Improving the tensile strength and durability of asphalt concrete as sustainable surface layer

Yassir Nashaat A.Kareem1, 2, 4, Mohammed Abbas Al-jumaili 3

1 PhD Candidate, Department of Highway and Transportation Engineering, Collage of Engineering, Al-Mustansiriah University, Baghdad, Iraq.
2 Lecturer, Department of Highway and Airport Engineering, Collage of Engineering, University of Diyala, Diyala, Iraq.
3 Professor, Civil Engineering Department, Collage of Engineering, University of Kufa, Najaf, Iraq.
4 E-mail: yasirna83@yahoo.com

Abstract. The construction and maintenance processes of asphalt pavements require many raw materials, high financial cost, and high energy. The sustainability strategy in pavement construction is the use of recycled and waste materials due to significant savings in material, cost, and energy as well as improving the environment through solid waste disposal. The aim of this research is to study the effect of reusing the reclaimed asphalt pavement and crumb-rubber to improve the tensile strength and durability of asphalt mixture as a sustainable method which can be used in construction of surface layer. In this study one proportion of reclaimed asphalt pavement RAP (25%) was used by weight of mixture with virgin and modified asphalt binders. The modified asphalt binders were prepared in three proportions of crumb-rubber (5, 10, and 15%) % by weight of the virgin binder. Many experimental tests were conducted on the modified and recycled mixtures such as Marshall stability and flow, indirect tensile strength and moisture damage induce. The results indicated that the adding of RAP material resulted in slightly improve in the strength and durability, while the adding of crumb-rubber as a modifier for asphalt binder with RAP material has given impressive results in improving the stability, tensile strength, and resistance to moisture damage.

1. Introduction

Urban and population growth requires the development of the road network, with new construction and periodic maintenance of the existing pavement to improve the performance. In Iraq, high traffic loads, severe climate change and poor construction are considered the major factors that affecting in the deterioration of asphalt pavement layers. The recycling of deteriorated asphalt pavement results in a recyclable mix of aggregate covered with aged asphalt binder known as Reclaimed Asphalt Pavement (RAP) [1]. This process is a sustainable strategy in the paving industry as it has economic and environmental benefits. The reuse of reclaimed asphalt pavement with new hot asphalt mixtures (HMA) contributes in reducing the amount of new materials used (asphalt binder and aggregate), and prevents disposal the RAP in landfills. Even though the old asphalt pavements have deteriorated and reached the end of their service lives, the aggregate and aged binder are still beneficial and can be reused once more. For many years, RAP materials have been used together with virgin materials in manufacturing of new asphalt pavements, showing to be economical and contribute to the improvement of the environment [2, 3].

As similar to reclaimed asphalt pavement RAP, the solid waste is the main source of environmental pollution for the difficulty of disposal and landfill, and the most important sources are scrap tires. Many of research agencies have tried to employ these tires in the asphalt paving industry as early as the 1960s [4]. Previous researches have shown that a scrap tires can be shredded and grinded into very small particles to produce a material called crumb-rubber or ground-rubber can be added to the asphalt mixture in several methods. There are two methods of blending, wet and dry. In the wet method, finely particles of crumb-rubber (0.075 – 1.2 mm) are blend with asphalt binder at a specific temperature before mixing it with aggregates. In this method, the crumb-rubber will interact with asphalt binder by...
swelling the rubber because of sucking of the light oils that existing in asphalt binder. This interaction will produce a viscous gel which causes an increasing in the overall viscosity of the modified binder [5, 6, 7]. In the dry method, crumb-rubber particles (0.4 - 9.5 mm) is used as a replacement for a small part of fine aggregate, then, these particles are blended with aggregates before adding the asphalt binder [5, 8, 9]. The crumb-rubber is composed of carbon black, natural rubber, and synthetic rubber. The carbon black enhances durability of asphalt binder, where the natural and synthetic rubber improves elastic properties and the thermal stability of the binder respectively [10]. Hence, the modified binders with crumb-rubber have the potential to improve the mixture performance compared to virgin binder which includes increased resistance to rutting and fatigue, reduced low temperature cracking and reflective cracking, and improved resilience, tensile strength, durability, and skid resistance [11]. Moreover, the use of recycled crumb-rubber has the ability to produce calmer surfaces with reduction in noise level of tire friction as well as maintain the environment by reuse the scrap tires [9].

Many previous research indicated that the old binder of RAP that blended with new hot mix asphalt HMA will reduce the fatigue life and resistance of thermal cracking, and adding the crumb-rubber is useful in elongating the long-term performance of HMA and possibly reducing the negative effect of RAP in HMA. According to the performance of modified mixture, the bonding interaction of these materials (virgin binder, RAP binder, and crumb-rubber) must be understood. Therefore, the main objective of this research are to study the effect of reusing a reclaimed asphalt pavement (RAP) and crumb-rubber (CR) individual or mixed to improve the tensile strength and durability of asphalt mixture as a sustainable method which can be used in construction of surface layer of flexible pavement in Iraq.

2. Experimental Program

2.1 Selected materials

There are two types of materials were used as virgin and waste materials. The virgin materials are asphalt binder, mineral aggregate, and filler, while the waste materials are reclaimed asphalt pavement (RAP) and crumb-rubber (CR). The experimental methodology of this study includes the production of modified asphalt mixtures containing two proportions of reclaimed asphalt pavement RAP (0 and 25%) prepared by virgin and modified asphalt binder. The virgin asphalt binder was used that has (40/50) penetration grade that supplied from Al-Durah refinery/Baghdad. The modified asphalt binder were prepared by adding three proportions of crumb-rubber (5, 10, 15) % by weight of the virgin binder. The physical characteristics of these binders (virgin, modified, and RAP binder) are shown in Table 1. In this study also, one gradation of aggregate was used with nominal maximum aggregate size (12.5mm) that used in construction of wearing course of asphaltic pavement according to Iraqi specifications SCRB [12]. The mineral aggregate (course and fine) were supplied from Al-Soudor quarry at northeast of Diyala governorate, while the filler is limestone dust that supplied from Karbala factory. All these materials are satisfied to Iraqi specifications SCRB. The gradation of the aggregate structure of virgin mixture and recycled mixture are shown in Figure 1.

The RAP material were supplied from maintenance site of the Baghdad-Diyala highway which is the same geographical area as the virgin aggregates used to obtain the same physical properties. After milling process, the RAP were collected as stock pile in the laboratory. Eight samples were selected randomly to analyze the RAP aggregate gradation, asphalt binder content, and the properties of aged binder. The aggregate gradations were found before and after the extraction of aged binder. The extraction process was conducted with accordance to AASHTO T164 [13]. The percent of aged binder in the RAP material was found to be with an average value 4%. Finally, the aged binder was recovered from the extracted solution by Rotary Evaporation system that conducted with accordance to AASHTO TP2 [13].

The crumb-rubber were obtained by shredding and grinding scrap and rickety tires by special machines at ambient temperature with particles -50 mesh (0.3 mm). Using the mechanical mixer available in the laboratory, the crumb-rubber was added and blended with the virgin asphalt binder as...
wet method, where the materials blended at a temperature of 190 °C and blending speed 2600 rpm for 60 minutes As specified in many agencies and previous studies [14, 15].

Table 1. Physical characteristics of asphalt binders

| Property                                      | Virgin Binder | RAP Binder | Modified Asphalt binder by CR |
|----------------------------------------------|---------------|------------|-----------------------------|
| Penetration at 25°C, (ASTM D5-06)            | 46            | 18         | 42                          |
| Softening point, °C, (ASTM D36-09)          | 48            | 58         | 50                          |
| Rotational viscosity at 135 °C, Pa.s (ASTM D4402) | 0.520         | 1.210      | 0.840                       |

Figure 1. Gradation of surface layer mixture containing virgin aggregate only, and combined with 25% of RAP aggregate

2.2 Mixes Design

The main object of mix design is to optimize asphalt content and produce a mixture with a good performance in resistance of rutting, fatigue cracking, thermal cracking, and overall durability. In addition to the strength and durability criteria, the mixture must be meet the desired volumetric properties which includes: air voids (VA), voids in mineral aggregates (VMA), voids filled with asphalt (VFA) [16]. In this study, Marshall method as laid in ASTM D 6927-15 [17] was used to design the virgin and modified mixtures and find the optimal asphalt content for these mixtures. The design criteria considered the results of Marshall stability and flow, maximum density, and a volumetric properties. The control mixture (virgin) was designed with 4.8% binder content, while the modified mixtures by crumb-rubber were designed with (5.1, 5.5, 6.0) % binder content for (5, 10, 15) % of crumb-rubber content respectively according to Marshall method. When adding the RAP material to the new hot mixture asphalt, it is necessary to consider the amount of aged binder that existing in the RAP. This amount must be deducted from the amount of virgin asphalt added. To calculate the weight of the dry RAP to be added to the new hot mixture asphalt, the asphalt institute set an equation to find the desired weight as shown in the equation (1) [18]:

\[
\text{Weight of Dry RAP} = \frac{\text{Penetration of virgin asphalt} \times \text{Percentage of RAP}}{\text{Penetration of modified asphalt}}
\]
Where $M_{\text{dry RAP}}$ is the mass of dry RAP material, $M_{\text{RAP Agg}}$ is the mass of RAP aggregate, and $P_b$ is the RAP binder content.

According to asphalt binder content the components proportions of materials (virgin binder, virgin aggregate, RAP material) for each mixture was calculated as shown in Table 2.

Table 2. Summary of the materials proportions in the designed asphalt mixtures

| Binder Type | CR% | RAP% | % Asphalt Binder | % Aggregate |
|-------------|-----|------|------------------|-------------|
| Virgin      | 0   | 0    | 4.8, 4.8, 0      | 95.2, 95.2  |
|             | 25  | 4.8  | 3.8, 1          | 95.2, 71.4, 23.8 |
|             | 5   | 5.1  | 5.1, 0          | 94.9, 94.9, 0 |
| Modified    | 10  | 0    | 5.5, 5.5, 0     | 94.5, 94.5, 0 |
|             | 15  | 5.5  | 4.5, 1          | 94.5, 70.875, 23.625 |
|             | 25  | 6    | 6, 0            | 94, 94, 0 |

2.3 Laboratory Tests
2.3.1 Marshall Stability and Flow Test
The stability, plastic flow values and volumetric properties, calculated according to Marshall test method were carried out as per ASTM D 6927-15 [17]. For each asphalt mixture three specimens were prepared and they exposed to short term aging before compacting. The compacted specimens were kept at room temperature during the night and then immersed in a water bath at temperature of 60 °C for 30-40 minutes. Next, it were placed in the mold and the load applied at a rate of 50 mm / min.

2.3.2 Indirect Tensile Strength
The Indirect Tensile test conducted as per ASTM D6931-12 [17]. Three specimens were prepared with 4% air voids for each mixture. This test was conducted at temperature of 25 °C and constant load rate of 50 mm/min. The tensile strength value is determined by equation (2):

$$ITS = \frac{2000 \cdot P}{(\pi \cdot D \cdot t)}$$

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

2.3.3 Moisture Susceptibility
Water and moisture penetration into asphalt concrete weakens the cohesion and adhesion properties due to loss bonds between the asphalt binder and aggregates resulting in decreasing in the load capacity of pavement. [19]. In this study the moisture susceptibility is evaluated by conducting the tests according to AASHTO T283-14 [13]. Six specimens were prepared with 7% air voids for each mixture. Three specimens were conditioned by immersing them in a water bath at temperature of 60 °C for 24 hours and then transferred to other water bath at temperature of 25 °C for 2 hours, then the indirect tensile strength test was conducted. Another three specimens were tested at 25 °C without conditioning. The Tensile Strength Ratio (TSR) can be calculated by dividing the tensile strength of
the conditioned specimens to the tensile strength of the specimens without condition. The minimum acceptable value of TSR is 80%. When the mixture have value more than 80%, it is relatively resistance to moisture damage.

3. Results Analysis and Discussion

3.1 Volumetric Properties

For different asphalt mixtures at different modified binders and RAP contents, the volumetric parameters were analyzed. These parameters are bulk unit weight (Gmb), air voids (VA), voids in mineral aggregate (VMA) and voids filled with asphalt (VFA) are presented in Table 3. For the recycled mixture with virgin binder, the unit weight decreased with adding RAP due to the effect of aged binder that will lead to increase in air void with in mixture. The voids in mineral aggregate and voids filled with asphalt also decreased with adding of RAP that due to the RAP aggregate are covered with aged binder. In the recycled mixture with modified binders, the volumetric parameters slightly changed due to effect of crumb-rubber. Where, the air voids decreased as crumb-rubber percentage increased and that resulted in decreasing values of unit weight. While the voids in mineral aggregate and voids filled with asphalt both were increased as crumb-rubber percentage increased. Hence, the Crumb-rubber has a significant role in improving these parameters as it is an elastomer as well as its role in the chemical change of the basic asphalt compounds. All the mixtures are meet the required of Iraqi specifications SCRB in mix design of asphalt mixture.

| Volumetric Parameter | RAP % | Virgin Binder | Modified Asphalt binder by CR |
|----------------------|-------|---------------|--------------------------------|
|                      |       | 5%            | 10%                           | 15%                           |
| Gmb                  | 0     | 2.354         | 2.341                         | 2.329                         | 2.312                         |
|                      | 25    | 2.346         | 2.343                         | 2.332                         | 2.319                         |
| VA                   | 0     | 4.04          | 4.1                           | 4.08                          | 4.09                          |
|                      | 25    | 4.24          | 4.03                          | 3.94                          | 3.8                           |
| VMA                  | 0     | 14.7          | 15.5                          | 16.3                          | 17.3                          |
|                      | 25    | 14.4          | 14.7                          | 15.5                          | 16.4                          |
| VFA                  | 0     | 72.8          | 73.5                          | 74.9                          | 76.4                          |
|                      | 25    | 70.5          | 72.7                          | 74.6                          | 76.8                          |

3.2 Marshall Stability and Flow

The stability and flow values are the results obtained by Marshall Test. Figure 2 shows the stability value of recycled mixture containing RAP and virgin binder is 17.5% higher than control mixture. This increase is due to the presence of aged binder in the RAP which leads to an increase in the stiffness of the mixtures. The addition of crumb-rubber to the asphalt binder affected the resistance and stability of the modified mixtures. At virgin mixtures prepared with modified binder, the increasing of crumb-rubber percentage caused to slightly increasing in stability to reach high value at 10% of crumb-rubber then afterward will decreased. At recycled mixture containing RAP and modified binder, incorporation of aged binder and rubberized binder enhanced the stability of mixtures. Therefore, the modified binder in both mixtures plays a key role in the film thickness of asphalt binder that increased as percentage of crumb-rubber increased due to increasing in binder content. Therefore, the aged binder which covered RAP aggregate and the increasing in film thickness of asphalt binder due to crumb-rubber both are result in improving the stability to reach highest value at 10 % of crumb-rubber.
Figure 3 shows the flow values decreased by adding the RAP material and crumb-rubber to the virgin mixture. The high viscosity of RAP materials and an increasing in viscosity of modified binder, both have the effect of decreasing the flow in the recycled mixtures.

3.3 Indirect Tensile Strength
The indirect tensile strength of mixtures prepared within 4% air voids were shown in figure 4. it indicate that indirect tensile strength (ITS) of recycled mixture with virgin binder increased by addition of RAP materials by 13.5% comparing with control mixture and that duo to presence of aged binder which may be plays in increasing the internal friction between the RAP aggregate and the film asphalt binder. The indirect tensile strength ITS of modified binder increasing by (12 to 20.3) % as crumb-rubber percentage increase (5 to 15) % due to increasing in the viscosity and binder content which leads to increasing the film thickness and the cohesion between asphalt mastic. The indirect tensile strength (ITS) for the recycled mixture with modified binder also will be increasing by (31.9 to
37.3\% as crumb-rubber percentage increase (5 to 15\%) comparing with control mixture. Therefore, addition of reclaimed asphalt pavement to the mixtures with modified binder by crumb-rubber results in an increase in stiffness due to improving the adhesion by RAP and the cohesion by crumb-rubber, and therefore the indirect tensile strength of mixtures also improved.

![Figure 4. Indirect tensile strength (ITS) at 4\% air voids](image)

3.4 Tensile Strength Ratio
The results of indirect tensile strength (wet and dry) for evaluation of moisture damage were shown in figure 5. The results indicate that the tensile strength of recycled mixture containing RAP and virgin binder is higher than control mixture with percent (25.5\%, 33.3\%) for dry and wet conditions respectively. The modified binder will useful in increasing the strength in both mixture control and recycled due to it improve the film thickness around the aggregate particles and that will prevent the bond losses due to permeation of water. At the virgin mixtures prepared with modified binder, the increasing of crumb-rubber percentage from (5 to 15\%) will result to increase the tensile strength up to (8-14.6\%) for dry condition and (15.7-21.3\%) for wet condition comparing with control mixture. While at the recycled mixtures containing RAP prepared with modified binder, the increasing of crumb rubber percentage up to 15\% crumb rubber will result to increase the tensile strength up to (42\%) for dry condition comparing with control mixture. In wet condition, when the crumb-rubber percentage increase up to 5\% then the tensile strength will increased up to (65\%) then afterward decreases as crumb rubber percentage increases to reach (61.8\%) comparing with control mixture.
According to the tensile strength values in dry and wet conditions, the tensile strength ratio (TSR) were calculated. Figure 6 shows the recycled mixtures preparations by RAP and modified binder have higher values comparing with control mixture. Where TSR at 10% of crumb rubber is higher (12.5%) than control mixture and at 5% of crumb rubber is higher (24.6%) than control mixture for modified and recycled mixtures respectively.

**Figure 6.** Tensile strength ratio (TSR) at 7% air voids

4. Conclusions

The aim of this study is to improve the tensile strength and durability of asphalt concrete by using solid waste that can be recycled in the production of new asphalt mixtures used in the construction of sustainable pavement layers. The reuse of some wastes in the asphalt mix industry will lead to environmental protection and economic benefit as well as improvement of some of characteristics of the modified mixture near or equal to the performance of the virgin mixture, this is called the concept of sustainability in the construction of pavement. Therefore, the results indicated that the addition of
RAP by 25% to the virgin mixture reduced the amount of virgin material used (aggregate by 23.8%, asphalt binder by 1%), and the presence of aged binder in RAP resulted in increased viscosity of the asphalt binder and stiffness of the mixture, which in turn increase the air voids content and reduce the bulk density, VMA, and VFA, increase the Marshall stability by 17.5% and decreasing the flow, and increase the tensile strength by 13.5% and durability by 7% respectively. The addition of crumb-rubber to virgin binder led to the fact that the content of asphalt binder in the mixture increases as the proportion of rubber increased and this generated an increase in the viscosity of the modified binder as well as an increase in thickness of film asphalt, which will improve the property of cohesion in the asphalt mastic. Compared with the control mixture, when the rubber proportion increased (5 to 15) %, the Marshall stability and the flow slightly improved, the tensile strength increased by (12-20.3) %, and the durability also slightly increased to be higher at 10% rubber then decreasing. When both RAP and crumb-rubber were added through the preparation of asphalt mixtures containing RAP using modified asphalt, the results indicated that increasing the proportion of rubber in the modified asphalt binder slightly reduced the Marshall stability compared with the mixture containing RAP. While the tensile strength increased by (31.9 to 37.3) % compared with the control mixture, as well as the durability improved by increasing the proportion of rubber due to interaction and good blending between the aged binder in RAP and modified asphalt that resulted to improving the cohesion and adhesion characteristics.

5. Reference

[1] Al-Qadi I, Elseifi M and Carpenter S 2007 Reclaimed asphalt pavement-a literature review. Research Report FHWA-ICT-07-001.
[2] Oliveira J, Silva H, Abreu L and Pereira P 2012 Effect of different production conditions on the quality of hot recycled asphalt mixtures Procedia-Social and Behavioral Sciences 53 266-275.
[3] Xiao F, Amirkhanian S, Shen J and Putman B 2009 Influences of crumb rubber size and type on reclaimed asphalt pavement (RAP) mixtures Construction and Building Materials 23(2) 1028-1034.
[4] Putman B, Aune J and Amirkhanian S 2005 Recycled Asphalt Pavement (RAP) Used in Superpave Mixes Made with Rubberized Asphalt In Mai repav 4th International Symposium Maintenance and Rehabilitation of Pavements and Technological Control (iSMARTi, Belfast, Northern Ireland).
[5] Aghapour M and Babagoli R 2019 Effect of reclaimed asphalt pavement on performance of rubberised asphalt mixtures Proceedings of the Institution of Civil Engineers-Construction Materials 1-14.
[6] Bahia H, and Davies R 1994 Effect of crumb rubber modifiers (CRM) on performance related properties of asphalt binders Asphalt paving technology 63 414-414.
[7] Kim S, Loh S, Zhai H and Bahia H 2001 Advanced characterization of crumb rubber-modified asphalts, using protocols developed for complex binders Transportation Research Record 1767 (1) 15-24.
[8] Heitzman M 1992 Design and construction of asphalt paving materials with crumb rubber modifier Transportation Research Record 1339.
[9] Airey G, Rahman M and Collop A 2003 Absorption of bitumen into crumb rubber using the basket drainage method International Journal of Pavement Engineering 4(2) 105-119.
[10] Singh D and Girimath S 2018 Toward Utilization of ground tire rubber and reclaimed pavement materials with asphalt Binder: Performance evaluation using essential work of fracture International Journal of Pavement Research and Technology 11(6) 594-602.
[11] Coplantz J, Yapp M and Finn F 1993 Review of relationships between modified asphalt properties and pavement performance (No. SHRP-A-631). Strategic Highway Research Program (National Research Council).
[12] Iraqi General Specification for Roads and Bridges 2003 *Standard Specification for Roads and Bridges* Revised Edition (The state Corporation for Road and Bridges).

[13] AASHTO 2015 *Standard Specification for Transportation Materials and Methods of Sampling and Testing* American Association of State Highway and Transportation Officials 35th Edition Part II (Washington D.C U.S.A).

[14] Ibrahim M, Katman H, Karim M, Koting S and Mashaan N 2013 A review on the effect of crumb rubber addition to the rheology of crumb rubber modified bitumen *Advances in Materials Science and Engineering*

[15] Sulyman M, Sienkiewicz M and Haponiuk J 2014 Asphalt pavement material improvement: a review *International Journal of Environmental Science and Development* **5**(5) 444.

[16] Izaks R, Haritonovs V, Klasa I and Zaumanis M 2015 Hot mix asphalt with high RAP content *Procedia Engineering* **114** 676-684.

[17] American Society for Testing and Materials 2015 Annual Book of ASTM Standards (ASTM International: West Conshohocken PA).

[18] Asphalt Institute 2015 *Asphalt Mix Design Methods* (1st ed. Lexington, KY: Asphalt Institute).

[19] Caro S, Masad E, Bhasin A and Little D 2008 Moisture susceptibility of asphalt mixtures, Part 1: mechanisms *International Journal of Pavement Engineering* **9**(2) 81-98.