Preliminary mechanical characteristics of asphalt concrete mixture containing RAP as the design of sustainable mixture

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Abstract: An asphalt pavements require to a wide variety of raw materials, costs and energy in a construction and repair processes. The using of recycled and waste materials in the pavement industry is one branch of the sustainability policy which is leading to substantial reductions in material, cost, and energy, as well as environmental enhancement. This research aims to evaluate the impact of reusing RAP materials in the production of recycled asphalt mixtures and investigate the mechanical characteristics depending on the criteria of mixture strength under affecting various testing conditions as a sustainable design method. Three proportions of RAP materials (12.5, 25, and 50 \%) were added to two types of mixtures these used in surface and base layers, one type of softening agent (vacuum residue liquid asphalt) was used to restore the RAP binder properties. Several laboratory experiments were carried out on the control and recycled asphalt mixtures such as Marshall stability and flow, indirect tensile strength and the resilient modulus. The results indicated that the adding of RAP materials with virgin binder resulted in improving the strength and mechanical properties of recycled asphalt mixtures, while the using of vacuum residue liquid asphalt as a softening agent in recycled mixtures has given impressive results in improving the durability and workability.

1. Introduction
The asphaltic pavement layers may deteriorate due to several factors such as heavy loads on the tires axels, Climate variability, and bad construction. So, maintenance process of these pavement results in removes a lot of deteriorated materials and replace with new ones. To save the source of materials used in maintenance, the removed materials can be again reused and recycled in new hot mix asphalt (HMA). From recycling of deteriorated asphalt pavements a recyclable material is result as known as Reclaimed Asphalt Pavement (RAP) which is a mix of aggregate covered with aged asphalt binder[1]. It is a method have environmental and economic advantages and can be used as a sustainable approach for the paving industry. The use of RAP material with new asphalt mixtures prevents the disposal of it in landfills, also it reduces the amount of new used materials (aggregates and asphalt binder). Therefore, the recycling of deteriorated asphalt pavements in the asphalt paving industry has had great success to produce new asphalt pavements since the early twentieth century and proving to be both economical and effective in protecting the environment [2, 3]. The aged binder in the RAP materials consider is a most decisive
characteristic that affects the properties and performance of recycled mixtures. Hence, the addition of high quantities of RAP material will affect the overall performance of the prepared mixtures resulting in an increment of the stiffness and the rutting resistance, and that leads to a reduction in resistance of fatigue and low temperature cracking [4, 5]. There are many of studies on worldwide concluded that 80% of RAP materials have been reued in paving industry, but many highway agencies limited the RAP materials usage between 5 and 50% for the production of new hot mix asphalt due effect of the aged binder and the degree of blending between the RAP and the virgin materials is not known [6]. To relieve affecting the aged RAP binder in recycled mixtures there are different techniques such as the use of recycling agents, a greater amount of asphalt binder, and warm mix technology [7]. The recycling agents include soft asphalt binder, softening and rejuvenating agents. Softening agents reduce the viscosity of the aged binder while rejuvenating agents restore the physical and chemical properties of the RAP binder [8]. According to National Cooperative Highway Research Program (NCHRP) study to use of reclaimed asphalt pavement in the Superpave mix design method, the recycling agent dose can be estimated from the blending chart which depends on the viscosities of RAP binder and virgin binder when the RAP content is known. [9]. Some studies indicated that the use of recycling agents in recycled mixtures results in a decrease in mixing and compaction temperatures [10]. Other researchers indicated that the use of a recycling agent contributes greatly decreases in the stiffness of the aged binder by reducing the complex modulus of the blend [11]. In Iraq there are many studies are available on the performance evaluation of conventional asphalt mixtures. Therefore there is a necessity for study on the mechanistic evaluation of hot recycled mixtures with and without utilization of softening agents. Hence, the main objectives of this study centered on the design of recycled asphalt mixture containing high content of RAP materials by using locally softening agent, and the investigation in mechanical properties such as Marshall properties, indirect tensile strength, and resilient modulus which are the basic criteria in designing asphalt mixtures in different method, and adopt it as a local method use in designing the sustainable mixture containing RAP materials.

2. Materials and Methods

2.1. Selected materials

2.1.1. Asphalt binder
One type of virgin asphalt binder with (40/50) penetration grade was used. This type of asphalt binder was supplied from (Al-Dura Refinery/Baghdad) which is widely used in flexible pavement construction in the middle of Iraq. Its physical properties are shown in Table 1.

| Property                        | ASTM Method | Test Results | SCRB Specification |
|---------------------------------|-------------|--------------|--------------------|
| Penetration @ 100 gm, 25°C, 5sec. (0.1mm) | D 5         | 46           | 40-50              |
| Softening point, (°C)           | D 36        | 49           | ----               |
| Rotational viscosity @ 135 °C, (Pa.s) | D 4402    | 0.520        | ----               |
| Flash Point, (°C)               | D 92        | 248          | >232               |
| Ductility @ 25°C, 5 cm/min, (cm) | D 113       | 120          | >100               |
| Specific gravity @ 25 °C, (g/cm³) | D 70       | 1.42         | ----               |

2.1.2. Mineral aggregate
Two aggregate gradations were used with nominal maximum aggregate size (12.5mm) and (25mm) that normally used in the construction of surface layer and base layer respectively as specified in Iraqi specifications (SCRB) [12]. These aggregates were brought from Al-Soudor quarry at northeast of Diyala governorate. It physical properties are shown in Table 2, while the gradation structures are shown in Figures 1- 2 for the reference mixtures of surface and base layers respectively.
2.1.3. Mineral filler
Limestone dust as filler was used in this study. It is non plastic material with specific gravity is 2.724 g/cc. It was brought from Karbala lime plant.

Table 2. Physical properties of virgin mineral aggregate.

| Property                                      | Coarse Aggregate | Fine Aggregate |
|-----------------------------------------------|------------------|----------------|
|                                               | ASTM method      | Test results   | ASTM method | Test results | SCRB |
| Bulk specific gravity, (g/cm³)                | C 127            | 2.610          | C 128       | 2.640        | ---- |
| Apparent specific gravity, (g/cm³)            | C 127            | 2.686          | C 128       | 2.690        | ---- |
| Water absorption, (%)                         | C 127            | 0.53           | C 128       | 0.72         | ---- |
| Soundness loss by sodium sulfate solution, (%)| C 88             | 3.12           |             |              | 12max|
| Wear by loss angelus apparition, (%)          | C 131            | 20.2           |             |              | 30max|

Figure 1. Aggregate gradation of reference mixture (Surface layer).

Figure 2. Aggregate gradation of reference mixture (Base layer).
2.1.4. Reclaimed asphalt pavement (RAP)

The RAP materials had been supplied from a highway renovation site (Baghdad-Diyala) which is the identical geographical location as the used virgin aggregates to make sure that the aggregates in the RAP materials have comparable properties to the virgin ones. After milling process, RAP materials were accrued as a stockpile in the laboratory. Eight samples had been chosen randomly to analyze the RAP combination gradation, asphalt binder content, and the characteristics of the recovered asphalt binder. The mixture gradations have been determined earlier than and after the extraction of aged binder, the extraction system carried out with accordance AASHTO T 164 [13]. The quantity of aged binder in the RAP was determined with average value is 4%. Finally, the aged binder was recovered via Rotary-evaporator machine that performed with accordance AASHTO T 319 [13]. The physical properties of RAP binder were evaluated with penetration value of 18 at 25 °C, and the rotational viscosity is 1.210 Pa.s at 135 °C.

2.1.5. Vacuum residue liquid asphalt

The vacuum residue asphalt (light liquid asphalt) was used in this study as a softening agent in the recycled mixtures to reduce the affecting of the aged binder in RAP materials. It is one of the remnants of cleaning and washing the vacuum distillation tower. The highest components of this material are heavy volatile oil with asphalt residues in the vacuum tower, so it does not have consistency and the penetration value could not measure. Only rotational viscosity was measured with value of 0.938 Pa.s at 60 °C. It was brought from private refinery plant in Diyala governorate.

2.2. Mix design

In this study, Marshall method was used to design the control mixtures and the optimal asphalt content was determined according to ASTM D 6927 [14]. The design criteria considered the test results of Marshall stability and flow, maximum density, and volumetric properties. The control mixture was designed with 4.8% and 4.1% binder contents for the mixtures of surface and base layers respectively. To design the recycled mixtures three percentages (12.5, 25, and 50) % of RAP materials were added. The design process included three major steps which are specifying the virgin asphalt binder grade/viscosity based on the percentage of RAP binder that blended with virgin binder, determining the combined aggregate gradation, and determining new virgin binder quantity as recommended in NCHRP (report 452), Asphalt institute Ms-2 [9, 15]. Following the guidelines enclosed in AASHTO M-323 [13], if the RAP content up to 15% no need to change in virgin binder grade, if the RAP content 15-25% the virgin binder must be change to one grade softer, and when the RAP content is more than 25% the blending chart used to select appropriate binder grade. Therefore, in this study the viscosity blending chart has been conducted for mixtures contained 25% and 50% RAP to restore the blended binder viscosity to the virgin binder viscosity (0.520) Pa.s. Through trial and error, the softening agent (vacuum residue liquid asphalt VL) was added by 5% and 10% to virgin asphalt binder to reduce the viscosity and relieve the affecting of RAP binder in the recycled mixtures. The combined aggregate gradations of recycled mixtures for surface and base layers are shown in both Figures 3 and 4. When RAP material adding to the new HMA, the quantity of aged binder must be take into account at addition of virgin binder. To determine the RAP blend percentage that would provide a given proportion of RAP-aggregate, the asphalt institute set an equation to find how much RAP to batch out as shown in the equation. (1) [15]:

$$ RAP_{Blend} = \frac{RAP_{Stockpile}}{1 - \frac{P_{b,RAP}}{100}} $$

Where $RAP_{Blend}$: is the total amount of RAP used in the mixture, (%); $RAP_{Stockpile}$: is the stockpile percentage of the RAP used in aggregate blending calculations, (%); $P_{b,RAP}$: is asphalt binder content of the RAP, (%).

Based on the asphalt binder content, the proportions of the components (virgin binder, virgin aggregate, RAP material) for each mixture have been determined as shown in Table 3.
Figure 3. The combined aggregate gradations of recycled mixtures for surface layer.

Figure 4. The combined aggregate gradations of recycled mixtures for base layer.

Table 3. Summary of the components ratio in the mixtures.

| Layers | Binder | RAP% | OAC | Vb | Rb | Total | Vagg | Ragg |
|--------|--------|------|-----|----|----|-------|------|------|
| Surface Mixtures | V | 0 | 4.8 | 4.8 | 0 | 95.2 | 100 | 0 |
| | VL5 | 12.5 | 4.8 | 4.3 | 0.5 | 95.2 | 83.3 | 11.9 |
| | VL10 | 50 | 4.8 | 2.8 | 2 | 95.2 | 47.6 | 47.6 |
| Base Mixtures | V | 0 | 4.1 | 4.1 | 0 | 95.9 | 100 | 0 |
| | VL5 | 12.5 | 4.1 | 3.6 | 0.5 | 95.9 | 83.9 | 12.0 |
| | VL10 | 50 | 4.1 | 3.2 | 0.9 | 95.9 | 71.9 | 24.0 |

OAC: optimum asphalt content; Vb: virgin binder; Rb: RAP binder; Vagg: virgin aggregate; Ragg: RAP aggregate
2.3. Testing methods

2.3.1. Marshall characteristics test
In this test, the volumetric characteristics, stability values, and plastic flow values of the prepared asphalt mixtures were determined using the Marshall test method as per ASTM D 6927 [5]. Three specimens were prepared for each mixture and subjected to short-term aging in compaction temperature for 2 hours prior to compacting. After curing at room temperature for 24 hours, the compacted specimens were submerged in a thermostatically controlled water bath at 60 °C for 30-40 minutes. Finally, the specimens were withdrawn from the water bath, and put in the Marshall head with applying constant load rate of 50 mm/min.

2.3.2. Indirect tensile strength test
The tensile strength of prepared specimens was determined at temperature of 25 °C and constant load rate of 50 mm/min as per ASTM D 6931[16]. Three specimens of each mixture were prepared and compacted with air voids content of 4% for the surface layer, and 4.5% for the base layer using Marshall apparatus. The Indirect tensile strength (ITS) value is calculated by given equation (2):

\[ ITS = \frac{2000 \times P}{\pi \times D \times t} \]  

(2)

Where ITS is the indirect tensile strength, KPa; P is the applied load at failure, N; D is the specimen diameter, mm; and t is the specimen thickness, mm.

2.3.3. Resilient modulus
The resilient modulus (Mr) is an estimate of elasticity property of asphaltic materials which are subjected to repeated loads. This test was carried out by applying repeated loads in the indirect tension test on the vertical diametral plane of a cylindrical specimen of asphalt concrete as per ASTM D 4123 [17]. In this study, Repeated Loads Testing System (RLTS) manufactured locally in Iraq by the authors was used to applying repeated loads in form of haversine wave by frequency of 1 Hz within 0.1sec loading time and 0.9sec rest period during one cycle as shown in Plate 1 and Figure 5. The test was conducted at temperatures (5, 25 and 40) °C where the specimens were conditioned in the environmental chamber of testing system for a minimum of 4 hours at the given temperature before being tested. The magnitude of applied repeated load was (30%, 15% and 5%) of the indirect tensile strength for temperatures (5, 25 and 40) °C respectively [18]. The resilient modulus value of the average of three specimens for each type mixture was then obtained by using equation (3) [14]:

\[ Mr = \frac{P}{Ht \times (0.27 + \mu)} \]  

(3)

Where MR is resilient modulus, MPa; P is repeated load, N; \( \mu \) is the Poisson ratio, which is assumed to be 0.35 in HMA; t is the specimen thickness, mm; and H is the recoverable horizontal deformation, mm.
3. Result Analysis and Discussion

3.1. Effect of RAP content on the Marshall properties

For different asphalt mixtures at two aggregate gradations the Marshall method characteristics which includes the volumetric parameters, stability, and flow values were analyzed. The volumetric parameters are bulk unit weight (Gmb), air voids (VA), voids in mineral aggregate (VMA) and voids filled with asphalt (VFA) for all types of mixtures are presented in Table 4. The results of these parameters compared with control mixtures showed that addition 12.5% of RAP with virgin binder reduced (Gmb, VMA, and VFA) values while the air voids increased regardless the type of layer gradations. The reduction in the volumetric parameters is due to presence of old aggregate covered with aged and stiffer binder that affecting the compaction process and that resulted in increased air voids content. Addition of the softer binders reduced the effect of added RAP. Also, all recycled mixtures conform to the requirements of Iraqi standards (SCRB) in the design of hot mix asphalt.

Table 4. Volumetric properties of prepared mixtures.

| Binder | RAP%  | Gmb   | VA    | VMA   | VFA   |
|--------|-------|-------|-------|-------|-------|
|        |       | Surface | Base | surface | Base | surface | Base | surface | Base |
| V      | Control | 2.354  | 2.370 | 4.0    | 4.4   | 14.7    | 13.2  | 72.8    | 66.8 |
| R12.5  | 2.351  | 2.368  | 4.1   | 4.5    | 14.5  | 13.0    | 71.6  | 65.6    |
| VL5    | R25   | 2.350  | 2.371 | 4.1    | 4.4   | 14.2    | 12.6  | 71.3    | 65.4 |
| VL10   | R50   | 2.352  | 2.370 | 3.9    | 4.4   | 13.5    | 12.0  | 71.0    | 63.5 |

Figure 6 shows the stability values of recycled mixtures of surface layer and base layer, where the results indicated to the stability value increased as RAP content increased due to affecting of aged and high stiff binder in RAP material regardless the type of layer gradations. For surface layer mixtures the stability value is 12.4% higher than control mixtures when 12.5% RAP added with virgin binder, as RAP content increased to 25% and 50% with softer binders the stability get relieve and reduced to be 10.2% higher than control mixture at 25% RAP added and 2.3% higher than control mixture at 50% RAP added. For base layer mixtures the stability value increased by 16.7% higher than control mixture as RAP content increased to 25% with softer binder (VL5%), then it get relieve and reduced to be 11.8% higher than control mixture at 50% RAP added with softer binder (VL10%).

Figure 5. Observed data of resilient modulus test.
Figure 7 shows that as RAP content increased the flow values reduced regardless the type of layer gradations. The softer binders added to mixtures containing RAP observed affecting in the flow due to rejuvenating the RAP binder and reduce the blend viscosity and stiffness of binder. Where for surface layer mixture with 25% RAP content, the softer binders (VL5%) affecting slightly increasing in the flow value. While for base layer mixture with 50% RAP content, the softer binders (VL10%) affecting considerably increasing in the flow value to be 1.8% higher than control mixture.

3.2. Effect of RAP content on the indirect tensile strength
The tensile properties of recycled asphalt mixtures in this study were evaluated through conducted of indirect tensile strength test at 25 °C. Figure 8 shows that the tensile strength of recycled mixtures paped with virgin binder increased as RAP content increased to 12.5% regardless the type of layer gradations. When the softer binders used with increasing of RAP content, the tensile strength remained
gradually increasing in recycled mixtures of surface layer to be higher by 17.5% comparing to control mixture when 50% of RAP mixed with softer binder (VL10%). For recycled base layer the tensile strength got slightly relieve when 25% of RAP mixed with softer binder (VL5%) and then increased to be higher by 17.8% comparing to the control mixture when 50% of RAP mixed with softer binder (VL10%). Therefore, addition of softening agent helped in rejuvenating and improved the adhesion properties of aged binder that highly affecting in improving the tensile property of recycled asphalt mixture.

![Graph showing indirect tensile strength.](image)

**Figure 8.** Effect of RAP content on the indirect tensile strength.

3.3. *Effect of RAP content on the resilient modulus*

The resilient modulus (Mr) is very essential property for assessing the strength of asphaltic materials under repeated loads at different conditions. In this regard, it consider as one of design inputs of the flexible pavements thickness. The resilient modulus values of a virgin and recycled asphalt mixtures for the surface and base layers are shown in Figures 9 and 10 respectively. It can be seen that as the temperature increases, the resilient modulus values significantly decrease regardless the type of layer gradations, RAP content, and binder type. These figures also show that the increase of RAP content to 12.5% and 25% with virgin and softer binder (VL5) respectively results in increase of resilient modulus values, while the increase of RAP content to 50% with softer binder (VL10) results in a significant decrease of resilient modulus values at the similar environmental conditions regardless the type of layer gradations. This increase related to the presence of aged binder of RAP, and the addition of residue liquid asphalt with high RAP content results in the relieve of binder stiffness in the mixture that leads to decreases in the resilient modulus. Comparing the two type of aggregate gradations (surface and base) layers, the results shows that the recycled mixtures of surface layer had significantly higher resilient modulus value than the recycled mixtures of base layer at the same testing conditions due to the gradation of RAP materials are more compatible with aggregate gradations of surface mixture, it also contains higher asphalt content with the RAP binder more effective.
Figure 9. Resilient modulus of surface layer mixtures.

Figure 10. Resilient modulus of base layer mixtures.

4. Conclusions
In this study, different RAP contents were added to investigate the mechanical characteristics of recycled asphalt mixtures depending on the criteria of mixture strength under affecting various testing conditions. The main conclusions drawn from laboratory test results are presented as follow:
1. Addition of RAP materials with virgin binder resulted in increasing the air voids content in the mixture and reduction in bulk specific gravity, voids in mineral aggregate, and voids filled with asphalt. Also, it resulted in an increase stability, indirect tensile strength, and resilient modulus in recycled asphalt mixtures that will contribute significantly to improve the rutting resistance.
2. The addition of the softening agent (vacuum residue asphalt) contributed in to restore the properties of aged binder in recycled mixtures through relieving the viscosity which leads to reducing the stiffness and mechanical properties generally, that improve the durability and workability properties of mixtures.
3. The recycled mixtures of the surface layer have performed much better than those of the base layer due to the gradation of RAP materials are more compatible with aggregate gradations, it also contains higher asphalt content with the RAP binder more effective.

4. The recycled mixtures containing 25% RAP with a softening agent (VL5%) showed the highest resilient modulus values at similar environmental conditions regardless the type of layer gradations. Therefore it is considered a better alternative to resist potential rutting at high-temperature conditions.

5. The recycled mixtures containing 50% RAP with a softening agent (VL10%) showed the highest indirect tensile strength regardless the type of layer gradations. Therefore it is considered a good alternative to resist potential fatigue cracking.

5. References

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