kPa)
Base course layer Overlaid with binder course layer	0.15	90
	0.33	166
	0.50	101

Table 12 exhibit the behavior of RC-70 tack coat when implemented between binder and wearing courses. It can be observed that the tack coat at an application rate of 0.33 l/m^2 exhibit maximum IBSS of 222 kPa as compared to higher application rate when tested at 40 °C. Great reduction in IBSS could be detected due to increment in testing temperature from (20 to 40)°C. IBSS decreases by (92, 84 and 89.7) % for tack coat application rates of (0.15, 0.33 and 0.50) liter/m^2 respectively.

Table 12. Impact of RC-70 Tack Coat Application Rate on IBSS (Wearing/Binder)

Pavement type	Application rate l/m^2	Interface Bond Shear Strength (kPa)
Binder course layer Overlaid with Wearing course layer	0.15	121
	0.33	222
	0.50	142

Influence of CMS Tack Coat application rate on Interface Bond Shear Strength IBSS at 40°C

Table 13 illustrates the behavior of CMS tack coat when implemented between base and binder courses. It can be observed that the tack coat application rate of 0.23 l/m^2 exhibit maximum IBSS of 344 kPa as compared to higher or lower application rates when tested at 40 °C. Great reduction in IBSS could be detected due to increment in testing temperature from (20 to 40)°C. IBSS decreases by (80.7, 78.7 and 83.4) % for tack coat application rates of (0.1, 0.23 and 0.35) liter/m^2 respectively.

Table 13. Impact of CMS Tack Coat Application Rate on IBSS (Binder/Base)

Pavement type	Application rate l/m^2	Interface bond strength (kPa)
Base course layer Overlaid with binder course layer	0.1	243
	0.23	344
	0.35	265

However, Table 14 exhibits the behavior of CMS tack coat when implemented between binders and wearing courses. It can be observed that the tack coat at an application rate of 0.23 l/m^2 exhibit maximum IBSS of 162 kPa as compared to other application rate when tested at 40 °C. The reduction in IBSS could be detected due to increment in testing temperature from (20 to 40)°C. IBSS decreases by (94, 88.2 and 92.4) % for tack coat application rates of (0.1, 0.23 and 0.35) liter/m^2 respectively.

Table 14. Impact of CMS tack coat application rate on IBSS (Wearing/Binder)

Pavement type	Application rate l/m^2	Interface bond strength (kPa)
Binder course layer Overlaid with Wearing course layer	0.1	81
	0.23	162
	0.35	99

Temperature Susceptibility at Interface

The temperature susceptibility of the interface shear strength issue is a perfect measure that can predict the durability of the asphalt pavement layers. It also can address the sustainability of the whole pavement layers throughout its design life. Table 15 demonstrates the variation in temperature susceptibility of the interface bond shear strength between asphalt concrete layers. It can be observed that the variation in temperature susceptibility at the base-binder interface was not significant among various application rates of RC-70 tack coat. On the other hand, an application rate of 0.33 l/m^2 exhibits the lowest susceptibility of the binder-wearing interface to the variation of testing temperature among other application rates of RC-70 tack coat.

Table 15. Impact of Tack Coat Application Rate on Temperature Susceptibility

Pavement type	Tack coat type	Application rate L/m^2	Temperature susceptibility kPa/°C
Base course layer Overlaid with binder course layer	RC-70	0.15	69.2
		0.33	71.7
		0.50	68.6
Binder course layer Overlaid with Wearing course layer		0.15	69.7
		0.33	58.3
		0.50	62.3
Base course layer Overlaid with binder course layer	CMS	0.1	51.0
		0.23	63.8
		0.35	66.7
Binder course layer Overlaid with Wearing course layer		0.1	64.3
		0.23	60.5
		0.35	60.3

However, when CMS tack coat was implemented, the lowest temperature susceptibility could be observed at 0.1 l/m^2 application rate for base-binder interface. It can be noted that the variation in temperature susceptibility at the wearing-binder interface was not significant among various application rates of CMS tack coat. It can be concluded that CMS Tack coat exhibit lower temperature susceptibility as compared to tack coat RC-70 regardless of asphalt concrete layer type or application rate.

CONCLUSIONS

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

1- Cationic emulsion CMS tack coat application rate of 0.23 $liter/m^2$ is suitable from the interface bond shear strength point of view regardless of testing temperature and pavement layer type.

2- Cutback RC-70 tack coat application rate of 0.33 $liter/m^2$ is suitable from the interface bond shear strength point of view at 40° C testing temperature regardless of the pavement layer type.

3- Tack coat CMS exhibit lower temperature susceptibility as compared to tack coat RC-70 regardless of asphalt concrete layer type or application rate.

4- Tack coat CMS can provide more sustainable and durable interface bond shear strength as compared to RC-70 tack coat.

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