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ASSESSING THE EFFECT OF EMULSIFIED ASPHALT AS A REJUVENATOR FOR HIGHLY OXIDIZED ASPHALT PAVEMENT

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ABSTRACT

Rejuvenation of highly oxidized asphalt pavement is a good choice in reducing the binder viscosity and hardness to reach the desired mixture workability and the necessary performance, especially when using high percentage of reclaimed asphalt pavement (RAP) in the mixture. Rejuvenating agents such as emulsified asphalt cements or emulsified recycling agents are utilized for fully cold recycling operations due to the liquid nature for them at ambient temperatures, also these agents have the ability for being scattered throughout the mixture, and do not consider a reason in main air pollution problems. The purpose of this research is studying the effect of emulsified asphalt type cationic slow setting low viscosity (CSS-1) as a rejuvenator material for an aged asphalt pavement, design cold recycled mixture (CRM) under Superpave system for binder course layer and evaluating the final mix design for stability and flow, index of retained strength and punching strength in comparison with hot recycled mixture (HRM). The results indicated that CSS-1 played an important role to help utilizing high RAP percentage in CRM as compared to HRM due to its effectiveness as softening agent to the hardening binder.

INTRODUCTION

Reclaimed asphalt pavement (RAP) consists of an old paving materials that has been deteriorated during its service life and so, they are removed usually by milling machines, resulting in production of large amount of wasted materials. Recycling is a good solution for restoring of damaged road networks (Jeff and Miles, 2006).

Generally, the recycling of waste asphalt mixture can be divided into two important types, cold and hot. The difficulties of the asphalt pavement conservation and rehabilitation can be solved by cold recycled technology which considers a cost-efficient and environmental friendly (Kandhal and Mallick, 1997). Besides the reduction of environmental effect intensity, cold recycling technique has the prospect to reuse higher percentages of RAP. A maximum of 40 % RAP is mostly accepted for the hot recycled asphalt mixtures in the base layers, and this worth being minimized to 15 % or even prohibitive in the surface layers. The reuse of RAP can be as high as 100 % for cold recycled asphalt mixtures, but this generally performs in a loss of mechanical properties and toughness. This can be handled by adding rejuvenating agents such as emulsified asphalt. Virgin aggregates and active fillers can be added to the cold recycled mixture to meet the grading criteria.

Rejuvenating agents are expected to restore the reclaimed binder characteristics to a consistency level appropriate for construction using purposes and pavement performance, and at the same time, to optimize the chemical properties with regard to the durability. It should also provide sufficient extra binder to coat and bind any new aggregate that is added to the reclaimed mixture and satisfy the design requirements. The softening impact of a rejuvenator is done by restoring the balance between maltenes, which are the volatile fraction of the bitumen lost with time, and the asphaltenes, which are generated and precipitated as a result of the ageing (Schiavi et al., 2003). The normal changes in chemical texture with aging of a typical asphalt pavement are shown in figure (1). Rejuvenators should easily be dispersed in the old binder, and as well be uniform from batch to batch, and practical to use, for example preventing flashing, smoking and health risks (Epps et al. ,1980).

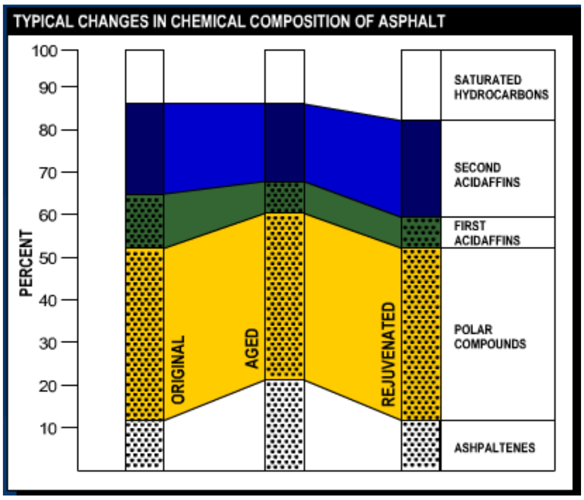

Figure (1): The Typical Changes in Chemical Composition of Asphalt (Brownridge and Grady, 2010).

MATERIALS AND METHODS

MATERIALS UTLIZIED:

I. Virgin Materials:

The emulsified asphalt used in this study as a rejuvenator was Cationic Slow-Setting type low viscosity (CSS-1) from MEGA INSAAT Company (Turkish company). Tests which conducted on the emulsified asphalt to check whether it meets the requirements in ASTM D2397 were Particle Charge test, Saybolt Furol Viscosity at 25°C, Residue by Distillation, Residue By Evaporation, Sieve test, Cement Mixing test, Settlement test (5 Day), Storage Stability test (1 Day), Penetration of Residue, Ductility, Solubility in trichloroethylene of Residue and Specific Gravity at 25°C and the results were Positive, 26, 55.3%, 54.9%, 0.02%, 0.732%, 0.1%, 0.04%, 133, 185cm, 99%, and 1.02 respectively.

Asphalt cement (40-50) penetration grade from AL-Daurah Refinery in Baghdad was used in this study. Several tests were conducted on it which were penetration, ductility, specific gravity, flash and fire points, kinematic viscosity at (135°C and 165°C), and loss on heating in order to check whether it meets SCRB (Section R9, 2003) specifications and the results were 47, 125cm, 1.032, (315°C and 338°C), (551cSt. and 127cSt.), and 0.226% respectively.

Coarse aggregate with nominal maximum size gradation (19 mm) and bulk specific gravity (2.588) and ***Crushed Sand*** with bulk specific gravity (2.604) were obtained from graded aggregate stockpiles used for locally asphalt concrete batch plant located in Jurf Al-Naddaf, in the eastern south of Baghdad where its source was Al-Nibaie Quarry. The physical properties which were wear by (Los Angeles Abrasion), soundness (Loss by Sodium Sulfate Solution) , flat and elongation for coarse aggregate with values 25%, 5.91%, 2% and 4% respectively and the clay content for fine aggregate with value 72% conformed the specifications in (SCRB/R9, 2003).

One type of ***mineral filler*** (***Ordinary Portland Cement***) had been used in this study, which was obtained from Mass Company which its source was Al-Sulaymaniyah City with bulk specific gravity (3.1) and passing from sieve No.200 (0.075 mm) (97%).

II. Recycled Materials:

The reclaimed asphalt mixture was obtained from Al-Sharif Al-Razi Street in Al-Kadhimiya district in Baghdad. This roadway was constructed in 1995. It was heavily deteriorated by different cracks, potholes, and ruts existing on the surface. Recycled materials were gained through milling machines at a depth of 5 cm or more from the surface of the road.

The bitumen content of RAP material was determined by centrifuge extractor method (according to ASTM D2172 standard) and the result was (3.8%). The gradation of RAP was determined before and after the extraction test according to AASHTO T27 and T30 respectively, so as to determine whether it meets the grading envelope of a conventional wearing course mixture adopted by (SCRB/R9, 2003) as illustrated in figure (2). The bulk specific gravity of RAP aggregate after extraction test was (2.402) for coarse aggregate, (2.479) for fine and (2.45) for filler.

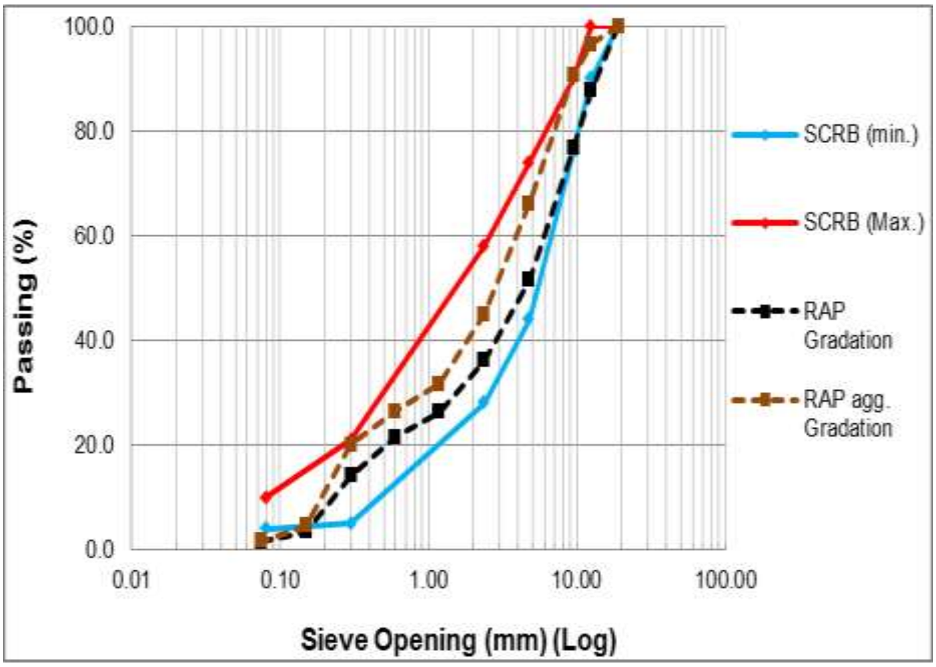

Figure (2): RAP Gradation before and after the Extraction Test and the Limitations of SCRB/R9 for Wearing Course.

PREPARATION OF RECYCLED MIXTIRES UNDER SUPERPAVE SYSTEM:

I. Cold Recycled Mixture (CRM):

Three trial gradations were compared with the gradation recommended in accordance to the specification limits of (SCRB/R9, 2003) and (Asphalt Institute, 2007) to be used in asphalt concrete binder course (nominal maximum size 19mm) as illustrated in figure (3). Each blend is a combination between RAP material gradations before extraction test and virgin aggregate gradation. The residual asphalt content was initially estimated by using five percentages (2.0, 2.5, 3.0, 3.5 and 4.0 %) for each trial blend. The initial emulsion content (IEC) used to produce mixtures was calculated as below:

$$IEC = \left(\frac{P}{X}\right) * 100 \qquad (1)$$

Where: P =Percentage of Initial Residual Bitumen Content by mass of aggregate, and X =Percentage of asphalt content in the emulsion which was (55%). IEC for emulsion type used was calculated from the above equation and the results found as (3.64, 4.55, 5.45, 6.36 and 7.27 %) by mass of aggregate. RAP material batch weight was taken as a percentages (90.50, 75.34 and 60.40%) by mass of aggregate for blends one, two and three respectively.

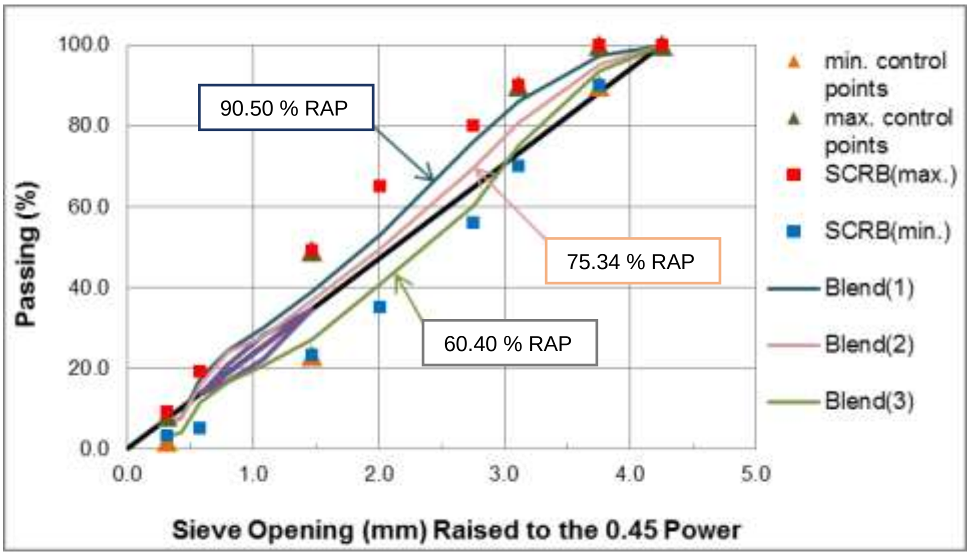

Figure (3): 0.45 Power Gradation Chart for CRM Trial Blends Grading.

The mixture was prepared by mixing the virgin aggregate and filler with the initial asphalt emulsion content at ambient temperature for (2-5) minutes. The RAP material was then added with continuous mixing for additional time until even coating obtained. Samples were immediately compacted after mixing by using the Superpave Gyratory Compactor, then were extruded after compaction from mold and allowed to cure at room temperature for 24 hours and then placed in a forced draft oven at 60 °C for 24 hours (minimum 16 hours). After curing, specimens were cooled to room temperature overnight before testing them for the bulk specific gravity in accordance to (ASTM D 2726) to check the volumetric properties. Blend two at 3.0% residual content was selected to be the design blend where it meets the specifications of AASHTO M323 for ESALs (10 to <30) and nominal maximum size (19mm).

Once the aggregate structure was chosen, start to select design residual bitumen content, the specimens were compacted at varying residual binder contents (estimated residual binder content %, estimated residual binder content ±0.5%, and estimated residual binder content +1%). The design residual binder content at 4% air voids was (3.7%) and the voids in mineral aggregate, voids filled with asphalt, dust to binder ratio, $\%G_{mm}$ @ $N_{initial}$ and $\%G_{mm}$ @ $N_{maximum}$ corresponding to 3.7% were (16.3, 75.5, 1.06, 86.6 and 96.56 %), respectively.

II. Hot Recycled Mixture (HRM):

The trial blends were established by incorporating RAP material depending on its gradation after extraction test with virgin aggregate at different percentages to meet the specification of (SCRB/R9,2003) and (Asphalt Institute, 2007) for binder course with nominal maximum size 19mm as shown in figure (4). The initial asphalt content was estimated by trial and error to be 4.8 % and it represented the total from the existing asphalt surrounding RAP aggregate and new asphalt suggested to add. The percentage of asphalt cement which actually added during mixing was calculated from the following equation:

$$\%\,Asphalt\ Cement\ Added = \frac{Weight\ of\ virgin\ aggergate\ in\ the\ blend * \%\,Total\ AC}{total\ batch\ weight\ of\ the\ blend\ (Agg.+RAP)} \qquad (2)$$

The weight of dry RAP was calculated from the following equation:

$$Mass\ of\ Dry\ RAP\ = \frac{Mass\ of\ RAP\ Aggregate}{(100-Pb)} * 100 \qquad (3)$$

Where Pb = RAP binder content (3.8 % from extraction test).

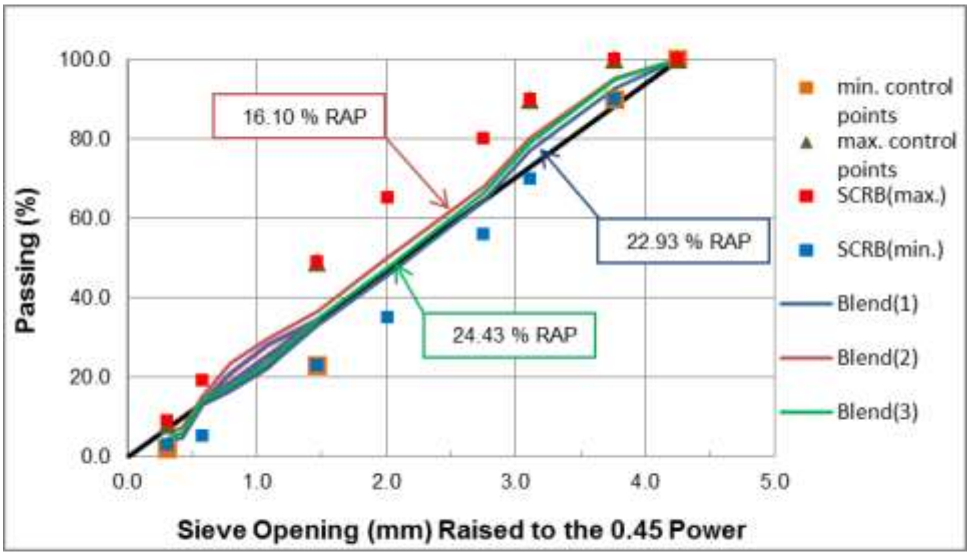

Figure (4): 0.45 Power Gradation Chart for HRM Trial Blends Grading.

The mixture was prepared by heating the virgin materials (Asphalt cement and aggregate) to the temperature of mixing (160±2 ºC). RAP material was heated to (110ºC) for not more than two hours to avoid change in RAP binder properties before mixing with virgin materials. The mixture was then short-term aged by being placed in oven at (135 ºC) for (2-4 hours) according to (AASHTO R30-06) for short term aging. After that, the mixture and compaction mold were placed in another oven for 30 minutes to reach compaction temperature which was (150±2ºC). Superpave Gyratory compactor was used in HRM compaction. The specimen was then left in the mold for 5 minutes before extruding, and cooling it for 24 hours at ambient temperature preparing for testing according to ASTM D 2726 to check the volumetric properties and select the design blend which was blend three.

After selecting the design blend which conforms with AASHTO M323 specifications, the estimated bitumen content, estimated bitumen content ±0.5% and estimated bitumen content +1% were mixed and compacted as the same procedure for the design aggregate structure for the hot recycled mixture to determine the design asphalt content. It was 5.1% at 4% air voids which gave (13.4%) voids in mineral aggregate, (70.1%) voids filled with asphalt, (1.117%) dust to binder ratio, (85.45%) %G_{mm} at $N_{initial}$ and (96.43%) %G_{mm} at $N_{maximum}$.

RECYCLED MIXTURES EVALUATION

I. Stability and Flow:

Generally, the purpose of this test is to measure the resistance to plastic flow of cylindrical specimens for both designed recycled asphalt mixtures loaded on lateral surface by means of Marshall Apparatus according to (AASTHO T245-08) as shown in figure (5). A total of nine specimens were prepared for both mixtures with batch weight 1200gm in the same manner of mixing used for design. The CRM samples were divided into two groups, one group of three specimens were compacted with 150 blows on each face and the other three were exposed to 75 blows ,like the three samples of HRM using compaction hammer of 4.536kg weight and 457.2mm drop to produce specimen with 101.6mm in diameter and (65.5 to70.5)mm in height. The procedure, however, had been modified for CRM so that the samples were conditioned in water bath at 25°C for 30 minutes (Ministry of Public Works Republic of Indonesia, 1990)**,** instead of at 60°C which was used for HRM.

Figure (5): Marshall Stability and Flow Machine.

II. Immersion–Compression Test:

In this test, two sets of three specimens were prepared for both recycled mixtures by using gyratory compactor, because field compaction can be simulated in a progressive way using this method of compaction. This test was conducted according to ASTM D1075. An air void content of 6 percent was attained. One set of specimens was tested for the compressive strength at 25.0± 1ºC without conditioning and the other set of specimens were conditioned by immersing them in water bath at 60.0 ± 1ºC for 24 hours. After conditioning, the set was transferred to another water bath where temperature was maintained at 25.0 ± 1ºC. After storing the specimens for 2 hours in this bath, the compressive strength of the each conditioned specimen was determined in accordance with ASTM D1074 as shown in figure (6). A numerical index of resistance of bituminous mixtures to the damaging impact of water as the percentage of the main strength that was retained after the immersion period, which should be a minimum of 0.7 (or 70%) as adopted by (SCRB/R9, 2003) for binder course as follows:

$$Index\ of\ Retained\ strength = \left(\frac{S2}{S1}\right) * 100 \quad (4)$$

Where:
S_1 = compressive strength of dry specimens (Set 1),
S_2 = compressive strength of immersed specimens (Set 2).

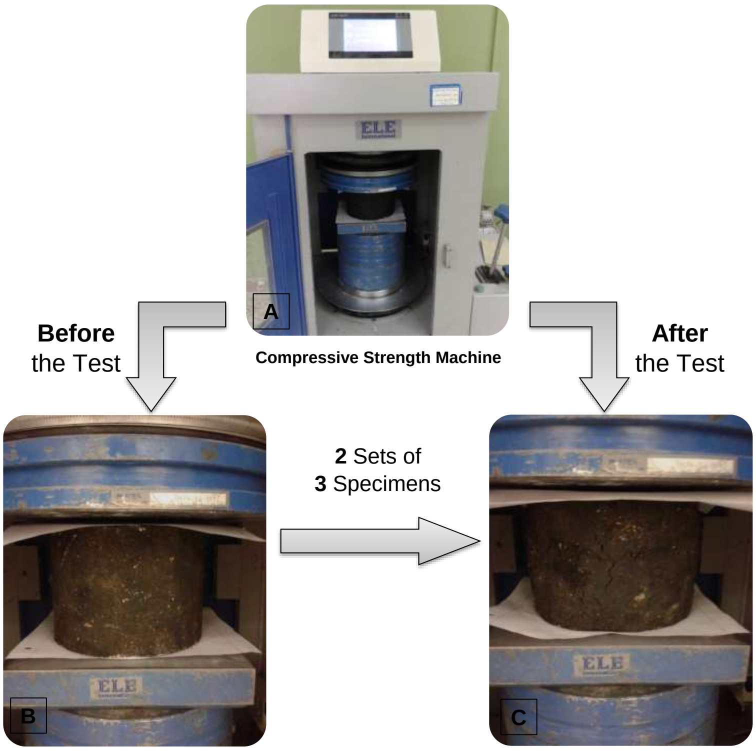

Figure (6): Compressive Strength Machine: (A) View of the Machine, (B) Sample before the Test, (C) Sample after the Test.

III. Double Punch Shear Test:

This test was advanced at the University of Arizona by (Jimenez 1974) for measuring the stripping of the bitumen from the aggregates. Marshall Specimen was used for this test for both recycled mixtures and at the same manner utilized for mixing and compaction of stability and flow test specimens. A total of fifteen specimens were prepared for punch shear test, (12) specimens for CRM and three for HRM. Half of CRM (3 for heavy compaction and 3 for medium) and the three HRM specimens were conditioned by placing in water bath at 60ºC for 30 minutes and the other half CRM specimens were placed in water bath at 25ºC for 30 minutes before testing. The test was conducted by centrally loading the cylindrical specimen which was placed between two cylindrical steel punches (2.54cm in diameter) on the top and bottom surface of it, skillfully aligned one over the other, and then loaded at a rate of 2.54cm /minute until failure. The maximum load resistance was recorded from the reading of dial gage. Figure (7) shows Double Punch test apparatus.

The punching strength was calculated by the equation (Farouki, O.T. and Rolt, J., 1985):

$$\boldsymbol{\sigma t} = \frac{\boldsymbol{P}}{\boldsymbol{\pi}(\mathbf{1.2}\boldsymbol{bh}-\boldsymbol{a}^2)} \qquad (5)$$

Where:
$\boldsymbol{\sigma t}$ = Punching shear stress, Pa.
P = Maximum load, N.
$\boldsymbol{a}$ = Radius of punch, mm.
b = Radius of specimen, mm.
h = Height of specimen, mm.

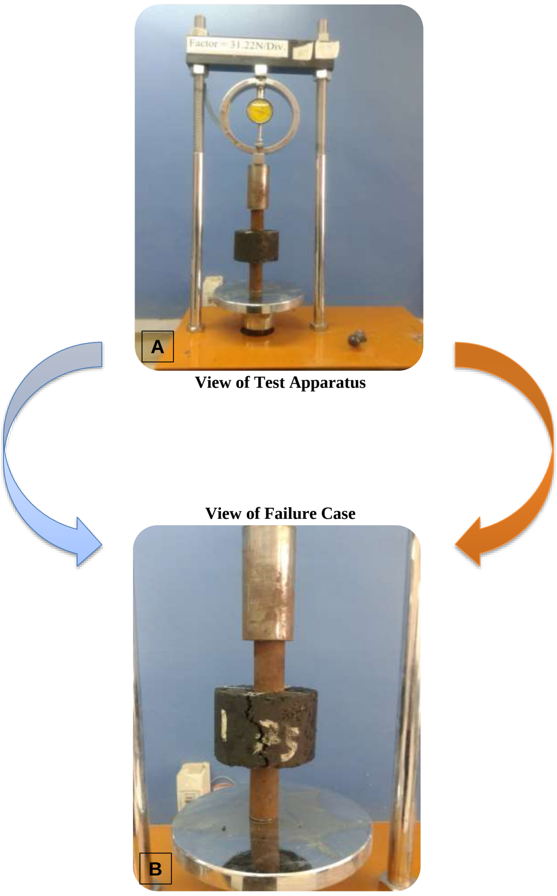

Figure (7): Double Punch Test Apparatus:
(A) View of Test Apparatus, (B) View of Failure Case.

RESULTS AND DISCUSSION

I. Marshall Stability and Flow Test Results:

The results in figure (8) showed when doubling compaction effort for CRM samples, the stability value increased as a result of reducing air voids and rising density and stiffness. HRM stability value was higher by about 26.6% and 4.5% from that of CRM at 75 and 150 blows per side respectively. This is because of weak strength for CRM at the age of one day curing and lower mixture density, hence higher air voids as compared to HRM. It is noticed that all stability values was higher than the minimum requirement which was (7) KN for binder course layer (SCRB/R9, 2003).

Flow knows as the amount of vertical deformation of the specimen to the moment of failure and it whenever flow values are high, denotes mix flexibility. It is demonstrated in figure (9) that flow value downward trend and approached to that for HRM when heavy compaction efforts for CRM specimens were used. All results within the specification range which was (2-4) mm (SCRB/R9, 2003).

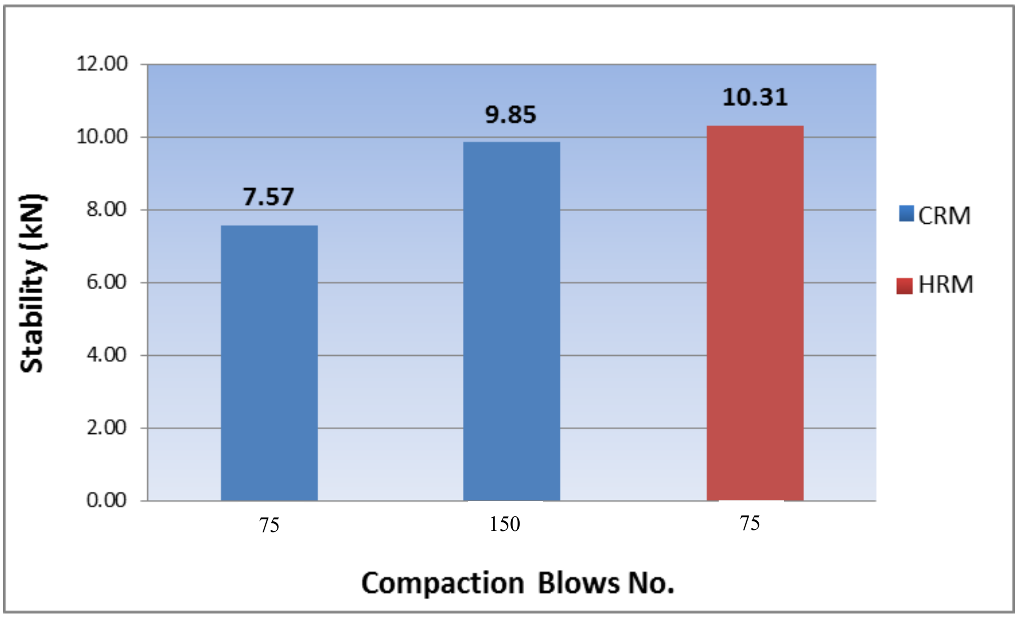

Figure (8): Marshall Stability Results for CRM and HRM.

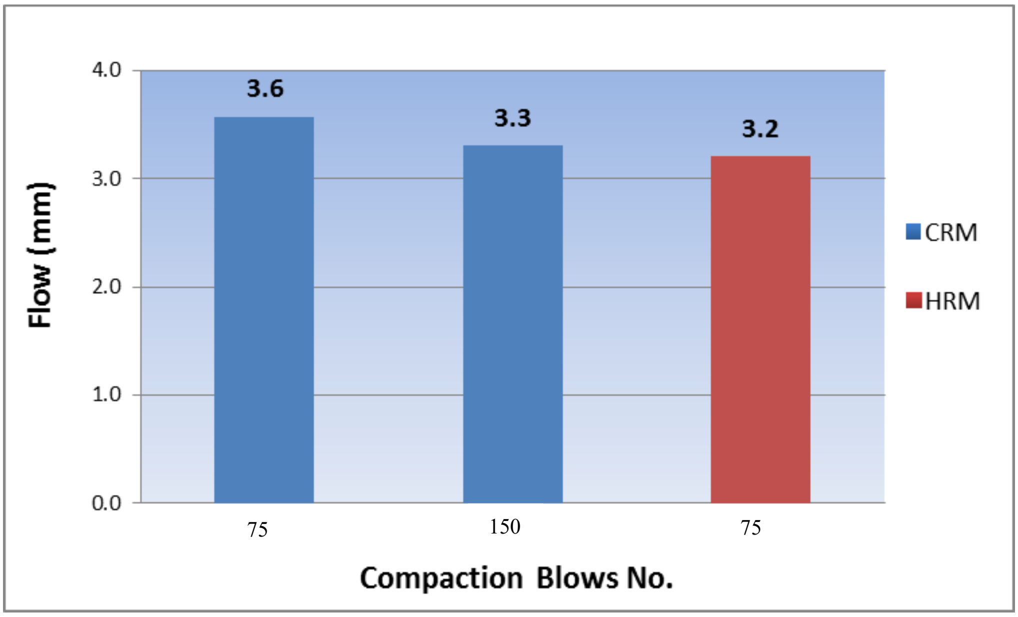

Figure (9): Marshall Flow Results for CRM and HRM.

II. Immersion-Compression Test Results (Index of Retained Strength):

Index of Retained Strength (I.R.S) is a reference for mixture impedance to water damage. It is obtained as the ratio of average compressive strength of conditioned specimens (wet) to that of unconditioned (dry) specimens in each category. Figure (10) shows that I.R.S for CRM was higher than HRM by 12.8%, which indicates that these mixtures were less susceptible to water damage as compared to HRM. This is may be because of the effect of recycled binder which gave better coating of aggregates. All of (I.R.S) values for both recycled mixtures exceeded the target of (SCRB /R9, 2003) for binder course which was 70%.

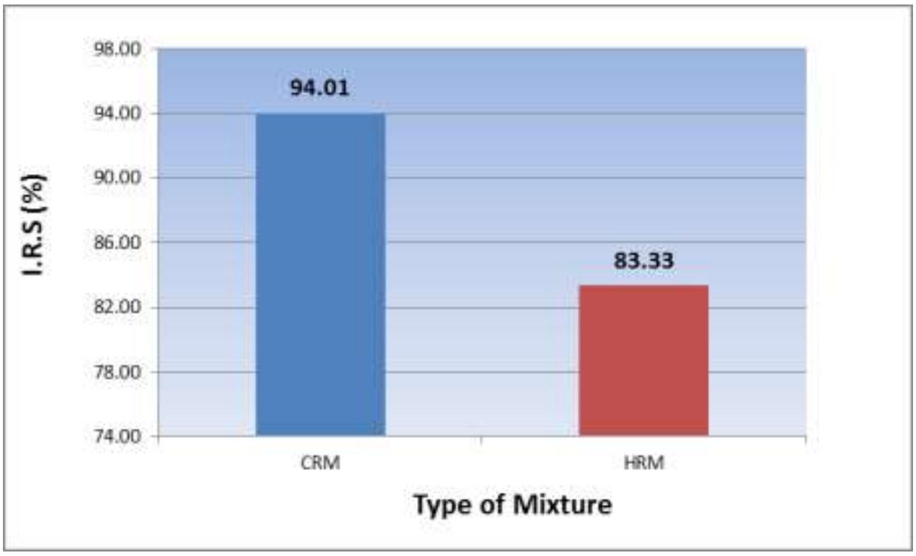

Figure (10): I.R.S Results for CRM and HRM.

III. Double Punch Shear Test Results:

Double punch shear test denotes the shear resistance action between binder and aggregate. Figure (11) presents double punch test results for both cold and hot recycled mixtures. It can be seen that CRM with 75 blows per side at both temperatures (25 °C and 60 °C) had punching strength values lower than that with 150 blows per side by about 10.5% and 46.2% respectively. This is may be related to the fact that air voids of specimens at medium compaction were higher than that at heavy compaction. It is also noted that punching strength values for CRM at 60 °C were less than that at 25 °C at both compaction conditions by about 70.3% and 60.8% respectively. This gave an indication that CRM was more affected with hot water even after doubling compaction efforts.

In general, HRM had the higher punching strength value as a result to the softening effect of emulsion in CRM, which declined the viscosity, hence less resistance to the load carried by the machine (punching load).

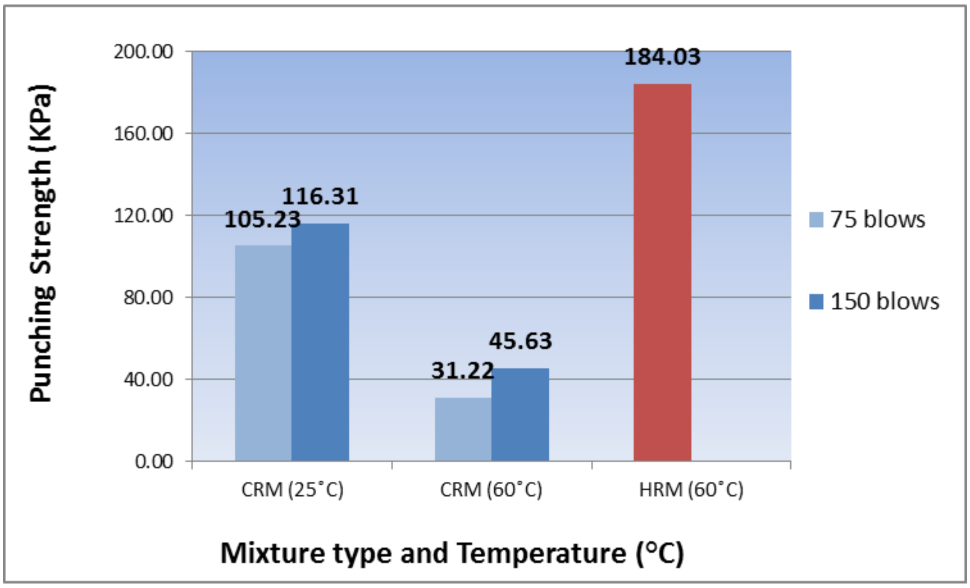

Figure (11): Double Punch Shear Results for CRM and HRM.

CONCLUSIONS

1. Cold recycled mixtures show better behavior and greater coherence when using high RAP percentage, in contrast to hot recycled mixtures.
2. Emulsified asphalt type (CSS-1) can help to use high RAP percentage in the mixture because its ability to rejuvenate aged binder due to the softening effect of reducing viscosity and bring the mixture to the required design properties.
3. From the three trial blends in the design of aggregate structure of CRM, it is found that the best percentages of initial residual asphalt content to produce adequate results for coating test ,mixing ,compaction and curing were ranged from (2.0% to 4.0%), and hence the design percentage was (3.7%).
4. Marshall stability values for CRM when using heavy compaction effort are higher than medium compaction, but they still lower than that for HRM, knowing that CRM was tested at 25ºC while HRM at 60ºC.
5. It is concluded that when air voids of specimens demonstrate downward trend, stability values show upward trend and flow values decrease.
6. Index of retained strength (I.R.S) for CRM was higher than HRM by 12.8%, which indicates that these mixtures are less susceptible to water damage as compared to HRM.
7. Punching strength values for CRM decline at heavy compaction effort for tested temperatures (25ºC and 60ºC) from that at medium compaction as a result of reducing air voids, but they are still lower than HRM at 60ºC.
8. CRM appears lower punching strength values during conditioning with hot water (at 60ºC) than that at 25ºC.

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