



Evaluating hot mix asphalt for different recycled asphalt pavement contents and filler kinds utilizing marshall characteristics and moisture damage



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HIGHLIGHTS

- Three asphalt grades (40-50, 60-70, 85-100) were used with hydrated lime, Portland cement, and limestone fillers.
- Optimal binder content was determined using the Marshall method, with 10%, 20%, and 30% RAP used.
- Asphalt with hydrated lime showed the best stability, flow, and air voids compared to other fillers.
- Two recycling agents, waste oil and softer asphalt (85-100), were studied for their effects on RAP mixes.
- Adding 4% waste oil to asphalt (40-50) and 30% RAP increased Marshall stability from 13.5 KN to 15.31 KN.

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ABSTRACT

A significant amount of reclaimed asphalt pavement must be used to address the growing demand for sustainable road-building materials. One of the problems of employing RAP in mixes is that it makes them more rigid. The guideline specifies that when the amount of RAP is greater than 15%, softer-grade asphalt should be used; however, the asphalt used in Baghdad is 40–50 grade, and its high viscosity makes it challenging to mix when adding RAP. Sometimes, softer grades are not readily available and must be made upon request. Therefore, using some waste oil as a rejuvenator was the task. It is more economical and environmentally friendly. In this study, three asphalt grades (40-50, 60-70, and 85-100) are used, and three distinct types of fillers; hydrated lime, Portland cement, and limestone dust; with an aggregate gradation of maximum size (12.5 mm). Three percentages of recycled asphalt pavement (RAP) materials, 10%, 20%, and 30%, are used. Based on Marshall graphs, the optimum asphalt cement content for each grade was calculated. The samples in all blends were subjected to volumetric analysis, Marshall Stability, flow, and water sensitivity testing. The findings of this study showed that adding hydrated lime enhanced Marshall properties and reduced the sensitivity of asphalt mixes to moisture. Stability increases as the proportion of RAP increases. Asphalt (40-50) with 4% waste oil showed improved stability than the original asphalt mix and presented better Marshall properties than the softer grade (85-100). Additionally, mixes containing RAP may be less moisture-resistant than conventional mixtures.

1. Introduction

The pavement industry has long highlighted the need to reuse RAP materials from damaged roads. These materials still have the necessary properties; if the standards are met, they can be used for surface layers. RAP is a good approach to saving non-renewable resources, such as the bitumen and aggregates used in asphalt mixes, because of the decreasing amount of fresh resources available and the rising cost of commodities [1,2].

The road-building industry has been pushing for increasing RAP percentages to lower road project costs due to the rise in the price of asphalt ingredients. Elevating the RAP percentage might potentially decrease the amount of trash and increase the value of recycled pavements. Because RAP is economical and environmentally beneficial, its application in asphalt concrete complies with the demand for sustainable solutions in pavements [3].

It is predicted that the environmental effect of manufacturing will decrease by 23% when RAP is added to asphalt mixes. Moreover, RAP offers a noteworthy decrease in material costs. Getting hold of high-quality virgin aggregate material is getting

harder and harder. Consequently, by using RAP, road authorities may develop and renovate more roads with comparable financial resources by offsetting expenses. To prevent any negative impacts on the mix qualities, most road authorities permit the integration of no more than 30% RAP in hot mix asphalt (wearing course) [4-6]. For example, depending on the traffic volume on a particular road, the Illinois Department of Transportation only permits up to 30% RAP in binder and surface combinations. This is because oxidative hardening and other aging processes that RAP experiences while exposed to the environment over its service life are the main reasons it is typically seen as a stiff material. Consequently, manufacturers and road authorities may be discouraged from raising the RAP content further because of the potential for cracking failures caused by the increased stiffness in RAP [7,8]. According to the Asphalt Institute, adjusting the asphalt grade is unnecessary when RAP is utilized in a mix at a rate of 15 percent or less [9]. Comprehending the impact on asphalt mixture parameters is essential to integrate RAP into mix design [10]. In HMA pavements, the use of RAP has become more widespread. The reason behind this change is the increased need for recycled asphalt pavement (RAP) and the advancement of reclamation techniques, which have made it easier to substitute RAP for new asphalt binders and aggregates [11]. Waste engine oil (WEO) is any synthetic or petroleum-based oil that has lost its original qualities or become unfit for its intended use, yet it may be utilized as a recycling (rejuvenating) agent in the paving industry. WEO was made from the used motor oil. In numerous research studies, WEO has been used as a rejuvenating agent to restore the physical qualities of the aged binder in RAP in recovered asphalt pavement. Waste motor oil was employed as a recycling agent by Hayner [12], Collins and Jones [13] to decrease the stiffening impact of RAP in asphalt paving mixes. Because waste engine oil has a significant percentage of maltene components, Zaumanis [14] employed it to rejuvenate RAP while researching the performance characteristics of recycling asphalt mixture.

Resolving quality-related problems is the primary obstacle to implementing RAP (reclaimed asphalt pavement). RAP has to be updated because it is an old material and doesn't perform like new pavement. This puts forward the need for additional procedures like using rejuvenating agents. Oil-containing additions can be useful since bitumen loses its oily components as it ages. In a previous study by [15], an aging asphalt mixture was revitalized using two types of waste oils. The ideal contents of Waste Engine Oil (WEO) and Waste Vegetable Oil (WVO) additives were found to apply different RAP contents. The findings showed that adding WEO and WVO to mixes containing RAP rejuvenators increases the quantity of RAP used in bituminous mixtures. Asphalt mixes incorporating RAP renewed with WEO are a promising new technique for environmentally friendly road building and restoration. Marshall stability, indirect tensile strength, moisture resistance, resilience to stripping, and rutting resistance could all rise using the WEO [16]. The aged RAP bitumen became softer due to the application of waste engine oil, which increased fracture energy and decreased rutting resistance, resilience modulus, and stability. Because stiff RAP bitumen was present, the RAP-incorporated mixtures exhibited lower fracture energy. Nevertheless, including WEO increased fracture energy, indicating that WEO's softening effect enhanced these blends' resistance to cracking. At all rejuvenator doses, increased CS content decreased the stiffness-indicating Marshall quotient [17].

Utilizing waste oil shale as a mineral filler (OSMF), this study examines the performance of aged asphalt mixtures. The results show that using 50% and 100% OSMF in asphaltic mixes improves the performance of the mixes by lowering the average losses in both design mixes' ITS and Marshall stability. Comparing the Superpave mixes to the Marshall mixes, the former exhibits greater stability and lower flow values across all OSMF% combinations. Additionally, compared to the Marshall mixes under both aging circumstances, they performed better in the loss of stability and loss of ITS [18]. A few earlier studies have used waste oil, although most have used vegetable and culinary oils. The potential of using waste oil as a rejuvenator for RAP and improving the quality of asphalt mixes has been demonstrated by earlier studies; nevertheless, more research is needed to expand the scope of the study. Use of asphalt grade 40-50, which is the most common in Baghdad, Iraq, and according to the AASHTO M-323 [19], the kind of asphalt binder grade should be changed when the amount of reclaimed asphalt pavement increased by more than (15%), which means that softer asphalt was required, and asphalt grade (40-50) making problem when mixing with RAP because of its high viscosity and due to difficulty of providing softer grade asphalt, it is better to use of waste engine oil, as it is more available, more economical and improves the properties of the asphalt mixtures contains more than 15% RAP according to results from this study.

RAP as a recycled material in Iraq has not been sufficiently studied to show how to treat it so that it can be used correctly to improve the performance of asphalt paving. The use of RAP on Iraqi roads is not a new thing, but some points must be taken into consideration that are not sufficiently studied by the departments concerned with road construction in Iraq. For example, the date of construction of the road from which the RAP was taken, a study of the extent of damage to which this road was exposed, in addition to the location of this road and what were the conditions that led to these damages, whether they were caused by changes in temperature, humidity, unexpected high loads, and so on. It is clear that the asphalt material present in the RAP has been subjected to oxidation over time and has lost its elastic properties. Therefore, consideration must be given to using materials added to the RAP that restore the elastic behavior of the asphalt mixture in which the RAP will be used in grading. To improve the ability of asphalt pavements to be recycled, this study evaluates several asphalt mixes with various ratios of recycled asphalt pavement and fillers. It also investigates the possibility of using used motor oil as a rejuvenator for asphalt. The research's objectives are to determine the Marshall properties of asphalt mixtures that contain RAP in various amounts and with various fillers, as well as to investigate moisture resistance and the use of machine oil to enhance the behavior of recycled asphalt mixtures. An overview of the experimental study is shown in Figure 1.

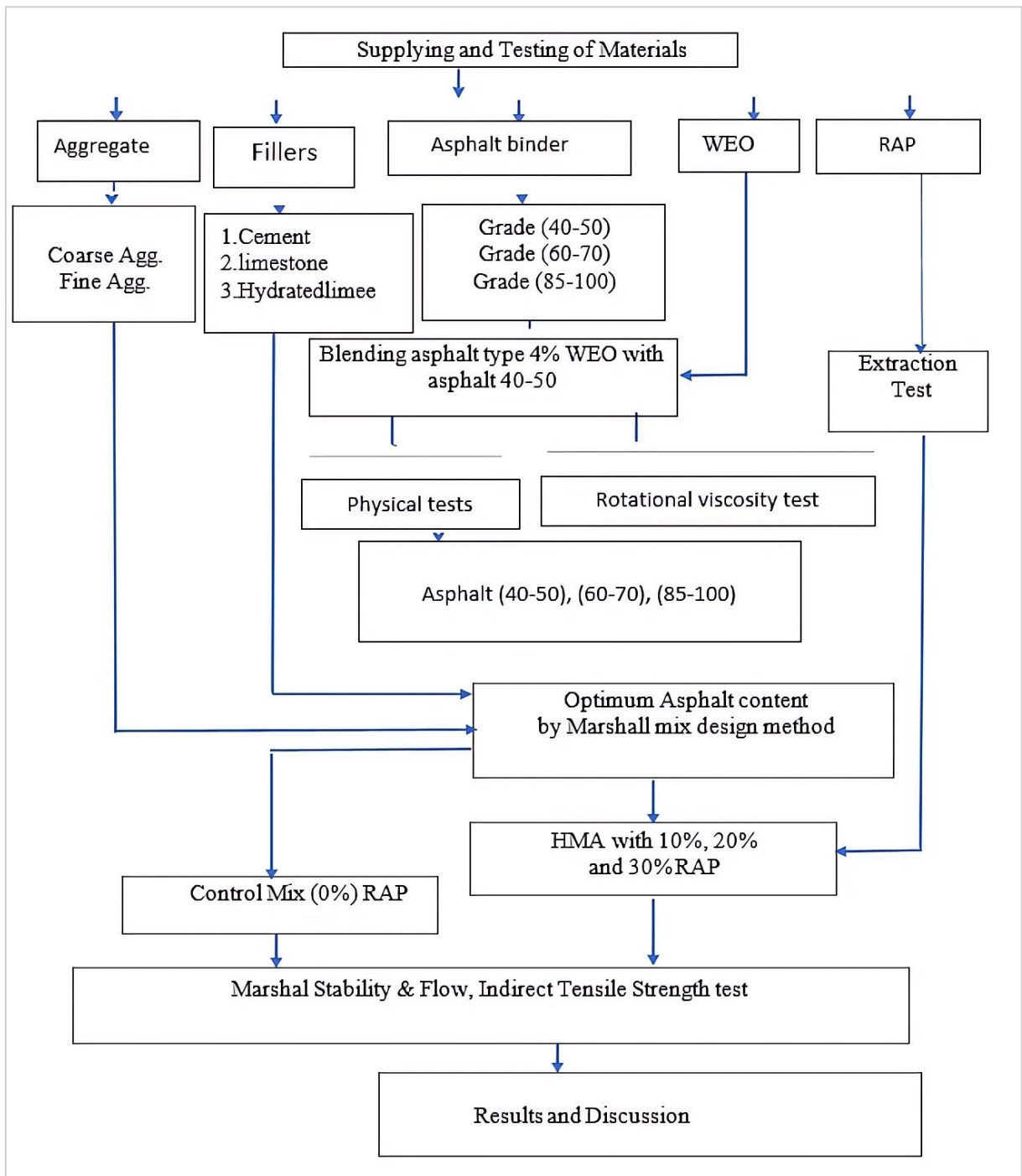


Figure 1: The methodology of the research work

2. Materials and experimental work

In this study, three grades of asphalt were used (40-50), (60-70), and (85-100) with three types of fillers: hydrated lime, Portland cement, and limestone in this study. For the three fillers, a total sample 135, 45 samples for each type of asphalt, with 15 samples for each filler, the optimum binder content (OBC) for the asphalt mixes were calculated using the Marshall mix design technique. Three percentages of RAP (10%, 20%, and 30%) were employed with the three types of filler. Three samples represented each filler type and percentage of RAP, and the average results were given. With an asphalt grade (40-50) and a RAP percentage of 30%, waste engine oil (WEO) was used as a recycling agent. There are 45 samples in all that Marshall Properties are examining. For the indirect tensile strength test, there were 90 samples in total. Each mixture requires six specimens—three conditioned and three unconditioned.

2.1 Asphalt cement

For this project, three types of asphalt cement have been used: asphalt cement with a penetration grade of (40-50), (60-70) and (85-100) was obtained from Baghdad Al-Dourah Refinery. Table 1 illustrates the physical properties of the three types of asphalt.

Table 1: The physical characteristics of asphalt cement

Test	ASTM Designation (2015)	Test results PEN (40-50)	SCRB specification (2003)	Test results PEN (60-70)	SCRB specification (2003)	Test results PEN (85-100)	SCRB specification (2003)
Penetration (25 °C, 100 g .5 sec)	D5	44	40-50	66	60-70	91	85-100
Ductility (35 °C. 5 cm/min)	D113	110	>100	130	>100	128	>100
Softening Point,	D36	54	-----	46	-----	41	-----
Flash Point, °C	D92	291	>232	251	>232	243	>232
Fire Point, °C	D92	305	---				
Specific Gravity of asphalt	D72	1.034	-----	1.03	-----	1.03	'-----
Rotational viscometer, (Pa. sec)	D4402	0.482@ 135 °C 0.121 @165 °C	---	0.425@ 135 °C 0.101 @ 165 °C		0.369@ 135 °C 0.085@ 165 °C	
Loss on Heating (5hrs at 163 °C)	D1754	0.29%	<0.75	0.47		0.37	

2.2 Aggregate and mineral fillers

The Al-Nibaie quarry, often employed in asphalt mixtures in Baghdad, provided the crushed aggregates used in this investigation.

The Iraqi State Corporation for Roads and Bridges (SCRB) [20] indicated in Table 2 that the nominal maximum size of the aggregate selected for the aggregate gradation used in asphalt concrete mix for the trail sample for the wearing course was 12.5 mm. Table 3 displays the physical properties of coarse and fine aggregates. The local market provides the mineral filler (three types of fillers: cement, limestone, and hydrated lime) to prepare the asphalt mixtures. These are the most often utilized filler kinds in Iraq, combined with asphalt concrete mixtures that are readily accessible locally and reasonably priced. The filler is a non-plastic material passing sieve No.200 (0.075 mm) free and dry lumps or fine particulates, as given in Table 4. Table 5 displays the chemical composition of each filler. Figure 2 shows Surface Layer Specification Limits and Selected Mid-Point Gradation.

Table 2: Gradation of the aggregate for surface course

Sieve Size		% Passing as by (SCRB/ R9, 2003) wearing course type IIIA		
Standard Sieves	English Sieves	Min.	Max.	%Passing
19.00 mm	3/4"	---	100	100
12.50 mm	1/2"	90	100	95
9.500 mm	3/8"	76	90	83
4.750 mm	#4	44	74	59
2.360 mm	#8	28	58	43
0.300 mm	#50	5	21	13
0.075 mm	#200	4	10	7
Pan	---			

Table 3: Physical properties of fine and coarse aggregate

property	ASTM Specification	Result	SCRB Specification
Coarse Aggregate			
Bulk Specific Gravity	ASTM C127	2.605	
Apparent Specific Gravity	ASTM C127	2.659	
percent wear (loss of Angel's abrasion)	ASTM C131	15	30 MAX
Fine Aggregate			
Bulk Specific Gravity	ASTM C128	2.653	
Apparent Specific Gravity	ASTM C128	2.689	

Table 4: Specific gravity of filler types

Filler type	Specific gravity
Portland cement (PC)	3.15
Hydrated Lime (HL)	2.50
Limestone (LS)	2.70

Table 5: Chemical composition of mineral fillers

Filler type	Chemical Composition, %						Loss on Ignition (L.O.I)
	Lime (CaO)	Silica SiO ₂	Alumina Al ₂ O ₃	Magnesia (MgO)	Ferric Oxide Fe ₂ O ₃	Sulfuric Anhydride (SO ₃)	
Limestone	50.5	2.09	3.7	8.25	0.09	0.37	35
Portland cement	53	20	6	2	1	0	18
Hydrated Lime	69	1	----	2	----	1	27

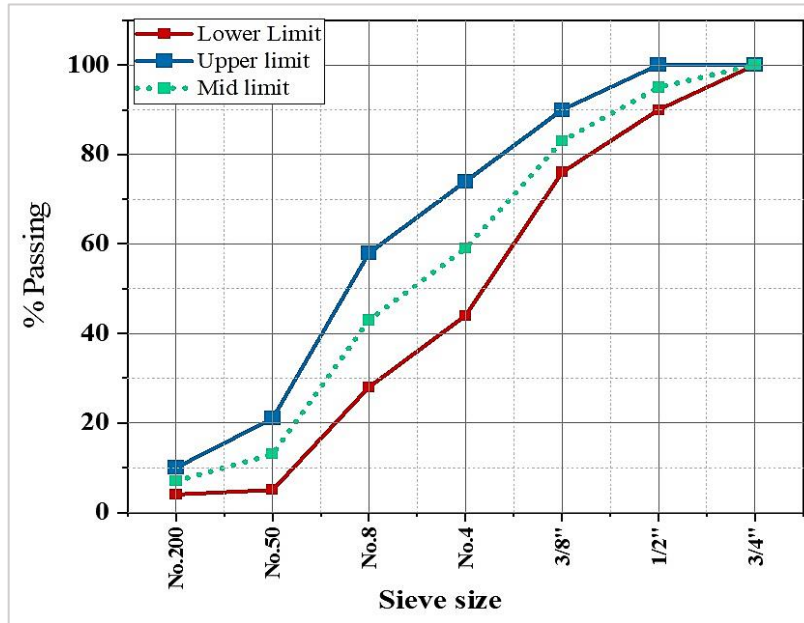


Figure 2: Surface layer specification limits and selected Mid-Point gradation of (SCRB R/9, 2003)

2.3 Reclaimed asphalt pavement (RAP)

The reclaimed asphalt road was obtained from the Mayoralty of Baghdad/ projects office in the Ziona area /Baghdad City and resurfaced in 2006. Reclaimed asphalt pavement was extracted from the surface at a minimum depth of five centimeters. The reclaimed asphalt pavement was guaranteed to be free of clay accumulating on the surface and other harmful materials. A random selection of ten samples was made from the stockpile of milling material. By ASTM D-2172 [21], these samples are put through an extraction test to remove the aged asphalt binder from the aggregate and determine the aggregate's gradation, characteristics, filler content, and asphalt binder content. Table 6 displays the characteristics of the recovered asphalt pavement after extraction, while Table 7 and Figure 3 display the gradation of the reclaimed asphalt pavement before and after extraction.

Table 6: Physical properties of reclaimed asphalt pavement (RAP)

Laboratory test	Test results	ASTM designation
Coarse aggregate	Apparent specific gravity	2.611
	Bulk specific gravity	2.549
	Water absorption, %	0.68
Fine aggregate	Apparent specific gravity	2.694
	Bulk specific gravity	2.654
	Water absorption, %	0.763
Asphalt cement, %	3.7	D2172

Table 7: Gradation of RAP materials before and after extraction test and limitations of (SCRB R/9, 2003) for surface layer

Sieve Size	Sieve Opening (mm)	Percentage Passing by Weight of Total RAP Aggregate		
		Before Extraction	After Extraction	Specification Limits (SCRB R/9, 2003)
3/4"	19	100	100	100
1/2"	12.5	91.6	94.9	90-100
3/8"	9.5	78.5	83.3	76-90
No.4	4.75	53.3	58.7	44-76
No.8	2.36	36.1	41.9	28-58
No.50	0.3	6.3	11.7	5-21
No.200	0.075	4.3	5.2	4-10

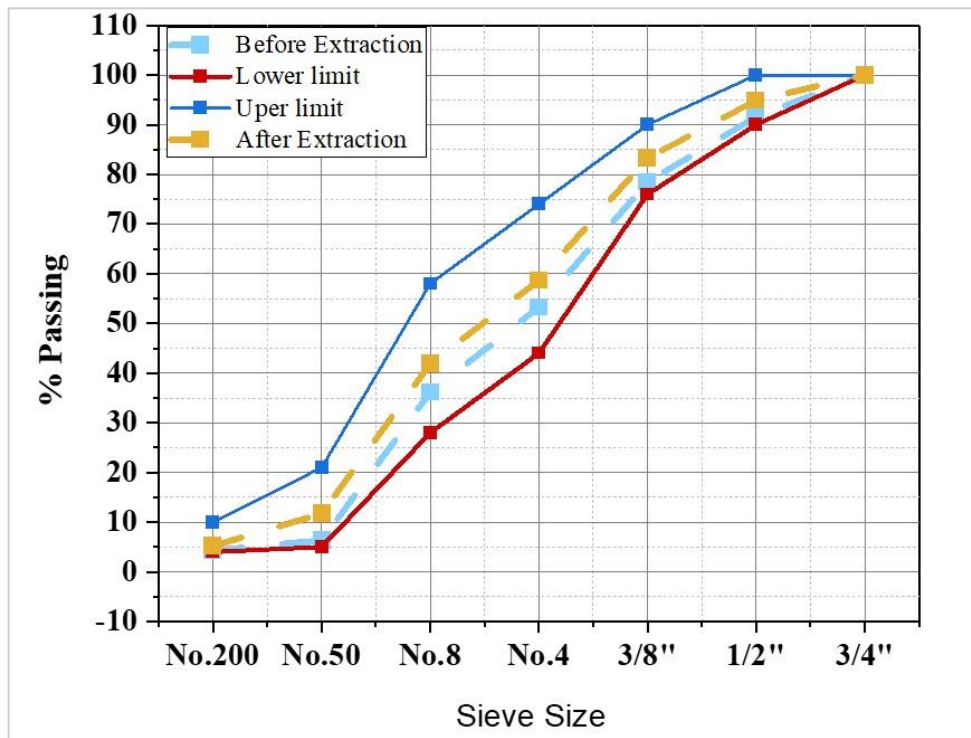


Figure 3: RAP material gradation before and after extraction test and (SCRB, R/9) surface layer limitations

2.4 Waste engine oil

The two recycling agents employed in this work are waste oil engines and softer asphalt with a grade of (85–100). The purpose of the former is to enhance the physical characteristics of the aged binder in RAP and to make up for the maltenes lost with time in the asphalt binder. Being compatible with the aged binder in RAP is crucial when choosing a rejuvenating agent.

Different percentages of WEO (2%, 3%, and 4% of the weight of the asphalt binder) are used to calculate the proper amount of rejuvenating agents for RAP. It is found via trial and error that the optimal amount of WEO is 4%, which is compatible with previous research [16,22]. Numerous studies have indicated that the penetration value may be used as a guide to estimate the optimal rejuvenator concentration [23,24], and [25]. Rejuvenating compounds with a high aromatic content and a low saturate level usually function well with old binders, according to Dunning and Mendenhall [26]. The Daura refinery provided asphalt grade (85–100) on special order, which was utilized as a softening agent. The bitumen that was amended was produced using a combination of 40–50 asphalt and three percentages (2, 3, and 4%) of WEO. To make a uniform mixture, the waste oil and asphalt were mixed for 30 minutes at 1,300 rpm using an experimental mixer [27]. Table 8 presents the physical properties of the waste engine oil.

Table 8: Physical characteristics of waste engine oil [27]

Test	Value
Specific Gravity	0.869
Kinematics Viscosity at 135 °C (CST)	3.86
Type	Petroleum
Polarity	Slight
Price per Liter	Free

3. Extraction test

According to ASTM D-5404 [28], extraction separates the asphalt binder from the aggregate and mineral filler by dissolving it in an appropriate solvent. In contrast, recovery is distilling the asphalt binder from the solvent. This test was utilized to examine aggregates' physical characteristics and accurate gradation to calculate the asphalt binder content and mineral filler percent. Ten samples were used in this test; they were chosen randomly from the stockpile of milling materials. After these samples are extracted (ASTM D-2172) [28], gasoline is used as a solvent with 1500 grams of recycled asphalt pavement, and the mixture is heated to 140 degrees Celsius. Next, add the gasoline solvent to the sample. Finally, the pan containing the sample and solvent is inserted into the centrifuge extraction apparatus. Figure 4 shows how the extraction test is conducted (A, B) milling process and (C, D) the equipment for the extraction test.

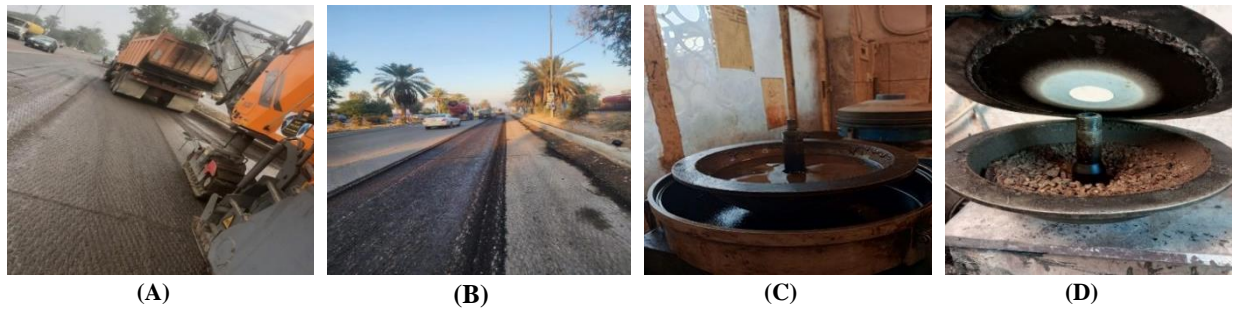


Figure 4: (A, B) Milling process and (C, D) the equipment for the extraction test

4. Production and compaction temperature (rotational viscosity test)

The hot mix asphalt (HMA) design was based on the Marshall Method criteria. Accordingly, the specimens must be mixed and compacted under equiviscous temperature conditions, which correspond to viscosities of 0.280 ± 0.03 and (0.170 ± 0.02) Pa.s [28]. The viscosity of each kind of asphalt binder was measured using a Brookfield viscometer at two different temperatures ($135\text{ }^\circ\text{C}$ and $165\text{ }^\circ\text{C}$) [29,30].

5. Marshall properties test

Laboratory samples were prepared per (ASTM D6926-10) (Standard Practice for Preparation of Bituminous Specimens Using Marshall Apparatus) to conduct the Marshall Stability Test. For wearing coarse, Marshall stability and flow values are determined using the Marshall stability and flow test (ASTM D6927-15) (Standard Test Method for Marshall Stability and Flow of Asphalt Mixtures). Figure 5(A, B, C) shows Marshall specimens' preparation steps and Figure 5D Marshall stability and flow Test. The codes for the nine varieties of asphalt mixtures are shown in Table 9.

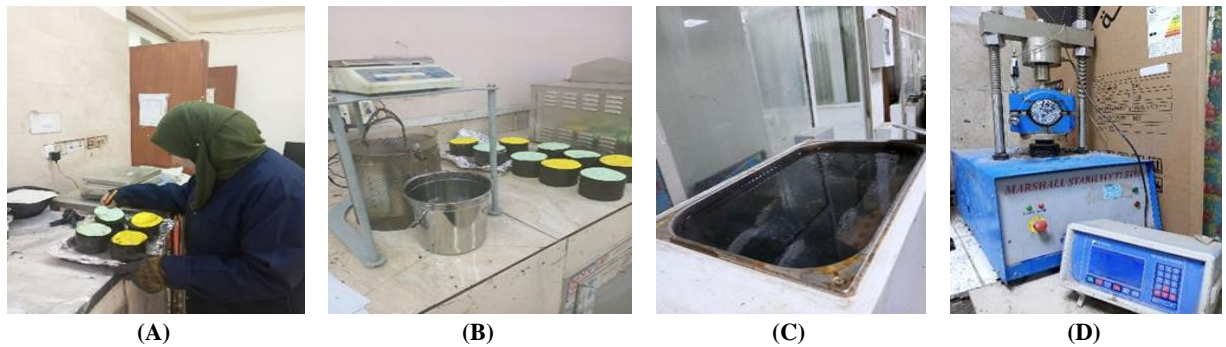


Figure 5: (A, B, C,) Marshall specimens' preparation steps (D) marshal stability and flow test

Table 9: The code for the nine asphalt mixture types

Asphalt mixture code	Explanation
A44HL	Asphalt (40-50) penetration with hydrated lime filler
A44PC	Asphalt (40-50) penetration with Portland cement filler
A44LS	Asphalt (40-50) penetration with limestone filler
A66HL	Asphalt (60-70) penetration with hydrated lime filler
A66PC	Asphalt (60-70) penetration with Portland cement filler
A66LS	Asphalt (60-70) penetration with limestone filler
A91HL	Asphalt (85-100) penetration with hydrated lime filler
A91PC	Asphalt (85-100) penetration with Portland cement filler
A91LS	Asphalt (85-100) penetration with limestone filler

6. Method for designing hot reclaimed asphalt pavement mixtures

This stage involves designing, fabricating, and producing the asphalt pavement to produce hot mix asphalt with the same qualities as conventional mixtures (a virgin mixture created from asphalt grade (40–50)). Since the characteristics of the asphalt binder predominantly determine the behavior of the asphalt mixture, mixture viscosity (as indicated by the viscosity of their binder) is a significant factor. The kind of asphalt binder grade changed when the amount of reclaimed asphalt pavement increased by more than (15%) Table 10, which means that softer asphalt was required, according to the AASHTO M-323 [19]

technique and the NCHRP Report-452 [31] method. The present study produces mixes with varying percentages of RAP (0, 10, 20, and 30 percent).

Table 10: Binder selection guidelines for RAP mixtures [26,12]

No.	Recommended Virgin Asphalt Binder Grade	RAP percentage
1	No change in the binder selection	≤15
2	Select virgin binder grade softer than normal	>15-≤25
3	Follow recommendations from blending charts	> 25

Equation (1) determines the quantity of virgin asphalt binder substituted with RAP binder [16].

$$Pr = Pc - (Pa \times Pp), \tag{1}$$

where Pr: is the percent of virgin asphalt to be added to the mix containing RAP, Pa: is the percent of (RAP asphalt) in the mix (mean the residual asphalt in RAP), Pc: is the percent of total asphalt in the mix and, Pp: is the percentage of RAP in the mix. (The percentage of RAP used in this study is 10%,20%, and 30%).

7. The indirect tensile strength test

ASTM D 4867 [32] is the method used to assess the moisture susceptibility of the HMA sample. Six specimens of each mix type were compacted using the Marshall compaction method to an air void level range of 6 to 8 percent (Figure 6). Three specimens from the subset, known as the unconditioned specimens, were tested in an indirect tension test at a temperature of 25 °C. In contrast, the other subgroup, known as the conditioned specimens, underwent one cycle of freezing and thawing (16 hours at -18 ± 2 °C and 24 hours at 60 ± 1 °C) and was then tested similarly to the first subset (conditioned specimens). The specimen is forced along the diameter during the indirect tension test, and the splitting force is noted in Figure 7. The following calculation of the test parameters;

$$ITS = \frac{2P_{max}}{\pi.h.d} \times 100 \tag{2}$$

Pmax is peak load (N); it stands for indirect tensile strength (MPa); h stands for sample height (63.5 mm); d stands for sample diameter (101.6 mm).

Tensile strength ratio (TSR):

$$TSR = \frac{ITS_{wet}}{ITS_{dry}} \times 100 \tag{3}$$

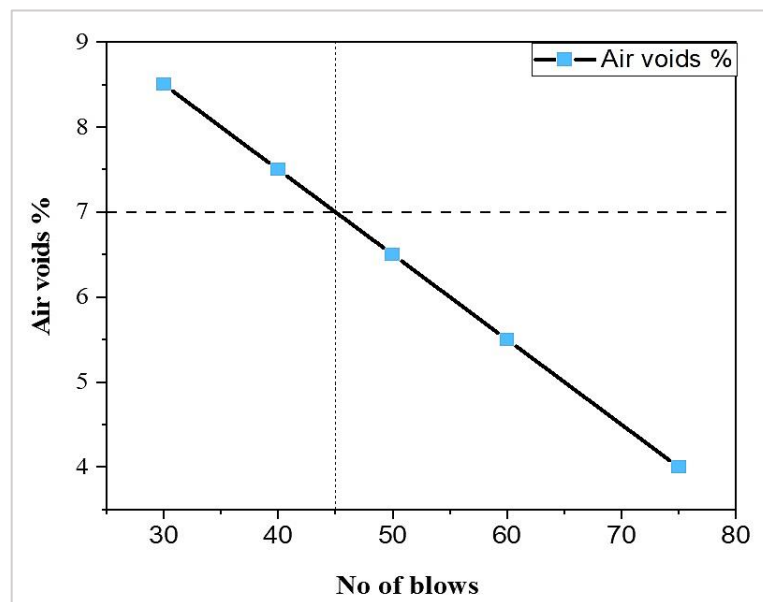


Figure 6: The percentage of air voids and the number of blows

The soaking samples were kept at (25±1) °C in a different water channel one hour before the test. Before being examined, the three specimens' dry temperature was brought to (25±1) °C by immersing them in a water bath for 20 minutes. An indirect tensile strength (IDT) test was performed on each sample before failure from vertical deformation. The test was conducted at a constant loading rate of 50 mm/min at 25 °C. Equation (2), ASTM [33], may be used to find the maximum load recorded for determining the tensile strength of all specimens tested. To find out how sensitive each combination is to moisture, the tensile strength ratio (TSR), which compares the indirect tensile strength of wet specimens to that of dry specimens, is computed. The

TSR value for each combination was calculated using Equation (3) below. By (ASTM D4867M-09) [33], the TSR value should be more than or equal to 80%, indicating appropriate moisture resistance—a selection of the samples produced and assessed. Figure 7 shows the Indirect tensile strength test (ITS) test. (A) Vacuum Saturation, (B) Freezing Samples, (C) Thawing Samples, and (D) ITS Test.

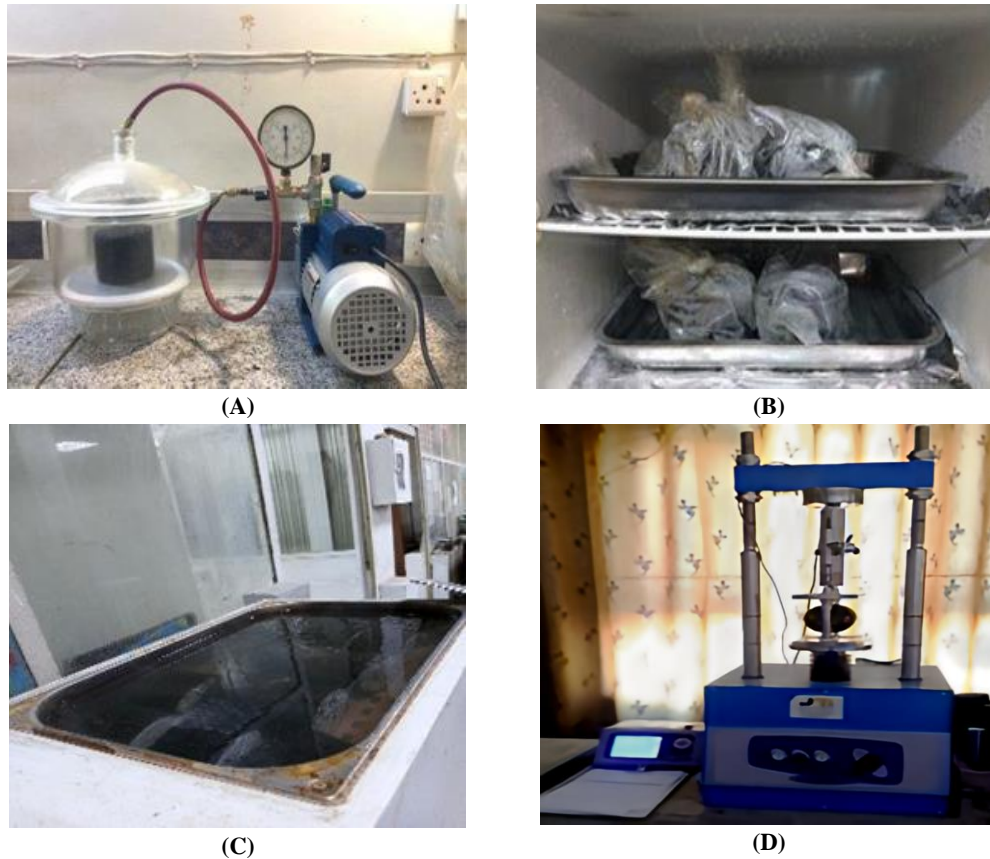


Figure 7: Indirect tensile strength test (ITS) test (A) vacuum saturation, (B) freezing samples, (C) thawing samples, (D) ITS test

8. Results and discussion

8.1 The extraction test

The results from the extraction test process showed that the amount of asphalt residual in the RAP is (3.7%). The asphalt binder content in reclaimed asphalt pavement is summarized in Table 11. The reason that the optimum asphalt ratio is a few 3.7% is that the street from which these samples are subjected to distortions as a result of the street's exposure to high temperatures during the summer in addition to highly unexpected traffic.

8.2 Finding from rotational viscosity test

The mixing and compaction temperature values are displayed in Table 12.

Table 11: Content of asphalt binder as a percentage of RAP

Sample	Asphalt Content%
S1	3.75
S2	3.83
S3	3.88
S4	3.82
S5	3.68
S6	3.57
S7	3.53
S8	3.68
S9	3.63
S10	3.63
Average	3.7%

Table 12: Temperatures of mixing and compaction

Asphalt Binder Penetration Grade	Temperature	
	Mixing Temp.	Compaction Temp.
(40-50)	155 – 160	144-148
(60-70)	152-158	142-146
(85-100)	148-153	138-143
(40-50+4% waste oil)	152-157	142-146

8.3 Results of mixing asphalt with different percentages of waste engine oil

Waste oils were added while the asphalt was heated. The mixing temperature, as shown in Table 10, is based on the findings of the rotational viscosity test performed on the asphalt. Table 9 displays the WOE-modified asphalt with various percentages. Waste oil will be used for 30% RAP proportion with asphalt (40–50). Because of its high viscosity, using asphalt grade (40–50) creates problems with mixability when adding RAP. However, the remaining varieties do not present this problem because of their low viscosity; therefore, this kind will be blended in varying proportions with waste oil to improve its functionality and facilitate mixing or combining with recycled aggregate, Table 13 illustrates, that as the waste oil percentage increases, the penetration increases and the viscosity decrease.

Table 13: Asphalt’s physical characteristics both with and without WEO and asphalt (40-50)

Tests	Test Results			
	0% WEO	2% WEO	3% WEO	4% WEO
Penetration (25 °C, 100g .5 sec)	44	48	54	67
Ductility (35°C. 5cm/min)	133	136	138	140
Softening Point,	54	51	49	47
Flash Point, °C	291	288	279	274
Specific Gravity of asphalt	1.034	1.03	1.028	1.026
Rotational Viscometer, (Pa. sec)				
@ 135 °C	0.482	0.442	0.432	0.422
@ 165 °C	0.121	0.123	0.120	0.112
After Thin Film Oven Test (ASTM D-1754, 2015)				
Retained Penetration, % of Original	80	92	80	90
Ductility @ 25 °C, 5 cm/min, (cm)	92	102	110	123

8.4 Determine the quantity of virgin asphalt binder substituted with RAP binder

As mentioned in Section 7 the virgin asphalt can be calculated by using Equation (1) as shown in Table 14.

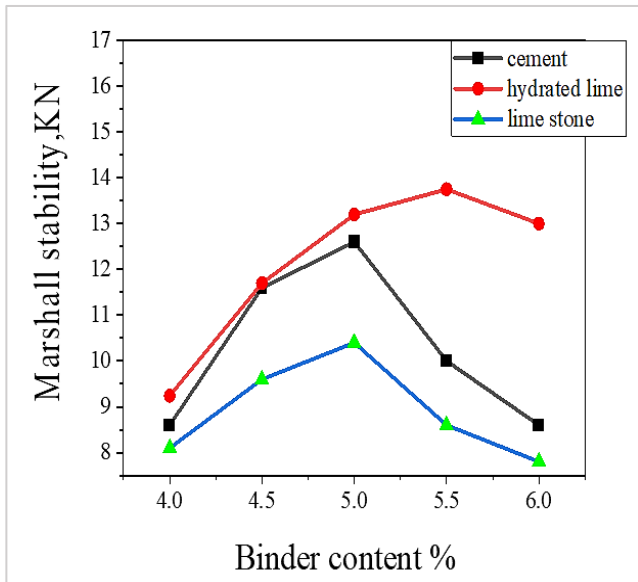
Table 14: Displays the percentages of asphalt

Percent of RAP (Pp)	Asphalt mix+HL* (Pc)	New Asphalt % (Pr)	residual asphalt in RAP (Pa)	Asphalt mix+*C (Pc)	New Asphalt % (Pr)	residual asphalt in RAP (Pa)	Asphalt mix+*LS (Pc)	New Asphalt % (Pr)	residual asphalt in RAP (Pa)	Asphalt grade
0%	5.5	5.5	0							40-50
10%	5.5	5.13	0.37	5	4.63	0.37	5	4.63	0.37	40-50
20%	5.3	4.56	0.74	4.8	4.06	0.74	4.8	4.06	0.74	60-70
30%	5.16	4.05	1.11	4.6	3.49	1.11	4.7	3.59	1.11	85-100

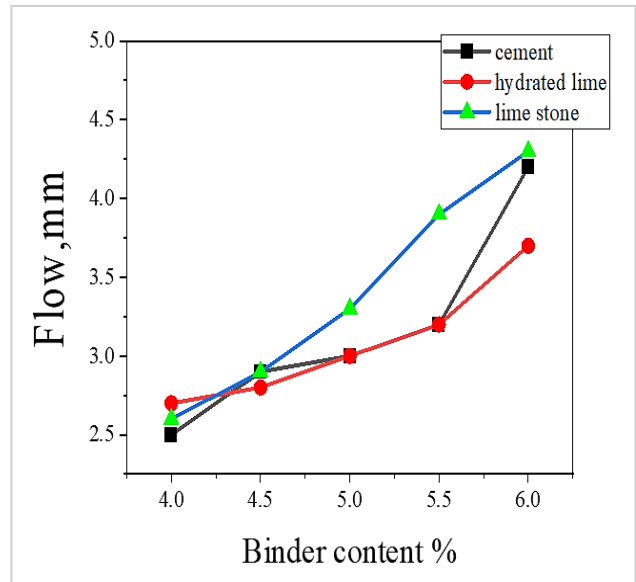
hydrated lime, *C: cement, *LS: limestone

8.5 Marshall properties test

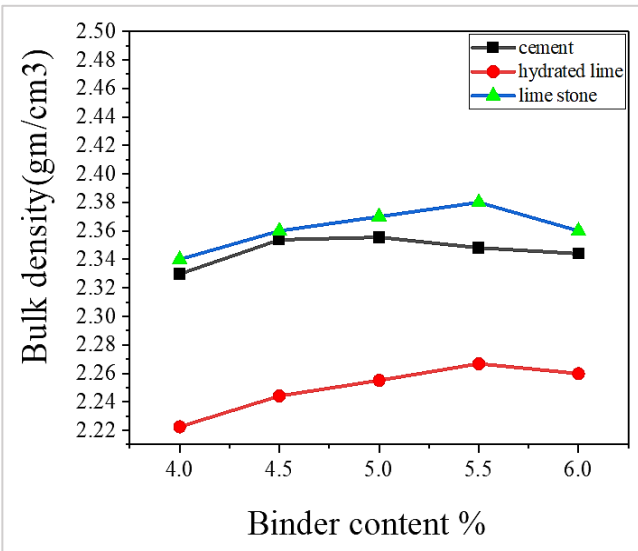
As illustrated in Figures (8,9,10) the optimum asphalt binder is (5.5%,5%, and 5%) for hydrated lime, limestone, and cement, for asphalt grade (40-50); (5.3%,4.8%, and 4.8%) for asphalt grade (60-70); and (5.16%,4.6%, and 4.7%) for asphalt grade (85-100) respectively, which is obtained from the average asphalt binder content of maximum stability, maximum unit weight, and 4% air voids. The characteristics (stability, flow, % VA, VMA, and % V.F.A) are determined at the optimum asphalt binder and compared with the Iraqi State Corporation for Roads and Bridges (SCRB) 2003 specifications for wearing course type IIIA. Table 15 illustrates that asphalt mixed with hydrated lime has the highest stability, flow, and air void value compared with other fillers, followed by cement filler and limestone filler. The opposite appears for voids in mineral aggregate and voids filled with asphalt, where the cement percentage is higher than that of limestone and hydrated lime, but all results are within the limit of Iraqi specifications for roads and bridges. Figure 8 shows the relationship between the HMA volumetric characteristics and different binder percentages. (A) Stability, (B) Flow, (C) Unit Weight, (D) Air Voids, (E) VMA, (F) VFA, for asphalt grade (40-50). Figure 9 shows the relation between the HMA volumetric characteristics and different binder percentages: (A) Stability, (B) Flow, (C) Unit Weight, (D) Air Voids, (E) VMA, (F) VFA for asphalt grade (60-70). Figure 10 shows the relation between the HMA volumetric characteristics and different binder percentages: (A) Stability, (B) Flow, (C) Unit Weight, (D) Air Voids, (E) VMA, (F) VFA for asphalt grade (85-100).



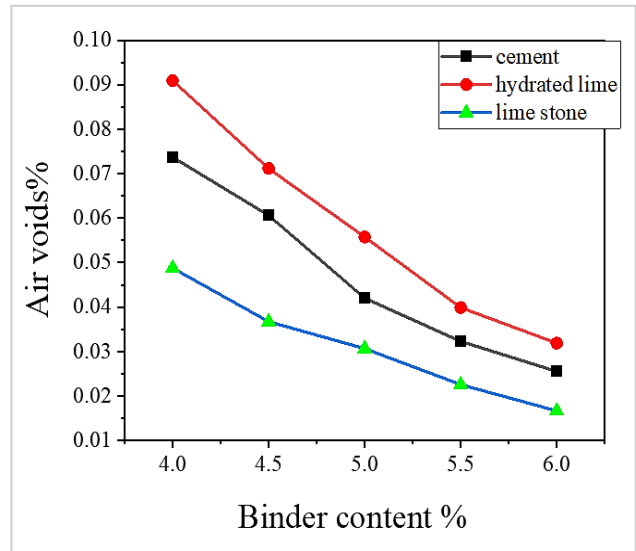
(A) Stability



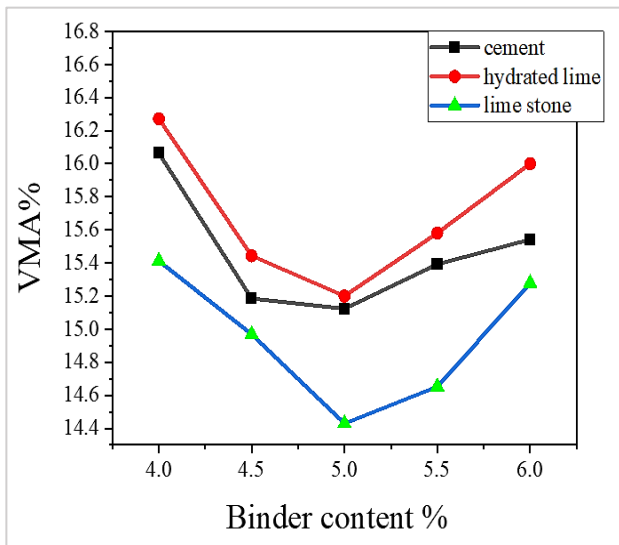
(B) Flow



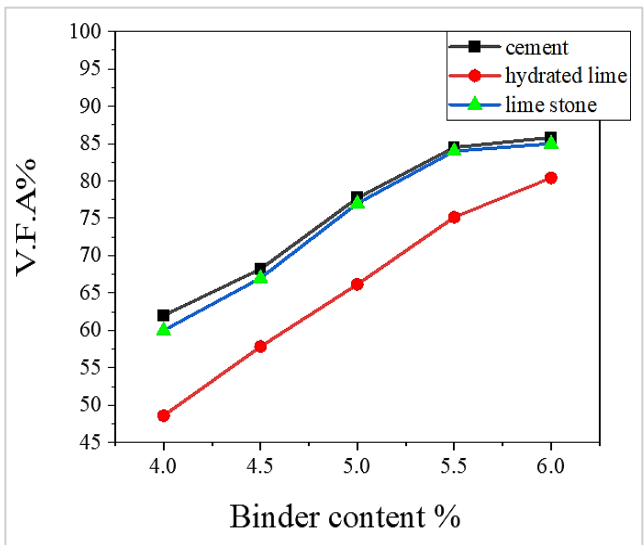
(C) Density.



(D) Air voids.



(E) VMA.



(F) VFA.

Figure 8: The relationship between the HMA volumetric characteristics and different binder percentages (A) stability, (B) flow, (C) unit weight, (D) air voids, (E) VMA, (F) VFA, asphalt grade (40-50)

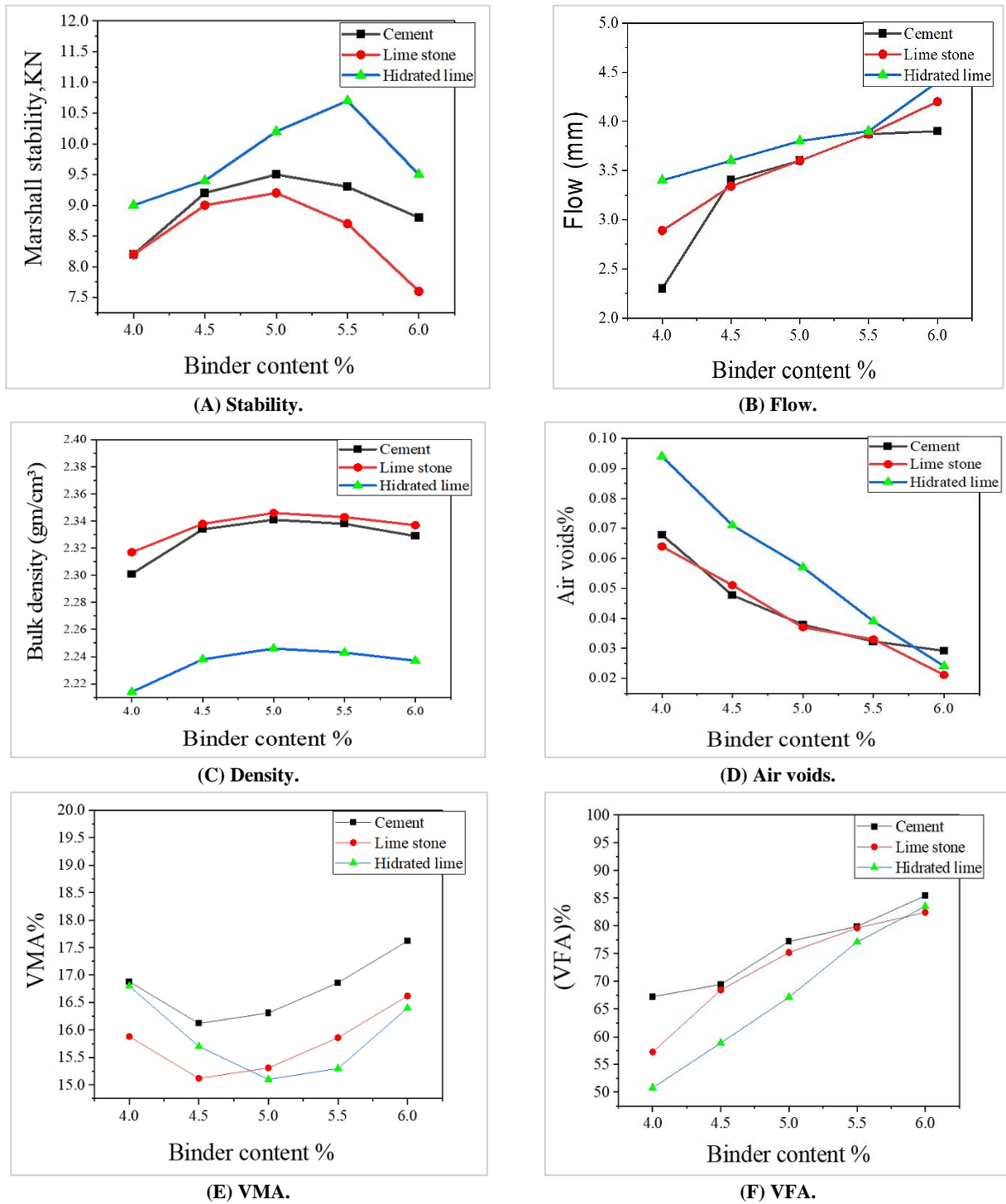


Figure 9: The relation between the HMA volumetric characteristics and different binder percentages: (A) stability, (B) flow, (C) unit weight, (D) air voids, (E) VMA, (F) VFA, asphalt grade (60-70)

Table 15: Marshall properties of different asphalt mixture types at optimum asphalt content for HMA (control mixtures)

Property	Asphalt mixture type									SCRB Specifications
	A44 HL	A44 PC	A44 LS	A66 HL	A66 PC	A66 LS	A91 HL	A91 PC	A91 LS	
Marshall stability (KN)	13.5	12.4	10.4	10.5	9.5	9.2	10	9.8	9.2	Min. 8 KN
Marshall flow(mm)	3.3	3	3.2	3.7	3.4	3.5	3.9	3.3	3.8	2-4 mm
Voids in the total mix (%)	4	4	3.1	4.4	4	3.8	4.7	4.5	3.9	3-5 %
Voids in mineral aggregate (VMA) (%)	15.7	15.3	14.5	15.2	16.2	15.2	15.1	16.1	15.5	Min. 14
Voids filled with asphalt (VFA) (%)	75	77.5	77	72.3	76.6	76.2	70	72	71.6	65-85 %
Optimum asphalt content (%)	5.5	5	5	5.3	4.8	4.8	5.16	4.65	4.7	4-6 %

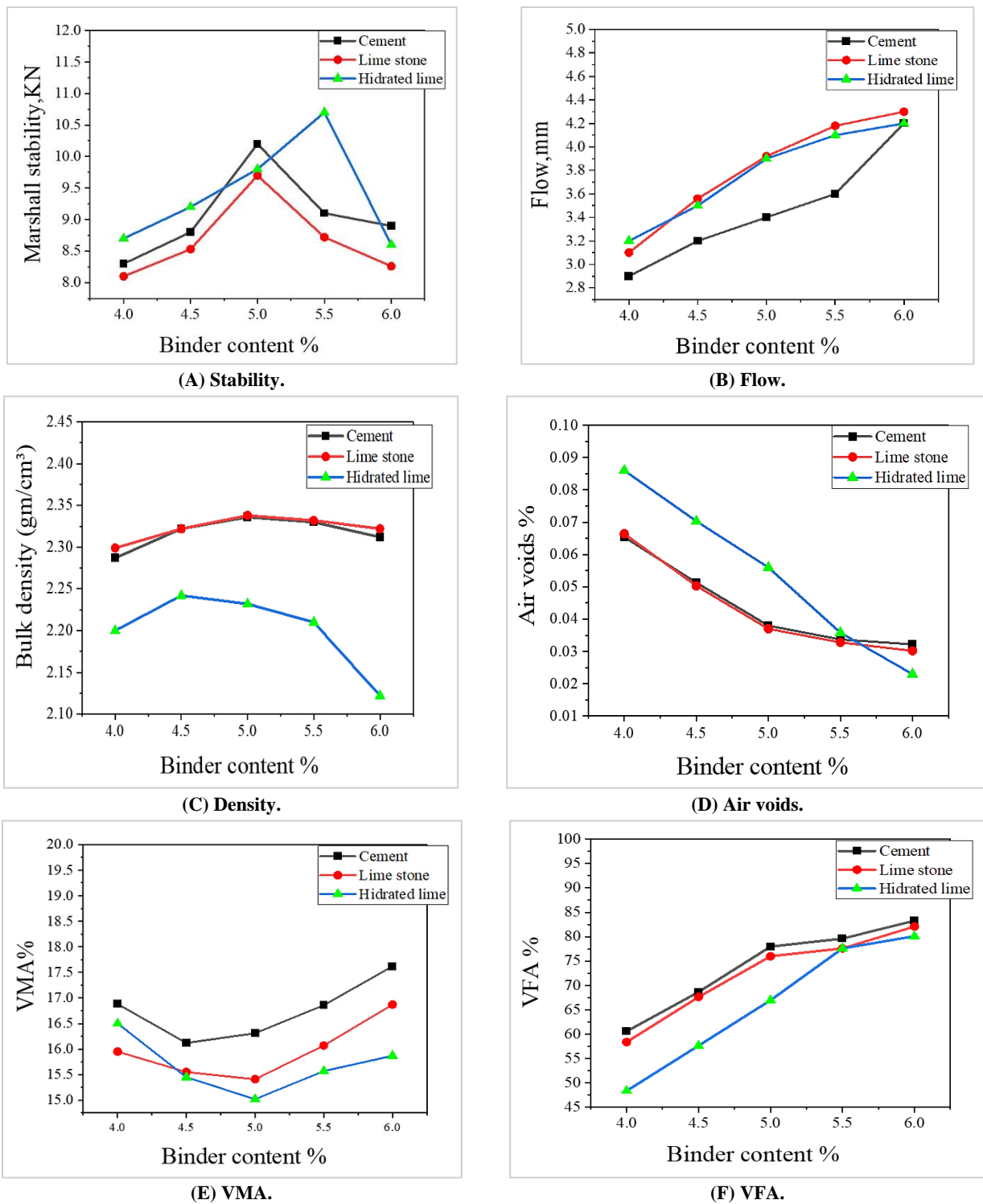


Figure 10: The relation between the HMA volumetric characteristics and different binder percentages (A) stability, (B) flow, (C) unit weight, (D) air voids, (E) VMA, (F) VFA, asphalt grade (85-100)

8.6 Effect of RAP materials on marshall properties

Table 16 and Figure 11 show that RAP with three percent (10%,20%, and 30%) improves Marshall properties. With a percent of 10% for asphalt grade (40-50) mixed with hydrated lime, stability raised from 13.5 kN to 14 kN. While for 20% of RAP, the grade changed to (60-70) as mentioned in section 7, stability increased from 10.5 kN to 11.4 kN, and for 30% of RAP, asphalt grade (85-100) was used as a softer grade, stability value increased from 10 to 11.2 kN for hydrated lime. Asphalt (40-50) +4% waste oil showed better stability than the original asphalt mixture with a value of 15.3 kN. This can be explained by adding more RAP to the asphalt, which increases its stiffness and provides high cohesive strength while preserving the interlocking between the coarsely crushed aggregate. These results are consistent with previous studies [34,35]. Regarding the flow test, adding RAP with (10%,20%, and 30%) has no effect, or its effect may be very little Figure 12.

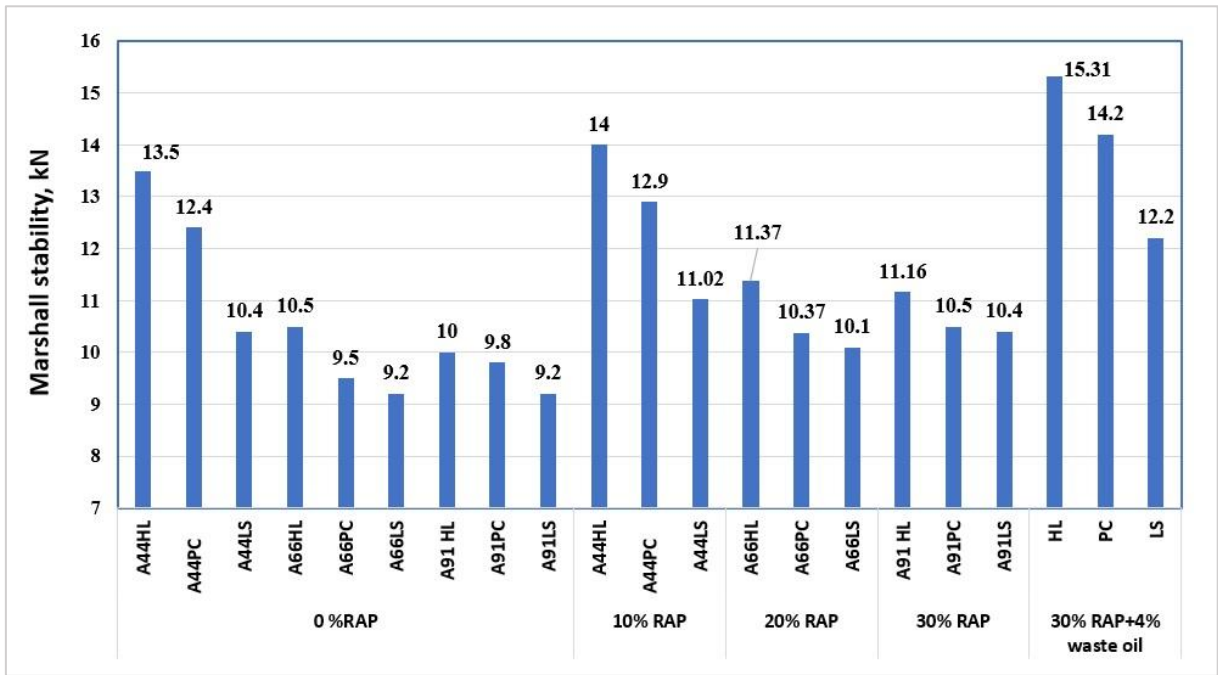


Figure 11: Effect of RAP on Marshall stability

Table 16: Effect of RAP on Marshall properties

Property	10% RAP			20% RAP			30% RAP			30% RAP+ (Asphalt (40-50) + 4%Waste oil)		
	A44 HL	A44 PC	A44 LS	A66 HL	A66 PC	A66 LS	A91 HL	A91 PC	A9g LS	HL	PC	LS
Marshall stability (KN)	14	12.9	11	11.4	10.37	10.1	11.2	10.5	10.4	15.3	14.2	12.2
Marshall flow(mm)	3.3	2.9	3.2	3.6	3.3	3.4	3.8	3.2	3.7	3.3	3	3.2
Voids in the total mix (%)	4	4	3	4.3	3.9	3.7	4.5	4.3	3.7	3.9	3.8	2.9
Voids in mineral aggregate (%)	15.5	15.1	14.3	14.8	15.7	14.9	14.7	15.5	15.1	15.3	14.9	14
Voids filled with asphalt (%)	75.3	77.6	77.2	74.7	78.7	78.4	73	75.2	74.9	77.5	79.7	79.4

While Air voids% decreased as RAP% increased, it still within the limitation and satisfied the requirements Figure 13; this indicates that the older asphalt in RAP does not function as black rock and can increase the amount of asphalt in the new mix reducing the air voids in the mix. Voids in mineral aggregate (%) decreased as the percentage of RAP increased, and Voids filled with asphalt (%) rose as the amount of RAP increased (see Table 16). For asphalt mixed with hydrated lime, the difference in VMA (%) between the control mix(0%RAP) and (10%, 20%, and 30%) RAP is equal to (0.2, 0.4, and 0.4). This decrease in the percentage of air voids is the cause of the (% VMA) decline.

The increase in VFA% for (10%, 20%, and 30%) from the control mix is equal to (0.3, 2.4, and 3), which indicates that the residual asphalt in the RAP and new asphalt cement increased the amount of asphalt in the mix. The values of (VFA) fall within the required range of 70-85%, as stated by SCRB.

The stability of asphalt (40-50) plus 4% waste oil was superior to that of the original asphalt mixture. As shown in the results, the asphalt mixture with hydrated lime filler. Marshall stability increases from 13.5 KN for 0% RAP+ asphalt grade (40-50) to 15.31 KN for 30% RAP with 4% waste oil plus asphalt grade (40-50).

The Marshall characteristics of asphalt (40-50) + 4% waste oil were superior to those of softening grade (85-100). For example, in asphalt with hydrated lime, cement, and limestone filler, the difference between the Marshall stability for 30% RAP+4% waste oil and asphalt grade (85-100) + 30% RAP is equal to (4.15, 3.7 and 1.8) kN. These results prove that using 4% of used engine oil with asphalt 40-50 gives effective stability and Marshall properties better than the original mixture that does not contain RAP and the mix with asphalt 85-100. Thus, the softer asphalt can be replaced with used engine oil and mixed with the available asphalt 40-50 and dispensed with the unavailable asphalt in addition to the environmental and economic benefit of using used engine oil as waste material. This leads to the possibility of increasing the amount of RAP used in road paving and producing asphalt mixtures with available materials that are no less efficient than mixtures containing new materials. Encouraging the reuse of recycled materials and lowering the need for new asphalt may be considered an environmentally friendly strategy supporting sustainability ideals. This was also concluded by Fattah et al., [34].

This study is unique since it uses three filler kinds that are most frequently used with asphalt mixes in Iraq and applied with a percentage of RAP. According to the Marshall properties test results and indirect tension test, the most effective filler is hydrated lime. In addition to the findings, this study describes the impact of the fillers available in Iraq on the asphalt mixture with new materials and mixtures containing RAP. This can assist employees at asphalt factories in selecting the best options in terms of cost and characteristics. The findings demonstrated that RAP may be effectively combined with hydrated lime to enhance the qualities of the resulting asphalt mixture. This can create a highly stable, cost-effective, and environmentally friendly asphalt mixture.

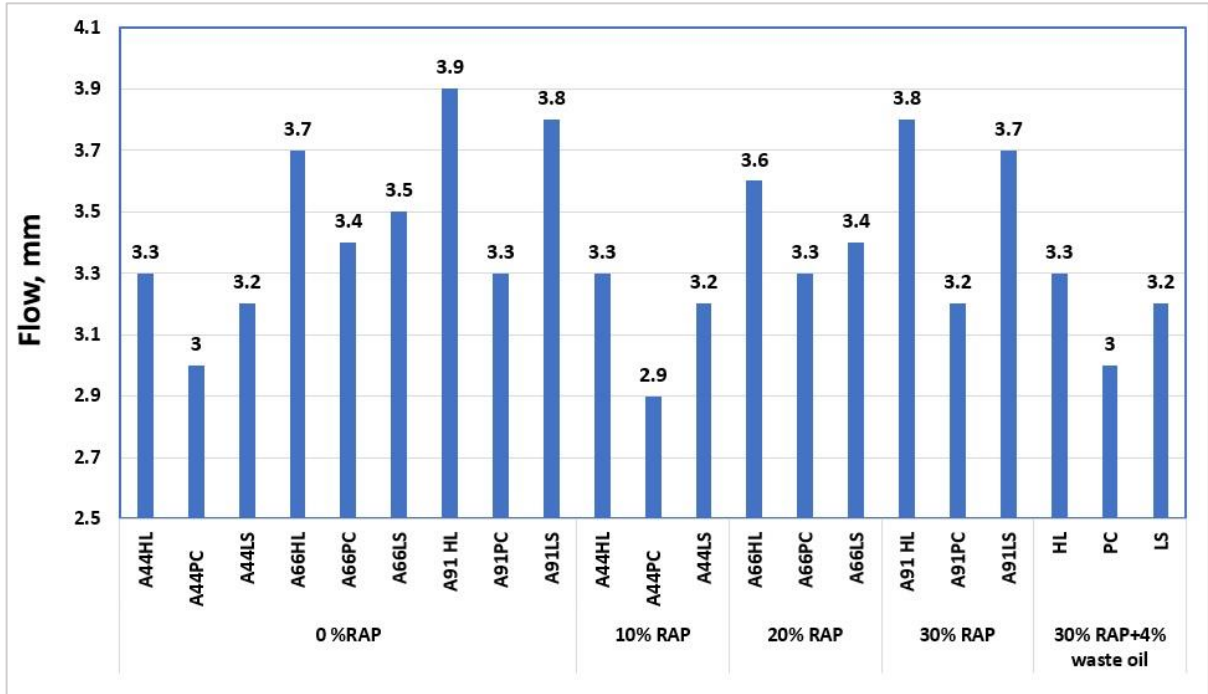


Figure 12: Effect of RAP on Marshall flow

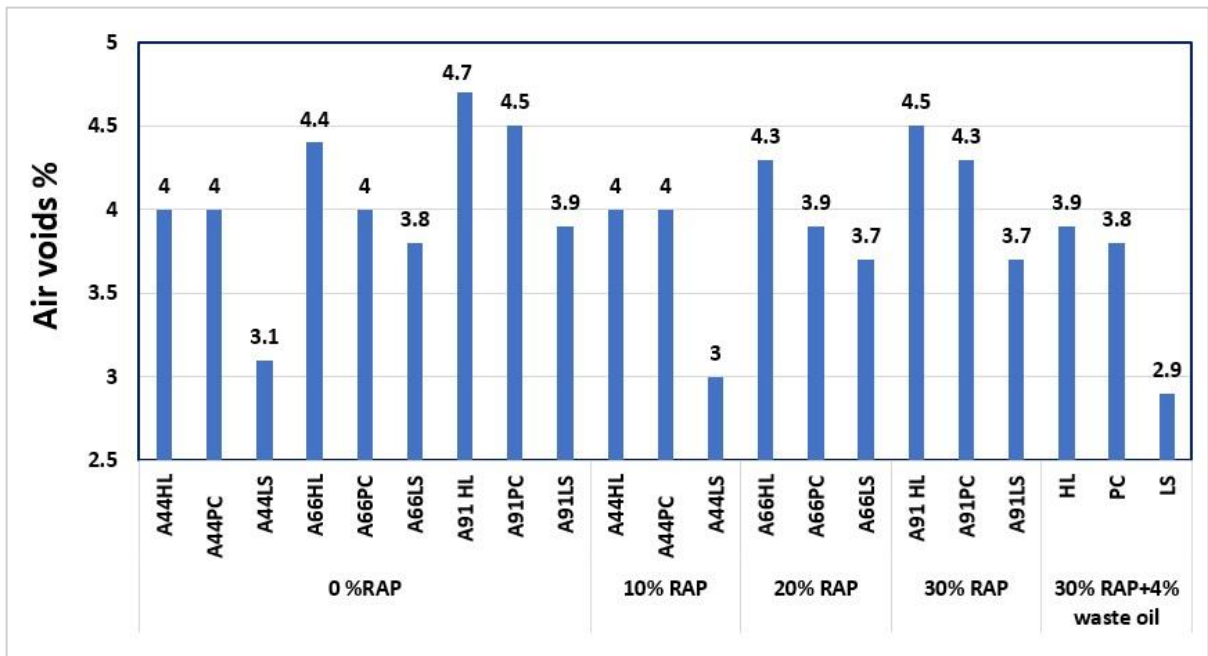


Figure 13: Effect of RAP on Air voids%

8.7 Effect of RAP materials on the indirect tensile strength test

With an increase in the amount of RAP, Figure 14 shows that the ITS increases. Moreover, it revealed that the ITS was higher for dry specimens than wet ones. With a high percentage of RAP of 30%, Figure 14 also generally illustrates the impact of recycling agent types on the ITS. The results show that the ITS for a type of rejuvenating agent [asphalt grade (40–50) + 4% waste oil] is lower than the ITS for a type of softening agent [asphalt grade (85–100)].

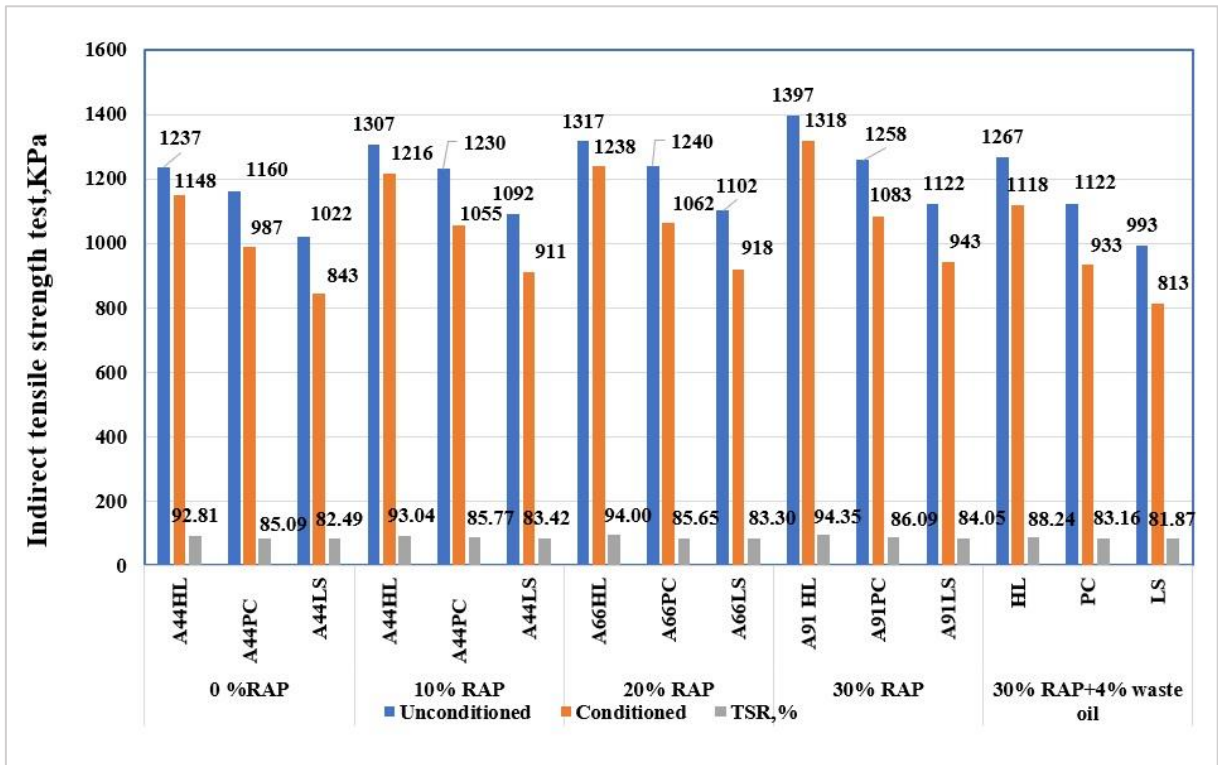


Figure 14: Effect of RAP content on the Indirect tensile strength

It may also be concluded that mixtures containing RAP are better than typical mixtures in resisting the damaging effects of water and are less vulnerable to moisture. Several researchers have explained why this is the case. They suggested that because RAP is a material that has previously experienced aging and the aged binder prefers to adhere to the RAP aggregates, the RAP binder gets stiffer. When RAP materials are used as their aggregate is covered with a thick layer of asphalt binder, the bond between the aggregate and RAP binder becomes stronger, reducing the absorption of water [35-38] and [39]. The combinations, including a softening agent (asphalt grade (85-100)), have a greater TSR than the mixtures containing a rejuvenating agent (asphalt grade (40-50) +4% waste oil), as can be observed. The problem may arise from adding waste oil to asphalt binder grade (40-50), which weakens the bond between the asphalt and the aggregate under specific conditions, or from the RAP demonstrating a weak adhesion between the aggregate and the asphalt binder. If adhesion additives are not added to the newly created (remade with RAP) HMA mixture, the problem will likely recur. As a result, the asphalt binder is displaced from the aggregate surface when moisture reaches the aggregate-binder contact. This weakened the adhesive connection or, in extreme cases, the bond breaking between the aggregate and binder [40].

9. Conclusion

The following conclusions were reached in light of the experimental results from a lab investigation that evaluated the function and impact of various rap percentages on the characteristics of Marshall and the volumetric and indirect tensile strength properties:

- 1) In terms of stability, asphalt combined with hydrated lime is superior to other fillers, while cement and limestone fillers come next. For asphalt grades (40-50), (60-70), and (85-100), the corresponding values for hydrated lime, cement, and limestone are (13.5, 12.4, 10.4) KN, (10.5, 9.5, 9.2) KN, and (10, 9.8, 9.2), respectively. And that suggests that Marshall's properties are enhanced by hydrated lime.
- 2) When adding RAP with percentages (10%,20%, and 30%), stability rises as the amount of RAP increases for the same asphalt grade. High stability is seen in asphalt with hydrated lime filler, cement filler, and limestone filler.
- 3) Flow increases as RAP increases, whereas air void percentage reduces as RAP% climbs; still, both trends remained within bounds and met the criteria.
- 4) As the proportion of RAP grew, the voids in mineral aggregate (%VMA) dropped, while voids filled with asphalt (%VFA) increased.
- 5) Compared to the original asphalt mixture, the 40–50% asphalt + 4% waste oil combination had higher stability. The findings demonstrate that the asphalt mixture included hydrated lime filler. When 4% waste oil is added to the asphalt grade (40-50) and 30% RAP is used, Marshall stability rises to 15.31 KN from 13.5 KN for the 0% RAP+ asphalt grade.
- 6) Softening grade (85–100) exhibited inferior Marshall properties compared to asphalt (40–50) + 4% waste oil. The Marshall stability difference between asphalt grade (40-50) + 30% RAP and asphalt grade (85-100) + 30% RAP, for instance, in asphalt containing hydrated lime, cement, and limestone filler is equivalent to (4.15,3.7, and 1.8) KN.

- 7) The indirect tensile strength increases as the amount of RAP increases for percentages of RAP used in this study 10%, 20%, and 30%. Additionally, it may be said that mixes containing RAP are less susceptible to moisture and more effective at withstanding the destructive effects of water than usual combinations. This is clear; for example, the mixture with hydrated lime increases the indirect tensile strength ratio from (92.81 for 0% RAP) to (93.04, 94 and 94.34) for (10, 20 and 30) % RAP, respectively.
- 8) The findings indicate that an asphalt grade (40–50) + 4% waste oil rejuvenating agent has a lower ITS than an asphalt grade (85–100) softening agent. For example, in asphalt with hydrated lime, the difference between the tensile strength ratio (TSR) for 30% RAP+4% waste oil asphalt plus grade (40-50) and asphalt grade (85-100) + 30 RAP is equal to 6.11.
- 9) A careful coherence analysis is recommended because cohesive bonding between the asphalt and WEO is expected. In these cases, several properties of aged asphalt for varied WEO levels, such as adhesion and surface energy, may be examined using atomic force microscopy.

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Author contributions

Conceptualization, M. Fattah. and M. Hilal; data curation, H. Jabbar.; formal analysis, H. Jabbar.; investigation, H. Jabbar.; methodology, H. Jabbar.; project administration, M. Hilal. and M. Fattah, resources, H. Jabbar.; software, , H. Jabbar.; supervision, M. Hilal. and M. Fattah.; validation, M. Hilal., M. Fattah. and H. Jabbar.; visualization, H. Jabbar.; writing—original draft preparation, H. Jabbar.; writing—review and editing, H. Jabbar. All authors have read and agreed to the published version of the manuscript.

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Data availability statement

The data that support the findings of this study are available on request from the corresponding author.

Conflicts of interest

The authors declare that there is no conflict of interest.

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