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SUSTAINABILITY OF COLD RECYCLED MIXTURE WITH HIGH RECLAIMED ASPHALT PAVEMENT PERCENTAGES

[1*] **Mohammed Abbas Al-Jumaili and [2] Ons Deyaa Issmael**

[1] *University of Kufa, Faculty of Engineering, Civil Engineering Department, IRAQ.*
[2] *Al-Mustansiriah University, Faculty of Engineering, Highway and Transportation Engineering Department.*

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ABSTRACT

The main goal of this study is to evaluate cold mixtures incorporating various percentages of reclaimed asphalt pavements (RAP) which is a typical sustainability technique to enhance the modern flexible pavement technology. The physical properties of RAP materials, new emulsion asphalt and new aggregate have been tested to evaluate the characteristics of these materials. Two mix design methods have been developed for control cold mix without RAP and recycled cold mixes containing 25 to 90 % of RAP by weight of total aggregate. First mix design depended indirect tensile strength as an indicative measure to determine optimum emulsion asphalt content while the second mix design method used Asphalt institute method (MS-14 and MS-21) . It found that Asphalt institute method required higher percent of optimum asphalt content than ITS method. The test results indicated that the recycled cold mixes containing high percent of RAP (75 to 90 %) are superior to control cold mix in traffic loading resistance and moisture susceptibility.

1. INTRODUCTION

Recently, availability of good quality paving materials has been constrained by boarding limitation, high cost and environmentally restriction .Conversation of materials, energy and environment are important for achieving sustainability in construction of highways. The performance of asphalt pavement in service is gradually deteriorated due to traffic loading repetitions and environmental factors. When pavement condition reaches a certain unacceptable level, it has to utilize reasonable rehabilitation methods to restore its performance. In addition to its environmental benefits, pavement recycling technologies provide cheaper, faster, and less traffic disruptions alternative to conventional reconstruction strategies [1, 2]. Cold recycling is one of the most popular pavement recycling methods. During cold recycling, existing asphalt pavement is pulverized by cold milling machine. It is suggested to use 100% reclaimed asphalt pavement (RAP) to design cold recycled mixture. In some cases, new aggregates are also used to adjust the RAP gradation. These loose aggregates are stabilized by bonding materials and recompacted into a base course of new pavement structure without the application of heat [3]. Normally, RAP is treated as “black stone” and stabilized by bonding materials to design cold recycled mixture. The most common stabilizing materials for cold recycling mixtures are mixing grade asphalt emulsions because they are liquid at ambient temperatures and can be easily dispersed throughout the mix [3, 4].

Asphalt emulsion has been used to stabilize RAP with a long history. However, there are still some problems on the performance properties of the emulsion recycled mixture, for example, low early-stage strength, inadequate resistance to moisture damage, and permanent deformation [3, 4]. These shortcomings are derived from the breaking and curing characteristic of asphalt emulsion. It has been demonstrated that asphalt emulsion needs extended curing time to restore the rheological properties of asphalt binder before being emulsified [5, 6]. Since the early 1970s, many studies have shown that cement can improve the early

Corresponding author:* **Mohammed Abbas Al-Jumaili, Email: drmoh_kufauniv@yahoo.com
University of Kufa, Faculty of Engineering, Civil Engineering Department, IRAQ.

mechanical strength and performance properties of asphalt emulsion mixture [7–10]. With the development of cold recycling technology, some researches also recommended using cement to modify the cold recycled mixture with asphalt emulsion. The improvement of cement on the performance properties of asphalt emulsion recycled mixture is also verified by some studies [11–13]. Moreover, some researchers suggest using hydrated lime, fly ash, or other chemical materials to enhance the performance properties of the emulsion recycled mixture [14–16]. However, there is still a lack of understanding about the combined effect of chemical additives and asphalt emulsion on the recycled mixture performance.

The objective of this research is to investigate the suitability of cold recycled asphalt mixture (CRAM) containing high RAP percentages up to 90 % by weight of total aggregate. A mix design procedure based on the selection of optimum premix water content and optimum emulsion content is proposed. In this study , two mix design methods were evaluated first method was Asphalt Institute [3] and the second The performance of the recycled mixtures was evaluated by indirect tensile strength (ITS) test, moisture susceptibility test and rutting resistance test. Furthermore, this research also provides insight into the interface adhesive mechanisms of the recycled mixture with emulsion and cement by observing the interface microstructure between the cement asphalt mastic and RAP.

2. MATERIALS

2.1. Evaluation of RAP Material

RAP material after proper milling and screening process will produce high quality and well-graded aggregates coated by asphalt .In this study , RAP materials obtained from in-service highways in Al-Najaf city and runway pavement of international najaf airport after making maintenance of surface layers . The aggregate and asphalt in the reclaimed material have properties that must be evaluated separately. Therefore, it is necessary to extract the aged asphalt from a representative sample of the old pavement materials. When tested according to ASTM D 2172 [17], the average asphalt content in the three samples of RAP material was found to be 3.91 % by weight of total mix. Then, the distillation process for asphalt recovery was done according to ASTM D1856 [18]. The physical properties of aged asphalt cement in RAP are given in Table 1 .

Finally, the gradation of RAP material was done and is summarized in Table 2. In this study recycling cold mix (RCM) has been designed for grading requirements of SCRB specifications for binder course [19].

Table 1 Test results of extracted asphalt cement

Property	**ASTM Designation**	**Test Results**
1.Penetration at 25 ^oC , (0.10mm)	D5	28
2. Ductility at 25 ^oC , (cm)	D113	53
3.Specific gravity at 25 ^oC	D70	1.03
4.Softening point –ring and ball , (^oC)	D136	64.7

Table 2 Asphalt Mixture Gradation for Binder Course

(% passing by weight of total aggregate + filler)				
Sieve size		***Specification limits***	**Mid-limit *gradation* specifications**	**RAP material**
Standard sieves (mm)	***English sieves (in)***			
25	1"	100	100	100
19	3/4"	90-100	95	97
12.5	1/2"	70-90	80	82
9.5	3/8	56-80	68	71
4.75	No.4	35-65	50	46
2.36	No.8	23-49	36	39
0.3	No.50	5-19	12	9.4
0.075	No.200	3-9	6	2.13

Referring to Table 2, the gradation analysis of RAP indicted deficiency of fine aggregate passing sieve no. 4 and smaller sizes especially by lacking the minimum requirements of 3 % materials passing a 0.075 mm sieve. In order to satisfy the standard gradation, RAP material was blended with new aggregate

2.2. Slow-Setting Cationic Asphalt Emulsion

The selected mixing grade emulsion was slow-setting cationic asphalt emulsion. The physical properties of the emulsion are provided in Table 3 . This type of emulsion (CSS-1h) has been bought from Richmond Company in EAU.

Table 3 Test results of cationic asphalt emulsion.

Test	ASTM Designation (D244)	Value	Specification Limits (D2397) for CSS-1h	
			Min.	Max.
Viscosity, Saybolt Furol at 25°C SFS	D244	26	20	100
Particle Charge Test	D244	positive	positive	
Residue by Distillation, %.	D6997	61	57	……
Sieve Test,%	D6933	0.03	……	0.10
Cement mixing test, %	D6935	0.732	……	2.0
Storage stability test-24 h, %	D6930	0.04	……	1
Tests on Residue from distillation test				
Penetration, 25°C (77°F), 100 g, 5 s	D5	57	40	90
Ductility, 25°C (77°F), 5 cm/min,	D113	100	40	……
Solubility in trichloroethylene, %	D2042	99	97.5	……

2.3. New aggregate and filler material

The new aggregate used in this study (coarse and fine) were originally obtained from AL Najaf quarries. The physical properties of aggregate are shown in Table4 while the filler materials, including type I ordinary Portland cement (OPC), was used in combination with new aggregate . The basic properties of these materials are presented in Table 5.

Table 4 Physical properties of new aggregates

Property	ASTM Designation	Test results	SCRB specifications
Coarse aggregate			
• Bulk specific gravity	C 127	2.614	….
• Apparent specific gravity	C 127	2.686	….
• Percent wear by Los Angeles abrasion , %	C131	22.7	30 Max.
• Soundness loss by sodium sulfate solution,%	C88	3.4	12 Max.
• Degree of crushing, %		98	90 Min.
Fine aggregate			
• Bulk specific gravity	C127	2.664	….
• Apparent specific gravity	C127	2.696	….
• Sand equivalent, %	D2419	57	45 Min.

Table 5 The basic properties of ordinary Portland cement

Physical Properties	
Specific surface area (m^2/kg)	418
Density (gm./cm^3)	3.12
Passing sieve No.200	95%
Chemical testing (XRF)	
SiO_2	SiO_2
Al_2O_3	Al_2O_3
Fe_2O_3	Fe_2O_3
CaO	CaO
MgO	MgO
K_2O	K_2O
Na_2O	Na_2O

3. MIX DESIGN ALTERNATIVES

Although universal accepted mix design procedure for asphalt emulsion recycled mixture is not available at present, guidelines have been developed by several agencies based on laboratory tests [20, 21]. In this study, the recycled mixtures were designed using the modified Marshall volumetric mix design method.

3.1. Determination of Initial Emulsion Content (IEC)

The amount of initial asphalt emulsion was determined using the Asphalt Institute [3] empirical formula as in Eq. (1):

$$P_b = (0.05\,A + 0.1\,B + 0.5\,C)\,0.70 \quad (1)$$

Pb=Percent by weight of initial residual asphalt content by mass of total mixture ;A=percent of mineral aggregate retained on 2.36mm ; B=percent of mineral aggregate passing 2.36 and retained on 0.075mm; and C= percent of mineral aggregate passing 0.075 mm.

With virgin aggregate gradation having A= 64%, B=30% and C=6, Pb was 6.4%. The available emulsion has a bitumen content of 61%; it implies that bitumen emulsion demand is 10.5%.This value will be used in calculation of TFC of cold mix without RAP material.

The quantity of new emulsion asphalt , that is Pnb , to be added (as percentage of total aggregate weight) in preparing of recycled mix using the Asphalt Institute (2007) manual series (MS-21) empirical formula is calculated by Eq.(2):

$$P_{nb} = P_b - \frac{(100-r)P_{sb}}{100} \quad (2)$$

Where

r = Percentage of new aggregate to be added in the recycled cold mix,

Psb= Asphalt content in RAP.

The average value of asphalt content obtained in RAP was 3.91 %. The new asphalt to be added is asphalt emulsion containing 61 % of residue asphalt. The initial trial asphalt emulsion content to be added to the recycled mixture works out to be approximately 5-11% by weight of aggregate as reported in Table 6.

Table 6 Initial emulsion content of various recycled cold mixes

RAP percent	Percentage of new aggregate(r)	New asphalt emulsion (Pnb),%	Initial emulsion content(IEC)
0	100	6.4	11
25	75	5.42	9
50	50	4.45	8
75	25	3.47	6
90	10	2.90	5

3.2. Determination of Optimum Total Liquid Content (OTLC) based on ITS method

In order to determine (OTLC), samples were prepared by keeping the initial emulsion content constant by mass of the aggregate as empirically determined in previous table. Mixes were prepared with premix water contents ranging from 1.0% to 4% by mass of the aggregate. A study indicated that the OPWC of asphalt emulsion mixture corresponding to the maximum density is a little greater than the OPWC corresponding to the maximum ITS [10]. During mixing of the recycled mixtures, the premix water was added in RAP before the addition of asphalt emulsion to optimize the asphalt emulsion content. Specimens were prepared at 75 blows per side with Marshall Hammer. All compacted samples were left in the mold and cured at room temperature for 24 h. After initial curing, the samples were then extruded and cured in a forced draft oven at 40°C for 72 h. The cured samples were allowed to cool at room temperature at least 24 h before the ITS was tested at 25°C according to ASTM D 6931 [22].

3.4. Determination of Optimum Pre-Wetting Water Content for Best Coating (OPWwc) based on Asphalt Institute (MS-14)

Ensuring high aggregate coating percentage is reflected in the final mixture properties. The coating of aggregate by emulsion is highly dependent on the percentage of the fine materials in the mix. However, MS-14 suggests examining different percentages of pre-mixing water with the estimated emulsion content to find the lowest pre-mixing water content that ensures the highest coating percentage. Thanaya [21] reported that inadequate pre-wetting water content results in balling of the binder with the fines portion of the aggregate, and this provides unsatisfactory coating.

For example , whilst keeping the IEC which equal 11% of aggregate weight constant, six pre-wetting water contents of 2, 2.5, 3, 3.5,4 and 4.5% of aggregate weight were investigated to find the lowest percentage to ensure highest coating percentage, the test procedure achieved by visual estimated as a percentage of total area of the mixture, this according to the Asphalt Institute MS-14, while in this work depended on maximum density and maximum stability relatively of the mixtures in addition to visual test are used to determine the (OPWwc).

3.5. Determination of Optimum Residual Asphalt Content (ORAC) and Optimum Emulsion Content (OEC)

To optimize the residual bitumen content a series of tests were conducted with different residual bitumen percentages, using the determined of (OPWwc) constant. The prepared specimens were subjected to the curing protocol, then tests such as volumetric characteristic and Marshall Stability were conducted and ORBC was determined accordingly.

In this study, whilst keeping the (OPWwc) constant, the IRBC that is calculated from the equation (1) = 6.5% approximately, increments/decrements of 1% of IRBC which steps in 0.5% and according to the volumetric properties and Marshal tests, for each mixtures were the ORBC are 5.5%, 6% , 6.5%,7.0and 7.5 % respectively. OEC for these mixtures above were 10.2%, 11.1% and 12% from the aggregate weight, respectively. Thus, all specimens that produced for all tests methods using the

The fifteen specimens were prepared and tested and the optimum emulsified asphalt is found as a percentage by weight of the mixture. Marshall Specimens prepared according to **ASTM D6927** [23]. The compaction effort was 150 blows per face using the Marshall compactor. Followed placed the specimens in a water bath at 60 °C for 30 to 40 min.

4. MOISTURE SUSCEPTIBILITY TEST

During the mix design of the emulsion recycled mixture, water was introduced into the aggregates to increase the workability of the mixture. Wet aggregates, added water, and water in the emulsion adversely impact the cohesion of asphalt mastic and the adhesion of mastic aggregate. Adhesion and cohesion failures lead to moisture damage. To combat moisture damage, the potential moisture resistance ability of the preliminary designed recycled mixtures should be verified by moisture susceptibility test.

In this study, moisture resistance was evaluated using the soaked ITS test. A study also recommended evaluating the moisture resistance of cold asphalt emulsion mixture by these two methods [24]. Moisture susceptibility of the recycled mixture was appraised by soaked ITS test. The air void of specimens was equal to that of the mix design results. Testing is carried out **ASTM D4867 [25].** The test is normally carried out were the first subset was tested in a dry condition (soaked in water for 2 hours at 25 ^{o}C).The second subset was tested in wet condition were inundated for 24 hours at 60 ^{o}C followed by 25 ^{o}C for 2 hours in water bath. Moisture damage was evaluated by using the soaked tensile strength ratio (TSR), which was defined as the percentage ratio of soaked to dry tensile strength at 25°C.

5. TEST RESULTS AND DISCUSSION

5.1. Mixes Design Results

5.1.1. Optimum Emulsion Content Based on ITS results

Similarly ITS dry were determined as an average of three replicate samples in all the mixtures of varying percentages of RAP and plotted graphically, as shown in Fig. 1. Using ITS parameter, (OTLC) was found to be 13, 11, 11, 9 and 8% by weight of aggregates in 0, 25, 50, 75, and 90% RAP, respectively.

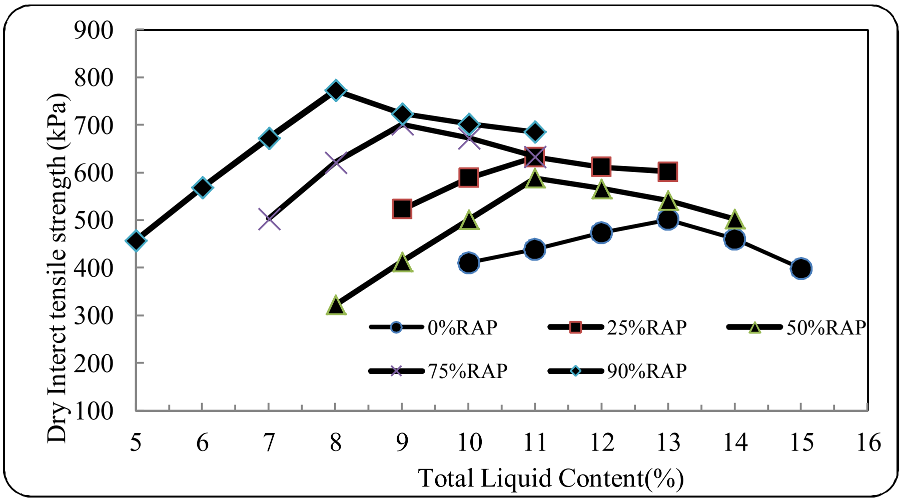

Figure 1 Indirect tensile strength of various recycled cold mix

In order to optimize the optimum emulsion content , the method adopted kept the total liquid content constant for certain mixture while the emulsion content varies at an interval of 1 % starting from 3 and ending at 11 % making a total of five trial of each mixture. ITS dry as average of three samples were conducted to find optimum emulsion content of various recycled cold mixes containing 0, 25 ,50,75,and90% RAP as shown in Fig. 2 .

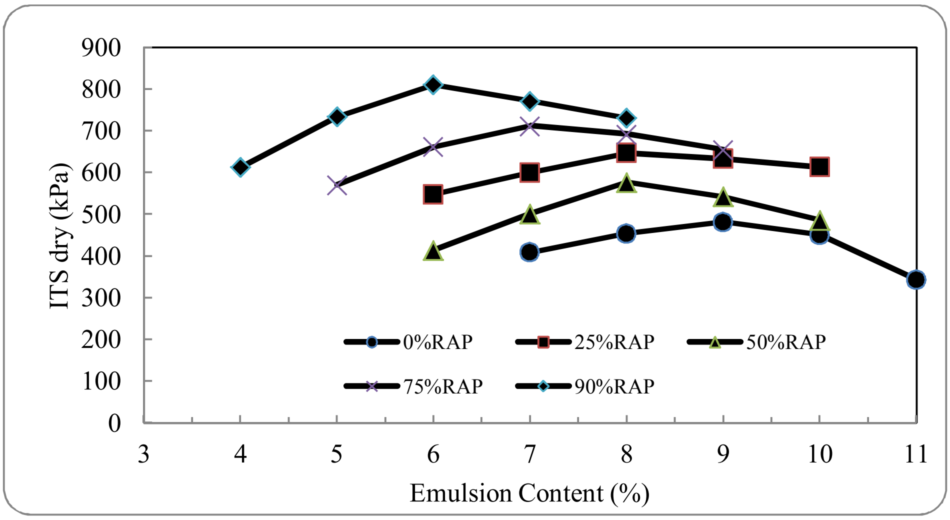

Figure 2 Indirect tensile strength dry of various cold mix with

From above figure , the corresponding OEC of maximum ITS was found to be 9% , 8%,8%,7% and 6% by weight of aggregate containing 0,25,50,75,and90% RAP respectively.

5.1.2. Optimum Emulsion Content Based on Bulk density and Dry Marshall stability (Asphalt Institute MS-14)

The optimum prewetting water content (OPWwc) that gave the best coating of the aggregate by emulsion (in which the mixture is not too sloppy or too stiff) can be also determined on basis of maximum bulk density. Fig. 3 shows Determination of optimum prewetting water content (OPWwc) for different recycled cold mixes.

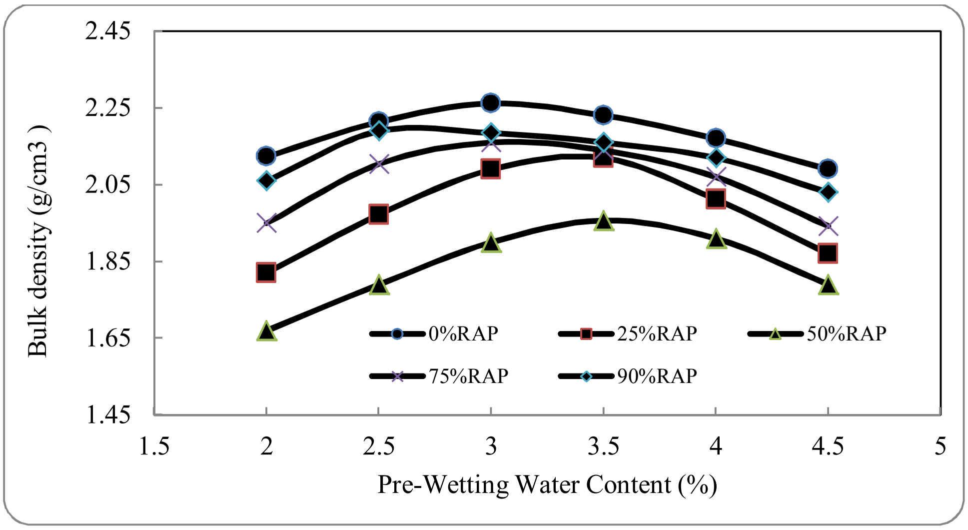

Figure 3 Determination of optimum prewetting water content (OPWwc) for different recycled cold mixes

The maximum bulk density and peak value of dry Marshall Stability are main parameters that were considered to determine optimum residual asphalt content (ORAC). Figures 4 and 5 are used to determination of optimum residue asphalt content (RAC) by using maximum bulk density and dry Marshall stability for different recycled cold mixes respectively .

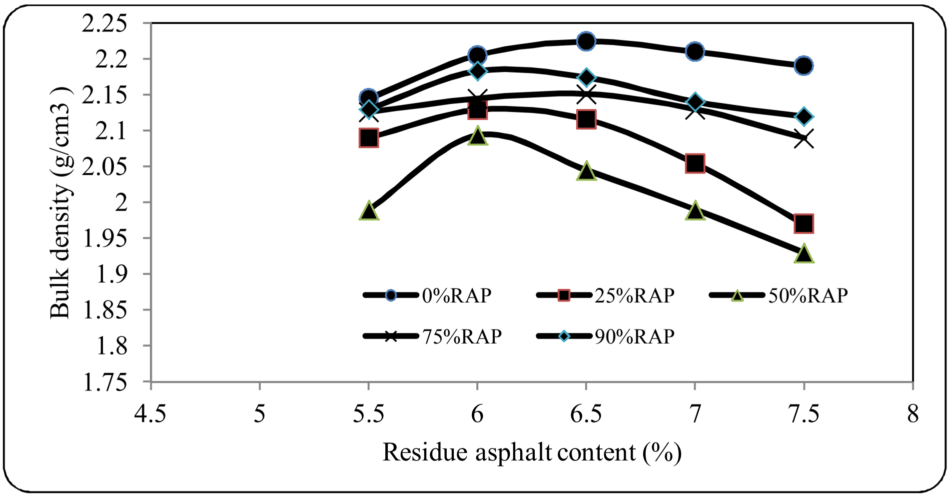

Figure 4 Determination of optimum residue asphalt content (ORAC) by using maximum bulk density for different recycled cold mixes

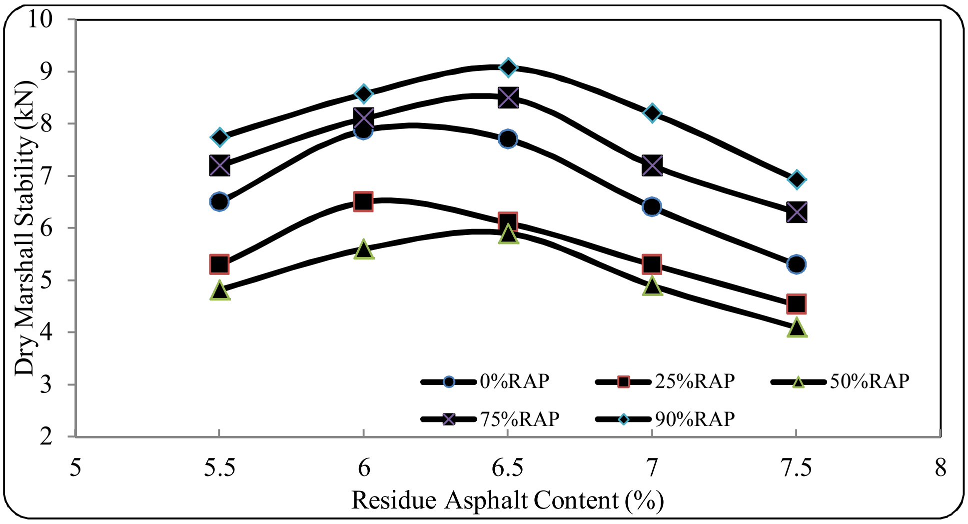

Figure 5 Determination of optimum residue asphalt content (ORAC) by using maximum dry Marshall Stability for different recycled cold mixes

The test results of the OPWC, OEC and OTLC for different recycled cold mixes obtained by using Figures 3 , 4 ,and 5 are summarized shown in Table 7.

Table 7 Optimum emulsion content and total liquid content of different recycled cold mixes

RAP percent	Initial emulsion content	Optimum pre-wetting water content (OPWwc)	Optimum residue asphalt content	Optimum emulsion content (OEC)	Optimum total liquid content(OTLC)
0	11	3	6.5	10.7	13.7
25	9	3.5	6	9.83	13.3
50	8	3.5	6	9.83	13.3
75	6	3	6.5	10.7	13.7
90	5	2.5	6	9.83	12.3

To compare the optimum total liquid content determined by two methods, Table 8 presents the (OTLC) percent obtained by two methods

Table 8 Comparison Optimum total liquid content (OTLC) based on ITS and Asphalt Institute (MS-14)

RAP percent	Optimum total liquid content(OTLC) based on ITS method	Optimum total liquid content(OTLC) based on Asphalt Institute (MS-14)	Different in OTLC (%)
0	13	13.7	5
25	11	13.3	21
50	11	13.3	21
75	9	13.7	52
90	8	12.3	54

It can observed that the optimum total liquid content (OTLC) based on Asphalt Institute (MS-14) is more that determined by ITS method by percent of (5 to 50) %.

5.2. Tensile Strength Ratio

Tensile strength ratio (TSR) was tested to evaluate the moisture susceptibility of cold recycled mixtures containing various RAP percentages. Table 9 illustrates the average dry and moisture-conditioned ITS of three replicate Marshall specimens as well as TSR.

Table 9 Results of moisture susceptibility tests (three replicates).

RAP percent	Dry ITS (kPa)	Conditioned ITS (kPa)	Tensile strength ratio (TSR),%
0	482	439	91.1
25	647	568	87.8
50	577	476	82.5
75	712	604	84.8
90	811	716	88.3

As it is clear that all TSR values are greater than 80 % indicating acceptable resistance to moisture damage of all mixes. This resistance was maintained even when a high percentage of RAP was used.

6. CONCLUSIONS

Results discussion and analysis lead to the following conclusions:

a) ITS test is mainly considered as the basis in the design of cold recycled asphalt mixtures because it measures the tensile properties and it is easy to conduct.
b) It can concluded that the optimum total liquid content(OTLC) has been determined based on Asphalt Institute (MS-14) is more that determined by ITS method by percent of (5 to 50)%.
c) The effect of moisture on recycled cold mixtures with RAP indicated that high RAP offers acceptable resistance to damage by moisture which is comparable to recycled cold mixes with lower RAP content.

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