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Assessing the Influence of Moisture Damage under Repeated Load on Multilayer Interface Bond Strength of Asphalt Concrete

Samah Abdul Razzaq Al Nuaimi
M.Sc Student
Department of Civil Engineering, College of Engineering, University of Baghdad, Iraq
Email: s.wahab1011@coeng.uobaghdad.edu.iq

Saad Issa Sarsam*
Professor
Department of Civil Engineering, College of Engineering, University of Baghdad, Iraq
Email: saadisasarsam@coeng.uobaghdad.edu.iq

ABSTRACT

The performance and durability of the asphalt pavement structure mainly depend on the strength of the bonding between the layers. Such a bond is achieved through the use of an adhesive material (tack coat) to bond the asphalt layers. The main objective of this study is to evaluate the effect of moisture in conjunction with repeated traffic loads on the strength of the bonding between asphalt layers using two types of tack coats with different application rates. Using the nominal maximum size of aggregate (NMAS), the layers were graded (25/19) and (19/9.5) mm. The slabs of multilayer asphalt concrete were prepared using a roller compactor using two types of tack coats to bond between layers, namely rapid curing cut back asphalt (RC-70) and cationic medium setting emulsion (CMS), with different application rates. Six extruded cores with a diameter of 116 mm each form the prepared slab has been obtained. Core specimens were subjected to moisture damage according to the American Association of State Highway and Transportation Officials (AASHTO), after which repeated bond shear stresses and monotonic tests are practiced. It is concluded that permanent deformation increased with moisture-induction under repeated load for both interfaces and tack coat types. The (CMS) as a tack coat had less permanent deformation values than RC-70 for both interface types and all application rates. In contrast, the interface bond strength (IBS) value was higher than that for (RC-70) in both interface types after moisture conditions. The trend of the results illustrates that (IBS) decreased with moisture conditions under repeated load, as compared to samples under repeated load only.

Keywords: Interface bond strength, Moisture, Multilayer asphalt concrete, Repetition traffic load, Tack coat

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*Corresponding author
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تقييم تاثير ضرر الرطوبة تحت تاثير الحمل المتكرر على قوة ربط السطح البيني متعدد الطبقات للخرسانة الاسفلتية

سعد عيسى سرسم
استاذ
كلية الهندسة –جامعة بغداد

سماح عبد الرزاق النعيمي
طالب ماجستير هندسة مدنية
كلية الهندسة – جامعة بغداد

الخلاصة

يعتمد أداء ومتانة القطاع الانشائي للرصف الأسفلتي بشكل أساسي على قوة الربط بين الطبقات. يتم تحقيق قوة الربط من خلال استخدام مادة لاصقة لربط طبقات الاسفلت ببعضها البعض .الغرض الأساسي من هذه الدراسة هو تقييم تأثير الرطوبة بالتزامن مع الحمل المروري المتكرر على قوة الربط بين الطبقات الاسفلتية باستخدام نوعين من المادة اللاصقة بمعدلات رش مختلفة. تم تصنيف الطبقات باستخدام الحجم الاعتباري الاكبر للركام (25/19) و (19 / 9.5) ملم. تم تحضير بلاطات من الخرسانة الاسفلتية متعددة الطبقات بواسطة جهاز الحدل المدولب باستخدام نوعين من المادة اللاصقة للربط بين الطبقات بمعدلات رش مختلفة، هما الأسفلت السائل سريع التطاير ، و المستحلب الاسفلتي متوسط الصلابة الموجب . تم الحصول على عدد (6) عينات اسطوانية بقطر 116 ملم لكل لوح بلاطة اسفلتية تم تحضيرها. تعرضت العينات الاسطوانية لتأثير الرطوبة وفقا لمواصفات المنظمة الامريكية للطرق والنقل , ثم تم تطبيق اجهادات قص متكررة و اختبار القص الساكن. اثبتت النتائج أن التشوه الدائم يزداد مع زيادة الرطوبة تحت تاثير الحمل المتكرر بغض النظر عن نوع الطبقات ونوع المادة اللاصقة. والمادة اللاصقة من النوع المستحلب الاسفلتي المتوسط الصلابة اعطت قيم اقل للتشوه الدائمي عن مثيلاتها باستخدام الاسفلت السائل السريع التطاير لكل انواع الطبقات ولجميع معدلات الرش في حين كانت قيمة قوة الربط لمادة المستحلب الاسفلتي اعلى من الاسفلت السائل سريع التطاير في كلا النوعين من الطبقات بعد تاثير الرطوبة. توضح النتائج أن قوة الربط تنخفض مع تاثير الرطوبة تحت الحمل المتكرر مقارنا بالعينات تحت الحمل المتكرر فقط.

الكلمات الرئيسية: قوة ربط السطح البيني , الرطوبة , طبقات الاسفلت المتعددة, الحمل المروري المتكرر , تاك كوت

1. INTRODUCTION

The road network is designed in such a way to be economical so that it can bear traffic loads and environmental effects during the design service life. The asphalt pavement structure consists of multilayers of asphalt concrete bonded by a tack coat. The layers are generally a dense-graded mixture; the surface layer of the pavement is designed to provide an appropriately smooth ride of traffic as well as to aim to prevent water from entering the underneath layers. The two layers are the binder and base layers, the main structure of which distributes traffic loads to the sub-layers and protect them from excessive stresses **(Sutanto, 2009)**. Cut back, emulsion and asphalt binders are used to bond the layers and to provide an integrated pavement structure that works as a single layer resistant to traffic loads and weather conditions, aiming to prevent premature failure **(Mohammad et al., 2002)**. The weak bonding between the two layers of the hot mix asphalt (HMA) causes many problems, fatigue cracking, top-down cracking, slippage, and delamination. Such bonding also results in a real tension on the bottom of the surface layer, where the stress concentration accelerates fatigue cracking and eventually leads to the failure of pavement structure **(Mohammad et al., 2002; West et al., 2005)**.

In general, the strength of the bonding between the base layer and the upper layer is affected by several factors, including the application rates, curing time, and methods of testing, as well as the surface, load, and tack coat types and weather conditions such as moisture rate and temperature. Moisture is one of the crucial factors that affect the performance of the pavement in terms of its durability and bearing capacity for traffic loads. Its effect appears in the case of water entering quickly into the pavement structure because of the weak bond, causing the pavement to fail within a few years of construction **(Sha, 1999)**.

(**Al-Qadi et al., 2008)** reported that the influence of moisture is reflected upon the strength of bonding between rigid and flexible pavements. Two types of binders have been used: standard IM195 and striping–vulnerable binder mix. It was found that the bonding strength decreased by 43% for the standard samples, whereas for the striping–sensitive binder mix, the bonding strength decreased by 67% after exposure to moisture. (**Ghabchi et al., 2017)** observed that moisture conditioning reduced the interface shear strength values when no tack coat has been applied. The use of a tack coat improved the extent to which it resists moisture-induced damage when applied at optimum residual application rates. As a result, tack coats can thus significantly reduce the effect of moisture-induced damage by acting as moisture –barrier only.

The present investigation aims to assess the influence of moisture under repeated load and the use of two types of tack coat on the permanent micro-strain and interface bond shear strength of multilayer asphalt concrete.

2. MATERIAL CHARACTERIZATION USED IN THE EXPERIMENTAL WORK

The materials used in this study were estimated conferring to the ASTM standard specification and compared with the requirements of the (SCRB, R/9 2003)**.**

2.1 Asphalt Cement

The asphalt cement used in a mixture component with a (40-50) penetration grade is brought from Al-Dura Refinery, south of Baghdad. The physical properties of the binder are presented in **Table 1**.

Table 1. Physical Properties of Asphalt Cement.

Test	Units	Test condition and ASTM,2013 Designation	SCRB,2003 Specification	Test result
Penetration	1/10mm	100gm, 25C^{o} , 5 sec (1/10mm)**,** D-5	40-50	46.5
Specific Gravity	1/10mm	@ 25 °C , D-70	--------	29.9
Flashpoint	gm/cm^3	Cleveland open cup ,D-92	>232	30.0
Ductility	°C	25 **°C**, 5cm / min ,D-113	>100	24.7
Softening point	cm	Ring and ball, D-36	-------	18.1
Kinematic viscosity	°C	9.5	--------	12.7

The residue after thin film oven test				
Penetration of residue	1/10mm	100gm, 25C , 5 sec (1/10mm) ,D-5	40 – 50	36.5
Ductility of residue	cm	25 °C, 5cm / min ,D113	>55	145
Loss in weight	%	5 hours at 163 C^{o},50 gm, D1754	<0.75	0.13

2.2 Cut Back Asphalt.

Cut back is a type of asphalt cement that is blended with a gasoline type distillate. In this research, the cut-back asphalt rapid curing of RC70, which is commonly used in Iraq, has been implemented as a tack coat. 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) l/m^2 have been implemented, which all fall within the limitations of the State Corporation for Roads and Bridges (SCRB) requirements (R/9 2003).

Table 2. Physical Properties of RC-70 Cut Back according to ASTM, 2013 Designation.

Test	**Specification Limits ASTM, 2013**		**Test Result**
	Minimum	**Maximum**	
Density (gm/liter), D2028D3142	---	---	995
Water concentration (%),D95	---	0.2%	0.1%
Residual by Evaporation(%), D2028	55%	---	0.9%
Kinematic viscosity (C. Stoke), D2170	70	95	75

2.3 Cationic Emulsion

The medium setting cationic emulsion CMS has been implemented as a tack coat. The residue of bitumen emulsion depends on the desired application of the latter. The physical properties of emulsion are illustrated in **Table 3**. Three residual application rates of (0.1, 0.23, 0.35) l/m^2 have been implemented, which are within the SCRB requirements (SCRB, R/9 2003).

Table 3. Physical Properties of Emulsion.

Property according to ASTM, 2013 Designation	Limits	Test Result
Emulsion type , D2397	Medium setting	Cationic (CMS)
Residue by evaporation %, D6934	Min 40	54
Specific gravity, gm/cm3 , D70	-------	1.04
Penetration (mm) , D5	100 - 250	219
Ductility(cm) , D113	Min 40	46
Viscosity, Saybolt-Furol viscometer @ 50 °C – AASHTO, 2013, AASHTO M208	110 - 990	348
Solubility in Trichloroethylene (%), D2042	Min 97.5	97.7
Emulsified asphalt/job aggregate coating practice, D244	Good	Fair

2.4 Aggregate

The aggregates are classified according to the sizes of the granules into coarse and fine aggregates. The Coarse Aggregate (uncrushed) is used for the bitumen's base layer, and crushed aggregate is used for the binder and wearing layers, obtained initially from the Babil Municipalities Directorate, through Al-Nibaee Quarry. The physical properties and the chemical composition of the graded coarse and fine aggregate are shown in **Table 4.**

Table 4. Physical Properties of Aggregates.

Property	**Coarse Aggregate**	**Fine Aggregate**	**SCRB, 2003 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

2.5 Mineral Filler

One type of mineral filler was used, namely Portland cement. It is completely dry and free of lumps or fine particles collected. The chemical compositions and physical properties are presented 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 compositions of Portland cement filler.

Property	**Test result**
%passing Sieve NO.200(0.075mm)	97
Specific Gravity	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 are sieved, after which they are reassembled onto their appropriate proportions to meet the requirements of the base, binder, and surface course gradations. **Fig. 1** exhibits the aggregates gradations used to prepare mixtures for wearing, binder, and base courses, respectively, as per SCRB (2003).

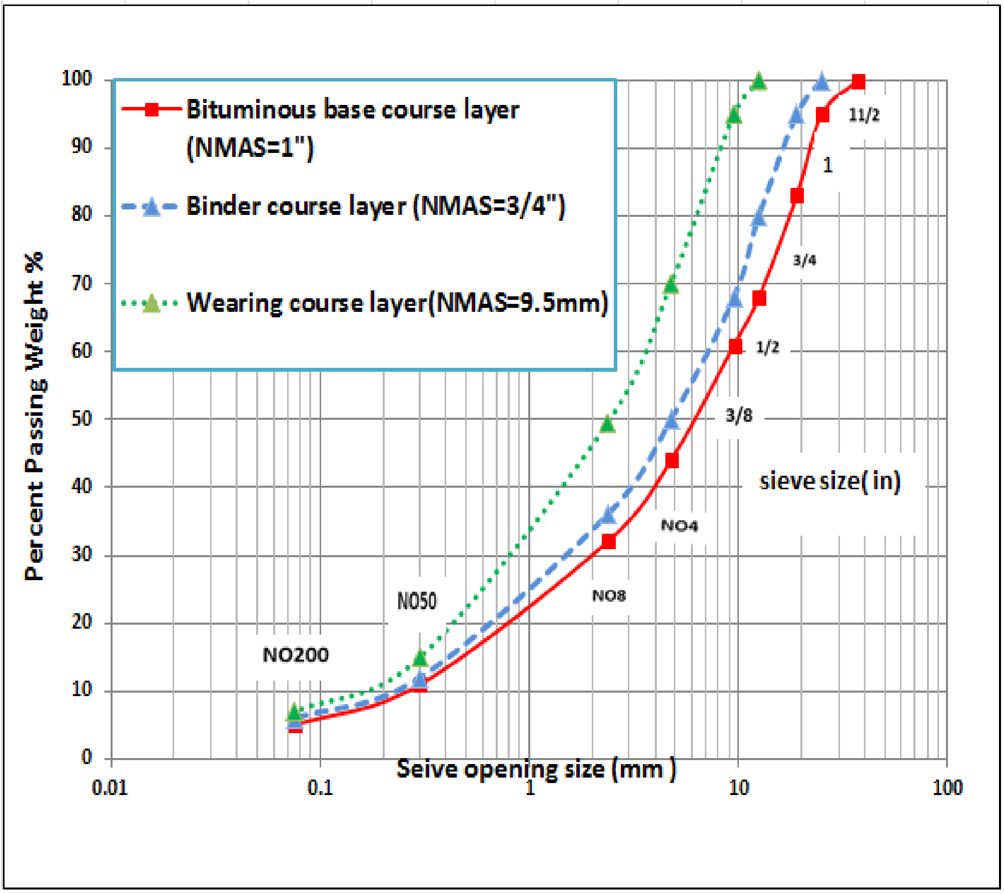
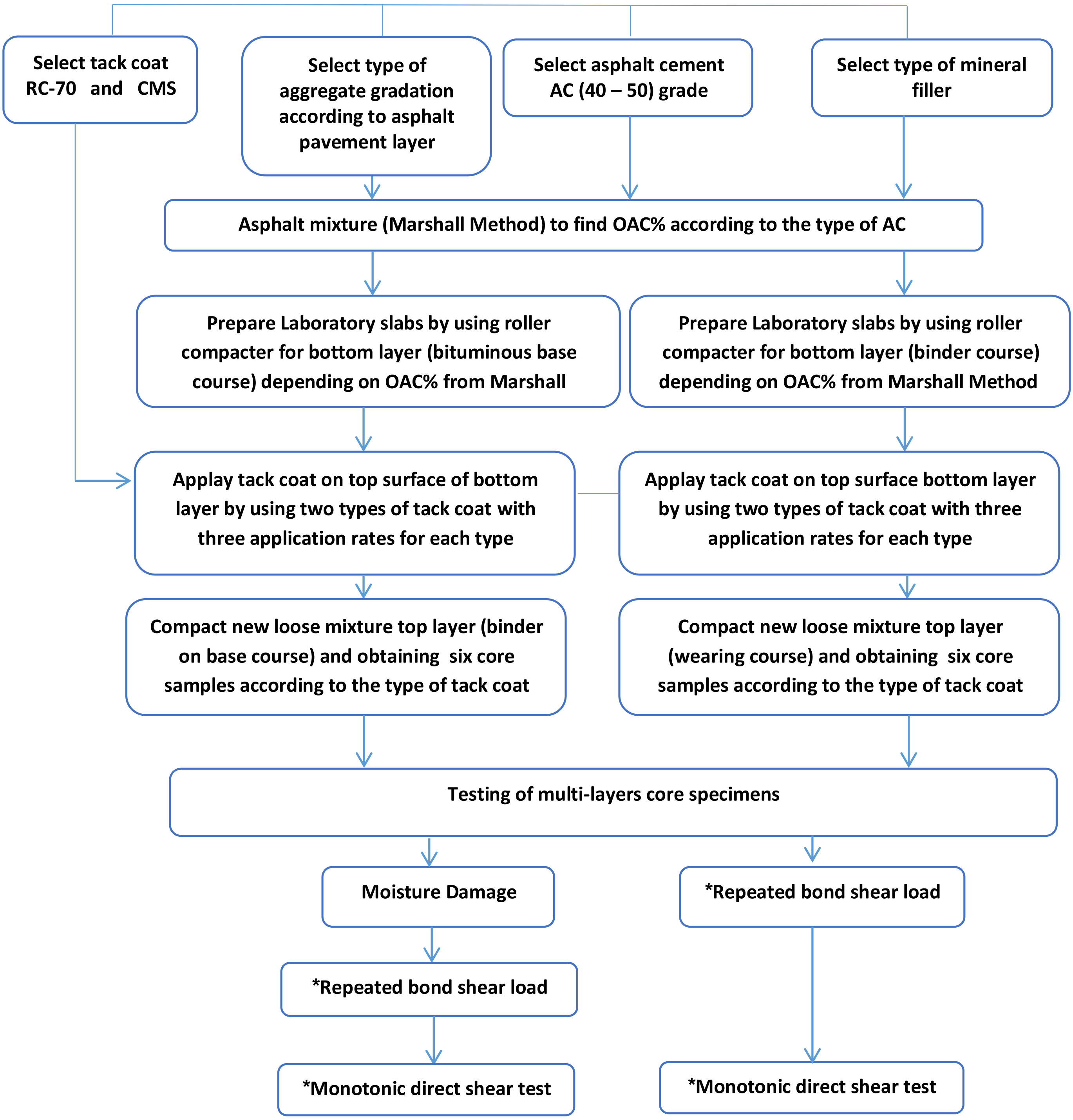


Figure 1. The Aggregate gradation, according to SCRB, 2003.

3. EXPERIMENTAL WORK

The flow chart below represents the research methodology, as seen in **Fig. 2**



*****as compared between test results

Figure 2. Flow chart of laboratory work.

3.1 Design of Hot Mix Asphalt using Marshall Method

The Marshall Size specimens were prepared under (ASTM D1559, 2015) using 75 blows of the automatic Marshall compactor on each face of the samples for the binder and wearing course mixtures. However, 50 blows of Marshall Hammer were used on each face of the sample for bituminous base course mixture according to SCRB, 2003 requirements. A total of 45 cylindrical specimens were prepared with a 101.6 mm diameter and a height of 63.5mm. The specimens were tested to determine their Marshall stability, flow value, air voids (Av%), Voids in Mineral Aggregate (VMA), Void Field with Asphalt (VFA), Bulk density, and the Optimum Asphalt Content (OAC). It was found that the OAC% is (5, 4.7, and 4.35) % for the layers. More detailed analysis to determine the optimum asphalt content value is given in section 4.1

3.2 Preparation of Asphalt Concrete Slab Samples and Core Specimens

The multilayer asphalt concrete slabs of a (400x300mm) dimension are prepared to depend on the optimum values of density and asphalt content of Marshall Specimens, using a Roller Compactor to simulate work on site. Preparation of the lower interface layers are of two types: a bituminous base course layer with a thickness of (80mm) and 4.35% asphalt content, and a binder course layer with a depth of (60mm) and 4.7% asphalt content, compacted by the Roller compactor adopted as per (EN12697-33, 2007) with a static load start from 2.4 KN for ten cycles. The load increased every ten 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 compacting temperature was 135˚C. After compaction, the asphalt concrete slab is left in the mold for 24 hours until it cools in a laboratory environment. The next step involves the tack coat application. The tack coat layer must be applied regularly and correctly to the surface of the bottom layer prepared with the correct weight for each application rate according to the percent of the residue asphalt after evaporation and density, as shown in **Tables 2** and **3**. In this study, the application is performed using a brush, and three different applications rate are used for each type of tack coat, within the limits of Iraqi specifications SCRB, R8 2003: (0.15, 0.33, 0.5) l / m^2 for RC-70, and (0.1, 0.23, 0.35) l / m^2 for CMS tack coat. The RC-70 is heated to a temperature (65 to 85)˚C and then applied to the upper surface of the bottom layer, while the emulsion is applied at laboratory temperature. Then it was left for two hours (breaking time) followed by the final step. Preparation of the upper layer of the asphalt pavement is the same as the process for the lower layer; the difference lies in the use of two types of asphalt pavement, the first being of a 40 mm thickness had laid over the base course, and the second is the surface layer with a thickness of 40mm had laid over the binder. Slab samples are left for 24 hours to cool. Afterward, six core specimens of 116 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. Steps prepare slab samples and cores.

3.3 Moisture Susceptibility

This study aims to evaluate the effect of moisture on the interface bond shear strength. The standard conditioning procedure described in AASHTO Designation T283-02 for conditioning the HMA specimen was implemented. The interface shear strength was determined before and after the moisture damage under repeated load conditioning. Two subsets (I and II) of the base/binder and binder/surface specimens were tested, each having three replicates for every tack coat type. Subset I was tested dry after repeated load, and subset II was exposed to repeated load after practicing moisture damage. Subset II was conditioned according to the following procedure. As shown in **Fig. 2**, the specimen was first placed in the vacuum bowl at 28mm Hg (3.74kPa) for (5 to 10) min. After removing the air bubbles by vacuum, the specimen was submerged in water both at (25ºC) for a short time (5 to 10 min).

3.3.1 Calculation of the degree of saturation (S)

Formula (1) was implemented for the calculation of the degree of saturation.

$$S=100J/Va \qquad (1)$$

Where,

S = degree of saturation, percent, %;

J = volume of absorbed water, cm^3; and

Va = volume of air voids, cm^3.

The degree of saturation was between (70 to 80%). The specimens were placed in a freezer at (-18°C) for 24 hours, after which the samples are put in a bath containing potable water at (60±1 °C) for 24 hours. Next, the specimens were placed in a water bath at temperature (25 °C) for 2 hours. The specimens were then tested for PRLT at 20°C and fractured using a Versa device to evaluate the interface bond strength. **Fig. 4** presents the saturation and moisture damage process.

Figure 4. Steps exposed specimens to moisture susceptibility.

3.4 Repeated Loading Test

The Pneumatic Repeated load system PRLS device has been used in the test, as developed by **Al-Bayati (2006)**. The direct repeated bond shear stress was applied for cylindrical specimens, with a 116mm diameter and a 120 mm depth, and a diameter of 116mm and depth of 100mm. The pneumatic repeated load system used shear loading with a stress level of (20 psi) applied with a constant frequency of 1hz load duration (0.1sec) and a rest period of (0.9sec). **Fig.5** demonstrates specimen testing in PRLT. The direct repeated load tests were done at 20°C. The permanent strain (εp) is calculated by applying the following equation, (2), where the measurement of the permanent micro-strain is at the subsequent load in the equation:

$$\varepsilon\rho=\frac{\rho d\times10^{6}}{D} \quad (2)$$

Where:
ερ : Permanent microstrain (mm/mm)
pd: reading of dial gage for permanent strain (1degree=0.01min)
D: specimen diameter

The specific details of the measurement procedure have been reported previously in the scatter equation (3) suggested by (**Monismith et al., 1975) and (Barksdale, 1971).**

$$\varepsilon\rho= a\ Nb \quad (3)$$

Where
ερ= permanent microstrain
N=number of load repetition
a= intercept microstrain
b=slope coefficient.

The higher value of intercept, the higher the strain, and hence the higher potential for permanent deformation. The steps of the analysis process are outlined by (**Sarsam and Alwan, 2014).**

Figure 5. Mold and specimen in chamber pneumatic repeated shear load test .

3.5 Interface Bond Shear Strength Test.

The direct shear test is the most common way to check the interface bond strength of its quick and frequent use in a laboratory. In previous research, the shear strength obtained was found to be parallel to the interface of two asphalt layers. As for the mold to assess the bond strength, it was made locally consisting of two parts, one being fixed, while the other is movable. The sub-layer is placed in the stator that does not allow any movement, and the upper layer is placed under the influence of a direct shear load of (1cm) from the bond area between the two layers. The mold and sample are placed in the chamber to achieve the test temperature 20˚C. Then, they are put in the Versa device, applying a constant shear load of 50.8 mm/minute. The interface bond strength is calculated by dividing the highest shear force that caused the failure over the cross-sectional area. **Fig. 6** shows the inspection steps of the bonding strength. The observations also agree with the results reported by (**Ghaly et al., 2013) (Yaacob et al., 2018) and (Mohammad et al., 2002).**

Figure 6. Interface bond strength testing (Monotonic shear load test).

4. TEST RESULTS AND DISCUSSION.

4.1 Optimum Asphalt Content (OAC) %

The main objective Marshall tests determine is to OAC% for the various nominal maximum size of aggregates of (25, 19, and 12.5) mm for the base, binder, and wearing courses respectively, as well as the different asphalt content of (5, 4.7 and 4.35) % for the base, binder and wearing courses layer respectively. The Marshall and volumetric properties are summarized in **Table 6.**

Table 6.Summary Marshall Properties at OAC %.

layer	Optimum asphalt cement			Average optimum asphalt
	Max stability	Max unit weight	Air void 4%	
Surface	4.55	5.3	5.15	5
Binder	4.8	4.3	5	4.7
Base	3.9	4.65	4.5	4.35

4.2 The Influence of moisture under Repeated Shear Load and tack coat type on Permanent Microstrain.

The influence of moisture and tack coat type with application rate under repeated load on permanent microstrain after 1200 load repetitions with shear stress 138Kpa, before and after moisture was evaluated as is described below.

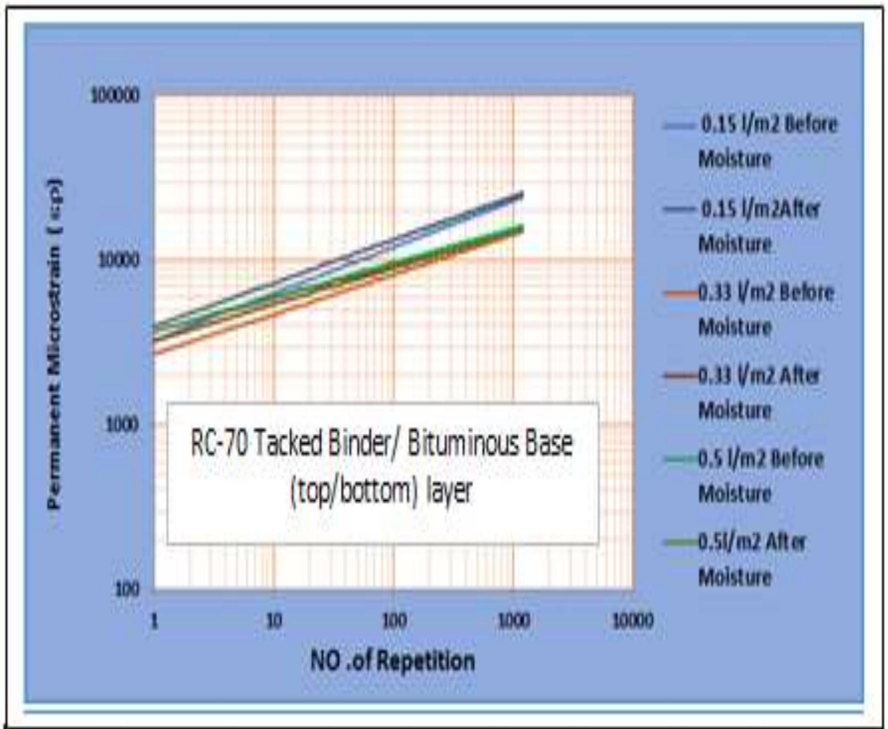
4.2.1 Using RC-70 tack coat

4.2.1.1 Application of RC-70 tack coat between the binder/bituminous base layer:

This tack coat is applied with residue application rates (0.15, 0.33, 0.5) l/m^2. The deformation varies according to the application rate, the application rate of the tack coat increases. The rate of increases in permanent deformation decreases as compared to the 0.15 l/m2 application rate. On the other hand, the application rate of the tack coat increases, the permanent microstrain increases. This value may be attributed to the more flexible binder added to the interface. The permanent microstrain slightly increases for all application rates by (4.37, 4.27, 3.76) % after moisture conditions. This rate of increase is considered to be significant after moisture damage under the influence of repeated loads. **Table 7** and **Fig. 7** shows the details of permanent deformation, intercept, and slope. The values of the intercept increase by (21.63 and 22.13) % for (0.15, 0.33), respectively, whereas a decrease in application rate (0.5) l/m^2 is (0.9) % was considered to be insignificant.

4.2.1.2 Application of RC-70 tack coat between the wearing /binder layer:

Table 7 and Fig. 7 illustrate that the values of permanent deformation increase due to the effect of moisture by (28.69, 27.23, 16.17)% for all application range limits (0.15,0.33, 0.5) l/m^2, indicating a low resistance to moisture damage under the influence of repeated loads. The increased value of the intercept seems significant. The values of the intercept increased by (14.02, 49.9, 43.11)% after moisture damage for all application range limits (0.15, 0.33, 0.5) l/m^2, as compared to samples under repeated load only.



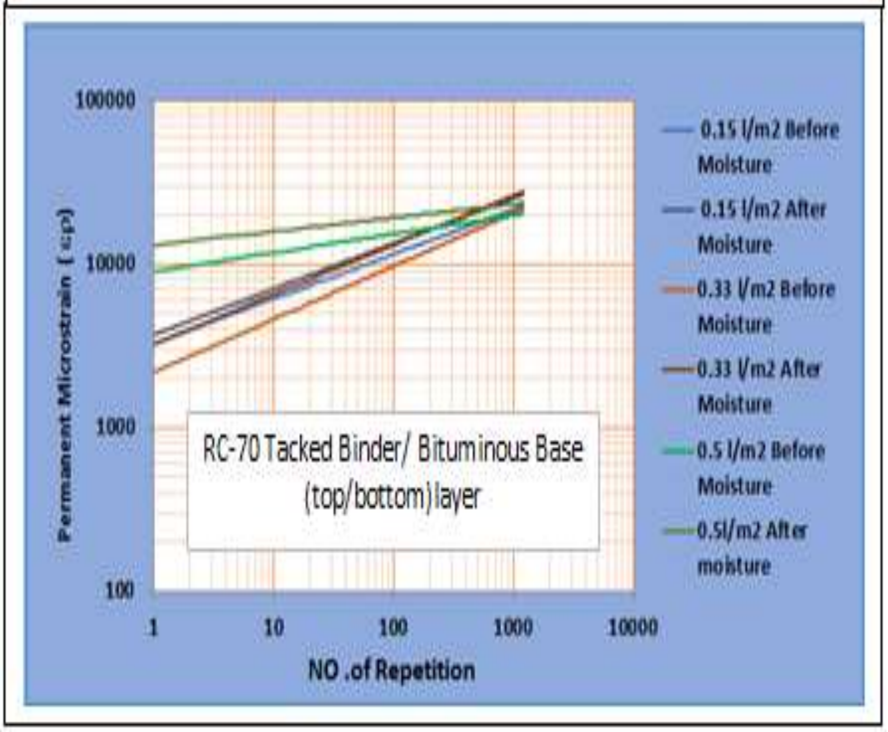


Figure 7. Typical relationship between permanent microstrain, intercept and slope before and after moisture conditioning under repeated load with RC-70 as tack coat and different percent.

Table 7. Summary intercept, slope, and microstrain for each surface type with RC-70 tack coat in control and moisture.

Tack coat type	Surface existing layer	Stress level (KPa)	Process	Application rate(l/m^2)	intercept	Slope	microstrain
RC-70	Base course	138	Before Moisture under Repeated load	0.15	3287.1	0.2822	25200
				0.33	2674.3	0.2433	16400
				0. 5	3742.8	0.24064	18600
			After Moisture under Repeated load	0.15	3989.2	0.2625	26300
				0.33	3266	0.22	17100
				0. 5	3707.5	0.2006	19300
Tack coat type	Surface existing layer	Stress level (KPa)	Process	Application rate(l/m^2)	intercept	Slope	microstrain
RC-70	Binder course	138	Before Moisture under Repeated load	0.15	3296	0.2724	23000
				0.33	2194.2	0.3243	22400
				0. 5	9216.6	0.1121	23500
			After Moisture under Repeated load	0.15	3758.2	0.2767	29600
				0.33	3290.7	0.3008	28500
				0. 5	13097	0.0836	27300

4.2.2 Use CMS tack coat

4.2.2.1 Application of CMS between the binder/ bituminous base layer:

In light of the application rates (0.1, 0.23, and 0.35) l/m2, the permanent deformation varies accordingly, as it increases for all applications with the effect of moisture by (33.54, 2.52, 2.15) % respectively. The slight increase in the rate (0.23, 0.35) l/m^2 is considered insignificant, indicating the resistance to moisture damage under the influence of repeated loads in **Table 8.** and

Fig. 8 shows the details of permanent deformation, intercept, and slope. The values of the intercept increase by (37.13, 80.67, 101.24) %.

4.2.2.2 Application of CMS between wearing/binder layer:

Table 8. and **Fig. 8** presents the values of permanent deformation, which increase with the effect of moisture and application rates (0.1, 0.23, 0.35) l/m^2 by (4.57, 3.27, 57.69) %. The percentage increased slightly for (0.1, 0.23) l/m^2, which is regarded to be of insignificance, indicating the resistance to moisture damage under the effect of repeated load. The intercept after moisture condition has increased for mid and high limit application rate by (60.93, 61.96) % while the low limit reduced the intercept by (31) %.

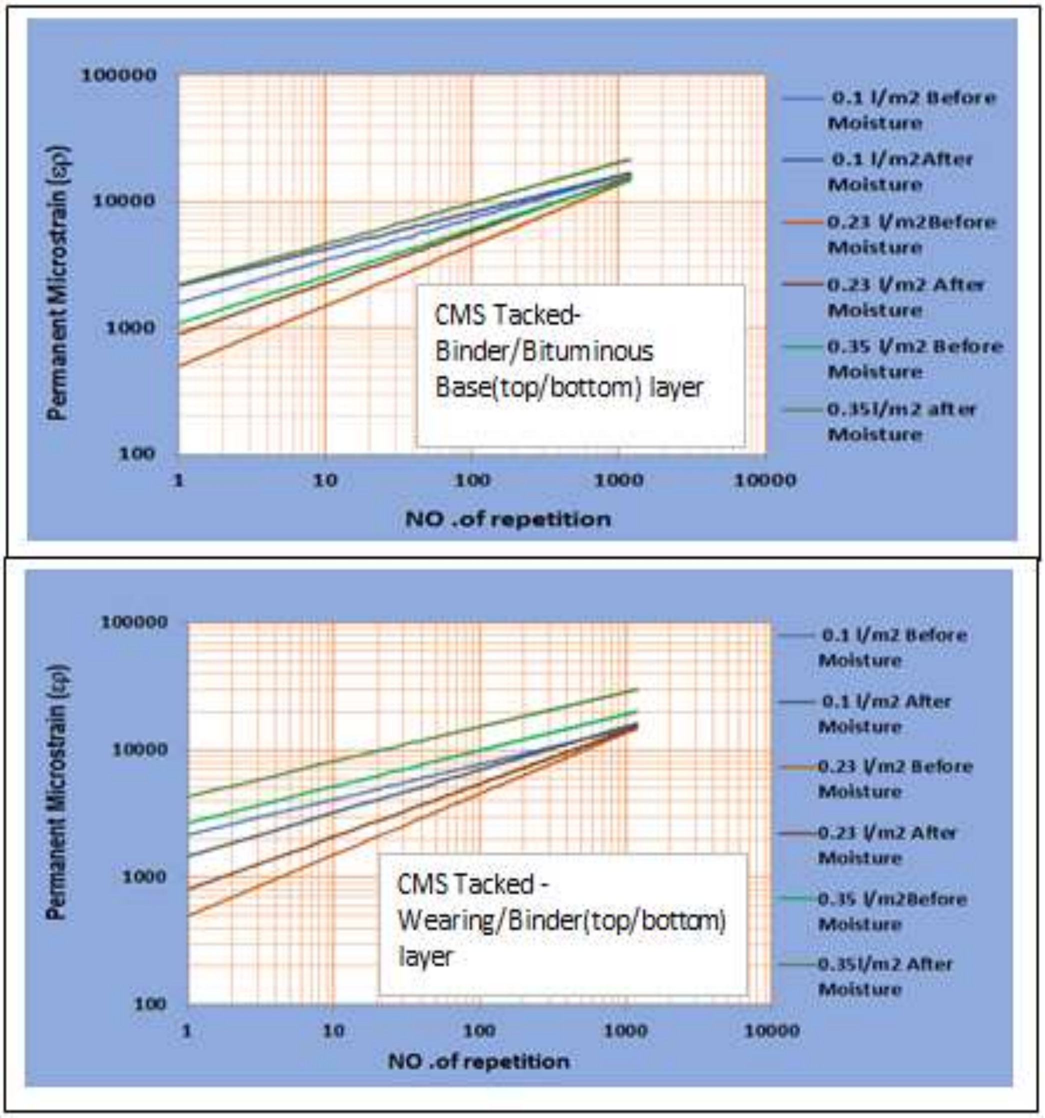


Figure 8. Permanent microstrain value of multilayer asphalt concrete before and after moisture under repeated load with CMS as a tack coat.

Table 8. Summary intercept, slope, and microstrain for each surface type with CMS tack coat in control and moisture.

Tack coat type	Surface existing layer	Stress level (KPa)	Process	Application rate(l/m^2)	intercept	Slope	microstrain
CMS	Bituminous Base course	138	Before Moisture under Repeated load	0.1	1583	0.3337	18600
				0.23	496.38	0.4795	15900
				0. 35	1091.5	0.3721	16400
			After Moisture under Repeated load	0.1	2170.9	0.2886	19000
				0.23	896.84	0.4044	16300
				0. 35	2196.6	0.3223	21900
Tack coat type	Surface existing layer	Stress level (KPa)	Process	Application rate	intercept	Slope	microstrain
CMS	Binder course	138	Before Moisture under Repeated load	0.1	2168.3	0.2756	17500
				0.23	498.62	0.4793	15300
				0. 35	2690	0.2837	20800
			After Moisture under Repeated load	0.1	1480.3	0.3375	18300
				0.23	796.98	0.4164	15800
				0. 35	4356.6	0.2718	32800

4.5 Influence of Moisture on Interface Bond Strength by using Static Load (Versa Device)

After exposing the samples to repeated loads by PRLS, the samples are tested by the Versa device to assess the interface bond shear strength between the layers of moisture and non-moisture-exposed samples to compare them. The Bond strength values vary according to the substrate surface type. The increase in the nominal maximum size of the aggregate in the asphalt mixture leads to a rise in the bonding strength. **Table 9** and **Fig.9** shows the differences in the bonding strength according to the application rate and the type of surface texture, using the RC-70 tack coat.

4.5.1 The application of the RC-70 tack-coat between the binder/base and wearing/binder layers:

Decreased the bond strength when exposed to moisture by (26.68, 23.7, 25.32) % for residual application rates of (0.15, 0.33, 0.5) l/m^2, respectively. The application of the RC-70 tack coat between wearing/binder was also found to reduce the bond strength when exposed to moisture, and the ratio of decrease in bonding strength, as compared to samples that are not exposed to moisture, is (34.71, 18.21, 27.28)% for each application rate, respectively. The IBS for each mixture type and application rate has a low value in the lower application rate. In contrast, a high IBS value is observed in the mid application rate (optimum application rate), followed by a subsequent decrease in IBS value, as it remains larger for the binder/base course layer than the wearing/binder course layer. It has been observed that they were more sensitive to moisture damage under repeated wearing/binder

Table 9. Change in IBS in moisture for each surface course layer with RC-70 tack coat.

Bottom layer sample	Tack coat Type	Application rate l/m^2	Interface bond strength (KPa)After repeated load (before moisture)	Interface bond strength(KPa) After moisture under repeated load	Change in Interface Bond Strength after Moisture %
Bituminous Base course NMAS 25 mm	RC-70	0.15	1473	1080	-26.68
		0.33	1599	1220	-23.7
		0. 5	1473	1100	-25.32
Binder course NMAS 19mm		0.15	1515	989	-34.71
		0.33	1389	1136	-18.21
		0. 5	1389	1010	-27.28

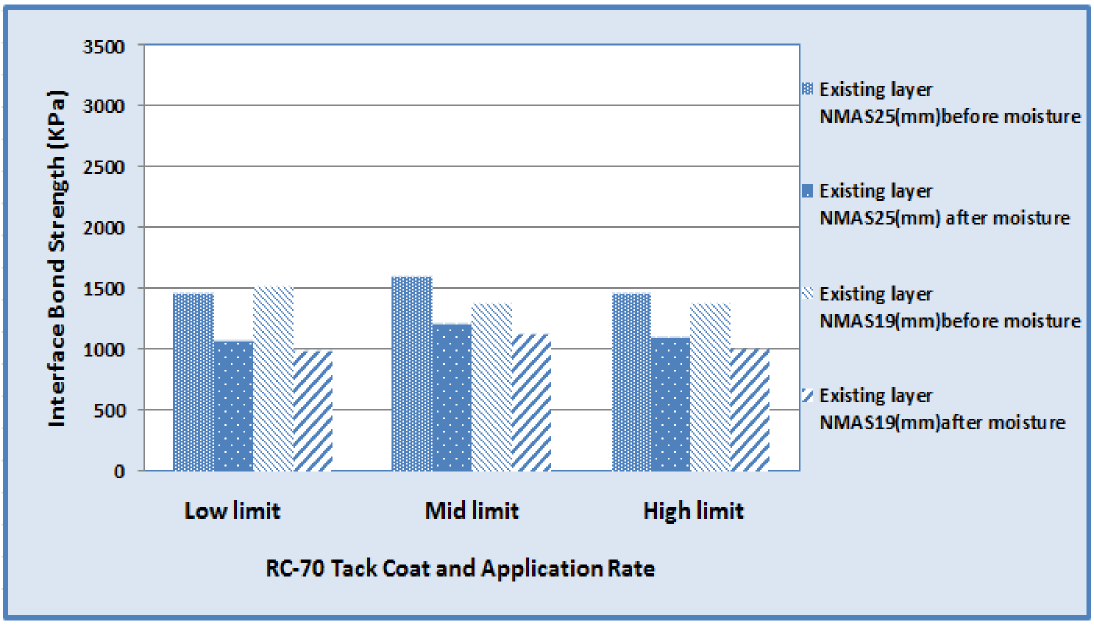


Figure 9. IBS for samples exposed to repeated load before and after moisture conditioning with RC-70 tack coat.

4.5.2 The application of the CMS tack coat between the binder/base and wearing/binder layers:

Reduces the bond strength when exposed to moisture at the application rates (0.1, 0.23, 0.35) l/m^2 by (11.71, 1.29, 16.32) %, respectively. At the same time, the CMS tack-coat implemented between wearing/binder reduces the bond strength in moisture by (12.28, 8.79, 14.55) % for all application rates (0.1, 0.23, 0.33) l/m^2, respectively. The IBS for each mixture type and application rate has less value in the lower application rate, while the IBS value is higher for the mid application rate followed by a subsequent decline in IBS value. These results indicated that CMS was slightly susceptible to moisture at (0.23) l/m^2 application rate. The IBS values remain larger in the wearing/binder course layer than in the binder/base course layer as compared to pre-moisture. Increased sensitivity is observed for the binder/base when moisture under repeated load, as is illustrated in **Table.10** and **Fig. 10**.

Table 10. Change in IBS due to moisture for each type course layer with each CMS tack coat

Bottom layer sample	Tack coat Type	Application rate l/m^2	Interface bond strength (KPa) after repeated load Before moisture	Interface bond strength (KPa) Moisture after repeated load	Change in Interface Bond Strength after Moisture %
Bituminous Base course NMAS 25 mm	CMS	0.1	1263	1115	-11.71
		0.23	1620	1599	- 1.29
		0.35	1599	1338	- 16.32

Binder course NMAS 19mm		0.1	1368	1200	-12.28
		0.23	2273	2073	-8.79
		0.35	1305	1115	- 14.55

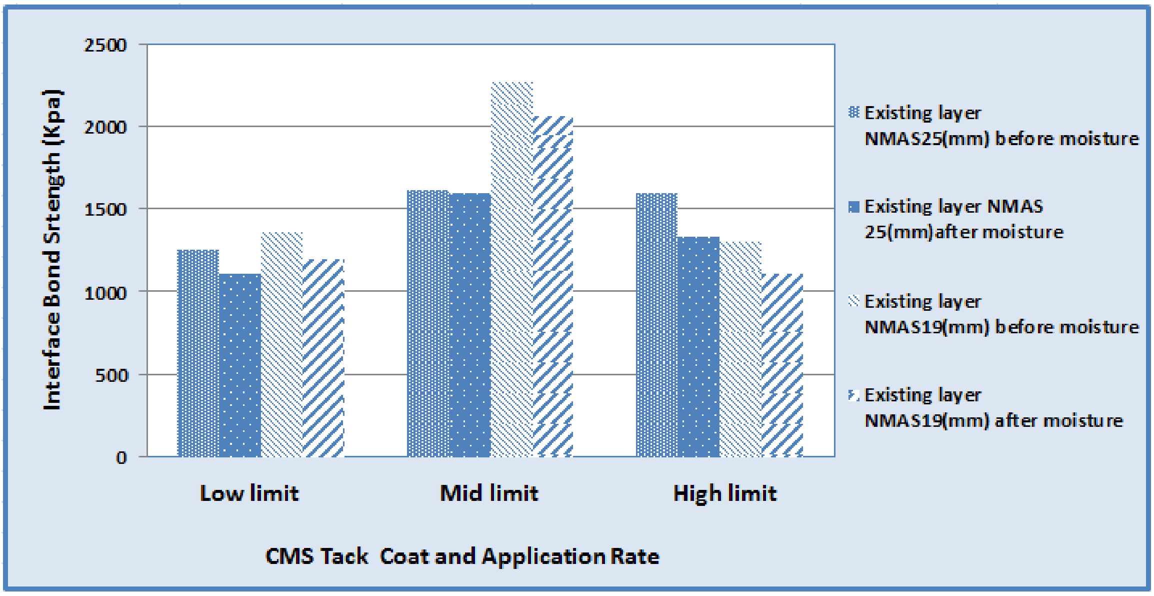


Figure 10. IBS for samples exposed to repeated load before and after moisture conditioning with CMS tack coat.

5. CONCLUSIONS

The most relevant conclusions are:

- The permanent micro-strain for samples with RC-70 binder/base before and after moisture under repeated load changes marginally by (4.36, 4.23, 3.76) %. Meanwhile, it increased significantly in the wearing/binder course layer by (28.69, 27.23, 16.17) % for each application rate, respectively. The permanent micro-strain for the binder/base with CMS as tack coat increased by (2.15, 2.52, 33.54) %, where a respective growth of (4.57, 3.23, 14.42) % is noted under moisture conditioning for the wearing/binder course layer.
- The IBS values rise subsequently with the increase of application rates until the optimum application rate is reached, after which it declines.
- The samples with RC-70 binder/base were less durable and having a lower IBS value to moisture by (26.68, 23.72, 25.33) % for the application rates of (0.15, 0.33, 0.5) l/m^2, respectively. The samples of wearing/binders have a lowered IBS value by (34.73, 18.21, and 27.28) % for the application rates (0.15, 0.33, and 0.5) l/m^2, respectively, as compared to the pre-moisture samples under repeated load.
- The impact of moisture conditioning for samples with CMS for binder/base shows a decline in resistance and a less IBS value to moisture for (0.1, 0.23, 0.35)l/m^2 at

application rate by (11.71, 1.29, 16.32)%. The samples of the wearing/binder had a less resistance for (0.1, 0.23, 0.35) l/m^2 by (12.28, 16.84, 14.55) %, respectively.

- In general, the IBS value observed was higher with CMS as a tack coat for all interface types in moisture conditioned, as compared to the RC-70 tack coat.

NOMENCLATURE

PRLS = Pneumatic Repeated Load System.
$\varepsilon\rho$ = Permanent Microstrain.
O.A.C = Percent Optimum Asphalt Cement, %
IBS = Interface Bond Strength, KPa
RC-70 = Cut Back Asphalt Rapid curing
CMS = Cationic Medium Setting Bitumen Emulsion.

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