Using Crumb of Tires in Hot Asphalt Mixture as a Part of Aggregate

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Abstract. Scrap tires are a major part of the global solid waste management problem. In recent years, the problem of waste tires has become very acute that there is an urgent need to find an optimal and efficient way to use scrap tires in asphalt mixtures. The previous studies showed that the utilization of crumb of tires has more effect on asphalt mixture performance, which is represented increasing in the Marshall Stability and increasing crumb of tires causes increasing in Marshall Flow and increasing in air voids content additionally more than original mixes. This paper used crumb of tires in asphalt mixture as a part of aggregate. Three sizes of the grade of crumb tires were used in asphalt mixture No. 4 (4.75 mm), No. 8 (2.36) mm and No. 50 (300µm). Three percentages of asphalt binder (4, 5 and 6) by weight with three percentages of crumb tires (2, 4 and 8) % by weight also were used with aggregates for preparing asphalt mixture specimens. Asphalt mixture specimens were conducted according to Marshall Methods. Thirty-six specimens were equipped for evaluating Marshall Properties (Marshall Stability and flow, air voids percentage, bulk density, maximum bulk density, and Marshall Stiffness). Indirect Tensile Strength test (ITS) has been applied to obtain the cracking resistance of asphalt mixture using twenty-four specimens, which contains crumb tires. The results showed that the applying of the crumb tires has a significant performance of asphalt mixture by increasing the Marshall stability, flow, air voids, and decreasing bulk density and indirect tensile strength compared to the original mixes.

1. Introduction

The nation faces a major ecological problem due to an accumulation of automobile waste and truck tires. Environmental regulations prohibit the open burning or burying of tires is a solid waste facility. These tires are accumulating at the rate of about (3/4) billion per year, An immense problem affecting environmental pollution is the increase of waste tyre vehicles. In an attempt to decrease the magnitude of this issue, crumb rubbermodifier obtained from waste tyre rubber has gained interest in asphalt reinforcement [1],[2].

There are approximately 270 million are waste tire generated annually in state of these 230 million are passenger car tire and 40 million truck tire according to the 800 million scrap tire currently stock piles throughout the country. A scrap tire passenger car weight approximately 9 kg and will provide 60% rubber 20% steel and 20% fiber and other waste product [3].

The paving industry uses (1 - 2) million tires per year. Each metric ton of hot mix asphalt containing rubber can utilize (2 - 6) tires [4],[5]. The purpose of modification includes: increase the viscosity at high temperature, increase the flexibility and elasticity of binders at low temperature, improve the adhesion to aggregates, and improve high thermostability and aging resistance [6]. The aim
of this paper is to study the effect of crumb rubber as part of aggregate on the performance of asphalt mixture for different percentage of adding (2%, 4% and 8%) by weight of aggregate. For this purpose the performance changes were evaluated by Marshall tests and Indirect Tensile Strength test at 25°C. Munder A Bilema and Mohamad Y Aman [7], calculate the optimum bitumen content for each percentage and evaluate the moisture sensitivity of crumb rubber modified asphalt at two different compacting temperatures. On the other hand crumb rubber dissolved in the binder and stiffened to increase its rutting resistance. Even though only up to (2.5%) coarse rubber particles could be used as compared to (15%) of crumb rubber. Rubberized asphalts resisted rutting better than conventional (unmodified) asphalt as well as polymer modified binder asphalts. Wheel tracking performance was similar for dry and wet mix asphalts, but fatigue life for dry mix was three times as long as that of wet mixes. Katelyn Nicole Love [8] the effects of rubber modified binder on the performance of porous asphalt by evaluating the porosity, permeability, long term draindown, abrasion resistance, fatigue resistance and dynamic modulus. Result study on cores of asphalt rubber mixtures indicated higher wet indirect tensile strength and tensile strength ratios than the control mixture. In addition, the result of friction testing indicates that the rubberized mixture is performing better than the control mixture [9].

Asphalt rubber is defined by the ASTM Standard D6114 as a "mix of grade asphalt cement paving, ground recycled tire (that is, vulcanized) rubber and other additives, as needed, for use in binder construction in pavement. Rubber is mixed and reacted in hot asphalt cement enough to cause swelling in rubber particles before use." Asphalt and rubber binder is a mixed mixture (in a hot mixing plant) and requires specialized mobile mixing equipment to produce it. Crumb rubber modifier (CRM) ranges from 18 to 22 percent.

The crumb rubber modifier used in rubber asphalt is in the 10-16 mesh range [10]. Powder rubber or polymers should be added to AC-30 to form the binder used in asphalt bases [11]. The resulting structural coefficient (a-value) for the powder rubber base is (0.45) compared to (0.40) for conventional base coarse using AC-30, addition of the powder rubber increases the cost of the binder (10%) only while increasing its coefficient by (12.5%) [12]. Many studies have reported that crumb rubber modifier (CRM) binders can produce asphalt pavements that pavement life, decreased traffic noise, reduced maintenance costs and resistance to rutting and cracking [13][14] and [15].

The objective of this study was to evaluate how the properties of rubber affect the properties of asphalt bonding material. The study used a rubber crumb of tires products to modify asphalt bonding material. The test of Marshall Stability, and flow, air voids percentage, bulk density, maximum bulk density, and Marshall Stiffness test. The objective was achieved by analyzing the performance characteristics of modified volumes to determine the impact of rubber properties on binder performance.

2. Materials and tests

2.1. Asphalt Cement

All data presented in this study had been collected in Jiangsu road Mstar Technology Ltd. The Road Laboratory of Department College of Transportation Engineering in Tongji University. One binder of asphalt cement was tested, from Venezuela heavy oil Refinery with a grade of (40-50) penetration. The physical properties (according to ASTM specification) of this type are illustrated in table 1.

| Test                        | Unit | Venezuela heavy oil (40-50) |
|-----------------------------|------|-----------------------------|
| Penetration at 25 C°        | 0.1 mm | 45                          |
| Ductility at 25 C°          | Centimeter | 100 +                      |
| Softening Point             | C°   | 50                          |
| Flash Point                 | C°   | 339                         |
| Specific Gravity            | ---  | 1.033                       |
2.2. Aggregate (coarse and fine materials)
Crushed aggregates are used in this work with a fixed dense gradation for all the specimens and from Liyang city quarry. The middle limits of the (19 mm) size dense gradation has been selected as a basic gradation in accordance with (ASTM D-3515) as shown in figure 1.

![Figure 1](image)

**Figure 1.** Specification Limits and Selected Gradation of Aggregate Maximum Size (19 mm)

2.3. Crumb of tires
Crumb of tyres was prepared by crushing, and grinding used tyres to small pieces about (3x3) cm, and using Nitrogen containers where the small pieces of tyres are put for (45 seconds) and crushing these freezing particles by using Marshall’s hammer to produce crumb of tyres.

The crumb of tyres was sieved to the sizes required, figure 2 shows crumb of tyres after freezing and crushing. Sieve analysis of crumb of tyres is shown in table 2.

**Table 2.** Properties of Crumb of Tires

| Sieve size (mm) | % Passing |
|----------------|-----------|
| 9.5            | 100       |
| No.4 (4,75)    | 67        |
| No.8 (2.36)    | 32        |
| No.50 (0.3)    | 11        |
| No. 200 (0.075)| 3         |
| Specific Gravity| 1.237     |
2.4. Mineral filler
One type of filler is used in this work which was Limestone dust obtained from Changjiang river Factory.

3. Test methods
The following tests were used in this work to evaluate the asphalt concrete mixture:

- Resistance to plastic flow (Marshall Stiffness) at (60°C).
- Indirect Tensile Strength (ITS) at (25°C).

3.1. Preparation of mixtures

The aggregates were first dried to constant weight at (110°C), separated into the desired sizes and recombined with mineral filler in order to meet the required gradation for each specimen. The aggregates were then heated to a temperature of (155°C) before mixing with asphalt cement. The asphalt cement is heated to a temperature, which produces a kinematic viscosity of (170±20) centistokes up to (163°C) as an upper limit. Then, asphalt cement was weighted to desired amount, added to the heated aggregates, and mixed thoroughly until all aggregate particles were coated with asphalt binder.

3.2. Preparation of asphalt mixture containing crumb of tyres

To prepare one sample of aggregates containing crumb of tyres, calculate weight of each grade size tires of (No.4), (No. 8) and (No. 50) were prepared according to added percentage of (2, 4, and 8)% by weight. After mixing the three sizes were stored in other container for final heating and mixing with aggregates. The total weight of crumb of tyres was reduced from the weight of aggregate for each selected sizes. The combined aggregates were put in the oven for heating to the temperature of mixing. Before mixing the aggregate with asphalt, and the combined crumb of tyres were put in oven for (15) minutes and after that added to the combined aggregate then the asphalt binder was added for mixing together.

3.3. Resistance to plastic flow (Marshall Method)

This method covers the measurement of the resistance to plastic flow of cylindrical specimens of bituminous paving mixture loaded on the lateral surface by means of the Marshall apparatus according to (ASTM D-1559). The test specimens were compacted using one compact effort, which is (75) blows each surface. The bulk specific gravity density (ASTM D-2726), theoretical (maximum) specific gravity (ASTM D-2041) and percent air voids (ASTM D-3203) are determined for each specimen. Marshall Stability and flow tests were performed on each specimen according to the method described by (ASTM D-1559). The cylindrical specimens (2.5" (62.5 mm) height * 4" (101.6 mm) diameter) were compressed on lateral surface with a constant rate of (50.8 mm/min) until the maximum load was reached. The
maximum load resistance and corresponding flow values were recorded. Three specimens for each combination were prepared and the average results were reported.

3.4. *Indirect tensile strength test*

The same methods illustrated in items (6.1. and 6.2.) were used for preparing (24) samples for Indirect Tensile Strength test (ITS) according to (ASTM D-4123). The specimens were left to cool at room temperature for 24 hours, immersed in a water bath at 25°C for 30 minutes, then tested for ITS at rate of 50.8 mm/min. (2 in/min) in a compression machine until recording the ultimate load resistance. Equation (1) used for calculating the indirect tensile strength after testing the specimens is [16].

\[
ITS = \frac{2P}{\pi TD}
\]

Where:

- ITS = indirect tensile strength (calculated for three specimens). N/mm\(^2\).
- P = Ultimate applied load required to fail specimens (N).
- T = Thickness of the specimen, mm.
- D = Diameter of the specimen, mm.

4. *Results and Discussion*

The data of the study are presented in table 3 and table 4.

| No | % Crumb of Tyres | Stability KN | Flow mm | % Air voids | Theoretical Density | Bulk density gm/cm\(^3\) | density |
|----|------------------|--------------|---------|-------------|---------------------|--------------------------|---------|
|    |                  | % asphalt    | % asphalt | % asphalt   | % asphalt           | % asphalt                |         |
|    |                  | 4 | 5 | 6 | 4 | 5 | 6 | 4 | 5 | 6 | 4 | 5 | 6 |
| 1.  | 0                | 9.45 | 7.33 | 6.63 | 2.7 | 3.2 | 4 | 3.8 | 2.4 | 1.9 | 2.49 | 2.46 | 2.42 | 2.397 | 2.406 | 2.374 |
| 2.  | 2                | 10.27 | 9.8 | 9.52 | 4.9 | 5.8 | 6.7 | 6.9 | 3.8 | 2.8 | 2.483 | 2.429 | 2.393 | 2.328 | 2.349 | 2.34 |
| 3.  | 4                | 9.03 | 7.95 | 7.8 | 5.6 | 6.6 | 7.1 | 7.8 | 6 | 4.3 | 2.447 | 2.414 | 2.384 | 2.269 | 2.283 | 2.298 |
| 4.  | 8                | 6.95 | 6.37 | 5.8 | 6.8 | 7.3 | 8 | 8.8 | 6.4 | 5.6 | 2.396 | 2.351 | 2.335 | 2.198 | 2.215 | 2.19 |

**Table 4.** Indirect tensile strength properties of the asphalt Mixture.

| No | % Crumb of Tyres | ITSN/mm\(^2\) | % Asphalt |
|----|------------------|----------------|-----------|
|    |                  |                | 4 | 5 | 6 |
| 1  | 0                | 0.993          | 0.744 | 0.718 |
| 2  | 2                | 0.684          | 0.813 | 0.503 |
| 3  | 4                | 0.727          | 0.684 | 0.624 |
| 4  | 8                | 0.856          | 0.521 | 0.607 |

According to the asphalt-rubber concrete mixes tested at the specifications followed the result obtained are:
Figure 3. The effect of the crumb of tires on Marshall Stability

Figure 3 shows the effect of the crumb of tires on Marshall Stability at different asphalt contents. Stability increases with increasing Crumb of Tyres content until (2%) after that, there is a reduction in the stability. At (4%) the stability remained near the original value but, at (8%) the stability became less than the original value.

Figure 4. The effect of asphalt content on Marshall Stability

Figure 4 shows the effect of asphalt content on Marshall Stability at the different crumb of tires contents. Stability decreases with increasing asphalt content but, the rate of decreasing with crumb of
tires content is lower compared with the original mixture.

Figure 5. Effect of Crumb of Tires Contents on Marshall Flow of Asphalt Mixture at Different Asphalt Contents.

Figure 5 shows the effect of the crumb of tires on Marshall flow. The flow increases with increasing in crumb of tires contents. The percent of increase at (2%) is about (75%) more than the original value. It increased gradually until it reached more than (100%) as compared to the original value. To explain this behavior, the Marshall flow with a crumb of tires was composed of deformations among the particles of aggregate and the deformations in the crumb of Tyres particles, while in the original mixture deformations were among the particles of aggregate only.

Figure 6. Effect of Asphalt Content on Marshall Flow of Asphalt Mixture at Different Contents of Crumb of Tires.

Figure 6 shows the effect of asphalt contents on Marshall flow at the different crumb of tires contents. The flow increases with increasing the asphalt content for different crumb of tires content. The flow
increases with increasing Crumb of Tyres contents.

Figure 7. Effect of Crumb of Tyres Contents on Marshall Stiffness of Asphalt Mixture at different Asphalt Contents

Figure 7 shows the effect of Crumb of Tyres on Marshall stiffness, where:

Marshall Stiffness = \( \frac{\text{Marshall Stability}}{\text{Marshall Flow}} \) (kN/mm) \hspace{1cm} (2)

Marshall Stiffness decreases with increasing crumb of tires contents. The rate of variance decreased with increasing crumb of tires content. This result is natural because the flow increases with increasing the crumb of tyre contents.

Figure 8. Effect of Asphalt Contents on Marshall Stiffness of Asphalt Mixture at the different crumb of tires contents.
Figure (8) shows the effect of asphalt contents on Marshall Stiffness for different crumb of tires contents. The rate of variance in Marshall Stiffness decreases with increasing crumb of tires contents, whereas the rate of change in Marshall Stiffness for the original mixture is higher than mixture content crumb of tires contents.

Figure 9. Effect of Crumb of tires Contents on Max Density of Asphalt Mixture at Different of Asphalt Contents.

Figure 9 shows the effect of the crumb of tires contents on maximum density. The crumb of tires content has a significant effect on maximum density because the specific gravity of crumb of tires is less than the specific gravity of aggregate.

Figure 10. Effect of Asphalt Content on Max Density of Asphalt Mixture at Different Crumb of tires Contents.
Figure 10 shows the effect of asphalt content on maximum density for different crumb of tires contents. There is a decrease in maximum density with increasing asphalt contents.

![Figure 10](image.png)

**Figure 11.** Effect of Crumb of tires Contents on Bulk Density of Asphalt Mixture at Different Asphalt Contents.

Figure 11 shows the effect of the crumb of tires contents on the bulk density of mixture. The crumb of tires contents has a significant effect on bulk density. By increasing the crumb of tires contents, the bulk density of mixture decreases because the specific gravity of crumb of tires is less than the specific gravity of aggregate and will operate larger volume as compared to the same weight of aggregate.

![Figure 11](image.png)

**Figure 12.** Effect of Asphalt Content on Bulk Density of Asphalt Mixture at Different Content of Crumb of tires.
Figure 12 shows the effect of asphalt contents on the bulk density of mixture for different crumb of tires contents. The variance in asphalt contents has not a significant effect on the bulk density of mixture for a different crumb of tires contents.

![Graph showing the effect of asphalt contents on the bulk density of mixture](image)

**Figure 13.** Effect of Crumb of tires Contents on Air Voids of Asphalt Mixture at Different Asphalt Contents

Figure 13 shows the effect of crumb of tires contents on the percentage of air voids in mixture. Air voids increase with increasing of crumb of tires contents because crumb of tires has specific gravity less than the specific gravity of the aggregate. On the other hand, the combined aggregate with crumb of tires particles has surface area greater than pure aggregate. Therefore, percent of air voids increase with increasing crumb of tires contents.

![Graph showing the effect of crumb of tires contents on air voids](image)

**Figure 14.** Effect of Asphalt Contents on Air Voids of Asphalt Mixture at Different Contents of Crumb of tires.
Figure 14 shows the effect of asphalt content on the percentage of air voids in mixture for different crumb of tyres content. Air voids decrease with increasing of asphalt content.

![Figure 14](image)

Figure 15. Effect of Crumb of tires Contents on Indirect Tensile Strength of Asphalt Mixture at Different Asphalt Contents

Figure 15 is a Histogram showing the effect of crumb of tires on the Indirect Tensile Strength (ITS) of asphalt mixture at different asphalt contents. The behavior of the variations gradually decreases at (0 and 4)% of crumb of tires additive with increasing asphalt contents. Variations at other percent’s of added crumb of tires take random behavior.

![Figure 15](image)

Figure 16. Effect of Asphalt Contents on Indirect Tensile Strength of Asphalt Mixture at Different Crumb of tires Contents

Figure 16 is a Histogram showing the effect of asphalt contents on the Indirect Tensile Strength (ITS) of asphalt mixture at different crumb of tires contents. The behavior of the variations for the (ITS) at (4 and 6)% of asphalt contents increases with increasing the crump of tyres contents but, the percent of reduction in (ITS) as compared to original mixture ( 0% crump of tyres), is about (10% to 30%). At
asphalt content (5%) (ITS) decreases with increasing crumb of tires contents, but the original mixture (0% crump of tires) is less than (2% crump of tires).

5. Conclusions and Recommendations
The study showed that the utilization of the crumb of tires have more effect on asphalt mixture performance as follow: -
a) Increasing the Marshall stability until (2%) Crumb of tires content and reduction in Stability after that percentage.
b) Increasing crumb of tires causes increasing in Marshall Flow about (75 - 100)%, in the same time an increase in the air voids content compared to the original mixture.
c) The crumb of tires additives caused a decreasing in the bulk density of the asphalt mixture.
d) Increasing crumb of tires causes a reduction in the indirect tensile strength about (10 to 30)% less than original mixtures.

a. Based on the results of this study, the effect of the crumb of tires on asphalt mixture performance at high temperature, need to a further study, moreover, the effect of aging on the performance of asphalt mixture containing crumb of tires.

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