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# THE IMPACT OF ADDING WASTE TIRE RUBBER ON ASPHALT MIX DESIGN

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As the number of waste tires increases due to the increase in the number of vehicles, it is necessary to benefit from the material out of which tires are made and this poses a real challenge. The purpose of this paper is to investigate the impact of using the rubber of waste tires (10 years of age) in an asphalt mix design (3/4" wearing course). The crumb (shredded) rubber is used with (60/70) bitumen grade. Four different percentages of rubber are used with bitumen: 5%, 10%, 15%, and 20%. The marshal test, as well as the ductility test, are to be performed when considering the following bitumen percentages: 4%, 4.5%, 5%, 5.5%, and 6%. The optimum asphalt and rubber contents are investigated by applying several trial mixes containing different bitumen and rubber percentages: 95% and 5% rubber, 90% and 10% rubber, 85% and 15% rubber, and 80% and 20%, respectively. Based on the lab test results, relevant entities and stakeholders are recommended to use such materials to pave asphalt roads. From an optimistic point of view, the use of such materials is expected to minimize the unit cost of pavement (square meter) as well as the environmental impacts (a friendly solution to tire waste problems). The results indicate that 10% and 15% of rubber satisfy the standards and specifications.

*Keywords:* Optimum asphalt content, Softening point, Ductility, Air voids, Voids in mineral aggregates, Marshall stability.

## 1 INTRODUCTION

Asphalt concrete is one of the most common types of pavement surface materials used. It consists of a mixture of asphalt binder (bitumen) and aggregates. Throughout a road's life and before it wears out and deteriorates, many degradation processes occur. Bitumen becomes more fragile, resulting in microcracks, and in the near future, cracks at the interface between bitumen and aggregates occur (Jendia and Alakhrass 2019). The characteristics of pavement performance are influenced by the features of the bitumen binder (Issa 2016). By considering continual growth consumption, a large quantity of remnant rubber material is collected yearly worldwide. In this research, several substantial characteristics of asphalt mixture, containing flow and stability, are checked with the added rubber. The potential benefits include social, economic, engineering, and environmental ones.

## 2 LITERATURE REVIEW

The asphalt and concrete have similar benefits when adding rubber for the first material and additives for the second material. These supplements improve asphalt for some specifically needed properties. The production of rubber asphalt is obtained by a wet or dry process. In the first process, the asphalt binder contains the melted rubber, and while in the dry process, a portion of fine aggregates replaces the rubber (Huang *et al.* 2007). The Rubber Pavement Association stated that the noise caused by tires could be decreased by 50% by using an open-graded mixture of tire rubber (Zhu and Carlson 2001).

Cao (2007) studied the effects of improving asphalt mixture properties, the properties of recycled tire rubber, and modified asphalt mixtures by using the dry process to minimize waste tire pollution. Three types of asphalt mixtures were tested. These contained different rubber contents (1%, 2%, and 3% by the weight of the total mix), in addition to a rubber-free sample. Based on the results, the rubber content had a significant effect on improving the engineering properties of asphalt mixtures, such as resistance performance to permanent deformation at high temperatures and cracking at low temperatures.

Shu and Huang (2014) stated that over the years, recycling waste tires into civil engineering applications, especially into asphalt paving mixtures and Portland cement concrete, has been gaining more and more interest. They indicated that the use of fragmented rubber in the AC mixture gave a very interesting result as it presents a good power, reaction in properties, and performance between rubber particles and asphalt mixtures, such as reclaimed asphalt pavement (RAP) and warm-mix asphalt (WMA).

Fontes *et al.* (2010) presented that one of the options to minimize persistent deformation in asphalt concrete layers is by mixing bitumen with crumb rubber, which improves the properties of conventional asphalt. The test outputs assuring that the use of rubber as a binder in the asphalt effectively improved rutting reluctance. However, the test results led to the conclusion that the properties of rubber as a binder might not be used to forecast the persistent deformation reluctance of mixing rubber with asphalt.

Rokade (2012) stated that it is becoming an important issue using fragmented rubber and plastic waste in the AC projects. Accordingly, the author made an attempt to use plastic waste in the dry process and the fragmented rubber in the wet process. Different percentages of plastic waste and fragmented rubber were examined using the Marshal Test to check the design characteristics.

Xiao *et al.* (2009) investigated and evaluated the fragmented rubber type and size effect as an engineering property on reclaimed asphalt pavement (RAP) mixtures. Two rubber types (ambient or cryogenic) and three rubber sizes were used in the experimental design, including about 25% RAP mixtures. As a result, from the aforementioned experiment, the added fragmented rubber was beneficial to the Superpave mix design by increasing the voids in minerals. Moreover, rutting resistance was also improved.

The effects of supplement fragmented rubber to AC mixtures using the wet process were investigated by Wulandari and Tjandra (2017). The Marshall Method approach was implemented in the lab of hot mix asphalt design. In this research, two percentages (1% and 2%) of fragmented rubber, as well as two fragmented rubber sizes, were checked by the weight of the asphalt mixture. Rapprochement research was carried out between the modified and unmodified AC mixtures concerning the volumetric characteristics and value stability. The output results indicated that fragmented rubber is advised as a genitive to AC mixtures as it tends to maximize both the quality and strength of the AC admixtures.

Farouk *et al.* (2017) investigated the effects of mixture design variables on the rubber–bitumen interaction and the properties of rubberized asphalt mixtures fabricated by the dry process. The authors prepared a dense-graded AC mixture, including four types of gyratory compacted samples. The prepared samples included one free of rubber sample, and the remaining three samples were with 2% of fragmented rubber. The fragmented rubber used was of different sizes (1.18, 3.35, and 5.0 mm). The output results indicated that an increase in the rubber-bitumen interaction could be achieved by using fine rubber size as well as high bitumen content, thus showing larger rubber swelling specifically in the first four hours of treatment.

The importance of this paper lies in the fact that this is the first attempt (trial) to benefit from the huge amount of waste tires in developing countries in general, specifically in Palestine. Moreover, the bitumen used in preparing the hot mix asphalt is expensive, as it is usually imported. Thus the results of this study give cheaper alternatives.

## 3 EXPERIMENTAL WORK AND RESULTS

### 3.1 Introduction

Various lab tests were conducted on bitumen with rubber, including softening point, ductility, and Marshall (stability and flow) tests. The used optimum asphalt content (OAC) is 5.03% based on the previously conducted Marshall Test.

### 3.2 Tests Applied on Asphalt with Rubber

#### *3.2.1 Softening point test (ASTM-D36/D36M 2014) and ductility test (ASTM-D113 2017)*

The results of the softening point test (using the ring and ball apparatus) values in ($C^0$) and ductility test values in (cm) are illustrated in Table 1. Figure 1 and Figure 2 show these tests.

Table 1. Softening point and ductility test results.

| **% Rubber by Weight of Bitumen** | **Softening Point ($C^0$)** | | **Mean ($C^0$)** | **Ductility Values (cm)** | | **Mean (cm)** |
|---|---|---|---|---|---|---|
| | **1** | **2** | | **1** | **2** | |
| 5% | 48 | 49 | 48.5 | 106 | 109 | 107.5 |
| 10% | 51 | 52 | 51.5 | 53 | 58 | 55.5 |
| 15% | 53 | 54 | 53.5 | 27 | 32 | 29.5 |
| 20% | 54 | 55 | 54.5 | 13 | 14 | 13.5 |

Figure 1. Softening Point test.

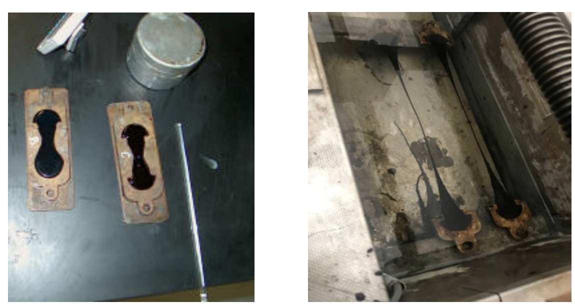

Figure 2. Ductility test.

#### *3.2.2 Marshall Test (ASTM-D6927 2015)*

The total mix weight was 1200gm, and the percentage of aggregate was 94.97%. Accordingly, total weight of aggregate was 1140gm. Table 2 and Figure 3 illustrate the aggregate quantities used in the test.

Table 2. Aggregate quantities by weight used in the test.

| Ingredient | % of Total Aggregate | Weight of aggregate (gm) |
|---|---|---|
| Coarse aggregate I | 25 | 285 |
| Coarse aggregate II | 20 | 228 |
| Small size aggregate | 15 | 171 |
| Crushed fine aggregate | 40 | 456 |
| **Total** | | **1140** |

Figure 3. Preparation and distribution of aggregate samples.

Table 3 illustrates the percentage of bitumen and corresponding rubber by weight used in the test (OAC = 5.03%). Moreover, the bulk specific gravity, unit weight, air voids, voids in mineral aggregates (VMA), Marshall Stability, flow, and the corresponding percentage of rubber are illustrated in Table 4, respectively. Finally, Figure 4 shows the mixing process of aggregates and bitumen with rubber.

Table 3. % of Bitumen and corresponding % of rubber used in the test.

| % of [Bitumen+ Rubber] | Weight of [Bitumen+Rubber] (gm) |
|---|---|
| [95%+5%] | [57+3] |
| [90%+10%] | [54+6] |
| [85%+15%] | [51+9] |
| [80%+20%] | [48+12] |

Table 4. % of rubber and corresponding average bulk specific gravity, unit weight **(γ)**, % air voids (pa), % vma, stability (kn), and flow (mm) results.

| Rubber (%) | $G_{mb}$ | γ | Pa (%) | VMA (%) | Stability (KN) | Flow (mm) |
|---|---|---|---|---|---|---|
| 5% | 2.31 | 2307.81 | 4.91% | 16.03% | 15.12 | 4.34 |
| 10% | 2.31 | 2308.52 | 4.34% | 15.10% | 16.15 | 3.90 |
| 15% | 2.25 | 2245.91 | 3.40% | 14.32% | 17.85 | 3.50 |
| 20% | 2.30 | 2299.86 | 3.93% | 13.58% | 19.70 | 3.12 |

Figure 4. Mixing process of aggregates and bitumen with rubber.

## 4 DISCUSSION

The following points illustrate the results of the previous section.

- The softening point increases with an increase of rubber percentage, while ductility decreases with the increase of rubber percentage.
- The unit weight decreases by increasing the rubber percentage by up to 15%. However, the unit weight increases by up to 20% of rubber.
- The air voids decrease by increasing the rubber percentage by up to 15%. However, the air voids increase up to 20% of rubber.
- The voids in mineral aggregates decrease by increasing the rubber percentage.
- The stability increases by increasing the rubber percentage.
- The flow decreases by increasing the rubber percentage.

Moreover, Table 5 summarizes the results of the different properties based on the different percentages of rubber (5% - 20%) and compares them with the specifications. In Table 5, only 10% and 15% of rubber meet all specifications. However, the remaining 5% and 20% are not satisfied.

Table 5. Summary table.

| % Rubber | $G_{mb}$ | Pa (3-5) | VMA>14 | Stability>10 | Flow (2-4) | Specifications (Yes/No) |
|---|---|---|---|---|---|---|
| 5% | 2.31 | 4.91% | 16.03% | 15.12 | 4.34 | No |
| **10%** | **2.31** | **4.34%** | **15.10%** | **16.15** | **3.90** | **Yes** |
| **15%** | **2.25** | **3.40%** | **14.32%** | **17.85** | **3.50** | **Yes** |
| 20% | 2.30 | 3.93% | 13.58% | 19.70 | 3.12 | No |

## 5 CONCLUSIONS AND RECOMMENDATIONS

Based on the above results, the following points can be concluded:

- The addition of 10% - 15% rubber to the bitumen in the asphalt mixture improves all properties such as air voids, VMA, stability, and flow. Standards indicate that the Marshall Test results are suitable for heavy traffic with minimum stability of 680 kg (75 blows) and a maximum flow of 4 mm. The minimum VMA for a 3/4" mix is 14, and the air void range is between 3 and 5.
- The percentage of rubber shall be compatible with the properties needed to be improved.

- The optimum percentage of waste tire rubber that can be used in asphalt pavement is (10% - 15% by the weight of the total bitumen). This is mainly suitable for Palestine.

The author recommends investigating the possibility of benefiting from the huge amounts of waste tires by applying further tests, which could contribute to minimizing paving work costs.

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