Assessment the performance of asphalt mixtures modified with waste tire rubber at high temperatures

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Abstract. Quality of roads pavement can consider as one of the essential criteria for the good transportation system. So, to reduce the problems of fatigue crack and rutting of roads, several actions have been taken including the improving of pavement quality and the structure design methods. The increasing in the attention of traffic engineers in the last few years to modify and improve the asphalt performance through providing a different type of additives and replace the raw materials of asphalt mixture with recycled materials, in order to improve the environmental as well as reduce the cost of modified pavement mixture. There were several types of research investigated the validity of using the waste material products in the mixtures of asphalt pavements, since these replacement materials could improve the performance of roads pavement, the researches that adopted the influence of usage recycle waste materials to improve performance of the asphalt of the road still limited compared with other construction fields. This paper briefly discussed the modified asphalt mixtures performance and the most used recycled material which is crumbs rubber used as modifier in the HMA. By using various proportions of crumbs rubber (2.5, 5, 7.5, 10, 15 and 20% by weight of asphalt), and investigate the effect of adding rubber crumbs waste on the most important dynamic and mechanical properties of asphalt mixtures, which is the rutting resistance. It aims also to understand the benefits and disadvantages of using recycled tire rubber and develop the idea on good inclusion of waste material in the road pavements.

Keywords. hot mix asphalt (HMA), waste tire rubber, crumb rubber (CR), crumbs rubber modified asphalt (CRMA), Marshall stability, Hamburg Wheel-Tracking Test.

1. Introduction:
Performance and efficiency of asphalt concrete mixes depends on several factors includes aggregate gradation, types of the aggregates, loading conditions, physical properties of binder and mixture volumetric properties[1]. Among these factors, binder is considered as viscoelastic behavior material acts Extremely important key in many aspects of the performance of the mixtures [2]. In the last years, various factors, for instance, growth permissible vehicle pressure and increased traffic load have increased the tension stresses in the layer of asphalt pavement and as a result, the service life of asphalt concrete pavements will be reduced[3]. Alligator cracks (fatigue) and permanent deformation (Rutting) are the most common important problems of the asphalt concrete pavement, which have a significant impact on the asphalt pavement performance[4]. To address early asphalt failure, one of the successful solutions is the use of modifiers in the paving industry[5].

In the developed cities, different waste products from industries are generally causing large environmental problems. For road construction, the stone aggregates, fine sand, cement, and bitumen are used for the road pavement. In addition to the high cost, the traffic engineers are looking for more practical and suitable alternative highway pavement materials by using these disposable waste products, where it will reduce the
pollution problems as well. Encouraging results have been predicted from the useful applications of some of the waste products in the highway roads. Therefore, recently, several types of research have been conducted in order investigate the validity of using an alternative the waste materials like (steel slag, plastic, and scrap tires, etc.) in asphalt pavement hot mix, which may reduce road deterioration[6]. There were several types of research investigated the validity of using the waste material products in the mixtures of asphalt pavements, since these replacement materials could improve the performance on roads pavement, as well as the countries, research that relied on the impact of using recycling of waste materials such as rubber crumbs, crushed concrete, fiberglass, plastic waste and steel slag in asphalt performance enhancement of the road still limited compared with other construction fields.

The growing up in the number of population and the types of industries have resulted in increasing the several sorts of waste materials. A numerous research has been conducted in order investigate the validity of using an alternative the waste materials (such as steel slag, plastic, glass fiber, crushed concrete, and scrap tires) in the Hot Mix Asphalt pavement, which could minimize the deterioration of the roads[6]. Recently, great attention has paid by the developed countries to utilize the waste products to reuse it in the construction and roads pavement field. Reusing waste material for road pavement has become an essential challenge in the worldwide to adopt in different construction fields. Because of the difficulty of finding environmental and economical ways to get rid of them, more than 285 million tons of scrap tires are discarded in the USA yearly, as an example, as well as used in Portugal, China, Canada and South Africa[7]. This matter has led to creating specific programs and plans to reuse this amount of scrap tires in different fields. For example, the recycling of scrap tires has a very important sign to use it again as crumb and powder rubber raw materials[8]. Also, further researches showed that the waste material like tire rubber could be used in the asphalt mixture since the reuse of this waste material will reduce the need of new raw material for roads pavement, as well as it can improve the performance of asphalt pavement[9].

One of the successful options in increasing the service life of the road paving is that the use of polymers as a modifier that have been proposed[10, 11]. Whoever, tire waste production has increased dramatically in recent years as one of the major sources of recycled polymers, the research development on using methods of recycling and environmental conditions improvement has made rubber crumbs an important source of energy and new polymer products[12, 13]. Accordingly, to achieve the functional and economic benefit of researchers in the field of pavement, rubber crumbs is used as one of the best and most popular recycled polymers[14]. A yearly, more than one billion tires are sold worldwide, and many of them will eventually be recycled within a few years[15]. The use of rubber crumbs in construction of pavement could improves the characteristics of asphalt binders and performance of mixtures as well as eliminates economic and environmental problems[16].

Adding crumb rubbers as a waste material to binder has the same benefits as adding special additives to concrete. Additives can help researchers meet the superior performance of asphalt mixtures to meet specifications and withstand high traffic and environmental conditions. Rubber asphalt is produced by two main methods: wet process and dry process. Through the use of the wet process, the rubber is melted into the preheated liquid asphalt binder before mixing with the aggregates. Either through the use of the dry mixing method: the rubber is replaced by a portion of fine or coarse aggregates and mixed with hot aggregates before mixing with asphalt[16]. The Rubber pavement Association found that using rubber tires in an open grade mixture can reduce tire noise by about 50%[17]. Rubber crumbs can be used to remove or reduce pavement defects like permanent deformation (rutting) and alligators’ cracks (fatigue)[18]. Rubber crumb is produced from scrap tires and is used in a wide variety of industrial and construction applications[16, 19]. Another researcher was investigated that the interaction of asphalt, rubber occurs through two opposite mechanisms that occur simultaneously: dissolution and swelling of the particles[20]. The swelling of the rubber particles and their increase in size to about three times their original size occurs due to the absorption of the rubber crumb to the light oils (maltenes oils) in the bitumen[21]. Many studies have reported a higher cost of building rubber asphalt pavements compared to traditional pavement[22].
2. State of problem
The temperature and stress caused by the load can be cited as two main parameters leading to breakage in asphalt pavement, especially rutting (permanent deformation). When the traffic loading increases and temperatures are high, rutting failure are more likely to occurring. Therefore, due to the climate change of the last 30 years, the significant rise in summer temperatures in the Middle East, especially Iraq, and the number and load of truck vehicles that adversely affect the performance of asphalt road pavement, with hot climate conditions. There is a need to find solutions and treatments that improve the performance of these asphalt mixtures under high load.

3. The objectives of the current study
The goal of the current study is to assessment the effect of crumb rubbers on the rutting resistance of the asphalt mixtures and the characteristics of CRM (Crumb Rubber Modified) asphalt by adding various proportions of rubber crumbs using wet process. For this purpose, the following procedure was performed in this study:
- At first, various CRM binders containing 2.5%, 5%, 7.5%, 10%, 15% and 20% of rubber crumbs by weight of the binders were designed and prepared.
- Temperature sensitivity and performance of asphalt mixtures samples obtained from Marshall and Wheel Track tests.

4. Research Methodology
The testing program consists of physical tests of asphalt binder that include penetration, ductility, specific gravity, and softening point. The mechanical tests include the Marshall test and the wheel track test for both modified and unmodified asphalt mixtures samples. The testing phase consisted of the designing and preparing the asphalt mixture samples, as well as the laboratory investigations before and after adding CRM to the mixtures.

5. Materials and experimental works
5.1. Asphalt cement
The asphalt cement with penetration grade (40-50) has been utilized in this work as virgin asphalt binder, provided from Al-Dura refinery which is located in south of Baghdad. The implemented tests on asphalt cement prove that its properties met with the specification of SCRB[23]. Table 1 illustrates the physical properties of asphalt cement.

| Property                                      | ASTM Designation | Test result | SCRB specification |
|-----------------------------------------------|------------------|-------------|--------------------|
| Penetration at 25 °C,100 gm,5 sec. (0.1 mm)   | D-5              | 44          | (40-50)            |
| Ductility at 25 °C, 5 cm/min. (cm)*           | D- 113           | 135         | >100               |
| Flash point (Cleveland open cup), (°C)*       | D- 92            | 323         | Min.232            |
| Softening point, (°C)*                        | D- 36            | 53          |                    |
| Viscosity @ 135 °C, Pa. Sec                   | D- 4402          | 0.612       |                    |
| Viscosity @ 165 °C, Pa. Sec                   | D- 4402          | 0.187       |                    |
| Specific gravity at 25 °C *                   | D- 70            | 1.04        |                    |
5.2 Aggregates:
The aggregate used is a quartz crushed aggregate that has been produced from Al-Nibaie quarry. The used aggregates satisfy the specifications of fine and coarse to meet Type IIIA of surface course gradation as required by State Corporation of Roads and Bridges (SCRB) specifications [23]. The standard tests have been done on the aggregate to assess its characteristics. Tables 3 and 4 demonstrates the results and the specification limits as determined by the SCRB [23]. The results indicate that the selected aggregate fulfilled the SCRB specifications. Figure 1 and tables 2 and 3 Show gradient curves of aggregate and characteristics of coarse and fine aggregates respectively being used in this study, the results are within the acceptable limits of SCRB [23].

| Property                  | ASTM Designation | coarse aggregate | Fine aggregate | Specification |
|---------------------------|------------------|------------------|----------------|---------------|
| Bulk Specific Gravity     | C127, C128       | 2.612            | 2.567          | -             |
| Apparent Specific Gravity | C127, C128       | 2.656            | 2.629          | -             |
| Percent Water             | C127, C128       | 0.94             | 0.91           | -             |
| Absorption Angularity     | D 5821           | 97 %             | -              | Min 95 %      |
| Toughness, by (Los Angeles| C535             | 20.8%            | -              | Max. 30%      |
| Abrasion) Soundness       | C88              | 4.1 %            | -              | Max 12 %      |
| Clay content              | D2419            | -                | 86.5%          | Min. 45%      |

Table 3. Characteristics of Course and fine aggregate

| Sieve size (in)          | 3/4" | 1/2" | 3/8" | No.4 | No.8 | No.50 | No.200 |
|--------------------------|------|------|------|------|------|-------|--------|
| Passing % (Mid-point Gradation) | 100  | 95   | 83   | 59   | 43   | 13    | 7      |
| Specification Limits (S.C.R.B) (R9/2003) | 100  | 90-100 | 76-90 | 44-74 | 28-58 | 5-21  | 4-10   |
Figure 1. Gradation curves of an aggregate for wearing coarse

5.3 Portland cement filler
The filler was used in the current study is Portland cement, table 4 shows the physical properties of Portland cement.

Table 4. Physical Properties of Portland cement filler

| Property                        | Result |
|--------------------------------|--------|
| Bulk specific gravity          | 3.15   |
| Passing Sieve No.200 (0.075 mm) | 97%    |

5.4 Additive
The rubber crumbs used as an additive in this study were sourced from tire factories in AL-Diwaniya governorate. The rubber crumbs are black particles which were produced from recycled waste tires. They have a specific gravity of 1.13. There are several types of compounds in tires and the component that has the most effect on the physical properties of modified asphalt rubber (AR) is the hydrocarbon content of the rubber; In contrast, additional effects can be achieved from the natural rubber content [24]. The rubber crumbs were sieved to the desired size by passing the shredded material through sieve No. 100, figure 2 shows the Crumb rubber waste material before and after recycling.
5.4.1 Methods of Mixing

Generally, there are two methods available for preparing CRMA, which are dry process and wet process [25]. The dry method means that crumb rubber (CR) mixing first with heated aggregate before mixing with preheated liquid bitumen, and it is well known for its environmental benefits. And the final product is called rubber modified asphalt concrete mixture. This method was first invented and applied in Sweden and then patented in the USA in 1978 as Plus Ride [20]. Through the dry process, approximately 1% to 3% of the weight of the aggregate is replaced by particles of rubber crumbs that are finer than sieve No. 8 [21] and the rubber crumb becomes part of the fine aggregate in the pavement concrete. The dry process method requires a higher production temperature for efficient mixing of rubber particles. The Federal Highway Administration (FHWA) recommends a production temperature between 149 and 177 °C (300-350 °F). [25, 26]. Dry process usually uses in open graded, dense graded and gap graded for HMA paving and crumb rubber particles acts as elastic aggregate [25].

The Wet Process: The original wet process was initiated in the 1960s in the United States and is frequently referred to as the 'McDonald process' [25, 27]. The modification of the wet process rubber requires combining the tire rubber with a binder in the mixing containers and allowing them to react at a set temperature (175 to 200 °C (350 to 400 °F)) for a set time (45 to 60 min) [27]. GTR-modified binder results when rubber absorbs asphalt binder and swells at a high temperature [25, 28, 29]. The addition of rubber to the binder could increase the binder blend's viscosity, rendering it stiffer and thereby improving the mixture's rut resistance. At the same time, the softened rubber grains enhance the toughness of the binder system, resulting in improved resistance to different forms of cracking [30].

5.4.2 Preparation of Modified Asphalt Cement

As mentioned above two methods available for preparing CRMA, which are dry and wet methods. A wet process was followed during the preparation of the modified asphalt in this study. First, the asphalt binder is heated to about (165 °C) before being mixed with various proportions (2.5, 5, 7.5, 10, 15 and 20% by weight of asphalt) of rubber crumbs. This mixing was performed with a shear mixer at a mixing speed of 3500 rpm and at 190 °C for a duration of 45 min [27]. Table 5 shows Physical properties of asphalts with and without crumb rubbers.
Table 5. Physical properties of virgin and crumb rubber modified asphalt binder

| Property                          | ASTM Designation | 0%  | 2.5% | 5%  | 7.5% | 10% | 15% | 20% |
|----------------------------------|------------------|-----|------|-----|------|-----|-----|-----|
| Penetration at 25 °C, 100 gm, 5 sec. (0.1 mm) | D-5              | 44  | 41   | 37  | 34   | 29  | 24  | 19  |
| Ductility at 25 °C, 5 cm/min. (cm)* | D-113            | 135 | 119  | 107 | 98   | 85  | 77  | 62  |
| Softening point, (°C)*           | D-36             | 53  | 55.3 | 57  | 59.2 | 61  | 63.7| 65  |
| Specific gravity at 25 °C*        | D-70             | 1.04| 1.04 | 1.04| 1.04 | 1.04| 1.04| 1.04|
| Flash point (Cleveland open cup), (°C)* | D-92             | 323 | 330  | 335 | 341  | 340 | 344 | 347 |

6 Preparation of Asphalt Mixtures samples:
During the current study, The Marshall mix design method was followed for both the conventional and rubber crumb modified asphalt mixtures. The Marshall mix design method is commonly used in Iraq to design asphalt mixtures. The current study involved several laboratory examinations stages; the first stage involved the selection of the aggregates (coarse and fine), comprising of determining their physical properties and composite grades that will meet the requirements for asphalt mixtures. This stage followed the specification provided by the General Standards of the SCRB [23]. The second stage is divided into two phases. First, conventional asphalt mixtures (without crumb rubber) were prepared by adding five proportions of preheated asphalt (4, 4.5, 5, 5.5, 6) % of the total mixture weight to the aggregate. The purpose is to investigate the percentage of optimum asphalt content that gives a good balance among the tested properties (flow value, Marshall stability, bulk density and total air voids) and the optimum binder content was found (4.9) % by weight of total mix, figures 3,4 respectively show preparation of Marshall samples and the volumetric properties of asphalt mixtures samples with different percentages of binder content in procedure of evaluation the optimum binder content (OBC). Second, the effect of CR on the resulting mixture was examined by heating the optimum content of asphalt cement with various proportions of CR. At this stage, three samples were prepared for each mixture. The rubber crumbs were added to the asphalt mixtures using a wet process. The rubber crumbs were added at various proportions of (2.5, 5, 7.5, 10, 15 and 20 %) by weight of asphalt. The asphalt was heated to about 165 °C prior to the addition of the rubber crumbs. The temperature of the blending (asphalt cement + crumb rubber) was maintained at the range of 170 – 190 °C for 45 min. Then, the hot blending of asphalt cement and crumb rubber were added to the heated aggregate and mixture was manually mixed until homogeneity was achieved. Having homogenized, the blending of asphalt rubber was added to the heated aggregate at the desired amount and thoroughly mixed manually for about 2 minutes until the aggregates were fully coated with asphalt. Finally, assessment of the performance of asphalt mixtures in terms of Marshall test and permanent deformation through wheel track test. Marshall and wheel track tests were performed for both conventional and modified asphalt mixtures as assessment of unmodified and modified mixtures at the higher temperatures.
Figure 3. Preparation of Marshall samples

Figure 4. The Relation between the HMA volumetric properties and various binder contents: Stability, Flow, Unit Weight, Air Voids, VFA and VMA.
7 Results and discussions:

7.1 Conventional tests of rubberized asphalt binder

In order to describe the traditional physical properties of asphalt in compliance with ASTM D5, ASTM D113 and ASTM D36, the penetration, ductility test at 25°C and the softening point test were carried out. The effects of the adding crumbs rubber on the penetration, ductility, and softening point of the asphalts have been shown in Figure 5. As seen in this figure, although the softening point increase with increasing crumbs rubber, there is a declining in penetration and ductility values. This increase in the softening point of the rubber-enhanced asphalt improves the performance of asphalt mixtures at high temperatures and thus reduces the sensitivity of the mixtures to high temperature due to the decrease in penetration and ductility values. Consequently, the viscosity of the asphalt binder is improved by polymer modification, and this increased viscosity induces a similar increase in the HMA's performance at higher temperature. In contrast, the continuous decreasing in penetration and ductility values up to (19,62) respectively with the continuous increasing in the crumbs rubber proportions up to 20 percent has a negative impact on the fatigue life of modified mixtures due to the overhardening of the modified binder which is make it very brittle especially in cold climates [25, 29].

Figure 4. Continue

Figure 5. Traditional physical properties of rubberized asphalt binder.
7.2. Marshall test
To assess the stability and flow of the conventional mixture and crumbs rubber modified asphalt mixtures, the Marshall Test was conducted. Asphalt mixes were designed in compliance with ASTM D6926, D6927 and asphalt institute (2014). Figure 6 shows Marshall stability, flow test and percentages of air voids results for unmodified and crumbs rubber modified asphalt mixtures samples. From these results we can indicate obviously the positive impact of crumb rubber on the mechanical properties of mixes through increasing the Marshall stability significantly, these increasing in Marshall stability is due to the improvement of the properties of the binder by increasing the hardness of binder and reducing the sensitivity of it to high temperatures as a result of the interaction of rubber crumbs with the asphalt binder and its absorption of the light asphalt fractions (maltenes fractions) during the mixing process by using relatively few proportions of rubber crumbs. Meanwhile, the use of high percentages of soft rubber crumbs (passing through the No. 100 sieve) up to 20 percent in the blending of asphalt and rubber with harder asphalt (40/50) penetration has an adverse impact on the most common important properties of the rubberized asphalt binder, which is adhesion and cohesion due to the overhardening of the rubberized asphalt, and this leads to the decrease of the bond between the aggregate and the binder which in turn leads to reducing the performance of modified mixtures especially rutting and fatigue life [25, 28], and this is the logical explanation of reduces in Marshall stability with using high proportions of crumbs rubber. Consequently, higher design bitumen content was recommended compared to traditional mixtures or higher penetration grade bitumen in design of rubberized asphalt mixtures [28]. On the other hand, the flow values for crumb rubber modified asphalt mixtures samples showed an obvious decrease with increase of the rubber crumb content is due to the increase in the hardness of the asphalt mixture as a result of the effect of the rubber on the properties of the binder. As the percentage of rubber crumbs continues to increase, the decrease in the flow continues until it reaches 1.75 mm, with a percentage of rubber crumbs up to 20 percent. This decrease is outside the Iraqi standard for roads and bridges SCRB [23]. It is also noticed from Fig. 6 that the percentage of air voids increased relatively significantly to 4.81 % with the percentage increasing of rubber in mixture up to 20 %. The reason for This remarkable increase in the percentage of air voids is may be due to the excessive hardness of the bitumen due to the higher proportions of rubber in the mixture, which negatively affects the bond between the aggregate and bitumen as mentioned earlier, as a result of the absorption of rubber crumbs to light asphalt compounds (aromatic oils) [25, 28, 29], but This noticeable increase in the percentage of air voids still within the limits of the Iraqi standard SCRB. In contrast, with the continued increase in the percentage of rubber crumbs in the modified mixture more than 20 percent, the percentage of air voids may increase outside the limits of the Iraqi standard SCRB, this increase in the percentage of air voids has a negative impact on the performance of asphalt mixtures and their resistance to environmental conditions, especially the risk of moisture.
Figure 6. Marshall stability (KN), flow(mm) and Air voids % for conventional and crumb rubber modified mixtures at optimum binder content

7.3. Wheel track test:

To assess the dynamic stability of the bituminous mixtures, the wheel tracking test has been described as a test machine to measure the rutting behavior in laboratory for unmodified and crumb rubber modified asphalt mixtures with various proportions of crumb rubber (0, 2.5, 5, 7.5, 10, 15 and 20% by weight of binder). Hamburg Wheel Tracking (HWT) is a widely used measure of loaded wheels. It is a device used to simulate paving conditions to test the fragmentation sensitivity of asphalt mixtures. The evaluation is performed according to (AASHTO: T324, 2013) and (BS EN 12697-22, 2003). A steel wheel (standard specification) rolls over the surface of the asphalt mixture sample with an additional load of 705 N (158 lb) at a standard inspection temperature of 50 C [31-33]. The test runs for 10,000 cycles (20,000 passes) or
before 20 millimeters of deformation is achieved. Seven compacted slabs specimens (unmodified asphalt mixture and rubber modified asphalt mixtures) were prepared for this test, the compacted asphalt slab specimens with a length of 40 cm, a width of 30 cm and a thickness of 5 cm were cooled at room temperature for a period of 24 hours in compliance with the standard specification (BS EN 12697 - 22, 2003). Figure 7 shows the obvious positive effect of adding rubber crumbs passing through the sieve (No. 100) on the dynamic properties of modified asphalt mixtures by reducing the rut depth by 57.5 percent from 20.35 mm to 8.65 mm with rubber content up to 10 percent through the improvement in mechanical properties of the modified asphalt mixtures by increasing its hardness and reducing its sensitivity to high temperatures and that is through improving the physical properties of the bitumen and increasing its hardness. On the other hand, continuing to increase the percentage of rubber crumbs in the mixture to reach 20 percent has an adverse effect by increasing the rut depth to 12 mm, as shown in Figure 7. This is due to poor bonding between the aggregate and modified bitumen due to the bitumen's excessive hardness as a result of the increase in the percentage of rubber crumbs that in turn absorb the light fractions of asphalt (maltenes fractions) in the asphalt.

![Figure 7. The effect of crumb rubber on rut depth.](image)

8. Conclusions:
The influence of waste crumb rubber on improving the performance of asphalt mixtures and reducing the rut depth induced by wheels moving through the wheel track test has been investigated in this study. Based on the results of this study, the following conclusions can be made:

1. The addition of soft rubber crumbs passing through the No. 100 sieve has an obvious positive impact on the performance of asphalt mixtures, especially increasing the rut resistance in hot climatic conditions by reducing the rut depth compared to the conventional mixture.

2. Through the results of this study (Marshall test and wheel track test), it was found that the optimum content of added rubber crumbs is 10% by increasing Marshall stability up to 12.7 (KN) and reducing the rut depth to 8.65 mm.

3. The addition of high percentages of rubber crumbs has a negative effect on the performance of asphalt mixtures, including resistance to rutting and reducing the fatigue life of the mixtures as a result of the decrease in the asphalt content due to the absorption of rubber crumbs to light compounds of asphalt and this leads to the excessive hardness of asphalt as indicated in the results above.
4. With reference to point (3) in the conclusions, higher design bitumen content was suggested compared to traditional mixtures or higher penetration grade bitumen in the mixture design of rubberized mixtures.

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