Evaluation The Moisture Sensitivity of Asphalt Mixtures Modified with Waste Tire Rubber

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Abstract: One of the most significant factors for a good transportation system is the quality of the road pavement. As a result, many steps have been made to address the concerns of moisture damage to roadways, including increasing pavement quality and structural design approaches. In the last few years, there has been an increase in the attention of respective engineers to enhance the asphalt performance and provides various types of modifiers and substituting the virgin of asphaltic materials with recyclable products, to attain sustainable while reducing the price of modified pavement mixture. This article discusses the performance of modified asphalt mixes and the most commonly used recycled product, crumbs rubber, which is used as a modifier in asphaltic mixes at various contents (0, 2.5, 5, 7.5, 10, and 15% by asphalt weight), and investigates the impact of the addition rubber particles on a critical characteristic of asphalt mixtures, particularly regarding their resistance to damage of moisture. The results showed that modification of asphalt binder with CR increased Marshall's Stability, and the inclusion of 10% of CR recorded the highest increment, increasing by 30.25%. According to increased TSR and IRS, the addition of CR improved the asphalt mixture's moisture resistance. The addition of 7.5% of CR resulted in the largest values of TSR and IRS, increasing by 8.8% and 12.9% respectively. Additionally, this study aims at understanding the benefits and drawbacks of recycling rubber tires and to build a concept for effectively incorporating waste materials into road pavement.

Keywords: Crumbs Rubber (CR), Indirect Tensile Strength Ratio (TSR), Marshall Stability, Index of Retained Strength (IRS).

1. Introduction:
The asphalt binder is defined as a viscous-elastic material with temperature and time-dependent properties in general[1]. Because of increased traffic loads and unfavorable environmental conditions, the pavement materials of roads have been subjected to several failures in recent years[2]. Moisture damage is a form of failure that affects a large number of pavements all over the world. Moisture damage can be thought of as a distress that has a variety of effects on society. Economically, Moisture damage to pavements costs a lot of money in terms of repairs and reconstruction [3, 4]. The aggregate's detachment from the mix is typically the biggest issue in asphalt pavements that are vulnerable to seepage of moisture [5]. The Moisture combined with a heavy traffic load induces a degradation of the asphalt mixture's mechanical properties, resulting in separation the bonding between the aggregate and asphalt. In certain cases, this form of disruption becomes a commonplace weakness and a source of decreased road safety,[6]. Stripping or
raveling of the asphalt mixture's wearing layer, as seen in figure (1) is one type of damage. Initial stripping damage may quickly progress to a more severe wearing surfaces disintegration, eventually leading to pothole formation as shown in Figure 1 [7]. The lack of asphalt-aggregate adhesion and the poor cohesion inside the asphalt binder are two types of failures caused by moisture damage in asphalt paving[8].

![Figure 1. Damage of moisture occurring in road Pavement](image)

Different waste products from industry are typically generating major environmental concerns in modern cities. For pavement construction, bitumen, coarse aggregate, fine sand and Portland cement are utilized. Due to the increased costs, traffic engineers seek to use these throwaway waste products to produce practical and acceptable alternative road pavement materials to alleviate the pollution problem. The beneficial uses of various waste materials in highway roadways are expected to yield encouraging results. As a result, various kinds of investigation have recently been done in order to evaluate the validity of utilizing waste materials like (plastic, scrap tires and among others) as an alternative in pavement construction, which may decrease road distresses[10].

The increase in the population number and the various kinds of industries has resulted in an increase in various waste products. Numerous studies have been done to determine the possibility of utilizing waste materials (such as glass fiber, plastic, waste tires and crushed concrete) as an alternative in Asphalt pavement to reduce road deterioration. [10]. In the United States, for example, over 280 million tons of waste tires are thrown each year, and they are also utilized in China, Canada, Portugal, and South Africa. [11]. This has resulted in the development of particular strategies and plans to utilize the large number of discarded tires in various industries. Recycling waste tires, for example, is a significant indicator that it may be used as powder rubber or crumb material again.[12]. Further research revealed that waste materials such as rubber particles of waste tires may be utilized in asphaltic mixtures, since the recycle of this disposable products reduces the demand for virgin raw materials for road pavement while also improving the quality of the asphalt pavement [13].

Polymeric materials usage as a bitumen modifier has been recommended as one of the promising solutions for improving the service life of the pavement [14]. Tire waste output has grown rapidly in last few decades which make it as a major sources of waste products, by pursuing recycling technology and environmental studies improving, this making rubber crumbs a new polymer product [15-17]. Rubber crumbs are utilized as a prevalent popular of recycled polymers to accomplish the economic and functional advantage of
researchers in the pavement field [18]. Annually, at least 1 billion of tires are sold throughout the world, and more of them will be waste during a few years [19]. The use of crumbs rubber in asphalt pavements may enhance the properties of asphalt binders and mixture performance while also resolving economic and environmental issues [20].

Rubberized asphalt is manufactured in two processes: dry and wet processes, during the wet method, the rubber particles is mixed with the heated asphalt before being mixed with the heated aggregates. However, by using the dry method: a portion of the aggregate is subtracted with rubber particles and blended with heated aggregates prior to mixing with asphalt [20]. According to the Association of Rubber Pavement, utilizing waste crumbs rubber in an open grade mixture may significantly decrease the noise of tire by around 50% [21].

Crumbs rubber can be utilized to eliminate or minimize pavement issues like rutting failure and moisture damage [22]. Crumb rubber is derived from recycled waste tires and is utilized in a number of construction applications [20]. Many researchers discovered that the interaction between asphalt and rubber happens by two opposing processes that occur concurrently: particle dissolving and particle swelling. [23]. The rubber particles swell and expand to approximately three times their original size as a result of their absorption of the light fractions in bitumen (aromatic oils) [24]. The purpose of this research is to determine the impact of concentrations of crumbs rubber on the moisture sensitivity of asphalt mixes and the properties of rubberized asphalt by utilizing a wet method to add various proportions of rubber crumbs. Numerous rubberized binders including (0 %, 2.5 %, 5 %, 7.5 %, 10 %, and 15 %) of rubber crumbs by weight of asphalt were prepared and produced. Marshall, indirect tensile strength, and index of retained strength tests were used to determine the moisture sensitivity and performance of asphalt mixes.

2. Materials and:

2.1 Asphalt binder

The asphalt binder which has penetration grade (40-50) is used in the current study as raw asphalt material, sourced from refinery of Al-Dura in Baghdad. The physical tests on bitumen show that its characteristics fulfill with the requirements of the Iraqi standard SCRB[25]. Physical properties of asphalt binder are shown in table 1 below.

| Property                                      | ASTM Designation | Test result | SCRB specification |
|-----------------------------------------------|------------------|-------------|--------------------|
| Penetration at 25 °C,100 gm,5 sec. (0.1 mm)   | D-5              | 46          | (40-50)            |
| Ductility at 25 °C, 5 cm/min. (cm)            | D- 113           | 140         | >100               |
| Flash point (Cleveland open cup), (°C)        | D- 92            | 323         | Min.232            |
| Softening point, (°C)                         | D- 36            | 52          | ——                 |
| Viscosity @ 135 °C, C.s                       | D- 4402          | 612         | Min. 400           |
| Viscosity @ 165 °C, C.s                       | D- 4402          | 155         | ——                 |
| Specific gravity at 25 °C                     | D- 70            | 1.04        | ——                 |

2.2 Aggregates:
The aggregate utilized in this study is crushed aggregate sourced from Al-Nibaie quarry which is located in north of Baghdad. The used aggregates meet the requirements of the Iraqi standard (SCRB /R9) of fine and coarse aggregate to satisfy the gradation of surface coarse as required by (SCRB) requirements [25]. The physical tests were conducted on the aggregate to evaluate its properties. Tables 2 and 3 shows the limits of specification as recommended by the SCRB and outcomes of physical tests, respectively. The results proved that the used aggregate meet the SCRB requirement. Tables 2, 3 and figure 2 present the curves of gradient of aggregate and properties of fine and coarse aggregates respectively which used in this work, The outcomes that have been reported meet Iraqi standards (SCRB) [25].

Table 2. The gradation of aggregate according to SCRB (R9/2003).

| Sieve size (in) | 3/4" | 1/2" | 3/8" | No.4 | No.8 | No.50 | No.200 |
|----------------|------|------|------|------|------|-------|--------|
| Passing % (Mid-point) | 100  | 95   | 83   | 59   | 43   | 13    | 7      |
| Gradation Specification limits | (100) | (90-100) | (76-90) | (44-74) | (28-58) | (5-21) | (4-10) |

Table 3. Physical properties of fine and coarse aggregate.

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

Min 95%  Max 30%  Max 12%  Min 45%
2.3 Portland cement filler
The Portland cement was used as a filler in this study, table 4 shows the Portland cement characteristics.

| Property                             | Result |
|--------------------------------------|--------|
| specific gravity                     | 3.15   |
| Passing Sieve No.200                 | 97 %   |

2.4 Additive
The rubber utilized as a modifier in the current research from tire factory in AL-Najaf governorate. The specific gravity of crumb rubber is 1.13 as reported by several experts. Tire rubber has a wide variety of chemicals, but according to some experts, the hydrocarbon content of rubber has the greatest influence on the properties of rubberized asphalt [26]. Particles of rubber have been sieved to get the appropriate particle size (passing sieve No 100), the waste crumbs rubber before and after recycling are shown in figure 3.
2.4.1 Mixing methods:

In General, two available methods for production rubberized asphalt, namely wet and dry process [27]. The dry technique, which is recognized for its environmental advantages, includes mixing rubber particles first with heated aggregate and then with hot asphalt. The dry technique is often used in dense graded, gap graded and open graded HMA pavements, and the particles of rubber function as an elastic aggregate [27]. While, the Wet technique was conducted in the USA at 1960 and is Known as the ’McDonald process[27, 28].

3: Experimental Works:

3.1. Preparation of rubberized Asphalt binder:

A wet mixing method was used in the production of the rubberized asphalt in the current study. Firstly, the bitumen is heated to approximately (170 °C) before blended with various contents (0, 2.5, 5, 7.5, 10 and 15% by asphalt weight) of crumbs rubber. The mixing process was performed with a proper mixer as shown in plate (1) at a speed of mixing 3000 rpm and at 180 °C for a period of 60 min [18, 27, 28]. The Physical properties of rubberized asphalts are shown in table 5.

| Property                                      | ASTM standard | 0%   | 2.5%  | 5%   | 7.5%  | 10%  | 15%  |
|-----------------------------------------------|---------------|------|-------|------|-------|------|------|
| Penetration at 25 °C, 100 gm, 5 sec. (0.1 mm) | D-5           | 46   | 41    | 39   | 38    | 34   | 24   |
| Ductility at 25 °C, 5 cm/min. (cm)            | D-113         | 140  | 125   | 111  | 98    | 86   | 64   |
| Softening point, (°C)                         | D-36          | 52   | 53.5  | 56   | 58    | 62   | 66   |
| Specific gravity at 25 °C                     | D-70          | 1.04 | 1.04  | 1.04 | 1.04  | 1.04 | 1.04 |
| Flash point (Cleveland open cup), (°C)        | D-92          | >232 | >232  | >232 | >232  | >232 | >232 |

Plate 1. preparation of rubberized asphalt binder with a proper shear mixer
3.2. Preparation of adopted Asphalt Mixtures specimens:

The Marshall procedure was used in the current investigation to produce both conventional and rubber crumb modified asphalt mixes. The present study included many steps of laboratory evaluations; the first step entailed the selection of various types of aggregates (both coarse and fine aggregate), which included establishing its physical characteristics and gradation that would fulfill the requirements of mixes. This step complied to the SCRB's General Standards [25]. The second step is comprised of two distinct stages. Firstly, typical asphalt mixes were created by adding five different quantities of heated asphalt to the aggregate (4, 4.5, 5, 5.5, 6). The purpose of this stage is to determine the optimal asphalt content in terms of percentage that provides a highest value of tested properties (Marshall stability, bulk specific gravity and with 4% total air voids), and the optimal content of binder was determined to be (4.9) % by total mix weight. Secondly, the impact of CR on the resultant mixture was investigated by heating the binder to its optimal concentration with varied amounts of CR. Wet method was used to incorporate the rubber crumbs into the asphalt mixes. Rubber crumbs were incorporated in various amounts (0, 2.5, 5, 7.5, 10, and 15% of the asphalt weight). Prior to adding the rubber crumbs, the bitumen was heated to around 165 °C. For 45 minutes, the mixing temperature of (asphalt cement + crumb rubber) was kept between 170 and 190 °C. Then, the heated aggregate was added to the blending of bitumen and crumbs rubber, and the mixture was continuously mixed for approximately 120 seconds, until the aggregates were completely coated with bitumen and until a homogeneous mixture was achieved. Eventually, the Marshall test, the indirect tensile strength and the retained strength index are all discussed in detail, were used to evaluate the performance of asphalt mixes for both conventional and modified mixes.

3.3. Indirect Tensile Strength Test:

This type of testing is used to determine the impact of moisture on an asphalt mixes. ASTM D-4867 covers this evaluation in detail. At first, four Marshall specimens with a diameter of 4-inch (101.1 mm) and a height of 2.5-inch (63.5 mm) are compacted by trial method with (40, 50, 60, and 70) blows, respectively, to determine the number of blows that result in 7 ± 1 % air voids. Following the number of blows being determined, six sets of Marshal specimens were produced, each with six specimens. The first set was with a virgin asphalt and the other five set were adopted with (2.5, 5, 7.5, 10 and 15) % of crumbs rubber respectively. After that, each set was categorized in two classes (three samples for each class). The first-class samples were put in a water bath at 25 °C for a period 20 minutes, and the indirect tensile strength (ITS) was measured for each sample, as well as the average ITS for three specimens. To extract the air, the second group samples were put in a vacuum container filled with distilled water at 25 °C. After that, the specimens were placed in a water bath at 60 °C for 24 hours, then it was removed and put in another water bath at 25 °C for a period of 1 hour, after which the ITS was calculated (conditioned samples). The indirect tensile strength (ITS) is calculated utilizing the procedure outlined by (ASTM D-6931-12). 'The' (ASTM D-4867-09) standard specifies that the TSR value must be at least 80%

\[
ITS = \frac{2000P}{n.t.D} \quad \text{Eq. (1)}
\]

\[
TSR = \frac{ITS(\text{con})}{ITS(\text{uncon})} \quad \text{Eq. (2)}
\]

Where:
P: the load required to make failure on the specimens (N);
t: thickness of specimens (mm);
D: diameter of specimens (mm);
ITS (con) = Indirect tensile strength for conditioned samples (kPa);
ITS (uncon) = Indirect tensile strength for unconditioned samples (kPa).
3.4. Test of Compressive Strength and index of retained strength (IRS):
This test method, which is entirely covered by ASTM D-1075-07, is beneficial as a measure of the moisture sensitivity of compacted bitumen-aggregate mixtures. Six sets of cylindrical specimens were prepared according to ASTM D-1074-02. The first set had no additive for asphalt cement. Whereas, the other five sets had asphalt cement modified with (2.5, 5, 7.5, 10, and 15%) crumbs rubber, respectively, and each set had six samples. Three samples from each group (dry specimens) were put in an air bath at 25 °C for around 4 hours before tested by compressive strength device. The remaining three samples from each group were submerged in a water bath for a duration of 24 hours at 60 °C (submerged samples), then removed and putted in a second water bath at 25 °C for a duration of 120 minutes before testing in compressive strength device. Finally, the index of retained strength (IRS) was measured. The minimum value of IRS should be 70 percent, in a compliance to (SCRB / R9 / 2003) and (ASTM D-1075-07).

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IRS = \frac{S_2}{S_1} \times 100 \quad \text{Eq. (3)}
\]

Where:
IRS: Index of retained strength
S1: Dry specimens’ compressive strength (unconditioned) (kPa);
S2: immersed specimens’ Compressive strength (conditioned) (kPa).

4. Results and discussions:

4.1. Marshall test results:
The Marshall Test was used to determine the Stability and Flow characteristics of control and asphalt mixes adopted with crumbs rubber. Marshall stability, Flow values and percentages of total voids are shown in Figures (4, 5 and 6) respectively, for unmodified and asphalt mixtures specimens modified with crumbs rubber. These results clearly demonstrate the beneficial effect of waste rubber on the mechanical characteristics of mixes by significantly increasing Marshall stability. The remarkable increase in Marshall stability is due to the rubberized binder's properties being enhanced especially its stiffness as a consequence of the chemical reaction of rubber particles with the bitumen. In contrast, through use of higher proportions of rubber particles up to 15% in the blending of bitumen and rubber negatively influenced on the most prevalent characteristics of the rubberized asphalt, notably cohesion and adhesion, as a consequence of the high stiffness of the rubberized asphalt binder, resulting in a decrease in adhesion and cohesion. As a result, in the design of rubberized asphalt mixes, higher design bitumen concentration was proposed as opposed to control mixtures or bitumen with higher penetration grade. From the other side, the flow characteristics of asphalt mixes amended with rubber crumb demonstrated adequate stability and were within the allowed limitations specified in the Iraqi requirements for roads and bridges SCRB as shown in Figure (5). Additionally, as seen in Figure (6), the proportion of air voids increased significantly to reach 4.4 percent, when the proportion of rubber in the mix increased to up to 15%. This substantial increase in the proportion of total voids might be caused by the bitumen's high stiffness caused by high rubber content of the mix, which adversely affects the bonding between the aggregate and the bitumen and reduces the amount of bitumen coating the aggregate particles, nonetheless, this significant rise in the proportion of total voids remains within the limitations of Iraqi standard SCRB [25].
Figure 4. Marshall stability for control mixture and mixtures modified crumb rubber

Figure 5. Flow values for control mixture and mixtures modified crumb rubber

Figure 6. Air voids percentages (Va%) for control mixture and mixtures modified crumb rubber
4.2. Indirect Tensile Strength Test Results:

The aim of this study was to determine the impact of polymer (CRM) on moisture resistance. The relationship between CRM content and TSR is depicted in Figures 7 in both cases (conditioned and unconditioned), the IDT for modified mixes with 7.5 % CRM is superior to the IDT for the control mix, according to the test results. As seen in Figure 7, it can be noted the apparent positive impact of using rubber crumbs to increasing the tensile strength of mixtures for both (conditioned and unconditioned) by 20, 30 % respectively compared to the traditional mixture, as well as reducing the risk of moisture by increasing the tensile strength ratio (TSR) to 86.5 % compared to the traditional mixture as well. In contrast, the continuous increase of rubber crumbs to more than 7.5 percent leads to a decrease in the tensile strength and TSR of the modified asphalt mixes as a result of the excessive hardness of the modified asphalt, thus reducing the workability of the mixtures and decrease in the amount of asphalt that coates aggregate grains, which makes them weak and easy for water penetration, but their resistance remains higher than the traditional mixture as shown in the figure.

![Figure 7](image-url)
4.3. Compressive Strength Test results and index of retained strength:

The index of retained strength (IRS) has been used to determine the compressive strength of an asphalt mixture under the influence of water. The minimum allowed value of IRS, according to (SCRB, 2003), is (70 percent), which is used to determine whether or not a mixture is sensitive to moisture. Figure 8 shows the magnitude of increase in the compressive strength of dry and wet asphalt concrete samples to reach (26) % and (43) %, respectively after adding rubber crumbs to optimum value to about 7.5% of the weight of asphalt in comparison with the conventional mixture. This increase in the values of compressive strength for dry and wet samples is due to the increase in the viscosity of the modified asphalt and its hardness and thus forms a thick layer that coats the grains of aggregate and prevents the entry of water into the mixture. In contrast, the continuous increase of rubber crumbs for more than 7.5 % of the weight of the asphalt negatively affected the results by reducing the compressive strength of dry and wet samples due to high stiffness and the high viscosity of the asphalt, this makes it difficult to obtain perfect workability and thus difficult to obtain a complete coating of aggregate grains, which makes the mixture weak and vulnerable to water attack.

![Compressive strength and IRS outcomes for conventional and rubber modified mixes](image)

**Figure 8.** Compressive strength and IRS outcomes for conventional and rubber modified mixes
5. **Conclusions:**
The impact of crumbs rubber on enhancing asphalt mixture performance and lowering moisture damage through the indirect tensile strength and index of retained strength have been evaluated during current study. The following conclusions may be drawn from the study's findings: The inclusion of rubber crumbs that have passed the No. 100 sieve has a clear beneficial effect on the performance of asphalt mixes, notably in terms of enhancing the tensile strength and compressive strength of modified mixes compared to the conventional mixture. Through the outcomes of this study, it was found that the optimum content of added rubber crumbs is 7.5% by weight of asphalt through increasing the tensile strength for unconditioned and conditioned samples up to 1712 (KPa), 1481 (KPa) respectively and compressive strength for unconditioned and conditioned samples up to 9900 (KPa), 8700 (KPa) respectively and reduced the risk of moisture through increase indirect tensile strength ratio (TSR) and index of retained strength (IRS) to 86.5 % and 87.87 % respectively in compared with conventional mixes. Rubber crumbs in large concentrations have a detrimental influence on the performance of asphalt mixes, by reducing the tensile and compressive strength of asphalt mixtures due to the high stiffness of bitumen as a result of the absorption of rubber crumbs to the light compounds of asphalt (aromatic oils). This leads to an increase in asphalt hardening and makes it difficult to obtain high workability.

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