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Prospect of Using Reclaimed Asphalt Pavement in Highway Wearing Asphaltic Layer

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Abstract

Reclaimed Asphalt Pavements (RAP) usually acquired from abandoned or damaged pavement, using it in HMA mixtures has grown into a regular practice all over the world. Incorporating RAP in fresh materials has been favored over fresh materials in the light of the increasing cost of asphalt, lacking of quality aggregate, lacking of asphalt and pressuring the need to preserve the environment. The use of reclaimed asphalt pavement is effective in improving the performance which is equal or better than the fresh mixtures. Unfortunately, asphalt pavement recycling is yet to take off in Iraq. The purpose of this study was to examine the performance between virgin mixtures and various RAP mixtures, whereas (10, 20, 30 and 40%) of RAP were obtained from two different sources. Best results can be achieved without any modifications by using 15% of RAP in both surface (IIIA & IIIB) A.M.S mixtures so that the volumetric properties were within the limits of Superpave volumetric design criteria (NCHRP-673, 2011) and by using 35% of RAP in both surface (IIIA & IIIB) A.M.S mixtures so that the volumetric properties were within the limits of Iraqi standards (SCRB, R/9 2003). Using waste engine oil (WEO) as a recycling agent to rejuvenate the aged RAP has proven to be very effective in the recycled mixtures, in which the best percentages of waste engine oil were found to be (2%, 4% and 6%) for (20, 30 and 40%) RAP in wearing mixtures, whereas all the volumetric properties and performance tests (Indirect Tensile Strength (ITS) and Tensile Strength Ratio (TSR)) were almost within Superpave and Iraqi standards.

Keywords: Reclaimed Asphalt Pavements, waste engine oil, Indirect Tensile Strength, Tensile Strength Ratio

1. Introduction

ASPHALT PAVEMENTS ARE REUSABLE-The effective life of an asphalt pavement structure depends on fundamental factors. The main ones are the volume and weight of traffic, quality of construction, subgrade strength, weather, drainage and quality of materials.

Pavement's usefulness can be extended through timely maintenance. Eventually, disintegration begins and the pavement needs to be reconstructed. Even so, the old materials do not have to be thrown away. They can be recycled as part of the rebuilding process. Consequently, an asphalt pavement structure is a reusable resource (Asphalt Institute Manual, 1986). The reclaimed asphalt pavement (RAP) is removed and/or processed materials containing asphalt cement and aggregates. Those kinds of materials are produced when asphalt pavements are removed for building, rehabilitation works, or to get access to buried facilities. RAP consists of graded aggregate coated by asphalt cement as a binder (NAPA, 2006). Asphalt pavement is formed of approximately 95% aggregates (gravel, sand and filler) and about 5% asphalt cement. Accordingly it is distinctive not only in the volume recycled, but also its renewability. When the RAP is used in new asphalt mixtures, the old binder is rejuvenated so that it becomes an effective part of the glue that holds the pavement together, same as the old aggregate becomes part of the aggregate content of the total mix. These particular properties make asphalt a uniquely renewable pavement. The same material can be recycled for multi times and never loses its value (NAPA, 2009).

Utilizing RAP in new mixtures can reduce the need to use virgin aggregate, also reduce the amount and costly of the new asphalt binder required in the manufacturing of asphalt paving mixtures; therefore, using the RAP conserve raw materials, energy and reduce overall asphalt mixture costs (NCAT, 2013). Reusing the RAP in a new mixture is requiring proper account of the old material in the new design of the mixture. The aggregate of the RAP has to be incorporated with the new aggregate, and that new mix of aggregate needs to meet certain specification. RAP must be engineered into the mixture not simply added (NCHRP, 2013). Marshall and Hveem method for handling RAP has shown that RAP mixtures can perform as the same as, or even better than, mixtures made with entirely new materials (Asphalt Institute Handbook, 2007). The RAP mixtures designed by

Superpave under (NCHRP, 2001) had shown great results.

In this current research, only the Superpave method was used for preparing and evaluating asphalt mixtures containing various RAP ratios. Wearing courses type (IIIA and IIIB) was mixed with 10%, 20%, 30% and 40% of RAP and compared the results with the control mixtures (No RAP content). The purpose of this research is to design efficient wearing surface with proper RAP content without compromising the performance. To be able to compare the effect of RAP source on HMA performance, same virgin aggregates were used for all Superpave mixtures. The developed Superpave mixes were then tested for performance in terms of fatigue cracking using indirect tensile test and moisture sensitivity using tensile strength ratio test.

2. Materials

2.1 Reclaimed Asphalt Pavement (RAP)

The first RAP source is a classified type obtained from wearing surface course as a large pavement chunks with average depth (60 mm) as shown in figure (1) which was collected from a construction site at Iraq, Babil province near Hammurabi patrol station. It is symbolized as (A/RAP). The second RAP source also is a classified type obtained from wearing surface course as a large pavement chunks with average depth (50 mm) as shown in figure (2) which was collected from a construction site at Iraq, Baghdad province near Al Yusufiya check point. It is symbolized as (B/RAP).

Figure (1) Photo of RAP chunk from the 1st source

Figure (2) Photo of RAP chunk from the 2nd source

Both sources of RAP were processed (crushed, screened, and stockpiled), then 3 samples from each stockpile were obtained for each test to characterize the RAP properties as follows:

Table (1) Reclaimed asphalt pavement properties

Property	**Standard**	**Test Result**	
		A/RAP	**B/RAP**
Moisture Content	AASHTO T 255	1.01%	0.81%
Bulk Specific Gravity (Coarse RAP)	NCHRP-752	2.527	2.531
Bulk Specific Gravity (Fine RAP)	NCHRP-752	2.506	2.51
Binder Content	AASHTO T 164	3.2%	3.3%
Absolute Viscosity at 60° C (poise) of Recovered Binder	D-2171	18000	20000

Table (2) Reclaimed asphalt pavement gradation

AASHTO T 27			
Standard sieves (mm)	**English sieves (in)**	**% Passing by Weight of the total recovered (Aggregate + Filler)**	
		A/RAP Gradation	**B/RAP Gradation**
19	3/4"	100	
12.5	1/2"	92.4	100
9.5	3/8"	81.3	90.1
4.75	No.4	49.5	58
2.36	No.8	42.6	43.7
0.3	No.50	9.5	9.2
0.075	No.200	1.9	1.5

2.2 Asphalt Cement

One type of asphalt cement was used with (40-50) penetration grade or PG (70-16) provided from Al Nasiriyah refinery in Iraq. The physical properties and tests of the asphalt cement used are shown in table (3).

Table (3) Physical properties and tests of asphalt cement

Property	**ASTM Method**	**Unit**	**Test Result**	**SCRB Specification**
Penetration at 25° C, 100 gm, 5 sec	D5	0.1mm	46	40-50
Kinematic Viscosity at 135° C	D2170	cst	382	----------
Absolute Viscosity at 60° C	D-2171	poise	4055	4000 ± 800
Ductility at 25° C, 5 cm/min	D113-99	cm	132	>100
Flash point (Cleveland open cup)	D92	°C	240	Min. 232
Softening Point	D36	°C	52	-----------
Specific gravity at 25° C	D70	----	1.04	1.01-1.05
After Thin Film Oven Test (ASTM D-1754)				
Retained Penetration at 25° C, 100 gm, 5 sec	D5	%	65	Min. 55%
Ductility at 25° C, 5 cm/min	D113-99	cm	79	Min. 50
Loss in Weight at 163° C, 50 gm, 5 hours	D1754	%	0.28	-----------

2.3 Virgin Aggregate

The coarse aggregate used in this study is a crushed aggregate from Al-Najaf quarry in Iraq, while the fine aggregate obtained from Karbala quarry in Iraq. The coarse and fine aggregates, utilized in this work, are sieved and recombined in the proper proportions to meet the wearing coarse gradation as required by the Iraqi specification **(SCRB, R/9. 2003)**. Routine tests were implemented on the aggregate to evaluate their physical properties. The results together with the specification limits as set by the SCRB are briefed in Table (4).The picked gradation and specification limits are demonstrated in Table (5).

Table (4) Physical properties of aggregate

Property	**ASTM Method**	**Coarse Aggregate (IIIA)**	**Coarse Aggregate (IIIB)**	**Fine Aggregate**	**SCRB Specification**
Bulk Specific Gravity	C-127 C-128	2.556	2.551	2.672	-------------
Apparent Specific Gravity	C-127 C-128	2.616	2.611	2.681	-------------
% water absorption	C-127 C-128	0.9	0.83	0.65	-------------
Abrasion Los Angeles	C-131	23%		------------	Max. 30%
Angularity	D-5821	92%		------------	Min. 90%

Table (5) Virgin aggregate gradation for surface (wearing) courses

Standard sieves (mm)	**English sieves (inch)**	**(% Passing by Weight of Total Aggregate + Filler)**			
		Surface Course (Type IIIA)		**Surface Course (Type IIIB)**	
		Gradation	**Specification limit**	**Gradation**	**Specification limit**
19	3/4"	100	100		
12.5	1/2"	95	90-100	100	100
9.5	3/8"	83	76-90	95	90-100
4.75	No.4	59	44-74	70	55-85
2.36	No.8	43	28-58	50	32-67
0.3	No.50	13	5-21	15	7-23
0.075	No.200	7	4-10	7	4-10

2.4 Mineral Filler

In this research, one type of fillers was used; Ordinary Portland Cement (Al Geser). The physical properties of the filler are demonstrated in Table (6).

Table (6) Physical properties of the used filler

Property	**Cement Filler**
Specific Gravity	3.1
Fineness, Blain, (cm^2/gm)	3200
Passing Sieve No.200	95 %

2.5 Combined Aggregate

By combining 10%, 20%, 30%, and 40% of RAP with virgin aggregate for both courses (IIIA and IIIB), the resulted gradation of the combinations are as follows:

Table (7) Combined gradation of (10% & 20% A/RAP + virgin aggregate)

Standard sieves (mm)	**English sieves (inch)**	**(% Passing by Weight of Total Aggregate + Filler)**						**SCRB Specification Limit**
		10% RAP			**20% RAP**			
		10% A/RAP	**90% Virgin Aggregate**	**Combined Aggregate**	**20% A/RAP**	**80% Virgin Aggregate**	**Combined Aggregate**	
19	3/4"	10.00	90	**100**	20.00	80	**100**	100
12.5	1/2"	9.24	85.5	**94.7**	18.47	76	**94.5**	90-100
9.5	3/8"	8.13	74.7	**82.8**	16.27	66.4	**82.7**	76-90
4.75	No.4	4.95	53.1	**58.1**	9.91	47.2	**57.1**	44-74
2.36	No.8	4.26	38.7	**43**	8.51	34.4	**43**	28-58
0.3	No.50	0.95	11.7	**12.7**	1.90	10.4	**12.3**	5-21
0.075	No.200	0.18	6.3	**6.5**	0.37	5.6	**6**	4-10

Table (8) Combined gradation of (30% & 40% A/RAP + virgin aggregate)

Standard	**English**	**(% Passing by Weight of Total Aggregate + Filler)**						**SCRB**
Standard sieves (mm)	**English sieves (inch)**	**30% RAP**			**40% RAP**			**SCRB Specification Limit**
		30% A/RAP	**70% Virgin Aggregate**	**Combined Aggregate**	**40% A/RAP**	**60% Virgin Aggregate**	**Combined Aggregate**	
19	3/4"	30.00	70	**100**	40.00	60	**100**	100
12.5	1/2"	27.71	66.5	**94.2**	36.94	57	**94**	90-100
9.5	3/8"	24.40	58.1	**82.5**	32.53	49.8	**82.3**	76-90
4.75	No.4	14.86	41.3	**56.2**	19.81	35.4	**55.2**	44-74
2.36	No.8	12.77	30.1	**43**	17.03	25.8	**43**	28-58
0.3	No.50	2.85	9.1	**12**	3.80	7.8	**11.6**	5-21
0.075	No.200	0.55	4.9	**5.5**	0.74	4.2	**5**	4-10

Table (9) Combined gradation of (10% & 20% B/RAP + virgin aggregate)

Standard sieves (mm)	**English sieves (inch)**	**(% Passing by Weight of Total Aggregate + Filler)**						**SCRB Specification Limit**
		10% RAP			**20% RAP**			
		10% B/RAP	**90% Virgin Aggregate**	**Combined Aggregate**	**20% B/RAP**	**80% Virgin Aggregate**	**Combined Aggregate**	
19	3/4"							
12.5	1/2"	10.00	90	**100**	20.00	80	**100**	100
9.5	3/8"	9.00	85.5	**94.5**	18.01	76	**94**	90-100
4.75	No.4	5.79	63	**68.8**	11.59	56	**67.6**	55-85
2.36	No.8	4.37	45	**49.4**	8.73	40	**48.7**	32-67
0.3	No.50	0.92	13.5	**14.4**	1.84	12	**13.8**	7-23
0.075	No.200	0.15	6.3	**6.5**	0.31	5.6	**6**	4-10

Table (10) Combined gradation of (30% & 40% B/RAP + virgin aggregate)

Design 7-Day Maximum Air Temperature (°C)

		30% RAP			40% RAP			
		30% B/RAP	70% Virgin Aggregate	Combined Aggregate	40% B/RAP	60% Virgin Aggregate	Combined Aggregate	
19	3/4"							
12.5	1/2"	30.00	70	100	40.00	60	100	100
9.5	3/8"	27.01	66.5	93.5	36.02	57	93	90-100
4.75	No.4	17.38	49	66.4	23.17	42	65.2	55-85
2.36	No.8	13.10	35	48.1	17.46	30	47.5	32-67
0.3	No.50	2.76	10.5	13.3	3.69	9	12.7	7-23
0.075	No.200	0.46	4.9	5.4	0.61	4.2	4.8	4-10

3. Methods of Testing

3.1 Superpave Specimens Preparation

Typically, the Superpave gyratory compactor (SGC) as shown in figure (4) was employed to generate compacted specimens intended for volumetric evaluation and determination of physical qualities. According to AASHTO T 312 (TP4) compaction process was achieved by applying a vertical stress (normally 600KPa) through a mechanical ram to a known mass of asphaltic mixture within a 100 or 150 mm internal Ø mold. The SGC base rotates at a constant speed of 30 revolutions per minute during compaction, while the mold was positioning at a compaction angle of (1.25° or 22 mrad) as shown in figure (3).

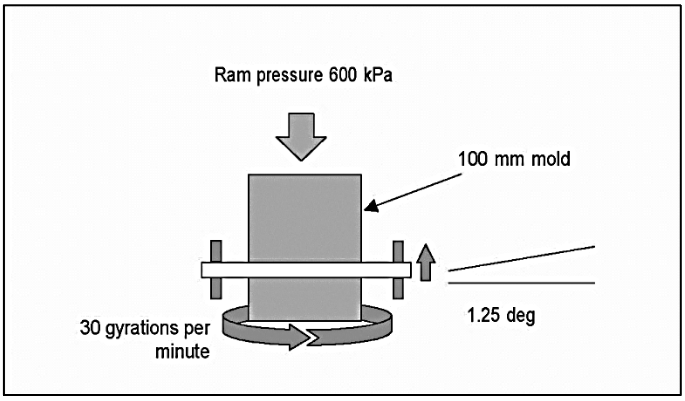

Figure (3) SGC mold configuration

Figure (4) Photo. Gyratory compactor

Design number of gyrations (N_{design} = 105) was selected depending on climate and traffic level in Iraq – Babil (<3×10^6 Traffic level) as shown in table (11) below:

Table (11) Superpave gyratory compaction levels **(SHRP-A-407)**

	<39			**39-41**			**41-43**			**43-45**		
	Ni	**Nd**	**Nm**	**Ni**	**Nd**	**Nm**	**Ni**	**Nd**	**Nm**	**Ni**	**Nd**	**Nm**
<3 x 105	7	68	104	7	74	114	7	78	121	7	82	127
<1 x 106	7	76	117	7	83	129	7	88	138	8	93	146
<3 x 106	7	86	134	8	95	150	8	100	158	**8**	**105**	**167**
<1 x 107	8	96	152	8	106	169	8	113	181	9	119	192
<3 x 107	8	109	174	9	121	195	9	128	208	9	135	220
<1 x 108	9	126	204	9	139	228	9	146	240	10	153	253
≥1 x 108	9	143	235	10	158	262	10	165	275	10	172	288

Four types of mixtures were prepared and compacted using SGC as below:

1. The Control Mixtures compacted at N_{design} = 105 gyrations:

Mixtures with zero percent RAPs for both wearing (IIIA & IIIB) aggregate gradations prepared and compacted according to Superpave design procedure (NCHRP- 673, 2011) to find the optimum asphalt content. Specimens were compacted at varying asphalt binder contents. Minimally, three specimens prepared for each of the following asphalt content:

- Estimated binder content
- Estimated binder content – 0.5%
- Estimated binder content + 0.5%
- Estimated binder content + 1.0%

The estimated binder content was predicted according to special design equations (AASHTO R 35), the estimated binder percent for wearing course (IIIA) was 4.8% and 5% for wearing course (IIIB). Consequently, four different percentages of binder content (4.3, 4.8, 5.3 and 5.8) percent were used for wearing course (IIIA), and (4.5, 5, 5.5 and 6) percent were used for wearing course (IIIB).

The optimum asphalt content for surface wearing (IIIA & IIIB) mixtures was 4.7% and 5.5% respectively, determined at 4% air voids. Mixtures volumetric properties (AASHTO R 35) were evaluated in term of (air voids, VFA & VMA), in addition to mixture stability, density and flow.

2. Mixtures with various percentages of RAP compacted at N_{design} = 105 gyrations

All the mixtures prepared and compacted according to Superpave design procedure (NCHRP-452, 2001). (10, 20, 30 and 40) % of RAP were used in both wearing (IIIA & IIIB) aggregate maximum size. The percent of new binder in HMA recycled mixtures at each percent of RAP was determined by using Marshall and Haveem design formula as follow:

$$Pnb = \frac{\left(100^{2} - r \times Psb\right) \times Pb}{100 \times (100 - Psb)} - \frac{(100 - r) \times Psb}{100 - Psb} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{(1)}$$

$$R = \frac{100 \times Pnb}{Pb} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{(2)}$$

Where:

P_{nb} = Percent of new asphalt binder in recycled mix

r = New aggregate expressed as a percent of the total aggregate in the recycled mix

P_b = Percent, estimated asphalt content of recycled mix (assumed to be the same as that of 100 percent virgin HMA mix)

P_{sb} = Percent, asphalt content of reclaimed asphalt pavement

R = % new asphalt to total asphalt content

Mixtures volumetric properties (AASHTO R 35) were evaluated in term of (air voids, VFA & VMA) in addition to mixture stability, density and flow.

3. Mixtures with various percentages of RAP compacted at 4% air voids

Prepared and compacted according to Superpave design procedure (NCHRP-452, 2001) at 4% air voids by coordinating the number of gyrations (N_{design}) in the (SGC) with each percent of RAP in order to achieve the 4% of air voids. (20, 30 and 40) % of RAP were used in both wearing (IIIA & IIIB) aggregate maximum size. The percent of new binder in HMA recycled mixtures at each percent of RAP was determined by using Marshall and Haveem design formula (1) as mentioned above. Three specimens also were prepared at each RAP percent and evaluated in terms of volumetric properties, stability, density and flow.

4. Mixtures with various percentages of RAP modified by waste engine oil as a recycling agent and compacted at N_{design} = 105 gyrations

Table (12) WEO properties

WEO Density at 25° C	0.83
WEO Absolute Viscosity at 60° C (poise)	2033

Several percent of automobiles waste engine oil mixed up with recycled mixes as shown in table (13) below:

Table (13) WEO percentages in the recycled mixes

Wearing (IIIA) Recycled Mixture		
% Waste engine Oil	**% RAP**	**N_{design}**
4 , 2	20	105
4 , 6	30	105
6 , 8	40	105

The process of mixing WEO with asphalt binder used in this study was the wet process, in which the WEO added to the asphalt binder before introducing it in the asphalt concrete mixture. The WEO was directly blended with asphalt binder in blending machine, as shown in figure (5) at suitable blending times at specified temperature. The WEO was added to the asphalt binder in the blending machine at a blending speed of 600 rpm for half an hour at 160 °C (Christopher Daniel DeDene, 2014) and (Nurul Hidayah et al., 2014). The modified recycled loose mixtures are short-term aged at 135 °C for four hours according to (AASHTO R 30) then compacted according to Superpave design procedure (NCHRP-452, 2001). Three specimens also were prepared at each RAP percent and evaluated in terms of volumetric properties, stability, density and flow.

Figure (5) Photo. Blending machine

3.2 Indirect Tensile Strength

The tensile strength of compacted asphalt concrete specimens was typically determined by the indirect tensile strength test, and according to method described in ASTM D 6931. Low temperature cracking, fatigue and rutting are the three major distress mechanisms. A higher tensile strength corresponds to a stronger cracking resistance. Specimens were prepared by Superpave method and left to cool at room temperature for 24 hours, then placed in a water bath at (20° C) for 30 minutes in order to evaluate the fatigue cracking resistance.

The indirect tensile strength (I.T.S) was calculated, as follows:

$$I.T.S = \frac{2 \times Pult}{\pi \times t \times D} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (3)$$

Where:

I.T.S = Indirect tensile strength (Mpa)

P_{ult} = Ultimate applied load at failure (N)

t = Thickness of specimen (mm)

D = Diameter of specimen (mm)

3.3 Tensile Strength Ratio

Moisture damage in bituminous mixes refers to the loss of serviceability due to the presence of moisture. The extent of moisture damage is called the moisture sensitivity. The ITS test is a performance test which is often used to evaluate the moisture sensitivity of a bituminous mixture.

Tensile strength ratio (TSR) (AASHTO T 283) is the ratio of the tensile strength of water conditioned specimen (ITS wet, 60°C, and 24 h) to the tensile strength of unconditioned specimen (ITS dry) which is expressed as a percentage. All specimens were compacted at 7±1% air voids, which is the air void content that approximates the recommended higher level of compaction in the field of 93 to 94% of G_{mm}. A higher TSR value typically indicates that the mixture will perform well with a good resistance to moisture damage. The higher the TSR value, the lesser will be the strength reduction by the water soaking condition, or the more water-resistant it will be.

$$T.S.R = \frac{I.T.S\ (Conditioned)}{I.T.S\ (Unconditioned)} \geq 80\% \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (4)$$

4. Results and Discussion

Four groups of specimens are prepared; first group is the control specimens with zero percent RAP for both wearing (IIIA & IIIB) aggregate maximum size. The optimum asphalt contents for 19 mm and 12.5 mm aggregate maximum sizes were 4.7 % and 5.5 % respectively. The volumetric properties of the control mixtures at optimum asphalt content must be compared with table (14), (15) & (16) that meets the Superpave standards (NCHRP-673, 2011) and the Iraqi standards (SCRB, R/9 2003) for surface layer of pavement. Figures (14) & (15) demonstrate the volumetric properties of the control mixes.

Table (14) Mixture properties at optimum asphalt content
as compared with Superpave standards (NCHRP-673, 2011)

Property	Mixture properties for 19 mm A.M.S (surface A)	Standards	Mixture properties for 12.5 mm A.M.S (surface B)	Standards	Tolerance
Air voids %	4.0	4.0	4.0	4.0	-------
VMA %	13.93	Min. 14	15.83	Min. 15	± 1.2
VFA %	71	65 - 75	75	65 - 78	± 4.0
O.A.C %	4.7	@ 4% Air voids	5.5	@ 4% Air voids	± (0.15 – 0.3)

Table (15) Mixture properties at optimum asphalt content
as compared with Iraqi standards (SCRB, R/9 2003)

Property	Mixture properties for 19 mm A.M.S (surface A)	Mixture properties for 12.5 mm A.M.S (surface B)	Standards
O.A.C %	4.7	5.5	4 – 6
Stability (kN)	11.9	10.3	Min. 8
Flow (mm)	2.95	3.4	2 - 4
Air Voids %	4.0	4.0	3 - 5

Table (16) Relative density of the extruded specimens expressed as a percent of the theoretical maximum specific gravity (% G_{mm}) at $N_{initial}$, N_{design} and $N_{maximum}$ (NCHRP-673, 2011)

Mixture type	**% G_{mm} @ $N_{initial}$ = 8 gyrations**	**Superpave criteria**	**% G_{mm} @ N_{design} = 105 gyrations**	**Superpave criteria**	**% G_{mm} @ $N_{maximum}$ = 167 gyrations**	**Superpave criteria**
Control wearing (IIIB) A.M.S	88	≤ 89 %	96	96 %	97	≤ 98 %
Control wearing (IIIA) A.M.S	89		96		97	

Second and third group is specimens with various percentages of RAPs for both wearing (IIIA & IIIB) A.M.S. The second group compacted at N_{design} = 105 gyrations and the third group compacted at 4% air voids. The RAP effects on the HMA mixture's volumetric properties for both wearing (IIIA & IIIB) A.M.S mixtures can be illustrated briefly as below:

- Total air voids content decreases by increasing the RAP content above 15%, that owing to the incompatibility in performance grade (PG) between virgin binder and RAP binder, whereas the combined blend of virgin binder (PG 70 – 10) with each percent of RAP (especially above 15% RAP) is considered a dense blend (high viscous blend) and getting denser at high RAP content under the same compaction efforts.
- Voids in mineral aggregate decreases by increasing the RAP content. This reduction in the amount of voids in mineral aggregate is owing to the variability between the bulk specific gravity of combined aggregate (G_{sb}), bulk specific gravity (G_{mb}) of compacted recycled mixtures, and theoretical maximum specific gravity (G_{mm}) of recycled mixtures at the same compaction efforts. VMA for specimens compacted at 4% air voids decreases slightly by increasing the RAP content which is due to the variability between the bulk specific gravity of combined aggregate (G_{sb}) and bulk specific gravity (G_{mb}) of compacted recycled mixtures. This result is supported by the findings of (Krugler P. Tahmoressi, 2000).
- Voids filled with asphalt increases by increasing the RAP content above 15%, which is owing to a decrease in the total content of air voids in the mix by increasing the effective asphalt content at each percent of RAP (especially above 15%) at the same compaction efforts. This result is supported by the findings of (Namir G. Ahmed & Abbaas I. Kareem, 2013). VFA for specimens compacted at 4% air voids have equal values at any percent of RAP which is almost equal to the content of VFA of the Control specimens.
- Stability values at 20% RAP decreases slightly below the control level which is owing to low internal friction powers between RAP and virgin aggregate particles due to an increase in the film thickness around RAP coarse aggregate particles. The cohesion powers of combined binder begin to decrease by increasing the RAP content owing to the loss of maltenes (the colloidal combination of oils and resin) in the aged RAP binder causing brittle pavement due to the lack of binder's cohesion. Stability level begins to increase by increasing the RAP above 20% which is attributed to the fact that RAP's binder is generally hardened and that naturally leads to an increase in the stability due to high viscous asphalt at the same compaction efforts. Hardened binder is basically more viscous than virgin one; therefore, when the two mixtures are immersed in hot water the level of stability of the recycled mixture (above 20% RAP content) will be less affected by the high temperature than the control mixture. This result is supported by the findings of (Kandahal et al., 1995). Stability level for specimens compacted at 4% air voids is relatively high especially at high RAP content (30& 40) % because the best aggregate interlock and binder cohesion ability achieved at 4% air content.
- Bulk density values increases by increasing the RAP content above 30% for surface (IIIB) mixtures and 20% for surface (IIIA) mixtures, due to high stiffness of the recycled mixtures and low air voids content at the same compaction efforts. This result is supported by the findings of (Namir G. Ahmed & Abbaas I. Kareem, 2013). Bulk density for specimens compacted at 4% air voids is relatively low owing to the decrease in the compaction effort to suit the 4% air voids content at each RAP percent.
- Flow level increases by increasing the RAP content above 20%, owing to low internal friction between combined aggregate particles which is caused by increasing the film thickness around RAP coarse aggregate particles at high RAP content at the same compaction efforts. In another words, at high content of RAP

(above 20%) the lubrication forces between the combined aggregate particles become relatively high. This result is supported by the findings of (Namir G. Ahmed & Abbaas I. Kareem, 2013). Flow level for specimens compacted at 4% air voids decreases by increasing the RAP content which is may be owing to a lesser contact between combined aggregate particles at high RAP content.

Fourth group is specimens with various percentages of RAPs modified by waste engine oil as a recycling agent and compacted at $N_{\mathbf{design}}$ = 105 gyrations, the volumetric properties as shown below:

- Total air voids content for specimens containing (RAP + WEO) are normally (≥ 4%), that means the air voids content increases by increasing the quantity of WEO in the recycled mix at the same compaction efforts. The WEO rule in the HMA recycled mixture can be interpreted as a softening agent used mainly to reduce the high stiffness of recycled mixtures by reducing the density of combined binder to suitable level. This result is supported by the findings of (Christopher Daniel DeDene, 2014).
- Voids in mineral aggregate for specimens containing (RAP + WEO) are higher than the ones containing only RAP, that means VMA increases by increasing the WEO content in the recycled mix at the same compaction efforts, which is owing to the reduction in the bulk specific gravity ($G_{\mathbf{mb}}$) of compacted recycled mixtures plus an increase in the air voids content of the recycled mixtures.
- Voids filled with asphalt for specimens containing (RAP + WEO) are lower than the ones containing only RAP, that means VFA decreases by increasing the WEO content in the recycled mix at the same compaction efforts, which is owing to an increase in the air voids content in the recycled mixtures.
- Stability values for specimens containing (RAP + WEO) are lower than the ones containing only RAP, that means its level decreases by increasing the WEO content in the recycled mix at the same compaction efforts. WEO works to rejuvenate the cohesion powers in the aged RAP binder, also it works to decrease the viscosity of the combined binder, so that when the specimens immersed in hot water, the level of the stability is affected (decreased) by high temperature. This result is supported by the findings of (Kandahal et al., 1995).
- Bulk density values decreases by increasing WEO in the recycled mixtures at the same compaction efforts, basically due to softening the combined blend between (virgin + RAP) binder, which leads to lesser density and high air voids content in the mix.
- Flow values for specimens containing (RAP + WEO) are slightly higher than the ones containing only RAP, that means its level increases by increasing the WEO content in the recycled mix at the same compaction efforts. The lubrication between combined aggregate particles has been increased slightly owing to a decrease in the viscosity of combined binder and as a result the mixture flow increases slightly.

4.1 Indirect Tensile Strength Test

4.1.1 Reclaimed Asphalt Pavement Effect on Indirect Tensile Strength

According to figure (6), the indirect tensile strength at (20° C) increases by increasing RAP content in the HMA mixture. The RAP binder is a brittle high viscous material due to aging effects, therefore viscosity level of combined (RAP + virgin) binder increases by increasing the RAP content in the mix causing hardened mixture. Accordingly, the level of indirect tensile strength at low temperature (0° or 20° C) is significantly high especially for mixtures containing high RAP (above 20%).

At high temperature (above 40° C) indirect tensile strength begins to decrease and continue to decrease by increasing the heating time. It can be concluded that using recycled mixtures in constructing surface course will increase the resistance of this course to tensile stresses which may be developed within this layer due to various traffic loadings and climatic conditions. This result is supported by the findings of (Namir G. Ahmed & Abbaas I. Kareem, 2013)

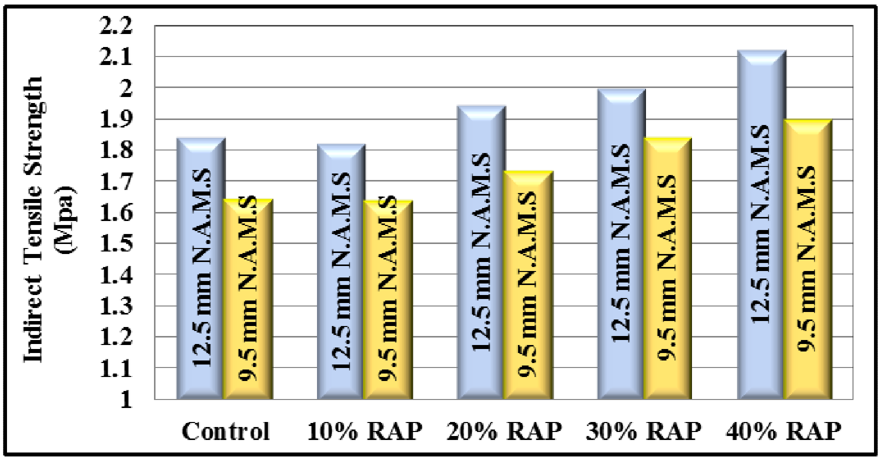

Figure (6) Graph. Indirect tensile strength test results for control and recycled mixtures compacted @ N_{design} = 105 gyrations

4.1.2 Air Voids Effect on Indirect Tensile Strength

In normal HMA mixtures, indirect tensile strength increases by decreasing air voids content in the mix. This result is supported by the findings of (Yasir M. Jebur, 2013). In recycled mixtures, indirect tensile strength increases by increasing RAP content in the mix due to variation in viscosity and not because the reduction in air voids content. We proved that by adjusting the air voids content in the recycled mix to 4%, and then the indirect tensile strength is measured at that content, where it has been found higher than the original level.

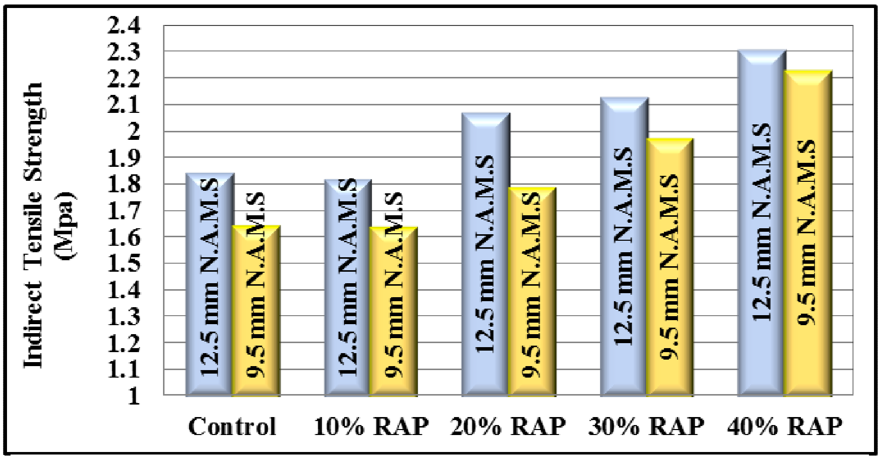

Figure (7) Graph. Indirect tensile strength test results for control and recycled mixtures compacted @ 4% air voids

4.1.3 Waste Engine Oil Effect on Indirect Tensile Strength

Indirect tensile strength level decreases by increasing WEO content in recycled mixture and that can be attributed to the fact that by increasing WEO content in the mix, the viscosity of the combined binder blend begins to decrease gradually. In this research, small quantities of WEO added to the recycled wearing (IIIA) A.M.S mixtures causing slight reduction in the level of indirect tensile strength. Therefore, it can be concluded that using small quantities of WEO in the recycled mixtures will not highly affect the resistance of mixture to tensile stresses.

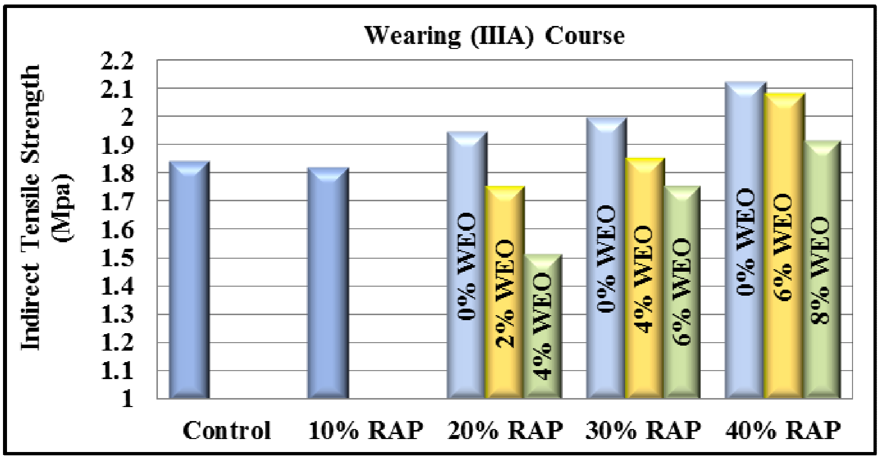

Figure (8) Graph. Indirect tensile strength test results for control and recycled mixtures compacted at N_{design} = 105 gyrations with various percentage of WEO as a recycling agent

4.2 Tensile Strength Ratio Test

4.2.1 Reclaimed Asphalt Pavement Effect on Tensile Strength Ratio

The level of tensile strength ratio increases by increasing the RAP content which indicated that HMA mixtures containing high percentages of RAP would exhibit a good resistance to moisture damage. The aged binder of RAP has strong adhesion powers due to high viscosity; therefore, the recycled mixture exhibits high resistance to moisture damage. This result is supported by the findings of (Zhao et al., 2012).

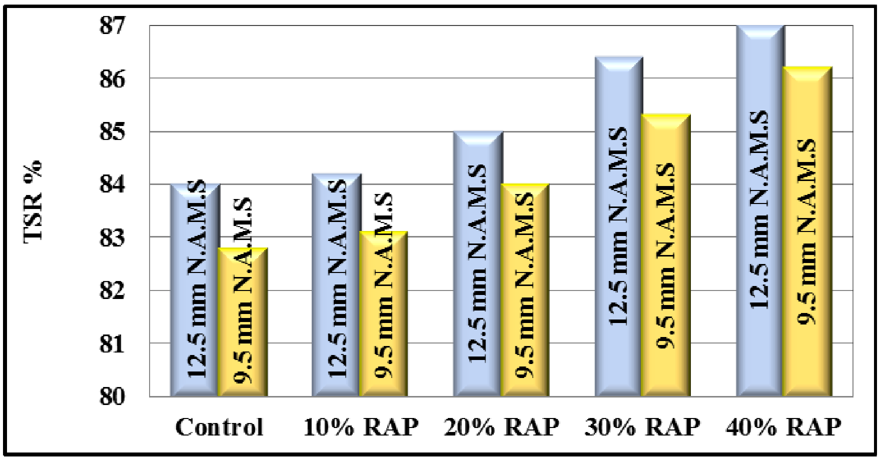

Figure (9) Graph. TSR test results for control and recycled mixtures

4.2.2 Waste Engine

The level of (TSR) decreases by increasing the WEO content in the recycled mixture and that can be attributed to the fact that by increasing WEO content in the mix, the viscosity of the combined binder blend begins to decrease gradually that means the adhesion power of the binder begins to decrease also. In this research, small quantities of WEO added to the recycled wearing (IIIA) A.M.S mixtures causing high reduction in the level of (TSR), but still within AASHTO T 283 specification limit (TSR ≥ 80%).

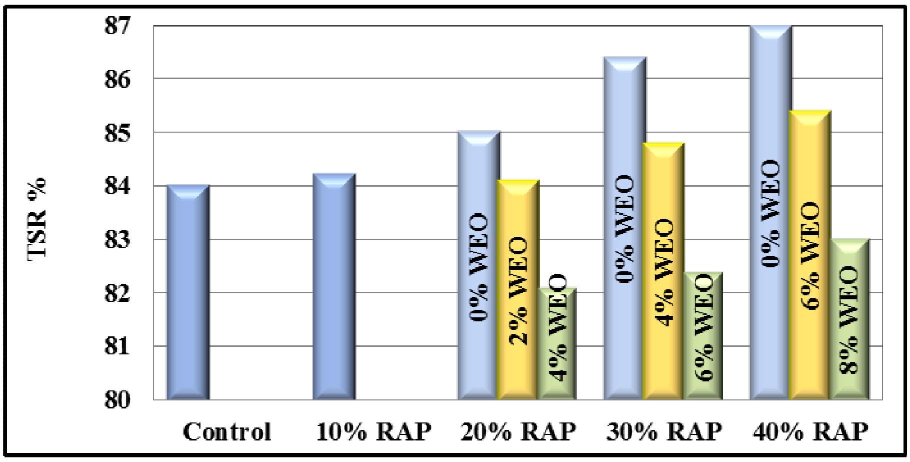

Figure (10) Graph. TSR test results for control and modified recycled mixtures

5. Conclusions

This study was conducted to investigate the effects of RAP on the volumetric properties and performance test of HMA mixtures, the following conclusions can be summarized:

1. RAP can be used successfully without any modification in the HMA surface mixtures up to:
    - A. 15% for both surface (IIIA & IIIB) A.M.S mixtures, so that total content of air voids, VMA, VFA & filler/asphalt ratio are within the limits of Superpave volumetric design criteria (NCHRP-673, 2011).
    - B. 35% for both surface (IIIA & IIIB) A.M.S mixtures, so that total content of air voids, stability & flow levels are within the limits of Iraqi standards (SCRB, R/9 2003).
2. The percentage of air voids content decreased by increasing the RAP content especially at high level of RAP, where it was found to be decreased by (7.5%, 20% and 35%) for (20, 30 and 40%) of RAP respectively in surface (IIIB) mixtures, and by (7.5%, 17.25%, and 27.25%) for (20, 30 and 40%) of RAP respectively in surface (IIIA) mixtures.
3. The percentage of voids in mineral aggregate decreased by increasing the RAP content, where it was found to be decreased by (0.25%, 3.1%, 6.7% and 10%) for (10, 20, 30 and 40%) of RAP respectively in surface (IIIB) mixtures, and by (1.8%, 5.4%, 8.3% and 11.4%) for (10, 20, 30 and 40%) of RAP respectively in surface (IIIA) mixtures. By adjusting the air content to 4% for all recycled mixtures, the percentage of VMA was found to be decreased by (0.25%, 0.82%, 1.45% and 1.45%) for (10, 20, 30 and 40%) of RAP respectively in surface (IIIB) mixtures, and by (1.8%, 3.1%, 3.1% and 4.5%) for (10, 20, 30 and 40%) of RAP respectively in surface (IIIA) mixtures.
4. The percentage of voids filled with asphalt increased by increasing the RAP content especially at high level of RAP, where it was found to be increased by (1.33%, 5.33% and 9.33%) for (20, 30 and 40%) of RAP respectively in surface (IIIB) mixtures, and by (1.41%, 4.23% and 7.04%) for (20, 30 and 40%) of RAP respectively in surface (IIIA) mixtures.

   By adjusting the air content to 4% for all recycled mixtures, the percentage of VFA was found to be decreased by (1.33%) for all used percentages of RAP in surface (IIIB) mixtures and by (1.41%) for all used percentages of RAP in surface (IIIA) mixtures.
5. Filler/asphalt ratio decreased by increasing the RAP content, where it was found to be decreased by (7.1%, 13.4%, 22.8% and 31.5%) for (10, 20, 30 and 40%) of RAP respectively in surface (IIIB) mixtures, and by (8.66%, 16.53%, 25.2% and 33.86%) for (10, 20, 30 and 40%) of RAP respectively in surface (IIIA) mixtures.
6. Stability values initially decreased by (1.65% and 3.61) for 20% RAP in both surface (IIIB & IIIA) mixtures. Afterwards it began to increase at high RAP content, where it was found to be increased by (18.25% and 42.14%) for (30 and 40%) of RAP respectively in surface (IIIB) mixtures, and by (16.3% and 39.16%) for (30 and 40%) of RAP respectively in surface (IIIA) mixtures. By adjusting the air content to 4% for all recycled mixtures, the level of stability was found to be increased by (7.57%, 32.3% and 63.2%) for (20, 30 and 40%) of RAP respectively in surface (IIIB) mixtures and by (2.61%, 29.24% and 54.8%) for (20, 30 and

40%) of RAP respectively in surface (IIIA) mixtures.

7. Density values increased by increasing the RAP content especially at high level of RAP for both wearing (IIIB & IIIA) A.M.S mixtures. By adjusting the air content to 4% for all recycled mixtures, the level of density was found to be decreased by (0.64%, 1% and 1.45%) for (20, 30 and 40%) of RAP respectively in surface (IIIB) mixtures and by (0.3%, 0.72% and 0.88%) for (20, 30 and 40%) of RAP respectively in surface (IIIA) mixtures.
8. Flow values increased by increasing the RAP content especially at high level of RAP where it was found to be increased by (3% and 14.71%) for (30 and 40%) of RAP respectively in surface (IIIB) mixtures and by (11.86% and 25.4%) for (30 and 40%) of RAP respectively in surface (IIIA) mixtures. By adjusting the air content to 4% for all recycled mixtures, the level of flow was found to be decreased by (5.9%, 11.76% and 23.53%) for (20, 30 and 40%) of RAP respectively in surface (IIIB) mixtures and by (5.1%, 11.86% and 25.4%) for (20, 30 and 40%) of RAP respectively in surface (IIIA) mixtures.
9. Indirect tensile strength increased by increasing the RAP content especially at high level of RAP where it was found to be increased by (5.52%, 11.91% and 15.48%) for (20, 30 and 40%) of RAP respectively in surface (IIIB) mixtures, and by (5.49%, 8.37% and 15.16%) for (20, 30 and 40%) of RAP respectively in surface (IIIA) mixtures. By adjusting the air content to 4% for all recycled mixtures, the value of indirect tensile strength was found to be increased by (8.91%, 20.1% and 35.56%) for (20, 30 and 40%) of RAP respectively in surface (IIIB) mixtures, and by (12.32%, 15.5% and 25.26%) for (20, 30 and 40%) of RAP respectively in surface (IIIA) mixtures.
10. Tensile strength ration increased by increasing the RAP content, where it was found to be increased by (0.32%, 1.4%, 3.1% and 4.1%) for (10, 20, 30 and 40%) of RAP respectively in surface (IIIB) mixtures, and by (0.25%, 1.13%, 2.8% and 3.44%) for (20, 30 and 40%) of RAP respectively in surface (IIIA) mixtures.
11. Using WEO as a recycling agent in recycled surface (IIIA) mixtures has affected the values of volumetric properties and performance tests positively as follows:
    A. As a result of mixing (2% and 4%) of WEO with recycled mixtures containing 20% RAP, the total air voids content increased by (8.1% and 34.3%), VMA increased by (4.7% and 11.53%), VFA decreased by (1.4% and 8.33%). Stability level decreased by (4% and 10.37%), density level decreased by (0.76% and 1.77%), flow level increased by (0% and 6.67%). Indirect tensile strength decreased by (9.8% and 21.9%), and tensile strength ratio decreased by (1.05% and 3.44%).
    B. As a result of mixing (4% and 6%) of WEO with recycled mixtures containing 30% RAP, the total air voids content increased by (17.8% and 33%), VMA increased by (4.1% and 7.2%), VFA decreased by (4.05% and 8.11%). Stability level decreased by (5.85% and 7.88%), density level decreased by (0.63% and 1.1%), flow level at 4% WEO decreased by 3.03%, then it has increased by 6.1% at 6% WEO. Indirect tensile strength decreased by (7.12% and 11.93%), and tensile strength ratio decreased by (1.83% and 4.6%).
    C. As a result of mixing (6% and 8%) of WEO with recycled mixtures containing 40% RAP, the total air voids content increased by (36.4% and 51.89%), VMA increased by (7.78% and 11.02%), VFA decreased by (7.89% and 10.53%). Stability level decreased by (3.38% and 6.52%), density level decreased by (1.1% and 1.55%), flow level at 6% WEO decreased by 5.4%, then it increased by 5.4% at 8% WEO. Indirect tensile strength decreased by (2.03% and 9.72%), and tensile strength ratio decreased by (1.87% and 4.59%).

As a result of using (2%, 4% and 6%) of WEO for (20, 30 and 40%) RAP respectively in surface (IIIA) wearing mixtures, all the values of volumetric properties and performance test were modified to be almost within Superpave and Iraqi standards.

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