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THE IMPACT OF ADDING WASTE TIRE RUBBER ON ASPHALT MIX DESIGN

AMJAD ISSA[1]

[1]*Department of Civil Engineering, An-Najah National University, Nablus, Palestine*

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 age) in 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 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 lab test results, relevant entities and stakeholders are recommended to use such materials in the paving of 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

As the number of waste tires increases due to the increase in the number of vehicles, it is necessary to attempt to benefit from the material out of which tires are made, which is considered a challenge. The purpose of this paper is to investigate the impact of using the rubber of waste tires (10 years age) in 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 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 lab test results, relevant entities and stakeholders are recommended to use such materials in the paving of 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).

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 deteriorate, many degradation processes occur. Bitumen becomes more brittle, causing a micro-crack, and in the near future, a crack at the interface between bitumen and aggregates occurs (Jendia and Alakhtass, 2019). The properties of pavement performance are affected by the bitumen binder properties (Issa, 2016). With the continuously increased consumption, a large amount of waste rubber material is generated annually in the world. In this paper, some important properties of asphalt mix, including stability and flow, are investigated with the added rubber. The potential benefits include social, economic, engineering, and environmental ones.

2 LITERATURE REVIEW

Adding rubber to asphalt has similar benefits to adding additives to concrete. The additive materials help engineers to improve asphalt for some special required specifications. Rubber asphalt is produced either by a wet process- rubber is melted in the liquid asphalt binder before mixing, or by a dry process- rubber is replaced by a portion of fine aggregate while mixing (Huang et al., 2007). The Rubber Pavement Association found that using tire rubber in open-graded mixture binders could decrease tire noise by approximately 50% (Zhu and Carlson, 2001).

Cao (2007) studied the effects of improving asphalt mixture properties, properties of recycled tire rubber, and modified asphalt mixtures by using the dry process in order to minimize waste tire pollution. Three types of asphalt mixtures were tested. These contained different rubber contents (1%, 2% and 3% by weight of 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 crumb rubber in asphalt paving mixtures has long been proven successful due to good compatibility and interaction between rubber particles and asphalt binder, leading to various improved properties and performance of asphalt mixtures such as reclaimed asphalt pavement (RAP) and warm-mix asphalt (WMA).

Fontes, et al. (2010) illustrated that one of the alternatives to reduce permanent deformation in asphalt pavement layers is through the use of mixtures produced with asphalt crumb rubber which improves the properties of conventional asphalt. The test results confirmed that the use of asphalt rubber binder significantly improved resistance to rutting. However, the test results led to the conclusion that the characteristics of the asphalt rubber binders cannot be used to predict the permanent deformation resistance of the asphalt rubber mixtures.

Rokade (2012) stated that the use of plastic waste (LDPE) and Crumb Rubber- the rubber obtained from vehicle waste tires in the construction of flexible pavements is gaining importance. The author made an attempt to use waste plastic, Low Density Polyethylene (LDPE) and Crumb Rubber blends using the dry process for LDPE and wet process for CRMB. Marshal Method of bituminous mix design was carried out for varying percentages of LDPE and Crumb Rubber to determine the different mix design characteristics.

Xiao et al. (2009) investigated and evaluated the influence of the engineering properties of crumb rubber size and type on reclaimed asphalt pavement (RAP) mixtures. The experimental design for this study included the use of three rubber sizes and two rubber types (ambient or cryogenic) in the mixture, containing 25% RAP mixtures. The results of the experiment indicated that the addition of crumb rubber was helpful in increasing the voids in mineral aggregate in Superpave mix design, and improving rutting resistance of mixture regardless of rubber size and type.

The effects of adding crumb rubber to asphalt mixtures using the wet process were investigated by Wulandari and Tjandra (2017). The laboratory hot mix asphalt design tests were carried out through the Marshall Method procedure. In this study, two different crumb rubber contents (1% and 2% by weight of asphalt mixture) and two different crumb rubber sizes (#40 and #80) were investigated. A comparative study was carried out between the unmodified and modified asphalt concrete mixtures considering the Marshall Stability value and the volumetric properties. The results showed that crumb rubber is recommended as an additive to asphalt mixture as it tends to increase the strength and quality of asphalt mixtures.

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. Four types of gyratory compacted specimens of a dense grade mixture of asphaltic concrete were fabricated. The four specimen types comprised a control specimen without rubber, and three other specimens with 2% crumb rubber of varying sizes (1.18, 3.35 and 5.0 mm). Results showed that higher rubber–bitumen interaction can be obtained with the use of fine rubber size and high bitumen content, thus exhibiting greater rubber swelling particularly in the first 4h of curing.

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, and Palestine in specific. 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 previously conducted Marshall Test.

3.2 Tests Applied on Asphalt with Rubber

3.2.1 Softening point test (ASTM-D36/D36M-14e1) and Ductility test (ASTM-D113-17)

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

Table 1. Softening Point and Ductility Tests 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

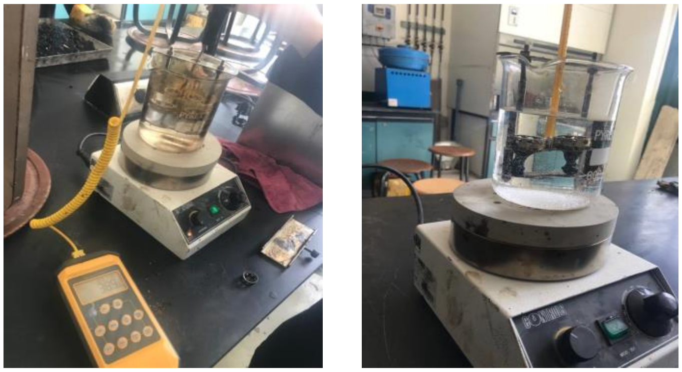

Figure 1. Softening Point test

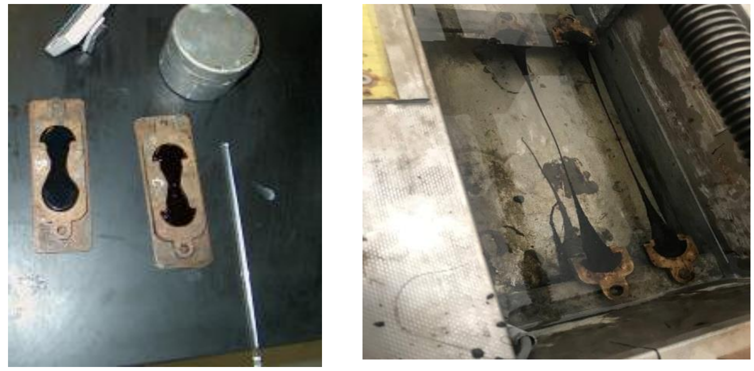

Figure 2. Ductility test

3.2.2 Marshall test (ASTM-D6927-15)

The total mix weight= 1200gm. The percentage of aggregate= 94.97%. Accordingly, total weight of aggregate= 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**

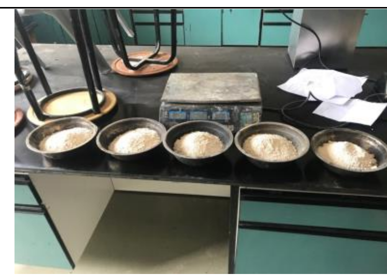

Figure 3. Preparation and distribution of aggregate samples

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, the air voids, the voids in mineral aggregates (VMA), Marshall Stability, flow, and 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

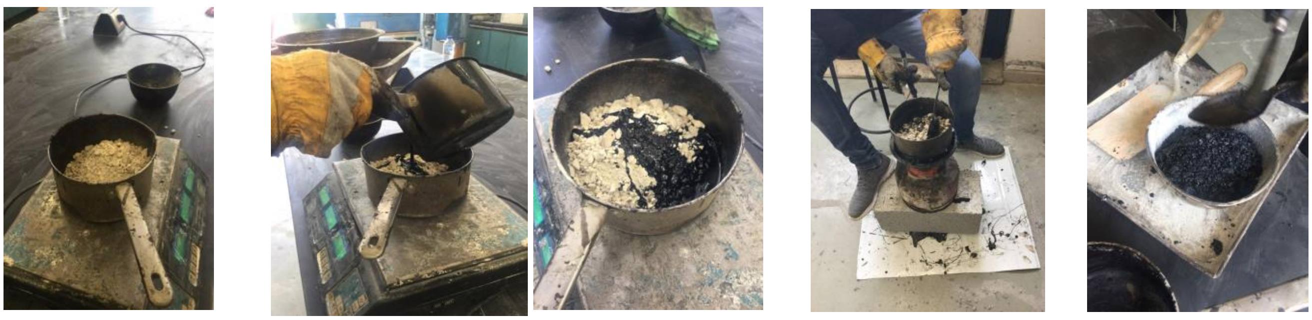

Figure 4. Mixing process of aggregates and bitumen with rubber

4 DISCUSSION

The following points illustrate the results of the previous section.

- The softening point increases with the increase of rubber percentage, while ductility decreases with the increase of rubber percentage.
- The unit weight decreases by increasing rubber percentage up to 15%. However, the unit weight increases up to 20% of rubber.
- The air voids decrease by increasing rubber percentage up to 15%. However, the air voids increase up to 20% of rubber.
- The voids in mineral aggregates decrease by increasing rubber percentage.
- The stability increases by increasing rubber percentage.
- The flow decreases by increasing 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 specifications. In Table 5, only 10% and 15% of rubber meet all specifications. However, the remaining 5% and 20% are not satisfied.

5 CONCLUSIONS AND RECOMMNDATIONS

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

- The addition of 10%- 15% of 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 maximum flow of 4 mm. The minimum VMA for 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.
- Waste tire rubber can be used in asphalt pavements with optimum ratio (10% -15% by weight of 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 the cost of paving works.

Table 5. Summary Table (Source: Federal Highway Administration, U.S. Department of Transportation)

% 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

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