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PERFORMANCE EVALUATION OF SUSTAINABLE WARM MIX ASPHALT MIXTURE UNDER REPEATED LOADING

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Abstract:
Warm mix asphalt (WMA) with sustainable material (RAP) is an environmentally friendly material that has economic, environmental, and social advantages. Warm mixtures can be produced and compacted at temperatures that are 15–40 °C lower than those used to produce hot mix asphalt. Six replacement percentages (0, 10, 20, 30, and 40%) for the coarse virgin aggregate with RAP have been examined in this study. The optimum content of asphalt cement has been quantified using the Marshall mix design technique for each replacement percentage of the warm mixture Containing RAP. Afterward, samples with the ideal asphalt content were made and evaluated using the pneumatic repeated load test to appraise their permanent deformation and resilient modulus. The findings showed that mixes containing more RAP had lower optimal asphalt contents. Additionally, Marshall stability was improved by around 28%, the best RAP ratio (20%) achieved the best resistance to permanent deformation, and it produced an elastic modulus that was 15% greater than that of a warm asphalt mixture. The AASHTO design procedure for the flexible pavement was then utilized to compute the thicknesses of the structural layers, and show the thickness of the asphalt layer decreases as the RAP ratio increases. The utilization of recycled materials (RAP) yields combinations with performance and efficiency comparable to that of hot mix asphalt and offers economic benefits in addition to environmental benefits.

Keywords: warm mix asphalt, Reclaimed Asphalt Pavement, Pneumatic Repeated Load test, AASHTO design method

1 INTRODUCTION

The recent utilization of warm mix asphalt in the creation of asphalt concrete has become increasingly important as a means of incorporating sustainability into the process of constructing road pavements. The manufacturing process of this category of asphalt mixture differs from that usually adopted in the production of hot mix asphalt concrete (HMA). The key difference is that the mixing and compaction temperatures of WMA are about 15 to 40 ℃ lower than that in HMA, the variation in temperature is due to the variation in additives used to yield WMA. Because less fuel was used to heat the raw materials, combined with lower carbon dioxide emissions, this reduction had positive economic and environmental effects[1].
WMA is typically produced using one of three different technologies. The first technique employs paraffin wax additives, such as Sasobit (an organic additive), which are added to asphalt cement in amounts ranging from (0.8 to 3)% by weight. This lowers the viscosity degree of the asphalt cement. The second approach works on strengthening the bond between aggregate and asphalt cement by using chemical additives such as Evotherm. These

additives should be added at a rate of (1 - 2)% by the weightiness of asphalt cement. In the third approach, foaming agents such Aspha-min or Advera (synthetic zeolite materials) are added at rates ranging from (0.2%-0.3%) by the weightiness of the entire blend. At mingling temperatures, zeolite releases water, causing the viscidness of asphalt cement to decrease [2].

With the aim of examining the potential influence of Aspha-min on the rendering efficiency of WMA, asphalt blends were compacted at four degree of temperatures (149, 129, 110, and 88)°C, with the temperature at mixing is nearly 19°C upper than the temperature of compaction [3]. According to their findings, the adding of Aspha-min did not affect the rutting potential or resilient modulus. However, as the compaction hotness dropped, the resilient modulus went down. Additionally, the moisture damage for WMA compared to HMA was less severe in terms of tensile strength ratio. These results are supported by [4].

The effectiveness of WMA produced with Aspha-min in comparison to control HMA was studied by [5]; two aspha-min dosages of 0.3% and 0.5% by weightiness of the full mix were considered. In their investigation, PG 64-22 was used. Whereas the warm mix asphalt mixes were compacted at degrees of temperature of 100°C and 120°C, the hot mix was only compacted at 120°C. The authors' major findings show that for all of the combinations under consideration, the value of the aspha-min additives has no impact on the dynamic modulus of asphalt concrete. Additionally, they stated that WMA mixes had anticipated rut depths that are lower than HMA, with the difference in rut depth being roughly 44%.

In recent years, Since the price of asphalt binder has risen so significantly, HMA has become much more expensive. To adequately maintain and renovate pavements with the available budgets, users are looking for ways to reduce the costs of asphalt mixtures. Increasing the amount of Recycled Asphalt Pavement (RAP) in mixtures is a central and effective strategy to lower the cost of asphalt construction [6].

According to some studies [7]and [8], using a certain percentage of RAP improves the performance qualities of mixes, while other studies showed that adding a given percentage of RAP had little to no effect on the operational characteristics of mixes[9]. Several researchers have discovered that recycled asphalt mixes with low proportion of RAP could provide proper moisture damage resistance, but that resistance to moisture damage does not significantly rise as the RAP ratio in the blend increases[10]. Additionally, some lessons claimed that the presence of RAP causes a significant decrease in moisture damage resistance [11].

According to various studies and some researchers, the inclusion of RAP both diminishes and increases the mix's stiffness [12],[8] and[11]. Similar to how fatigue life varies with temperature, it increases according to [13]and decreases according to[14].[15]. Tensile strength increases or is comparable to virgin blends[16].

Sasobit and Zycotherm considered investigating the relative effects of several additives on the characteristics of WMA mixtures incorporating RAP material in comparison with the same graded HMA. They utilized chemical and organic WMA additives in their experiments. RAP was added to mixtures in several amounts (0%, 25%, 50%, and 75% of the total aggregates). Based on the AASHTO T324 specification, the wheel track test (WTT) carried out at 50 C demonstrated that Sasobit WMA-RAP can provide higher resistance to rutting deformation than the Zycotherm WMA-RAP. This is due to Sasobit's high wax crystal content—which makes it tougher than other additions. Additionally, it was found that adding more RAP to combinations enhances its robust modulus and rutting resistance[17].

It was inform that fostering the technology of warm mix asphalt in blends with high recycled asphalt pavement content can yield several potential benefits. Examples of such benefits include minimizing the need for virgin asphalt and aggregates, lowering the cost of the mixture, reducing gas emissions, improving the performance of the mix, and reducing the amount of fuel used during the stages of production and placement. It was also mentioned that using a WMA mixture approach could improve the mixture's workability, lessen asphalt binder aging during construction, achieve a greater density in place, and help in reducing gas emissions. The technology of combining warm mix asphalt (WMA) with adequate levels of RAP is therefore recommended [18]. The use of RAP can also contribute to the economic and environmental dimensions of sustainability as a result of the attained reduction in the consumption and transportation total costs of asphalt and aggregates [19].

2 Experimental program and procedures

2.1. Materials

The raw materials that have been used in the current study to produce the warm asphalt mixtures include asphalt cement, aggregates, and mineral filler. The adequacy of these materials, to be used in designing the final mix (job mix), has been evaluated using several standard tests, and then by comparing the results with the corresponding specifications and requirements.

2.1.1. Asphalt. According to the performance grade criteria [20], the asphalt cement delivered from the refinery of Doura (Baghdad/Iraq) was tested. The findings clearly show that asphalt cement has a performance grade of (40-50).

2.1.2. Aggregates. In order to create asphalt concrete mixtures, two types of coarse aggregates (virgin aggregate (VA) and RAP) were used. The virgin aggregate consists of crushed quartz that has been brough from a site in the north of Baghdad (Al-Nibaie quarry), while the RAP was collected from a thorough excavation of an old paving slab on Salah Al-Din Road in the Al-Ameriya neighborhood of Baghdad. The used aggregates (both coarse and fine) have been firstly sieved and then mixed again using the correct ratios to fulfill the binder course gradation as needed by the Iraqi standard specification adopted by the Iraqi State Corporation for Roads and Bridges [20] as displayed in Figure (3)the aggregate's gradation curve.

2.1.3. Mineral Filler. Mineral filler is the only type of filler adopted in the current research to be used during preparing the warm mix asphalt mixture; it is an Ordinary Portland cement that is available in the local market. The filler is typically identified as a non-plastic completely dry material that have zero lumps or fine particulates and can pass sieve No.200 (0.075mm).

2.1.4. **Aspha-min.** As an ingredient in the creation of WMA, aspha-min powder (shown in figure (1)) is made of sodium aluminosilicate that has been hydrothermally crystallized into a fine powder. The heated aggregate blend received 0.3% (by the weight of the overall mix) of aspha-min, which contains around 21% water by weight. Table (1) lists the key chemical and physical characteristics of the aspha-min powder

Table 1. Chemical and physical features of the Aspha-min WMA additive.

Proper ty	Ingredients	SiO2	Al2O 3	Na2O	LOI	Physic al state	Col or	Odor	Speci fic

									gravity
Result	Na2O.Al2O3.2 SiO2 (sodium aluminosilicate)	32.80 %	29.10 %	16.10 %	21.20 %	Granular powder	White	Odorless	2.03

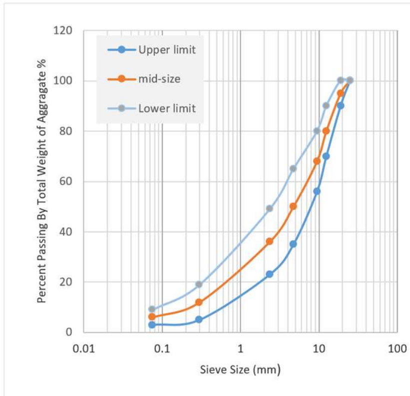


Figure3. Scope Requirements and Benchmark Grade for Binder or Leveling course.

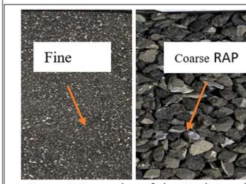


Figure2.Examples of the Reclaimed Asphalt Pavement.

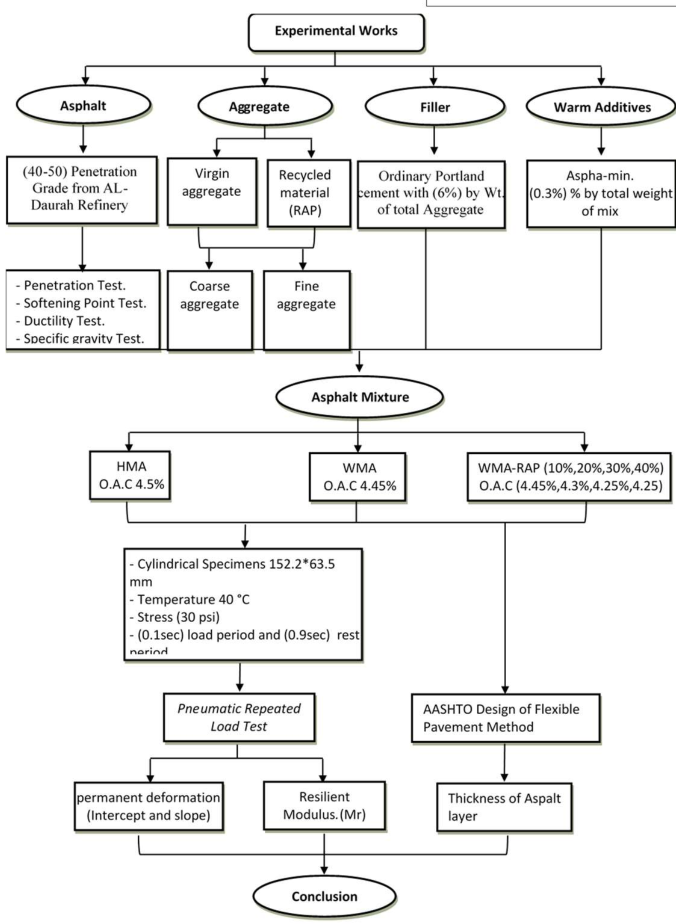


Figure 4. The work program flow chart.

2.2. Mix Design

Hot-mix asphalt controlled at a temperature of 150°C was manufactured and five sets of warm mixtures were prepared at a temperature of 125 °C, adding synthetic zeolite and different RAP ratios for each group. RAP ratio (0%,10%,20%,30%, and 40%). The mixtures were prepared according to the typical stages of the Marshall blend design approach to achieve the ideal quantity of asphalt content (OBC). A mix of aggregate and filler weighing around 1200 g was heated to 150°C. Asphalt was then heated to 145°C. The hot aggregate is mixed with four different weight percentages of asphalt, 4%, 4.3%, 4.6%, and 4.9%. To obtain the hot asphalt mixture, the ingredients were then completely and adequately combined. Lastly, for obtaining the warm asphalt mixture, 0.3% of synthetic zeolite is added. In the instance of a warm blend containing changed percentages of RAP, the RAP was heated to 120°C for two hours and it was added to the preheated aggregate. Four weight percentages (3.85%, 4.15%, 4.45%, and 4.75%) of bitumen were thereafter added to the hot mix of aggregate and RAP in addition to adding 0.3% of synthetic zeolite. The mixture is mixed systematically to form the warm - RAP mixture. The next step involves placing the obtained mixture into a (4in. diameter x 2.5in. height) standard compaction mold before being compacted with 75 blows on each side to best model the heavy traffic condition in the field. For each asphalt weight percentage, three samples of asphalt mixtures are made. Finally, the specimens are now ready to be tested, one by one, by the Marshall test machine in order to quantify their characteristics including stability, flow, bulk density, 4% air voids, voids in mineral aggregate %VMA), and voids filled with asphalt (%VFA). To determination the corrected stability values of the mixture a correction factor was used. The obtained characteristics for the both controlled (untreated) and RAP treated asphalt mixtures were plotted graphically versus the adopted percentages of asphalt contents. As an average mean from the curves, the ideal bitumen content for each blend was identified. The OBC findings for all combinations were presented in Table 3. The RAP content rose while the O.A.C dropped.

2.3. Laboratory Tests

2.3.1. **Marshall test**

Before conducting the Marshall stability tests [21] on all the previously prepared cylindrical specimens, they should be firstly submerged in a 60 °C water bath for 30 to 40 minutes. The test involves applying compression pressure at a continuous interval of 2 in. (50.8 mm) per minute on the sample's lateral surface until failure is occurred. Both the maximum load resistance (failure condition) and the matching flow values are noted. The results of the three prepared specimens for each combination are provided. The maximum theoretical specific gravity[22] of a blend is calculated, as well as its bulk specific gravity and density by[23]. Following that, the percentage of air voids is determined by [24].

Figure 5. Marshall test WMA sample in machine

2.3.2. Pneumatic Repeated Load Test

The pneumatic repeated load system (PRLS) was employed to conduct the axial repeated load test, and the apparatus used for this purpose was made by[25], Baghdad University's Highway Materials Laboratory. the gyratory specimens used a diameter and height of 4 inches (101.6mm) and 6 inches (152.4mm), respectively, and the aggregate was mixed into a batch of about (2850gm for cylinder specimens). In this test, the axial specimen is subjected to repeated compressive loading to measure the resilient modulus and define the permanent deformation properties of the paving materials (evaluate rutting in the WMA layer and characterize the rutting resistance capacities for the different mixes). Compressive loading is applied repeatedly 10,000 times with a loading cycle of 60 cycles per minute, and the loading sequence is (0.1sec) load period and (0.9sec) rest period for each cycle to mimic field conditions. The test temperature of 40°C with an applied stress intensity of (30psi). The building of permanent strain under repeated load is depicted in the figure (6). The specimen is tested by placing it in the testing chamber for two hours at the chosen testing temperature to ensure that the temperature is distributed evenly throughout the specimen. Following the conclusion of the specimen in the testing apparatus, the LVDT (Linear Variable Differential Transformer) is set to zero reading. The pressure actuator is then set to the required level of tension. Additionally, the timer is set to the required load and rest durations for both the loading port and the resting port The recording is stopped and the specimen is taken out of the test chamber once the test has been completed after (10,000) load repetitions (or any number for load repetition if the specimen failed earlier).

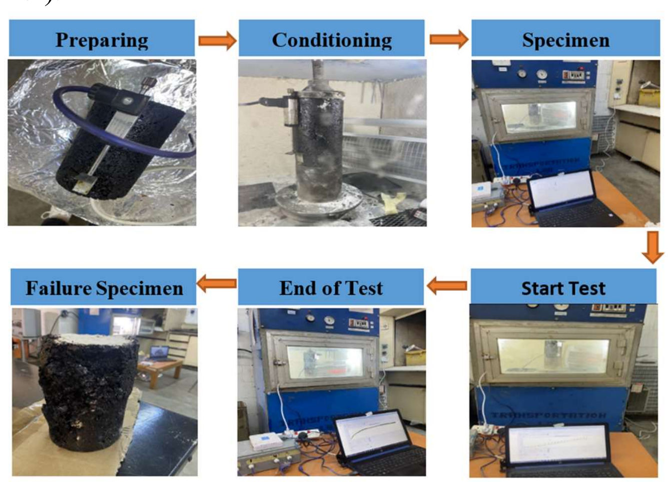


Figure 6. Steps for Pneumatic Repeated Load Test

3 RESULT AND DISCUSSION

3.1. Marshall Test Results.

The Marshall test was performed as shown in the [26]for all hot mixtures at 150 C and warm mixtures at 125 C by adding synthetic zeolite to 0.3%, Use Five Different Proportions of RAP. Founded on this test, the ideal asphalt cement contents obtained by the rate of three contents of asphalt cement, which produces greater stability, greater density, and Air void of 4% for all mixtures Hot and warm for five different replacement ratios of RAP.

Figure (6) shows the volumetric properties, stability characteristics, flow, and density with the contents of the asphalt cement for each replacement rate RAP.

We see from the figure (7A) the values of stability of Marshall increase with the increase in the percentage of asphalt cement and reach a certain limit begins to decrease, where we notice the stability at the percentage of rap 30% achieves its peak value.

For Marshall flow shown in figure (7C), as the quantity of asphalt increases, the value of flow increases; the flow values decrease with the increase in the percentage of RAP comparison with WMA (0% RAP). This is due to the reality that when the proportion of the RAP increases, the optimum asphalt cement content decreases, this is due to the good interlocking that provides asphalt mound and aggregate granules, and this leads to reducing the fluidity of the binder, that produces friction, which leads to reduced deformation and thus reduces flow and the flow values fall within the limits of the specification (2-4) mm.

As shown in figure(7B) the relationship between the content of asphalt cement per replacement rate RAP where there is a tendency to increase the specific gravity by increasing the content of asphalt cement to a certain point and then the additional increase leads to The asphalt cement to the decrease in the specific gravity where we notice the density in the warm mixtures is higher than the hot mixture and this is the result of the addition of RAP which increases the hardness of the mixture and makes its density greater Consequently.

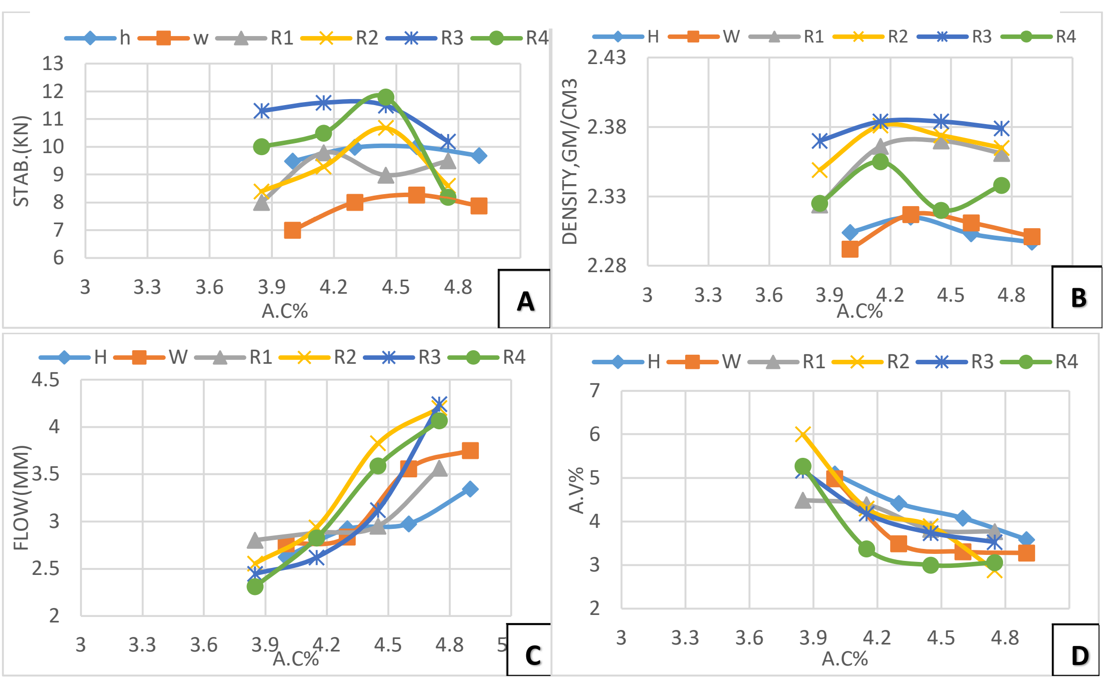
The volumetric properties, of the air voids, revealed that there is a tendency to reduce the air voids while increasing the content of asphalt cement as shown in figure(7D), values A.V for WMA with RAP ratios less than mixtures HMA, when adding a RAP, the air void increased compared to the warm mixture containing 0% RAP. This is due to the reason for this is that when the RAP is added up to the warm asphalt blend, it makes the mixture more solid and insufficient pressure, which leads to the formation of voids, where as shown previously that the optimal asphalt content decreased with the increase in the content of the RAP, the inhomogeneity of the RAP with the aggregates in the asphalt blend, as the lack of good bonding between the asphalt in the RAP, which was subjected to preliminary aging and hardening, where there is a possibility that this asphalt has been absorption and was not sufficient to fill the voids, and it led to expansion of the sample and helped to create voids. As we note all values A.V fall within the scope of the requirements of the standard SCRB (3to5) %.

The showed void in the mineral aggregate as shown in figure(7E) decreased with an increase in the content of asphalt cement and followed by a slight increase down to the ratio of 2% of the regional program of work, and when comparing the hot mixture with the warm mixture, we note that V.M.A for HMA Bigger than WMA, and when added RAP values V.M.A decrease compared to the warm mixture containing 0% RAP This is attributed to the decrease in VMA when the content of the RAP increased, the presence of asphalt surrounding the RAP filled the voids with asphalt, which led to a decrease in the voids surrounding the aggregates as it did not work the asphalt in the RAP is like a black rock .

As shown(7F), the VFA values of the warm mixture are higher by (5%) than the hot mixture, and when the material RAP was added to the warm mixture by (10%, and 40%) it increased by (0%,0.76%) in a row compared to a warm asphalt mixture (0% RAP), while the ratio of (20%,30%) the value of the VFA was constant and less by (10%) than compared to a warm asphalt mixture (0% RAP), the presence of the RAP led to an increase in the air voids, which caused the high permeability, as the asphalt was coated with the aggregate granules, that is, it was absorbed and did not fill the voids. It can be said that despite the presence of the old and hardened asphalt surrounding the RAP, it can be explained through what is shown by the VFA ratios that it did not play any role and the rap acted as a black rock.

Table 2. Marshall Design properties of All Mixture with the Optimum Binder Content for binder layer

Properties	SCRB requirement	HMA (H)	WMA (W)	WMA-RAP 10%(R1)	WMA-RAP 20%(R2)	WMA-RAP 30%(R3)	WMA-RAP 40%(R4)
O.A.C%		4.5%	4.45%	4.45%	4.3%	4.25%	4.2%
STAB. (kN)	7	10	8.2	9.2	10.2	11.7	11
FLOW (mm)	(2-4)	2.8	3.3	3	3.2	3	2.9
BULK DENSITY (gm/cm^3)		2.313	2.32	2.37	2.38	2.385	2.345
A.V%	(3-5)	4.2	3.5	3.4	4.2	4	3.2
V.M.A%	13	17	16.6	16.6	14.5	14	15.2
V.F.A%	70-80	75	78.9	79.5	71	71	78.9



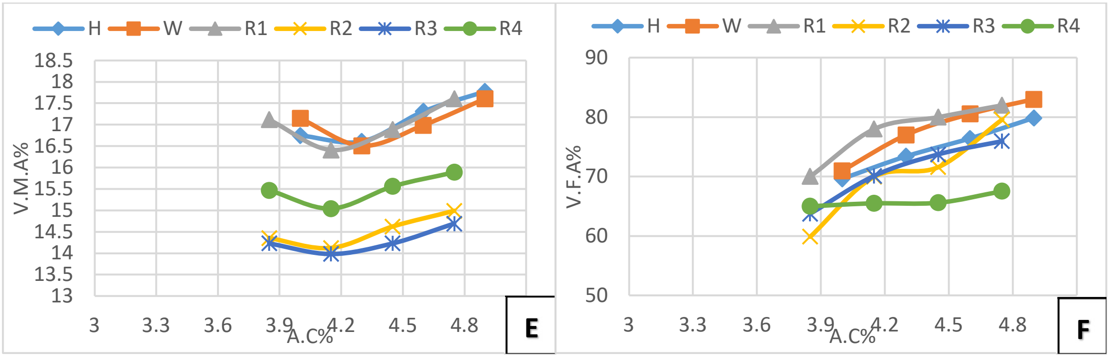


Figure 7. Marshall properties for all mixes (optimum asphalt content for HMA, WMA, WMA with 10%,20%,30%,40% RAP)

3.2. Permanent Deformation.

One of the fundamental demands of road users is the resistance of the surface to persistent deformations. Ruts have an impact on safety and comfort when driving. Traffic accidents are more likely when there is standing water in the ruts following rain and snow[27].

A warm environment and a large percentage of heavy cars on the road encourage the development of permanent deformations. In the WMA design process, it is stated that determining resistance to persistent deformation is a necessary step[28] Several techniques based on various mix asphalt properties have been devised for the evaluation of resistance to permanent deformations [29].

The Pneumatic Repeated Load test was achieved in accordance with the test conditions are 40°C, stress 30, loading and relaxation times 0.1 and 0.9, respectively standard on The effect of using zeolite and different proportions of RAP in warm asphalt mixtures and their comparison with hot asphalt mixture

The test's result proceeds using the equation. Power models are frequently fitted to the curve of cumulative permanent deformation. It is likely the equation for permanent deformation that is utilized the most. The following conventional power model was employed in this study [30]:

$$\varepsilon\rho = aN^b \; eq. (1)$$

For which,

a = the intercept of the bending in the log-log scale.

The intercept (a) is the permanent strain corresponding to N=1, where N is the load cycle repetitions. As the intercept magnitude increases, the amount of strain increases and consequently the possibility of permanent deformation increases as reported in the Superpave research work implemented by [31].

b = slope of the bending in log-log scale.

the slope (b) indicates the variation in the permanent strain in terms of the variation in a repetition of loading cycles (N) in the log-log scale. An asphalt mixture with high slope values reflects a rise in the rate of material deformation rate and as a result a reduction in rutting resistance capacity. Furthermore, a small slope value mix is more adequate as it can stop the incidence of the rutting mechanism at a slower rate[32].

Figure (8) presents the deformation curves obtained from Pneumatic Repeated Load tests (PRLS).

When comparing the hot mixture with the warm mixture, the values in intercept are low, while the values of the slope increased, by 4.8%, the results are in agreement with [33],the decrease in the production temperature using zeolite in warm mixtures has an did not lead Improves in the permanent deformation parameters. When using RAP material in warm mixtures, we notice a decrease in slope values and an increase in intercept values compared to the warm asphalt thread without RAP. This means that RAP material has a significant impact on the parameters of permanent deformation, as the use of contributed RAP to an increase in the strength of the mixture. this is a due finer aggregate skeleton, which participates in rising the number of contacts between particles, and the resistance to permanent deformation. This behavior evidently reflects the effective role of RAP in increasing the resistance capacity of the mixture to the permanent deformation.

Table 3. Effect of RAP on Intercept and slope coefficient of permanent deformation for binder layer

mixtures	a	b
H1(HMA)	126.9	0.2155
W1(WMA)	85.399	0.2266
R1(RAP10%)	105.08	0.0197
R2(RAP20%)	126.63	0.1774
R3(RAP30%)	76.435	0.1753
R4(RAP40%)	89.546	0.1149

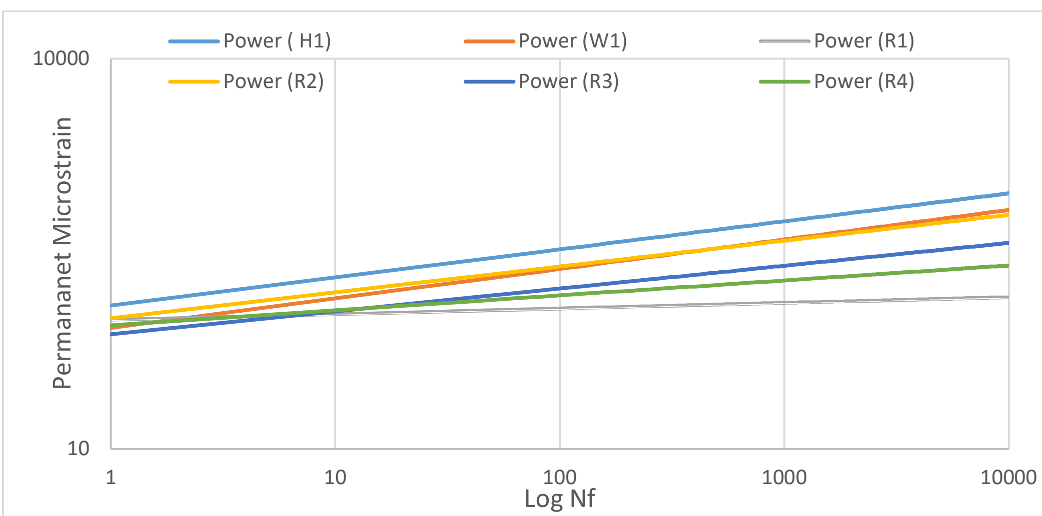


Figure 8. Effect of RAP ratio on permanent deformation at 40 °C

3.3. Resilient Modulus.

Resilient modulus is a measurement of the elasticity of a material. The design of asphalt pavement has undergone a philosophical shift in recent years, moving from a more empirical approach to a mechanical method based on elastic theory. The most common method of stress-strain measurement used to assess elastic characteristics is the resilient modulus of asphalt mixes. It is common knowledge that the majority of pavement materials are not elastic and undergo some permanent deformation with each application of stress. However, if the load is low in comparison to the material's strength and is repeatedly applied over a significant number of cycles, the deformation caused by for each load recurrence is virtually entirely recoverable and proportional to the load, and can therefore be careful elastic. The Resilient modulus (Mr) is typically appraised as an engineering characteristic that demonstrates the relation between the stress and strain values of the HMA mix; its value is estimated according to Equation (2). For this purpose, the Pneumatic Repeated Load test on compacted bituminous blends was achieved as per[21]. The resilience modulus (Mr) can be calculated using Equation (2). The resilient modulus data shown in Table are used to demonstrate the comparison between the different ratios of recycled asphalt pavement.

The resilient modulus is considered a qualitative test to estimate the severity of Permanent Deformation, which illustrates that the mixtures containing 10,20,30and 40% RAP provide a higher increase in resilient modulus compared with a mix without RAP. The highest Resilient modulus (Mr) value is achieved at 30% RAP content for mixtures by18.2% increase compared to 0% RAP, this is due to the hardness of the mixture after adding a RAP, as the mixture became more solid and thus increased its resistance.

$$M_r = \frac{\sigma}{\varepsilon_r} \; eq.(2)$$

Where:

$\boldsymbol{M_r}$= Resilient modulus (psi)

$\boldsymbol{\sigma}$ =repeated axial stress (psi)

$\boldsymbol{\varepsilon_r}$ =axial resilient strain (psi)

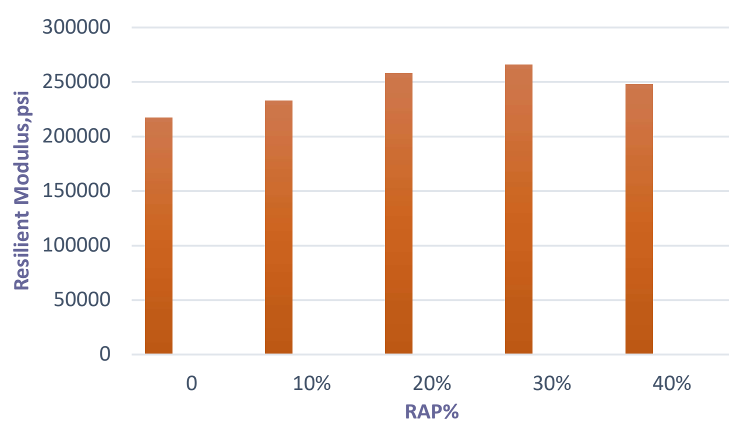


Figure 9. Resilient modulus of RAP mixtures

4 Design of Flexible Pavement

The prepared roadbed (subgrade), subbase layer, base layer, and the wearing surface layer are the four typical structural components of a flexible pavement (see Figure 10)

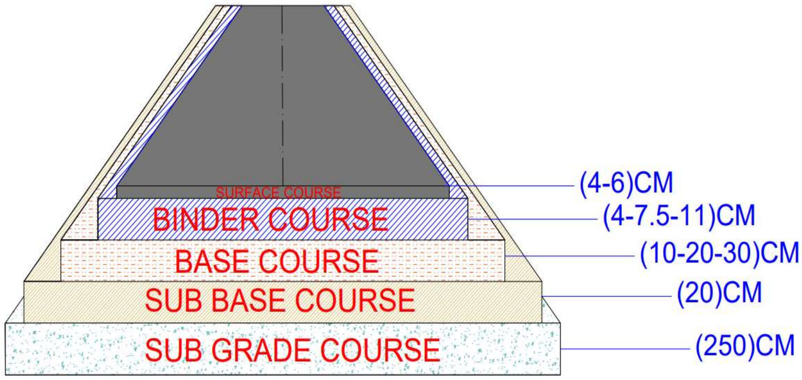
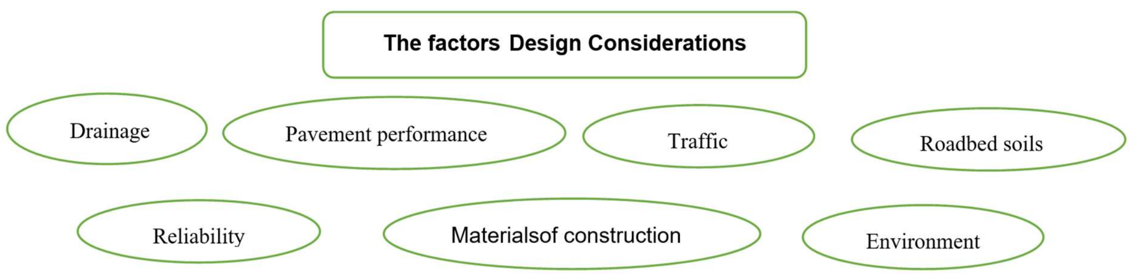


Figure 10. Structural Components of Flexible Pavement

4.1.AASHTO Design Method

The empirical findings of the AASHTO road test, that was carried out in Ottawa (USA), represent the basis for the AASHTO traditional method for designing highway pavements [34]



4.2.Structural Design

Using the AASHTO technique, the design's goal is to find the structural number (SN) of a specific flexible pavement that is sufficient to support the anticipated ESAL.

For the performance period, ESALs with a value higher than 50,000 are designed using this method. Ordinarily, low-volume highways are used to design ESALs with less than this capacity. SN is expressed as follows in the 1993 AASHTO guide:

$$SN = a_1 D_1 + a_2 D_2 m_2 + a_3 D_3 m_3 \qquad eq.(3)$$

Where

m_i: a coefficient for defining drainage condition for layer i

a_1, a_2, a_3: coefficients defining surface, base, and subbase layers, respectively

D_1, D_2, D_3: actual thickness of the surface, base, and subbase layers, respectively.

using the equation or chart in determine SN.

Table 4. parameter of AASHTO Design Method [34][35][36]

Parameter of design method	indicated	value
Reliability (R%)	urban interstate highway (range is 85 to 99.9 from Table 19.7)	99%
Standard deviation (So)	Flexible pavement (range is 0.4 to 0.5)	= 0.49
Initial serviceability index (pi) Terminal serviceability index (pt) serviceability loss (PSI) PSI	$\Delta PSI = P_i - P_t$ $eq.(3)$	4.5 2.5 4.5-2.5=2
equivalent single axle load (ESAL)	predicted number of 18,000-lb (80 kN) single-axle load applications	2*10^6
CBR for subgrade Mr for subgrade	$M_r(Ib/in^2)$ =1500 *CBR eq. (4) (for fine-grain soils with soaked CBR of 10 or less) (19.3))	6 =1500*6= 9000psi
CBR for subbase Mr for subbase	$M_r$for subbase (from figure 19.3)	35 16000psi
layer coefficients of surface (a_1) layer coefficients of subbase (a_2)	(from Figure 19.5 depended on Mr this from equation for asphalt layer $M_r = 483 * STAB.(kg)$ $eq.(5)$ (from Figure 19.3 depended CBR =35 for subbase)	Table for each mix 0.11
drainage coefficient mi	for subbase layers, (According to Table 19.5, the drainage quality is fair, and it takes a week for water to drain from beneath a pavement. According to Table 19.6, the proportion of time the pavement structure will be exposed to moisture levels nearing saturation is = 30.)	0.8

- Determine SN2 and SN1 depended on (R , S_o, ESALs, Mr subgrade and Mr subbase respectively ,ΔPSI from Figure 19.8 Design Chart for Flexible Pavements Based on Using Mean Values for each Input)
- Determine D1 and D2 from equation:

$$D_1 = SN_1/a_1 \quad eq.(6)$$

$$D_2 = (SN_2 - SN_1)/(a_2 * m_2) \quad eq.(7)$$

- Check with Table 19.9 that presents minimum depths of highway layers advised by AASHTO.

Table 5. Thickness of the asphalt layer

Type mixture	a_1	M_r(psi)	D_1 (mm)	D_2 (mm)
H	0.46	516786	148	203
W	0.4	403585	160	203
R1	0.43	442959	155	203
R2	0.45	492177	150	203
R3	0.48	575847	142	203
R4	0.5	566004	143	203

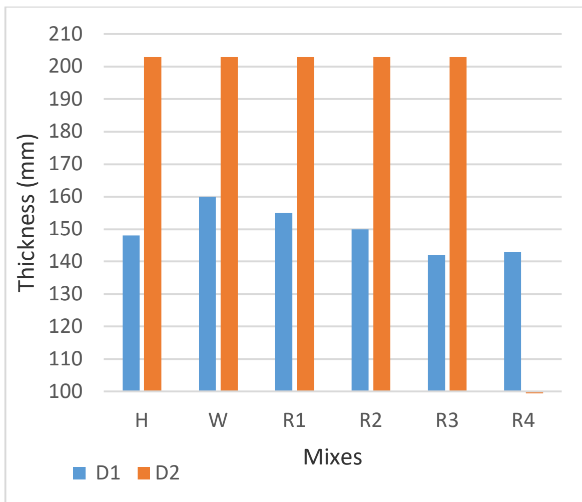


Figure 11. thickness of the asphalt course

The AASHTO design method was used (Pcase software) for the layers of flexible pavement, where the thickness of the asphalt course was calculated for six mixtures (hot and warm with five different ratios of RAP). As shown in table(5) warm mixture requires a higher thickness compared to hot mixture, that is, the decrease in the mixing temperature led to a weakening of the mixture and a decrease in the value of (Mr), which led to the requirement for a higher thickness of the design layer for WMA mixture, and as it is known that the greater the thickness of the layer, the more expensive it is, and therefore there is no economic feasibility despite the environmental benefits provided by the warm mixture, but in the case of the structural design of the layers, In the case of using RAP and as shown in table 5, the values of (Mr) increase with the increase in the stability of the blends containing the RAP compared to the warm mixture (0% RAP) and therefore require less thickness for the design of the layers containing the RAP, the reason for this is due to the presence of the RAP that made the mixture more rigid and thus the mixture became stronger, as 30% RAP gave less thickness compared to the rest of the mixtures.

5. Conclusions

Based on the experimental analysis and the corresponding results, several central conclusions can be reached, as follows:

(a) The Marshall mix design parameters are significantly influenced by the RAP replacement rate used, and some of the outcomes can be summed up as follows:

(1) Mixtures that contain a larger amount of RAP have Lower ideal asphalt content, the lowest optimum asphalt cement content (4.2%) corresponds to WRU 40%, which means that reduces the demand for the amount of asphalt cement, saving on material costs and providing economic benefits. In addition, the increase in the RAP led to a decrease in the content of the optimum asphalt cement. good interlocking and improved properties This indicates that the old asphalt present in the RAP have not performed as black rock and contributed to the coating of aggregate particles.

(2) An enhancement of about 28% in Marshall stability was attained in case the mix Contains RAP, the Marshall stability for the WMA-RAP 30% was the highest at $(11.7\ kN)$ as opposed to all other RAP replacement values.

(3) The addition of RAP increased the hardness and density of the mixture compared to the WMA, in addition to the good crosslinking provided by the asphalt binder and the aggregate particles.

(4) the air voids for the WMA-RAP 20% were higher than that of WMA-RAP 0% by approximately 14% at the highest Gm_{bulk}, however, both have fulfilled the standard requirements of (3–5%).

(b) The inclusion of RAP has boosted the rutting resistance of warm mix asphalt blends. The parameters of permanent deformation (a, b) when adding RAP increased while the latter decreased respectively, and at 20% RAP it achieved higher intercept and lower slope compared to the other ratio, and this increases the resistance of the mixture to rutting.

(c) The 20% RAP ratio, when compared with the hot mixture, the intercept is close to the values of the hot mix while the values of slope have decreased by an amount of 17.6%, meaning that 20 % of RAP gives the permanent distortion meter with an efficiency close to hot mix and perhaps better than that of the hot blend.

(d) The mixtures containing RAP are found with relatively higher resilient modulus values in comparison with the WMA(0%RAP) mix where the peak value was accomplished at 30% RAP content mixtures about an increase of 22%. The addition of RAP increased the resilient modulus ratio at all tested experimental periods, hence enhancing WMA-RAP resistance to Permanent Deformation.

(e) The higher the RAP ratio, the lower the thickness required for the asphalt layer. RAP 30% requires less thickness compared to other ratios, the more (Mr) the less thickness, because the mixture becomes stronger, and this is what the 30% rate of RAP provides.

(f) Using RAP in warm mix asphalt at a percentage between twenty percent and thirty percent has been found to significantly improve asphalt concrete behavior and to increase local knowledge of the possibility of developing more long-lasting mixtures with improved resistance to rutting.

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