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Research Paper

Investigating the Possibility of Using Roof Shingles Waste and Fibers in Stone Mastic Asphalt Pavements

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Abstract

In order to study the mechanical properties of stone mastic asphalt mixtures (SMA) which are used in roads pavement, the current study added various proportion of shingles (bituminous tiles with mineral aggregate coating) roofing (RAS), that are commonly used in sloping roofing, to SMA mixture containing 0.3% of added fibers. The percentage of 1, 2, 4, and 6% shingle particle wastes were respectively added to the SMA mixture samples on which Marshall Stability, moisture damage, dynamic creep and fatigue tests were performed. The comparison of the results revealed an agreement between the results from samples containing up to 4% of waste and normal samples. In addition, the mentioned samples were capable of providing the restrictions determined in the regulations. Thus, based on the results, it is suggested to use shingle wastes according to the suggested percentage. However, increasing the number of wastes will lead to a downward trend due to the disruption of uniform texture in the mixture.

Keywords: Marshall Stability, Fatigue, Moisture Damage, Dynamic Creep, Shingle Wastes

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1. Introduction

SMA mixtures are widely used in the top layer of high-traffic roads, mining access roads, racetracks, pavements of ports and airports of many developed countries. The limited resources and mines of raw materials and the growing importance of environmental issues have led studies to focus on recycling issues around the world and in various industries. Our homeland pavement industry is no exception to this rule. The most common methods in waste management includes incineration or landfilling and the creation of depot areas is one of the most fundamental problems, especially in issues related to urban management [Ahmed, 1993]. Studies by environmental organizations in the United States show that the country produces about 11 million tons of shingle waste annually. Around one million ton of this waste is in the production process and 10 million tons is related to the repair of roofs in residential areas, which constitutes about 8% of the total construction waste of this country [CIWMB, 2005]. Studies show that the use of 5% RAS in common hot asphalt mixtures improves the performance of these mixtures at low temperatures. Also, mixtures containing RAS show more resistance to rutting compared to control mixtures [Cooper .et al, 2014]. Laboratory research shows that the use of 10% RAS instead of aggregate in hot asphalt mix increases the cohesion of the mixture by 20 kPa compared to control samples. On the other hand, the internal friction angle is reduced by 20%. Therefore, based on the results, replacement of more than 10% of RAS with natural aggregates in hot asphalt mixtures is not recommended [Eachern, 2020]. Co-application of RAP and RAS in hot asphalts improves the behavior of these mixtures against moisture by 30 and 5%, respectively. Based on the results, the combination of RAP and RAS has a positive effect on the resistance of hot asphalt mixtures against rutting [Zhang, 2020]. The use of 5% RAS in hot asphalt mixtures improves the behavior of the mixtures against permanent deformations. In addition, the use of RAS in hot asphalt mixtures does not affect moisture resistance adversely. Research conducted at Oregon State University shows that hot asphalt mixtures containing RAP or RAS have no effect on the behavior of the mixture against cracking [Coleri, 2017]. The use of RAS or its combination with RAP in hot asphalt mixture makes it harder against temperature decrease and increase. Field visits of RAS-containing pavements show that the surface friction properties are in good condition in different rainfall and environmental conditions. According to the results of laboratory tests and field performance, it can be said that RAS can be a useful additive for hot asphalt mixtures. [Yang .et al, 2014]. Research shows that compared to mixtures containing RAP, mixtures containing RAS are harder at high temperatures and perform better against cracking in low temperatures. Also, based on the results of the current study, at moderate temperatures, RAP-containing mixtures showed poorer fatigue resistance in comparison to RAS-containing mixtures [Zieliński, 2018]. Based on a field study conducted in Washington State during 2009, asphalt core samples taken from RAS-containing asphalt pavement showed improved rutting resistance in comparison to the normal sample. However, there was no change in fatigue resistance and thermal cracks. Findings from the economic analysis of life cycle cost in asphalt pavements made with RAS in three levels of low, medium, and high traffic and two areas with hot and cold climates indicated their economic justification [Shirzad .et al, 2018]. As SMAs are one of the most resistant types of hot mix asphalts in which the transfer and reduction of load happens through the contact between aggregates [Babagoli et al., 2015]. Rutting resistance is one of the most significant features of SMAs, therefore, this type of mixture is widely used in countries around the world and is considered by design engineers and road construction professionals [Ziyari et al., 2015]. The chief disadvantage of SMA mixtures is their highcost as compared to HMA mixtures. However, according to economic analysis from multiple sources, their better performance during the pavements service period, lower maintenance cost, and improved pavement life time, make them the superior choice in long term[Titus .et al, 2006]. The high void between coarse aggregates and the relatively high consumption of bitumen and the thick coated bitumen of coarse aggregates in SMA mixtures is a factor for the bitumen to drain down during storage, transportation and distribution. Fibers are used as a type of stabilizer in SMA mixtures to prevent bitumen drain down and help it to reinforce. The most common types of fibers used in these mixtures are cellulosic and mineral fibers [Mohammad `Zade, 2011]. The use of Proplast fibers in SMAs has shown a useful role in reducing the bitumen drain down potential of these mixtures [Saedi .et al, 2018]. Studies show that beside the positive effects of using polyethylene terephthalate waste in SMAs, it significantly reduces the drain down of bitumen from the mixture [Ahmadinia et al., 2012]. According to another study, adding 5% of polypropylene waste to SMAs improves the performance of these mixtures compared to conventional hot asphalt mixtures. The results of multilayer elastic analysis show that the SMA pavement is modified with polypropylene as a surface layer is useful [Al-Hadidy, 2009]. The application of 0.3% of Viatop premium fibers, including cellulose fibers containing fatty arbocels, also has a beneficial role in reducing the potential for bitumen drain down in SMA mixtures [Saedi, Oruc 2020]. Also, the use of 0.3% by weight of the total mixture of Viatop premium fibers (cellulosic fibers with fatty arbocles) improves the fatigue resistance and the resistance of the mixture against permanent deformations [Irfan .et al, 2019]. Thus, the current study is aimed at reducing environmental problems, preserving material resources, improving the performance of SMA mixtures using economical additives and suggesting a convenient approach for production, distribution, and implementation stages.

2. Materials and Methods

2.1. Stone Materials

The aggregates used in this study are bazalts that were collected from Baghisli Machka in the southern part of Trabzon, Turkey. Qualitative mechanical tests were performed on samples and the results are described in Table 1.

Table 1. The Properties of Aggregates

haracteristic	Code	Unit	Results
Coarse specific gravity	ASTM C-127-15	gr / cm^3	2.625
Specific gravity	ASTM C-128-15	gr / cm^3	2.715

haracteristic	Code	Unit	Results
Filler specific gravity	ASTM C-128-15	gr / cm^3	2.735
Los Angeles abrasion	ASTM C-131	%	17
water absorption	ASTM C-127-15	%	0.75
Flat and Elongated	ASTM D-4791	%	14
Crushed content (two faces)	ASTM D-5821	%	98

Figure 1, shows the grading curve of the aggregates used in the mix [ASTM C136].

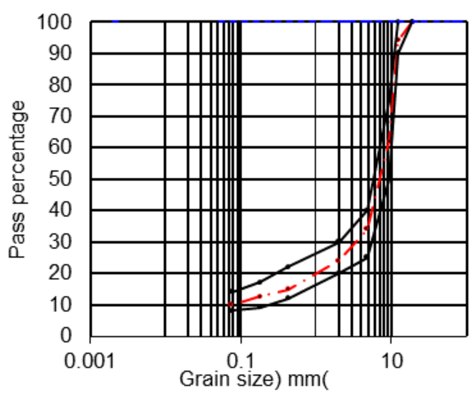

Figure 1. Granulation curve

2.2. Bitumen

The bitumen used in this study is 60.70 modified with 5% SBS produced by Pasargad Oil Company, the characteristics are presented in Table 2. According to research, the optimal amount of SBS copolymer for bitumen modification is 5% [Mokhtari, 2012], [Ghasemi, Marandi, 2010], [Khodaii, Mehrara, 2009].

Table 2.The physical properties of asphalt cement

Test	Code	Unit	Results
Ductility	ASTM D-113	Cm	107
Softening point (R&B)	ASTM D-36	˚C	50
Penetration at 25 °C	ASTM D-5	mm / 10	63
Flash point (°C)	ASTM D-92	˚C	338
Specific gravity	ASTM D-70	gr / cm^3	1.028
Solubility in trichlorethylene	ASTM D-2042	%	93.99

2.3. Fibers

The fibers used in this study are Viatop premium made of cellulose fibers which are manufactured by JRS company in Germany. The characteristics of fibers used in this research are presented in Table 3.

Table 3. The Properties of Viatop premium

Property	Results
Amount of cellulose	90% ARBOCEL ZZ 8.1
Amount of 70/50 bitumen	10%
Length of the fibers	2- 6 mm
Fiber thickness	3 mm
Ignition temperature	500 degrees Celsius

2.4. Shingle Wastes

The shingles used in this research are related to roof shingles produced by Yaltex Company in Turkey. The diameter of the shingle grains used in the mixture varies between 5 to 13.5 mm.

2.5. SMA Mixed Design

The current study applied modified Marshall method and ASTM D1559 code to determine the optimal bitumen percentage and mixing design. Since the main factor of empty space in sample is compacted in the design of SMA mixtures, the mean value of the empty space interval provided in the regulation is used to determine the optimal bitumen percentage and the minimum empty space of stone materials has a controlling role [Brown, 1997]. Marshall samples were prepared by increasing the percentage of bitumen in 0.5% steps from 4.5 to 7 and compacted by applying 50 blows to the upper and lower surfaces with a Marshall hammer. After determining the optimal bitumen content of the mixture according to the recommendations of Viatop Premium fiber manufacturer, It was added to the mixture at the rate of 0.3% of the total weight of the mixture. Also, shingle wastes with percentages of 1, 2, 4 and 6% of the total weight were added to the mixture. The image of the prepared samples is presented in Figure 2.

Figure 2. prepared samples

2.6. Marshall Quotient

The Marshall quotient reflects the stiffness and strength of the asphalt mixture against permanent deformation. The increase in the index value improves the resistance of asphalt mixtures against deformation [Sengul, 2010].

2.7. Moisture Damage

Latman has provided an indirect tensile test to predict the moisture sensitivity of the asphalt mixure under real traffic service conditions. In this test, which is according to the AASHTO T283 code, one group of samples is tested under dry condition and another group is processed before the test. Indirect tensile strength ratio (TSR) is obtained from the indirect tensile strength ratio of saturated to dry samples. [Saedi, Oruc, 2020]

$$ITS = \frac{2Pmax}{\pi Dt} \quad (1)$$

$$TSR = (ITS^{3}{}_{wet}/ITS^{4}{}_{dry}) \times 100 \quad (2)$$

2.8. Dynamic Creep Test

The purpose of dynamic creep test is to determine the amount of rutting due to dynamic loads on the asphalt mixture. According to ASTM D6927 standard, in this semi-sinusoidal loading (the sample is subjected to loading and rest time alternately) the test can be performed at different temperatures. [Oruc, Yilmaz, 2016]

$$\varepsilon c= (3n - L1)/G \quad (3)$$

$$\varepsilon r= (L2 - L3)/[G - (L3 - L1)] \quad (4)$$

$$\sigma=F/A \quad (5)$$

$$Ec=\sigma/ \varepsilon c \quad (6)$$

$$Er=\sigma/\varepsilon r \quad (7)$$

Where:

Ɛc : Plastic strain
Ɛr : Elastic strain
Ec : Plastic module
Er : Elastic module
σ : Stress

2.9. Indirect Strain Fatigue Test

Road paving materials are short time loaded due to the passage of any vehicle. Repetition of loading process leads to a decrease in cross-section and ultimately causes small breakdowns, the accumulation of which leads to a general

[3] Wet Indirect tenseil stress
[2] Dry Indirect tenseil stress

breakdown in pavement. In the indirect tensile fatigue test, the asphalt sample is subjected to repeated loading conditions until failure. In this test, the samples are tested under the influence of different sources of stress. Fatigue life (N_f) is calculated based on the amount of stress leading to failure from logarithmic graphs or the following equation.

$$N_f = K_1 \left(\frac{1}{\sigma}\right)^{K_2} \quad (8)$$

where:

N_f: Fatigue life

K_1, K_2: Material properties dependent coefficients

σ : Stress

3. Results and Analysis

3.1. Results of SMA Design

The steps in mixing process were performed by the modified Marshall method and the amount of optimal bitumen was the calculated which are illustrated in Table 4.

Table 4. Results of Marshall method

Optimal bitumen	Specific gravity of the mixture (gr / cm3)	Theoretical specific gravity of the mixture (gr / cm3)
6.85	2.304	2.380
Vh (%)	**Vma (%)**	**Vf (%)**
3.19	17.27	81.52

According to the results, 6.85% of bitumen was determined as the optimal percentage of bitumen in the mixtures and other parameters of the samples prepared with this percentage of bitumen met the conditions listed in the code.

3.2. The Results of Marshall Quotient

As presented in Figure 3, samples containing 4% RAS had a better index in comparison to other samples. Also, by increasing the weight percentage of waste in the mixture, the materials can replace rock materials which can lead to a decrease in the Marshall quotient. Therefore, it is suggested that increasing the amount of waste up to 4% can raise the stiffness of the mixture, and the mixture can show better resistance against permanent deformation. The results of these experiments and the decreasing trend of the index after reaching the maximum value, show a favorable convergence with the results of the experiments performed by Mr. Sengoz et al. that are given in their paper named “the study of the use of shingles in HMA” [Sengoz, Topal, 2005].

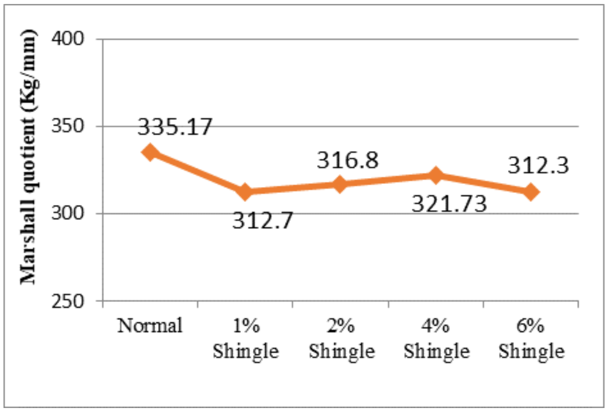

Figure 3. Marshall quotient results

3.3. Evaluating the Results of Moisture Failure

Indirect tensile strength (ITS) values are shown in Figure 4. The results show that by increasing the percentage of waste in the mixture, the tensile strength of the mixture decreases. The reason lies in the increased amount of mixed voids due to the increase in the weight percentage of waste.

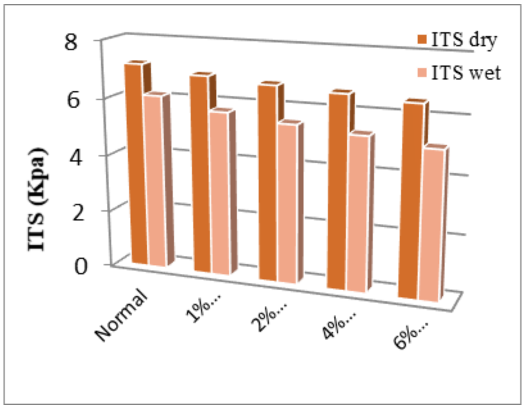

Figure 4. Results of indirect tensile strength test

The results of the tensile strength ratio of the samples in Figure 5 show a decrease in the ratio as a result of an increase in the percentage of waste indicating that samples containing 6% weight of RAS cannot meet the 80% TSR standard specified in the regulations.

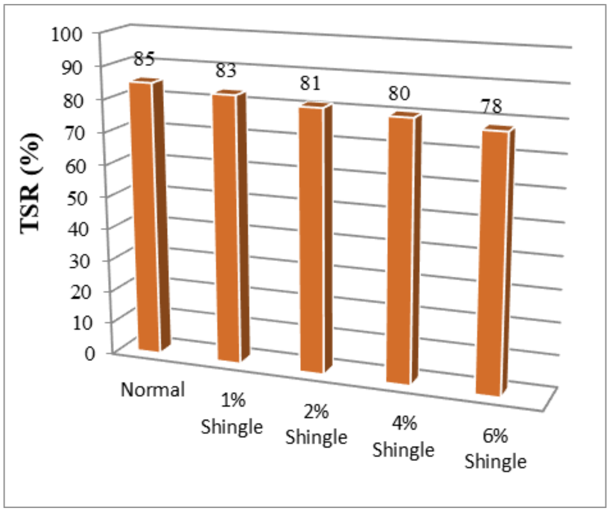

Figure 5. Tensile strength ratio evaluation results

3.4. The Results of Dynamic Creep Test

The flow number from the dynamic creep test results is shown in Figure 6. According to the illustration, increasing weight percentage of RAS results in an increase in the resistance against rutting. The reason can be attributed to the effect of the hardening monomer composition of styrene used in the mixture and the increase in coarse particles caused by RAS waste. The use of waste in SMA mixtures shows better performance results against rutting.

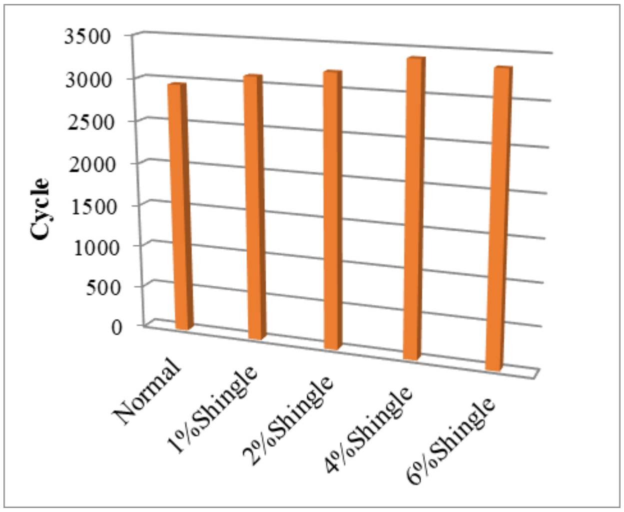

Figure 6. Dynamic creep test results

3.5. The Analysis of Fatigue Test Results

The test results are presented in Figure 7. Repeated loading was done until the samples reached 4 mm deformation at 25°C. The increase in the weight percentage of RAS resulted in an increase in the number of loading cycles up to a complete deformation.

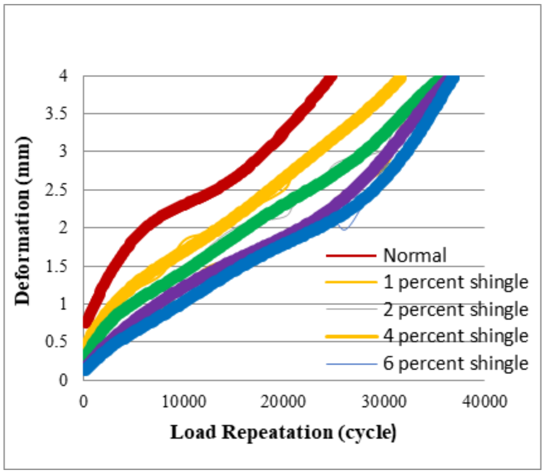

Figure 7. Fatigue test results

Experimental results showed that the addition of RAS wastes improved the hardness of the SMA mixture. Following an increase in the weight percentage of RAS, we observed an increase in the loading cycle which was about 40%.

4. Conclusion

The current study was aimed at evaluating the effect of shingle wastes on the mechanical properties of stone mastic asphalt mixture. According to the mentioned cases, the following results are presented:

1. Adding RAS waste to the mixture, in addition to environmental benefits, leads to an increase in the flow index of the mixture. This can improve the resistance of mixtures to permanent deformation.
2. Tensile strength of SMA mixtures decreases with increasing RAS wastes. The reason for this can be seen in the increase of empty spaces and disruption of the uniform texture of the mixture.
3. The ratio of the amount of tensile strength decreases with an increase in the number of losses. Samples containing 6% are not able to provide the standard criteria. Therefore, the use of more than 4% of waste weight is not recommended in this mixture.
4. The results of creep test indicate that increasing the empty space has no effect on the resistance of SMA mixtures against rutting. Also, the combination of modified fibers and bitumen that have better adhesion and elastic properties with coarse aggregate particles and RAS wastes in the mixture improves the transfer conditions and discounts the load to improve the behavior of the mixture against rutting.
5. The use of RAS waste in SMA mixtures improves the fatigue resistance of these mixtures against repeated loading. Therefore, the use of waste reduces the costs of maintenance and reconstruction due to fatigue.

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