University of Baghdad
College of Engineering
JOURNAL OF ENGINEERING

Journal of Engineering

journal homepage: www.joe.uobaghdad.edu.iq

Volume 29 Number 7 July 2023

Study the Effect of using RAP in Warm Mix Asphalt Pavement.

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ABSTRACT

Sustainability is providing the needs without compromising the ability of the strategical forming to meet their requirements. The production of warm asphalt mixtures using recycled pavements produces economic and environmentally friendly mixtures, which is the most important advantage of this work. This research aims to determine the effect of recycled asphalt concrete (RAP) on the indirect tensile strength of warm asphalt mixtures and Marshall Properties. Models of warm asphalt mixtures using Aggregate from the Al-Nibaay quarry, Asphalt with a degree of penetration (40-50) from the refinery of the cycle, and obtained Recycled asphalt concrete from Salah Al-Din Road, Al-Ameriya area in Baghdad are prepared. Use five ratios of (0, 10, 20, 30, and 40%) of recycled asphalt concrete. Marshall Design method is adopted to estimate the perfect existence of the asphalt cement for sample preparation. The mixtures properties, volumetric properties, and indirect tensile strength test are evaluated to assess bonding strength. Results show that the increase in the replacement percentage of RAP causes an increase in flow and air void and decreases the bulk density, voids in mineral aggregate (VMA), and voids filled with Asphalt (VFA). Stability increases with increased RAP content until it reaches its peak and falls. The highest stability value is at 30% RAP by 58%, about the indirect tensile strength test. The increase in the RAP ratio increases the tensile strength and the bonding between the components. So including RAP material in warm asphalt mixtures improves properties and meets performance requirements.

Keywords: Warm Mix Asphalt, Reclaimed Asphalt Pavement, Indirect Tensile Strength Test

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Peer review under the responsibility of University of Baghdad.

https://doi.org/10.31026/j.eng.2023.07.10

Article received: 22/01/2023

Article accepted: 19/03/2023

Article published: 01/07/2023

دراسة تاثير استخدام مواد المعاد تدويرها في رصف الاسفلت ذو الخلطة الدفئة

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الخلاصة

تعتبر الاستدامة من المفاهيم المهمة في الوقت الحاضر ، ويمكن تعريف هذا المفهوم على أنه توفير متطلبات الحاضر دون المساس بقدرة جيل المستقبل على تلبية متطلباتهم. ينتج عن إنتاج مخاليط الإسفلت الدافئة واستخدام الأرصفة المعاد تدويرها خلائط اقتصادية وصديقة للبيئة وهذه هي الميزة الأكثر أهمية للبحث. يهدف هذا البحث إلى تحديد تأثير استخدام خواص مارشال للخرسانة الإسفلتية المعاد تدويرها وقوة الشد غير المباشرة لخلائط الإسفلت الدافئة. يتضمن البرنامج المخبري إجراء الفحوصات المخبرية من خلال إعداد نماذج من الخلطات الإسفلتية الدافئة باستخدام الركام من محجر النبائي والأسفلت بدرجة اختراق (40−50) من مصفاة الدورة والحصول على الخرسانة الإسفلتية المعاد تدويرها من صلاح الدين. طريق العامرية في بغداد. استخدام خمس نسب من الخرسانة الإسفلتية المعاد تدويرها (40،30،20،10،0٪). تم استخدام طريقة تصميم مارشال لتحديد المحتوى الأمثل للأسمنت الإسفلتي لكل نسبة استبدال ثم استخدام هذه النسب المثلى من الأسمنت الأسفلت لتحضير العينة لاختبار مارشال لتقييم خصائص الخلائط والخصائص الحجمية واختبار مقاومة الشد غير المباشر لتقييم قوة الترابط . وفقًا للنتائج الموضحة ، تؤدي الزيادة في نسبة استبدال الخرسانة الإسفلتية المعاد تدويرها إلى زيادة التدفق وفراغ الهواء بينما تؤدي هذه الزيادة إلى انخفاض الكثافة الظاهرية والفراغات في الركام المعدني (VMA) والفراغات المملوءة بالإسفلت (VFA)) بالإضافة إلى ذلك ، يزداد الثبات مع زيادة نسبة الخرسانة المعاد تدويرها ثم الوصول إلى أعلى قمة وتبدأ في الانخفاض حيث نلاحظ أن أعلى قيمة للثبات عند 30٪ RAP ، حول اختبار مقاومة الشد غير المباشر يظهر النتائج. أدت زيادة نسبة الخرسانة الإسفلتية المعاد تدويرها إلى زيادة قوة الشد وبالتالي زيادة الترابط بين المكونات. يمكن القول أن إدراج مادة الخرسانة المعاد تدويرها في خلائط الإسفلت الدافئ يحسن الخصائص ويلبي متطلبات الأداء.

الكلمات الرئيسية: خليط الاسفلت الدافيء,الرصيف الاسفلتي المعاد تدويره,اختبار قوة الشد الغير مباشر

1. INTRODUCTION

Recently, there has been a great trend for using sustainable technology in asphalt pavement due to the rise in construction costs combined with the expansion of environmental rules and awareness. The definition of a sustainable pavement satisfies present-day needs without jeopardizing the ability of future generations to do the same. Warm asphalt combinations mix incorporating recycled materials and mixes containing waste materials are a few examples of sustainable pavement.

1.1 Warm Mix Asphalt

The warm asphalt mixture is an asphalt mixture similar to hot asphalt mixtures, but the difference is that these warm mixtures are produced and compressed at a temperature (15-

40) ° C lower than that hot mix asphalt according to the additives type for producing warm mix asphalt **(Albayati et al., 2018)**.

1.2 Recycled Asphalt Pavement

In the United States and the seventy's century, using reclaimed Asphalt for making pavements in asphalt mixtures became a common practice, especially during the oil embargo, which led to a significant rise in the cost of crude oil. Economic savings and environmental benefits are vital agents affecting the reclaimed asphalt pavements in constructing new asphalt road pavements **(Newcomb, et al., 2007).** The most important advantage of using reclaimed asphalt paving is reducing the cost of the materials used to produce Asphalt paving mixtures as a useful alternative in reducing the required amount of virgin aggregate and binder Asphalt materials. **(Behnia et al., 2011).**
RAP is the term for Asphalt and aggregate that must be removed from an existing pavement surface to resurface, rehabilitation, reconstruction, or gain access to buried infrastructure. The removed Asphalt and Aggregate are milled and saved to be used as a component of the new pavement later **(Jaafar et al., 2022)**.

1.3 RAP History

According to a study conducted by **(Daniel and Lachance, 2005)**, 20% and 40% of RAP affects the volumetric properties where an increase in the voids in the mineral aggregate and the voids filled with Asphalt in these proportions. A laboratory investigation was performed by **(Shu et al., 2008)** to assess the hot-mix Asphalt (HMA) fatigue properties. In this investigation, one type of binder, PG 64-22, and one Aggregate limestone supply were used to create HMA mixtures containing (0, 10, 20, and 30) % RAP. The findings of this investigation showed that when the right procedures were followed, the beam fatigue tests and indirect tensile strength classified the mixture's fatigue resistance in agreement with **(Shu et al., 2008). (Huang et al., 2011)** describe the mechanical behavior of bituminous mixtures incorporating a high percentage of (RAP). Two semi-dense mixtures with aggregate (12-20) mm and containing (40% and 60% RAP, respectively, the results demonstrate that the indirect tensile strengths of the mixtures with RAP are quite similar to and significantly greater than those of the conventional mixture **(Ahmed et al., 2013)**. The attributes of recycled hot dense graded asphalt mixes were designed and evaluated as part of an experimental program **(Tran and Hassan, 2011)**. The recycled mixes' RAP percentages varied between 10%, 20%, and 30%. The outcomes of this experimental program demonstrated that it is possible to produce recycled mixes that match specification requirements and contain up to 20% RAP. The results also show that adding RAP decreases the binder needed to reach 4% air void content and decreases the importance of aggregate mineral voids containing a film index and binder. Additionally, RAP makes a mixture stiffer after being added, and this effect gets stronger as RAP content rises **(Tran and Hassan, 2011)**.
Treating the material with RAP substances will form well-graded, excellent asphalt-coated aggregates that could be used in highway building applications, as most roads are built utilizing high-type bituminous pavements. RAP material is used in asphalt mixes to help lower costs, protect Asphalt and aggregate resources, and reduce trash going to landfills **(Copeland, 2011).** The current work aims to investigate the performance of RAP in warm mix asphalt with a view to more sustainable paving products. Much research is required to

use asphalt mixtures with many RAP.
This work aims to produce warm asphalt mixtures for the bond layer, evaluate the performance characteristics, study the effect of using RAP in warm asphalt mixtures, and evaluate the bulk density, stability, flow, and volumetric properties through the Marshall test and the bond strength through the indirect tensile test. **Fig. 1** shows a flow chart showing the method used to achieve the objectives.

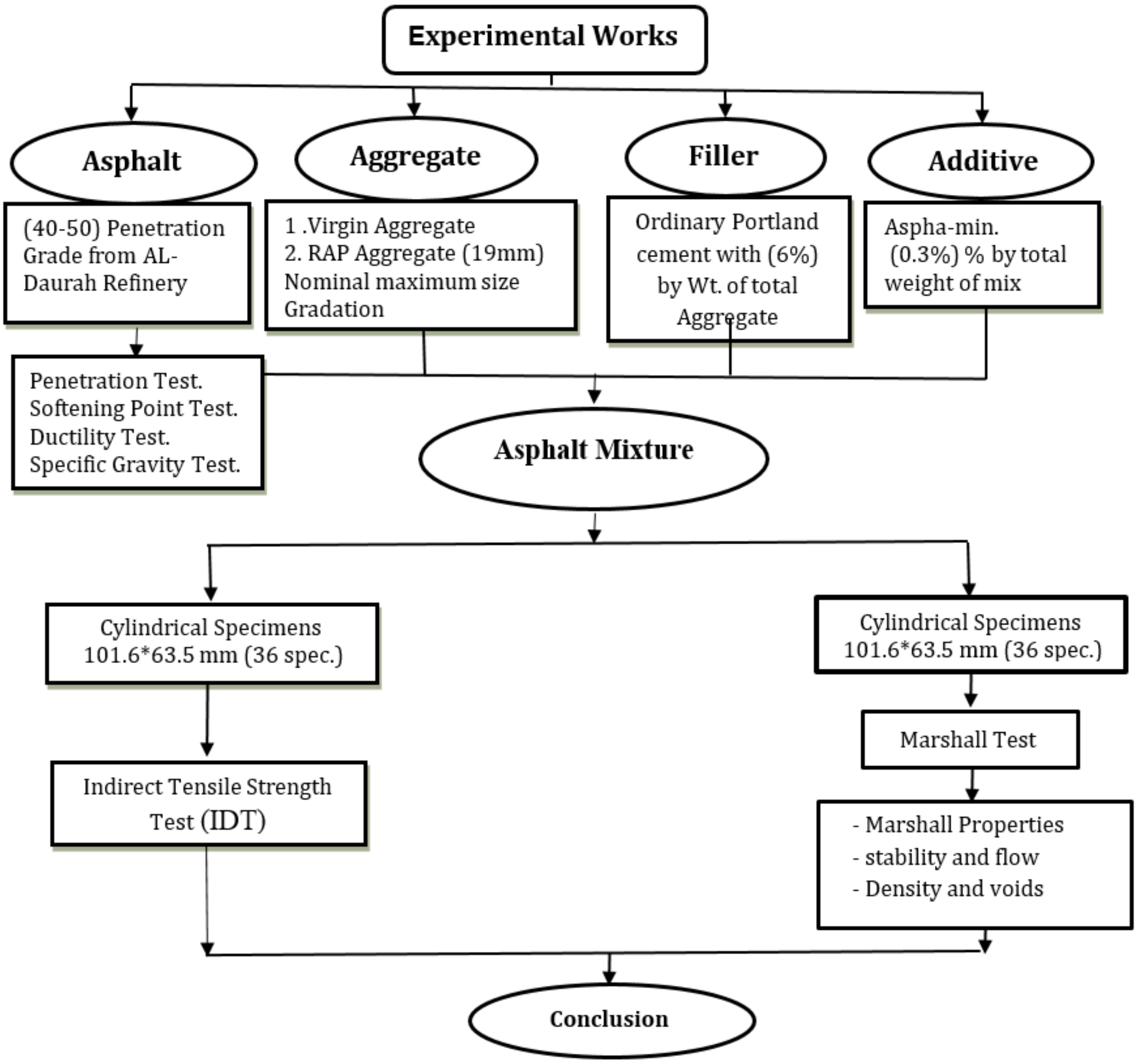


Figure 1. The work program flow chart.

2. MATERIALS AND EXPERIMENTAL WORK

2.1. Materials

The raw materials used to prepare warm asphalt mixtures are Aggregate, asphalt cement, and mineral fillers. Also, standardized tests were compared between the results to determine the suitability for the work mix using specific requirements.

2.1.1. Asphalt

The asphalt cement was obtained from AL-Daurah Refinery, located southwest of Baghdad, with a penetration grade of (40-50) as shown in **Table 1**

Table 1. Physical properties of the asphalt cement

Test	Unit	Results	SCRB 2003 Specification Limits	ASTM Specification No
Penetration (25 °C, 100g, 5 sec)	1/10 mm	47	40-50	D-5
Ductility, (25°C, 5 cm/min)	cm	145	≥100	D-133
Kinematics viscosity, at 135 °C	cSt	650	--	D-2170
Softening point (Ring & Ball)	°C	56	--	D-36
Flashpoint (Cleveland open cup)	°C	321	232 min	D-92
Specific gravity, at 25 °C	--	1.03	--	D-70
After Thin-Film Oven Test (ASTM D 1754)				
Retained Penetration of Residue (25 °C, 100 gm, 5 sec)	%	60	55 (Min)	D-5
Ductility, (25 °C, 5 cm/min)	cm	80	> 25	D-113

2.1.2. Aggregate

The Aggregate was crushed from the quartz provided by the Al-Nibaie quarry in Baghdad and used for Asphalt mixtures. The fine and coarse aggregates were sieved and reassembled appropriately to meet the required gradation by specifications with a size of 19.0 mm (fit to the bond layer that worked on **(SCRB/R9, 2003)**. The gradation of aggregates is illustrated in **Table 2**. The classical tests were done on the aggregates to determine the physical properties set by (State Corporation for Roads and Bridges SCRB) are summarized in Table. The results of the tests showed that the selective assembly with SCRB Specification.

2.1.3. Mineral Filler

The mineral filler (one type of ordinary Portland cement) is provided from the local market to prepare of warm mix asphalt mixture. The filler is a non-plastic material passing sieve No.200 (0.075mm) free and dry lumps or fine particulates, as given in **Table 3**.

2.1.4. RAP

it was provided from Salah Al-Din Road, Al-Ameriya area in Baghdad, through the percent of excavating an old pavement. Its asphalt content was 4.6% with a penetration degree of (40-50). The Asphalt's upper part (50) mm was removed and taken from the damaged pavement. The collected RAP material was sieved and reassembled at a pre-determined percentage using fresh Aggregate and grade of Asphalt 40-50. Using two types of RAP: fine and coarse of RAP (as given in **Table 4**).

Table 2. Physical Properties of Fine and Coarse Aggregate

Property	ASTM Specification	Result	SCRB Specification
Coarse Aggregate.			
Bulk Specific Gravity	C-127	2.61	----
Apparent Specific Gravity	C-127	2.67	----
Percent Water Absorption	C-127	0.94	----
Percent Wear (loss Angel's abrasion)	C-131	20.5	30 Max
Fine Aggregate			
Bulk Specific Gravity	C-128	2.62	---
Apparent Specific Gravity	C-128	2.68	---
Percent Water Absorption	C-128	0.91	---

Table 3. Physical Properties of Filler (Portland cement)

Property	Result
% Passing N0.200	97
Specific gravity	3.15

Table 4. Physical Properties of Recycled Asphalt Pavement

Test Method	ASTM designation	Coarse RAP	Fine RAP
Bulk specific gravity	C- 127& C- 128	2.549	2.654
water absorption, %	C- 127& C- 128	1.01	0.763

2.1.5. Aspha-min

Aspha-min (**Fig. 2**) is a fine powder crystallized from sodium aluminosilicate, which was then used as a factor in the manufacture of the WMA. The mixture of heated aggregates was treated using fine Aspha-min that added 0.3% to the total mix weight and included about 21% water by weight (as given in **Table 5**)

Table 5. Physical and chemical properties of WMA additive (Aspha-min).

Property	Ingredients	SiO_2	Al_2O_3	Na_2O	LOI	Physical state	Color	Odor	Specific gravity
Result	**$Na_2O.Al_2O_3.2SiO_2$** (sodiumaluminosilicate)	32.8 %	29.1%	16.1 %	21.2 %	Granular powder	White	Odorless	2.03

2.2. Designed aggregate gradation.

The aggregate gradation used in this work follows to comply with the requirements of (SCRB R/9, 2003) specification for the hot mix asphalt and warm mix asphalt paving mixture by the mid-point gradation.

Figure 2. The appearance of Aspha-min.

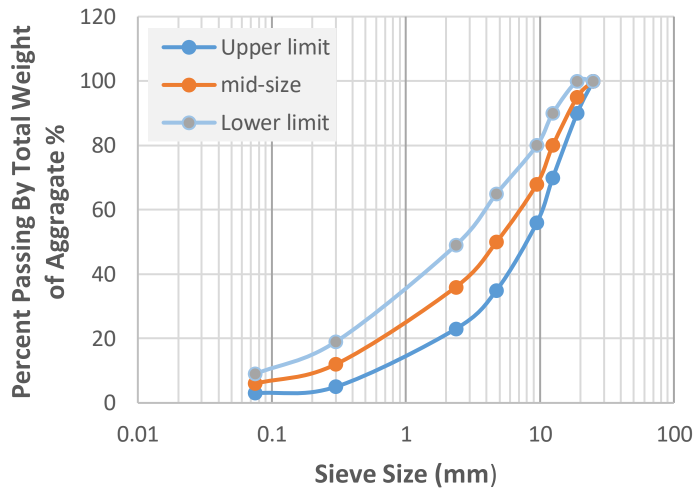


Figure 3. Design aggregate gradation.

The maximum aggregate size in the binder layer is (25 mm) and the nominal maximum size of (19mm) (binder course). Selected aggregate gradation is given in **Table 6** and **Fig. 3**.

2.3. Mix Design

Five replacement percentages with RAP were tested (0, 10, 20, 30, and 40%). The samples were tagged as WMA, accompanied by the replacement rate. The Marshall mix design method is used in the pilot work to determine the optimal asphalt content per replacement percentage. The samples are prepared using the optimal asphalt content percentage from the content of RAP to evaluate and analyze the characteristics of Marshall, including bulk density, stability, and flow. Also, the volumetric characteristics of air voids, voids in mineral aggregate (VMA), and voids filled with Asphalt (VFA) are evaluated. The samples for Indirect Tensile testing are prepared to evaluate the bonding strength of warm and recycled asphalt mixtures.

Table 6. Gradation of Combined Aggregate for Binder Course

Sieve Size	Sieve Size (mm)	Specification Passing Range (%)	Selected Gradation
1	25	100	100
3/4	19	90_100	95
1/2	12.5	70_90	80
3/8	9.5	56_80	68
No.4	4.75	35_65	50
NO.8	2.36	23_49	36
NO.50	0.3	5_19	12
NO.200	0.075	3_9	6

The different aggregate fractions (retained on each of the following sieves: 3/4, 1/2, 3/8, 4, 8, 50, and 200) with adding the mineral filler 1200 grams on the mixing bowl following the gradation criteria shown in **Fig. 3**. Before mixing, new aggregates are heated for 6 hours to

a temperature of 120°C, while RAP was heated at 120 °C for one hour. The container of Asphalt was heated to 155°C for 12 minutes, corresponding to a viscosity of 170 cSt according to the viscosity and temperature connection.
Aspha-min is added at the rate of 0.3% of the total weight of the mixture to the heated Aggregate mix the mixture for 30 seconds well and then pour the required amount of asphalt cement into the mixing bowl the ingredients of the bowl for 2 minutes well. The temperature used for mixing was 125°C (HMA concrete is 155°C at 30°C less than that temperature.). The bowl containing its contents was placed in an oven and heated to 115°C for 10 minutes to reach the compaction temperature required to compact the mixture (10°C below the mixing temperature). The mixture was then put into the compaction mold, prepared, and preheated to 115°C. The diameter was 4 inches (101.6 mm), while the height was three inches (76.5 mm). 75 blows of the automatic Marshall compactor were used on each side of the specimen to compact it utilizing the Marshal mix design approach. The value of optimum asphalt content for all mixtures is given in **Table 7**.

Table 7. Optimum Binder content of the designed mixes containing RAP

RAP%	O.A.C %
0	4.45
10	4.45
20	4.3
30	4.25
40	4.2

2.4. Test Methods

2.4.1. Marshall test

The Marshall test uses the Marshall equipment to measure the stability and plastic flow resistance of cylindrical samples of bituminous paving (ASTM, 2015). This procedure calls for fabricating cylindrical specimens with a diameter of 4 inches (101.6 mm) and a height of 2.5±0.05 inches (63.5±1.27 mm). On a hot plate, Marshall Mold, compaction hammer, and spatula are heated to a temperature of between (120 and 150) °C. The hot spatula aggressively shovels the asphalt mixture 15 times around the outside and 10 times within the heated mold once it has been put inside. The mixture's temperature is between (100-130)°C just before compaction **(ASTM, 2015)**. A compaction hammer weighing 4.535 kg sliding weight is then used to provide 75 blows to the top and bottom of the specimen, followed by a free fall of 18 inches (457.2 mm). The mold-containing specimen is removed after cooling for 24 hours at room temperature. On each specimen, Marshall stability and flow tests are run. The cylindrical specimen is crushed on the lateral surface at a continuous pace of 2 inches per minute (50.8 mm/min) until failure of the maximum load is attained. **Fig. 4** shows the Marshall test preparation and testing.
A record is made of the greatest load resistance and the corresponding flow value. The test was completed within 30 seconds of the specimen being withdrawn from the water bath. Three specimens were produced for each combination, and the average findings were reported. The bulk density, specific gravity (ASTM, 2009), and the specific gravity of void

less mixture are estimated according to **(ASTM, 2011)**. The air voids rate is then calculated according to **(ASTM, 2005)** and determined for each specimen, and then the void in mineral Aggregate filled with Asphalt is calculated.

2.4.2. Indirect Tensile Strength Test (IDT)

Asphalt mixtures' indirect tensile strength and temperature susceptibility were performed based on **(ASTM D-6931, 2015)**. The essential concepts are that a cylindrical test specimen is loaded on two opposite sides, and the results assess the relative quality and strength of the materials in pavement design, evaluation, and analysis. The test specimen experiences a tensile tension as a result. Up to failure, the test is run at a steady pace. The maximum load is noted and considered to determine the indirect tensile strength. The preparation of the specimens complies with **(ASTM D-6926, 2015).** This test employed Marshall specimens, and the percentage of air spaces in the specimens was the same as for the Marshall test. After preparation, the specimens were allowed to cool at room temperature for 24 hours. The specimens are then positioned vertically in the diametrical plane between the two parallel loading strips in the water bath for at least 30 minutes at a temperature of 25°C (as shown in **Fig. 5**).
The specimen has a strip width of 12.7mm, a diameter of 4 inches (101.6mm), and a height of 2.5 inches (63.5127mm). Vertical compressive load at the rate of 2 in/min (50.8 mm/min) by the master loader machine was applied until the digital reader reached the maximum load resistance; this value was recorded. The indirect tensile strength is calculated by:

(a) Preparing Mixture and putting in mold (b) Group of Samples

(c) Specimens in Water Bath (d) Test Running

Figure 4. Marshall test procedure

(a) Indirect tensile strength Specimen. (b) Test Running (c) Specimen after Test.

Figure 5. The Steps of the IDT Test

$$\text{IDT} = \frac{2000 * \text{P}}{\pi * \text{D} * \text{T}} \tag{1}$$

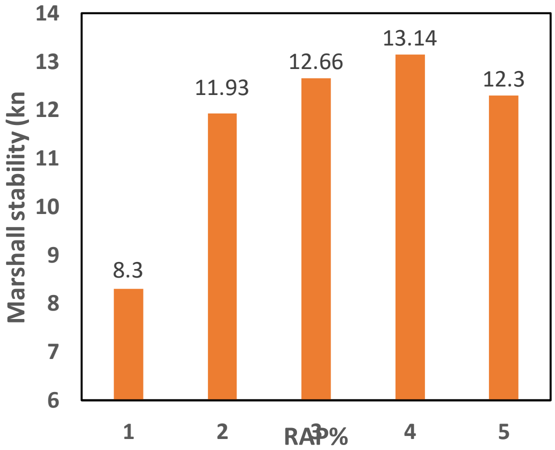
where:

IDT is Indirect tensile strength (kPa),
P is the Maximum load resistance at failure (kN)
D is the Diameter of the sample (mm)
T is the Thickness of the sample immediately before the test (mm)

3. RESULTS AND DISCUSSION

3.1. Marshall Test Result.

A full mix design used the Marshall approach described in Asphalt Institute series No. 2 (Institute, 1981). Using this methodology, the asphalt cement's ideal content is determined by averaging the three concentrations that produce the highest levels of stability, unit weight, and air voids (4%), respectively.
For each ratio of RAP, prepare four marshal specimens starting from 4% and increasing the content of asphalt cement at a constant rate of 0.3% per ratio.
According to the results of the Marshall Tests, there are typical correlations between Marshall Properties and the 0% RAP control mix, as well as mixes containing RAP (10% RAP, 20% RAP,30 %RAP, and 40% RAP).
Fig. 6 displays the results for Marshall Stability. It indicates that stability values for various blends follow the expected pattern when RAP is present. The stability levels rise until they reach a maximum point, after which stability tends to fall. The Asphalt's stiffening is caused by adding additional RAP, which provides high cohesive strength while retaining interlocking among coarse crushed Aggregate. The increase in asphalt layer thickness over the coarse aggregate particles, which reduces internal friction, causes a loss in stability at a particular RAP concentration. As seen in **Fig. 7**, higher lubrication also reduces internal friction, which is assumed to cause the Marshall Flow values' ongoing rise.



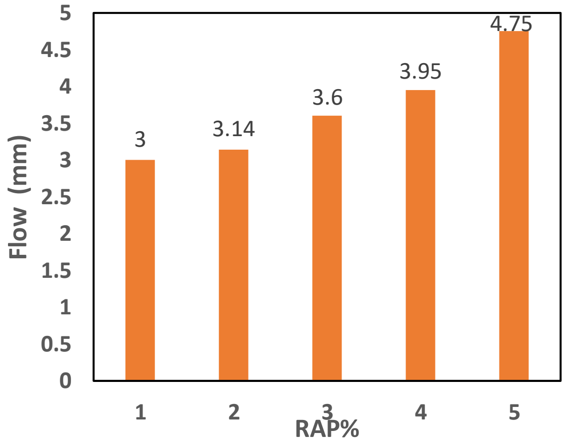
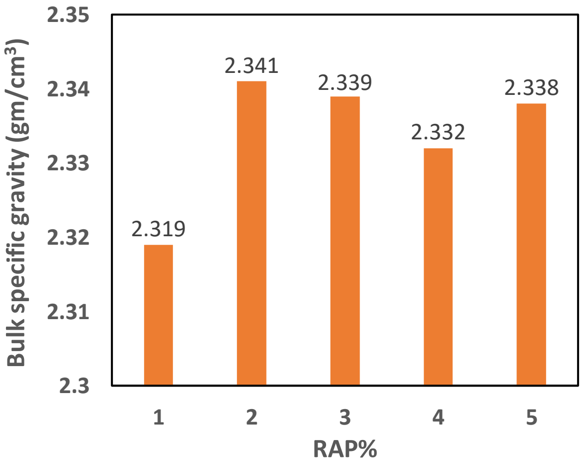


Figure 6. Effect of RAP% on Marshall Stability. **Figure 7**. Effect of RAP% on Marshall flow

The flow value indicates the displacement the asphalt mixture experiences due to the loads acting on it. The flow increases as the asphalt concentration increases. The components added to the asphalt mixture gave the samples great flexibility and made them unable to withstand loads. Hence at 40% RAP and when RAP is increased, the values (4.75mm) are beyond the bounds of the specification.
The bulk density values for various mixtures are displayed in **Fig. 8** as a function of RAP content. The figure shows that the bulk density increased compared to the warm asphalt mixture (0%RAP). At the same time, it decreased with an increase in the percentage of the RAP, where the highest value was 2.341at 10% RAP, the lowest value was 2.319 at 0% RAP, and the 20% and 40% RAP were close about 2.339 and 2.338 respectively. The bulk density decrease could be due to the sample expansion after compacting and extracting from the molds, which led to increased sample volume and, thus, decreased density.
Fig. 9 shows the relationship between the number of air voids and the RAP content. The proportion of air voids is shown to grow when RAP concentration rises. This demonstrates that the old Asphalt in the RAP aggregate did not function as black rock and instead contributed new asphalt cement (AC), increasing the amount of Asphalt in the final mixture.



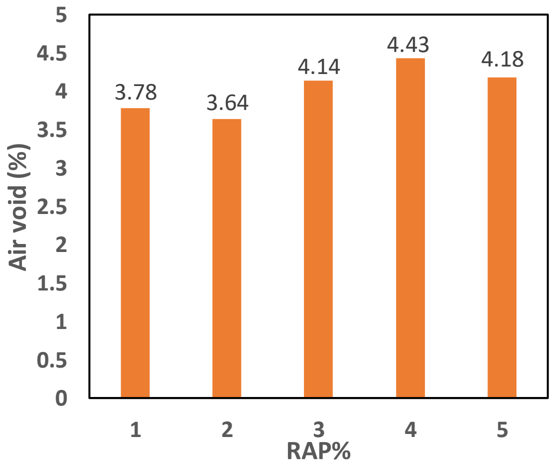


Figure 8. Effect of RAP% on Bulk Density. **Figure 9.** Effect RAP% CF on Air Voids.

Because of this, the aggregates and extra material (RAP) in the asphalt mixture were not uniform, and the subsequent expansion led to the creation of voids. The compressed specimen's bulk density dropped as a result, and its percentage of air void increased.
Mineral aggregate (VMA) voids are plotted versus RAP content in **Fig.10**. It was decreased compared to WMA (containing 0%RAP). When the content of the RAP increases, the V.M.A. rises and reaches a specific limit, after which it decreases. It was noticed that the VMA in a 40% RAP mix decreased by 10% due to increased RAP content. This is evidence that the old binder in the RAP worked with new asphalt cement and raised the amount of Asphalt in the mix Filling voids with Asphalt, leading to this decline. A rise in the percentage of air voids brought on this rise in (% VMA).
The values of (VFA) % versus RAP content are shown in **Fig. 11**. The proportion of (VFA) decreases with an increase in the proportion of RAP. This is because the granules of aggregates resulting from the presence of the RAP penetrated and filled the voids in the asphalt mixture. The (VFA) values fall within the range (of 70-85%) indicated by S.C.R.B.
The impact of RAP in many combinations on Marshall Stiffness is shown in **Fig. 12**. The ratio of Marshall Stability to Marshall Flow is known as Marshall Stiffness. Because of the high Marshall Stiffness (stability/flow), asphalt mixtures used for pavement have considerable resistance to plastic flow brought on by traffic loading. A high flow value can result in a low Marshall Stiffness, so an asphalt mix with a high stability value does not necessarily offer adequate plastic flow resistance. This shows that stiffness for many mixtures follows the conventional pattern in their relationship with asphalt rate, increasing as the percentage of RAP material increases until the top peak, at which point stiffness tends to fall.

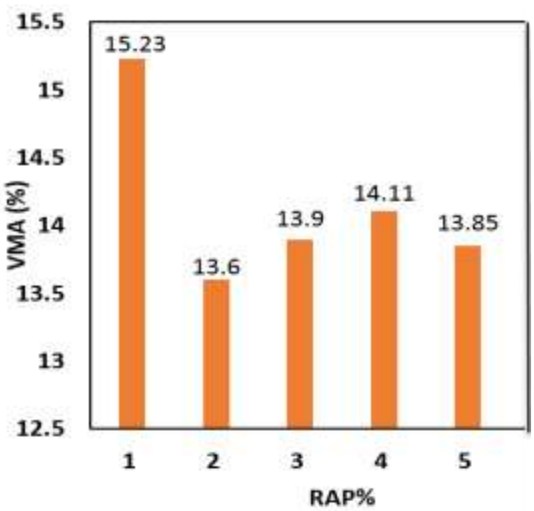


Figure 10. Effect of RAP% on VMA.

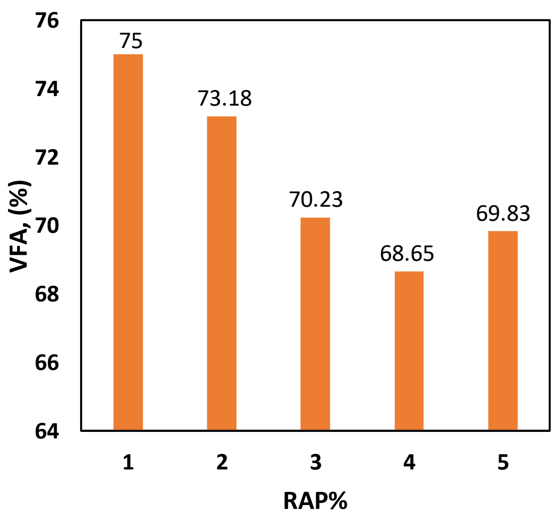


Figure 11. Effect of RAP% on VFA.

3.2 Indirect Tensile Strength Test (IDT)

An indirect tensile strength test was conducted on all the different mixture with RAP ratios of the warm asphalt design mixture to determine the amount of load that makes the sample fails. The IDT value represents the extent of the bonding between the mixture's components. All tests were performed at 25°C and a displacement velocity of 5 mm/min. The results shown in **Figs. 13 and 14**, the increase in RAP percentages leads to an increase in ITS value and an improvement in the strength of the bond between the components of the mixture compared to the mixture with 0% RAP. This is due to the percentage of Asphalt present in the RAP, which made the mixture more solid Pavement age.

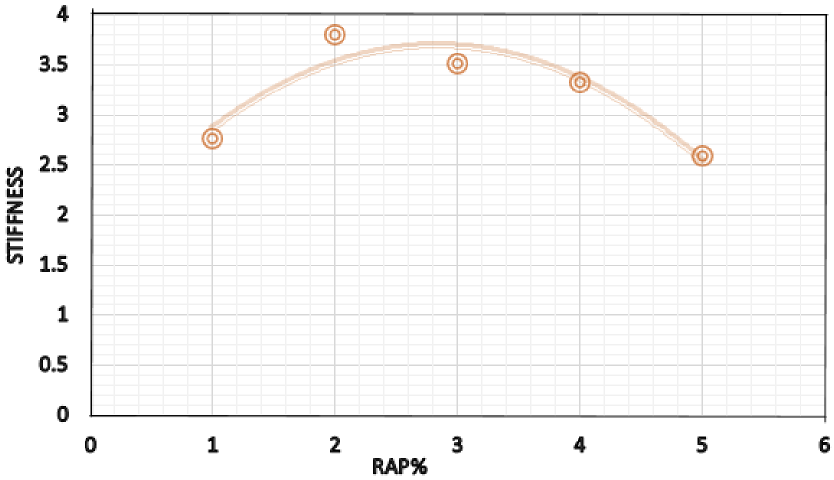


Figure 12. Relationship between RAP % and Marshall Stiffness

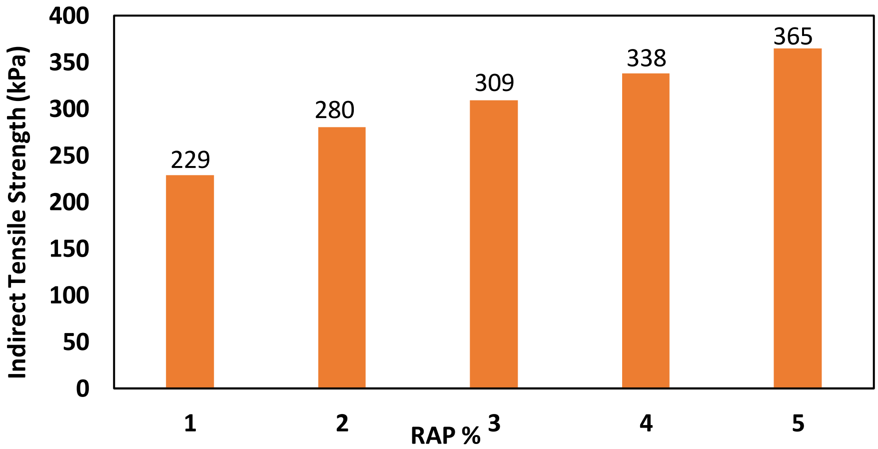


Figure 13. Indirect tension test for the WRU specimen.

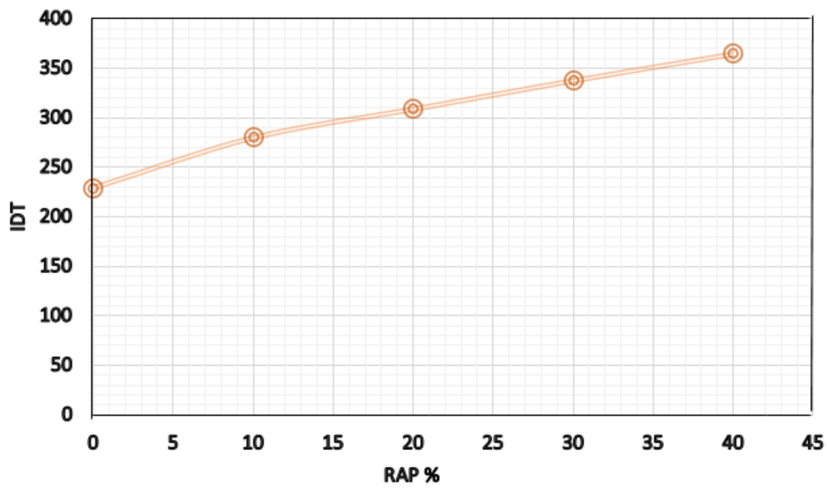


Figure 14. Relationship between RAP % and indirect tensile strength

4. CONCLUSIONS

Based on the results of the laboratory study of the regional work program that is conducted to assess the role and effect of different proportions of rap on the properties of Marshall and the properties of volumetric and indirect tensile strength, the following conclusions are extracted:-

1. Using several replacement percentages for rap significantly impacts the Marshall mix's design characteristics. We note that the higher the percentage of RAP replacement, the less optimal Asphalt for warm mixtures prepared using RAP, and at 10% RAP, the percentage of Asphalt was optimal, like 0% RAP.
2. An improvement in the stability of Marshall was obtained. The 55% RAP was the highest stability, 13.14 kN, compared to all RAP replacement ratios.
3. The air voids increased with the increase in the percentage of RAP replacement, which led to an increase in flow and decreased bulk density.
4. VMA increases when the percentage of RAP replacement increases; even at 30%, it increases, but all meet the standard's requirements.
5. The replacement of VA by RAP has improved indirect tensile strength; the higher the percentage of RAP replacement, the greater the indirect tensile strength.
6. The use of RAP showed improvement in the stiffness of the warm mixtures prepared with aspha-main watering and the production of more durable mixtures.
7. Finally, based on the test results, it seems possible for (20-30) % RAP to consider the ideal percentage of their use in the forming of warm asphalt mixtures using the Aspha-main watering to the bond layer, taking that into account in considering conducting large-scale laboratory and field tests to verify or confirm the ratio mentioned above.

REFERENCES

Ahmed, N.G., Kareem, A.I., and Abbas, A.S., 2013. Potential Use of Recycled Asphalt Pavement (RAP) in Hot MixAsphalt, *Journal of Engineering*, 19(10), pp.1244.

Albayati, A. H., Al-Mosawe, H. M., Allawi, A. A., & Oukaili, N., 2018.Moisture susceptibility of sustainable warm mix asphalt, *Advances in Civil Engineering*, P. 4, Doi: 10.1155/2018/3109435.

ASTM 2005. Standard test method for percent air voids in compacted dense and open bituminous paving mixtures.

ASTM, A., 2011. Standard test method for theoretical maximum specific gravity and density of bituminous paving mixtures, in. American Society for Testing and Materials West Conshohocken, PA.

ASTM, A., 2015. D6927-15 Standard Test Method for Marshall Stability and Flow of Asphalt Mixtures, *ASTM International: West Conshohocken, PA, USA* [Preprint].

Behnia, B., Dave, E. V., Ahmed, S., Buttlar, W. G., & Reis, H., 2011. Effects of recycled asphalt pavement amounts on low-temperature cracking performance of asphalt mixtures using acoustic emissions, *Transportation Research Record*, 2208(1), pp. 64–71, Doi.org/10.3141/2208-09.

Copeland, A., 2011. *Reclaimed asphalt pavement in asphalt mixtures: State of the practice*. United States. Federal Highway Administration. Office of Research, Development, and Technology.

Daniel, J.S., and Lachance, A., 2005. Mechanistic and volumetric properties of asphalt mixtures with recycled asphalt pavement, *Transportation research record*, 1929(1), pp. 28–36. Doi: 10.1177/0361198105192900104.

Hill, B., 2011. Performance evaluation of warm mix asphalt mixtures incorporating reclaimed asphalt pavement. MSc. thesis at Civil Engineering Department University of Illinois at Urbana-Champaign,

Huang, B., Shu, X. and Vukosavljevic, D., 2011. Laboratory investigation of cracking resistance of hot-mix asphalt field mixtures containing screened reclaimed asphalt pavement, *Journal of Materials in Civil Engineering*, 23(11), pp. 1535–1543.

Institute, A., 1981. *Thickness Design--asphalt Pavements for Highways and Streets*. Asphalt Inst.

Jaafar, M.A., Joni, H.H., and Karim, H.H., 2022. Evaluation of Reclaimed Asphalt Mixtures Modified by Nanoclay Powder on Moisture Damage, in *IOP Conference Series: Earth and Environmental Science*. IOP Publishing, P. 12047. Doi: 10.1088/1755-1315/961/1/012047.

Newcomb, D.E., Brown, E.R., and Epps, J.A., 2007. *Designing HMA mixtures with high RAP content: A practical guide*. National Asphalt Pavement Association.

SCRB/R9 2003.General Specification for Roads and Bridges, Section R/9, Hot-Mix Asphalt Concrete Pavement, Revised Edition, *State Corporation of Roads and Bridges, Ministry of Housing and Construction, Republic of Iraq* [Preprint].

Shu, X., Huang, B., and Vukosavljevic, D., 2008. Laboratory evaluation of fatigue characteristics of recycled asphalt mixture, *Construction and Building Materials*, 22(7), pp. 1323–1330. Doi: 10.1016/j.conbuildmat.2007.04.019.

Tran, B.T., and Hassan, R.A., 2011. Performance of hot-mix Asphalt containing recycled asphalt pavement, *Transportation research record*, 2205(1), pp. 121–129, Doi.org/10.3141/2205-16.

Ahmed, N.G., Kareem, A.I., and Abbas, A.S., 2013. Potential Use of Recycled Asphalt Pavement (RAP) in Hot MixAsphalt, *Journal of Engineering*, 19(10), P. 1244.

Albayati, A.H. *et al.*, 2018 .Moisture susceptibility of sustainable warm mix asphalt, *Advances in Civil Engineering*, P. 4. Doi.org/10.1155/2018/3109435.

ASTM 2005. Standard test method for percent air voids in compacted dense and open bituminous paving mixtures.

ASTM, A., 2011. Standard test method for theoretical maximum specific gravity and density of bituminous paving mixtures, in. American Society for Testing and Materials West Conshohocken, PA.

ASTM, A., 2015. D6927-15 Standard Test Method for Marshall Stability and Flow of Asphalt Mixtures, *ASTM International: West Conshohocken, PA, USA* [Preprint].

Behnia, B. *et al.*, 2011. Effects of recycled asphalt pavement amounts on low-temperature cracking performance of asphalt mixtures using acoustic emissions, *Transportation Research Record*, 2208(1), pp. 64–71. Doi.org/10.3141/2208-09.

Copeland, A., 2011. *Reclaimed asphalt pavement in asphalt mixtures: State of the practice*. United States. Federal Highway Administration. Office of Research, Development, and Technology.

Daniel, J.S., and Lachance, A., 2005. Mechanistic and volumetric properties of asphalt mixtures with recycled asphalt pavement, *Transportation research record*, 1929(1), pp. 28–36. Doi.org/10.1177/0361198105192900104.

Hill, B., 2011. Performance evaluation of warm mix asphalt mixtures incorporating reclaimed asphalt pavement.

Huang, B., Shu, X. and Vukosavljevic, D., 2011. Laboratory investigation of cracking resistance of hot-mix asphalt field mixtures containing screened reclaimed asphalt pavement, *Journal of Materials in Civil Engineering*, 23(11), pp. 1535–1543.

Institute, A., 1981. *Thickness Design--asphalt Pavements for Highways and Streets*. Asphalt Inst.

Jaafar, M.A., Joni, H.H., and Karim, H.H., 2022. Evaluation of Reclaimed Asphalt Mixtures Modified by Nanoclay Powder on Moisture Damage, in *IOP Conference Series: Earth and Environmental Science*. IOP Publishing, P. 12047. Doi 10.1088/1755-1315/961/1/012047.

Newcomb, D.E., Brown, E.R., and Epps, J.A., 2007. *Designing HMA mixtures with high RAP content: A practical guide*. National Asphalt Pavement Association.

SCRB/R9 2003.General Specification for Roads and Bridges, Section R/9, Hot-Mix Asphalt Concrete Pavement, Revised Edition, *State Corporation of Roads and Bridges, Ministry of Housing and Construction, Republic of Iraq* [Preprint].

Shu, X., Huang, B., and Vukosavljevic, D., 2008. Laboratory evaluation of fatigue characteristics of recycled asphalt mixture, *Construction and Building Materials*, 22(7), pp. 1323–1330. Doi: 10.1016/j.conbuildmat.2007.04.019.

Tran, B.T., and Hassan, R.A., 2011. Performance of hot-mix Asphalt containing recycled asphalt pavement, *Transportation research record*, 2205(1), pp. 121–129. Doi: 10.3141/2205-16.