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Use of Waste Phonolite as Filler Material in Flexible Asphalt Pavements

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In the scope of the study, the use of waste phonolite (PW) obtained from phonolite wastewater formed during the processing of phonolite stone blocks as filler in hot-mix asphalt (HMA) was investigated. For this purpose, samples were produced with 4 %, 5 %, and 6 % PW mineral filler and 5 % limestone (LS) mineral filler. Phonolite supplied as waste was sieved through a sieve no 200 and made ready for use as a filler. HMA specimens were prepared with PW and LS at the rates of 3.5 %, 4 %, 4.5 %, 5 %, 5.5 %, and 6 % bitumen. For each filler ratio, a bituminous hot mix design was made by the Marshall method and optimum bitumen ratios (*OBR*) were determined. Bituminous hot mixture specimens were prepared based on *OBR*. Retained Marshall stability (*RMS*) test, indirect tensile strength (*ITS*), and moisture damage resistance tests and Marshall stability (*MS*) test after the freeze-thaw (F-T) cycle was applied to the prepared Marshall samples. The results obtained were evaluated according to the Turkish Highway Technical Specification (HTS). As a result, it was determined that the PW could be used as filler in HMA under low-intensity traffic.

Keywords: Marshall design, hot mix asphalt, phonolite waste, mineral filler, sustainability.

1. INTRODUCTION

Industrialization and technological developments have brought urbanization and rapid population growth, which has increased the negative effects of human activities on the environment. The production and marketing activities that took place in this process caused more consumption of natural resources. Waste from consumption is constantly increasing and poses a threat to humanity. If the resulting wastes are not recycled effectively, efficient use of the world's resources will not be possible. In addition, the world economy is supported by recycling [1].

It has been stated by the World Bank that waste production is increasing day by day. It is predicted that by 2030, 2.59 billion tons of waste will be generated annually in the world. By 2050, the world's waste generation is expected to increase by 70 %, from 2.01 billion tons in 2016 to 3.40 billion tons [2, 3]. Recycling and disposal options are evaluated in waste management [3, 4]. Considering the current amount of waste and its potential increase, recycling of waste rather than disposal will be more important for sustainability.

Phonolites; Although it is a rock rich in nepheline, sodium feldspar and potassium feldspar, it also contains amphibole, cancrinite, biotite, plagioclase, pyroxene, sodalite minerals. When classified according to their total alkali and silicon content, they consist of SiO_2 in the range of 50 – 65 % and $Na_2O + K_2O$ in the range of 12 – 16 %. Between felsic and mafic depends on the chemical composition and brown, cream, gray, green, white, pink, etc. phonolites, a volcanic rock with colors; They show aphanitic (fine-grained) and porphyritic (mixed fine and coarse-grained) texture characteristics. Since they have a hardness strength (Mohs) of 5.5-6 according to the mineral content they contain, they are used for floor and wall coverings, exterior cladding, stair steps, paving stones, historical building restoration, interior decoration, etc. are used for the purposes [5].

A country's economy relies heavily on its transportation systems. Most road networks consist of flexible pavements that offer good engineering performance. Hot mix asphalt (HMA) has been preferred as a pavement coating worldwide for more than a century [6]. HMA consists of a combination of asphalt cement and aggregates. While aggregate forms the structural skeleton of the pavement, asphalt cement acts as the adhesive of the mixture. The mineral aggregate containing all the coarse and fine particles in the mixture constitutes approximately 90 % of the HMA volume. Aggregate has a direct and significant impact on the performance of asphalt pavements [7, 8]. HMA is the most widely used coating type in pavement due to its various advantages such as stability, water resistance and driving comfort [8 – 10].

The increase in axle loads and traffic volume within the permissible limits necessitates higher quality pavement materials. The main purpose of highway design is to transport expected loads in a safe, economical and durable manner. For this purpose, many researchers and engineers have turned to choosing pavement materials that can reduce the severity of deterioration and improve the performance of the pavement [11].

It is a viscoelastic composite material consisting of asphalt concrete, bitumen, coarse, fine and filler materials. Studies have shown that limestone has a significant effect on the performance of the pavement [12].

The filler material is defined as aggregate passing through a 0.075 mm sieve. The filler material not only improves the impermeability and density of the mixture by filling in between larger aggregates, but also helps to change the viscosity and consistency by wrapping the bitumen film.

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With this feature, filler plays an active role in various pavement problems such as material, rutting, cracking at low temperatures, moisture sensitivity [13].

With the use of waste materials in hot bituminous mixtures, the demand for natural materials, energy consumption and storage and disposal problems of waste materials are reduced [14]. Looking at the literature, it is seen that the use of waste materials in superstructures is based on many years. Especially, the waste materials used as fillers include tire-derived fuel fly ash [15], fluorescent lamps waste [16], Boron waste [17], Waste bleaching clays [18], incinerated acidic sludge [19], coal waste powder [20], industry wastes [21], rice husk ash [22], recycled waste lime [23], andesite waste [24], bauxite residue [25], red mud waste [26], brick powder [27], waste ceramic powder [28], and waste glass powder [29], etc.

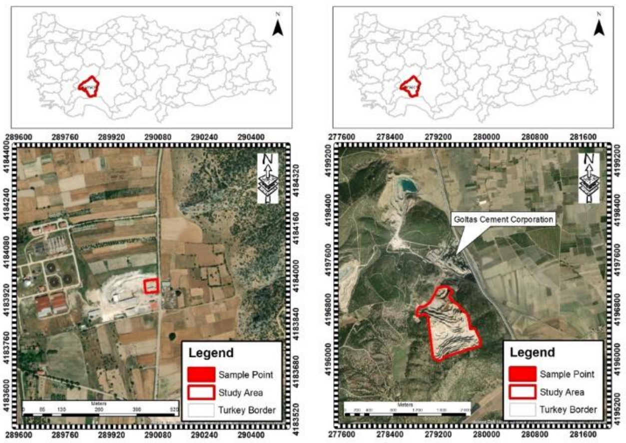
In this study, the effect of using waste phonolite (PW) as filler material on HMA was investigated. PW was supplied from the province of Isparta and added to the asphalt mixture.

2. MATERIALS

In this section, information about aggregate, bitumen, and mineral fillers used in experimental studies is given.

2.1. Aggregates

The limestone (LS) aggregate used in this study was obtained from a quarry in Isparta, Turkey (Fig. 1 b). The PW used in the study was obtained from the natural stone processing factory operating in the Isparta region (Fig. 1 a), and LS was used as the control sample (5 % LS). In terms of gradation of the mix, a coarse aggregate of 53 %, passing between 25 – 4.75 mm sieves, a fine aggregate of 42 %, passing between 4.75 – 0.075 mm sieves, and a filler of 5 % was used. As a result of the applied sieve analysis, it was determined that the mixture was within the limits determined by the Turkish Highways Technical Specification (HTS) [30].



a b

Fig. 1. Locations: a – LS; b – PW

The grading curve for the aggregate utilized in this study was close to the wearing course as shown in Table 1. The physical and mechanical properties of the aggregates used in the study were determined in accordance with American (ASTM) standards and are given in Table 2.

Table 1. Grain-size distributions of the LS

Sieve diameter		Limit values passing, %	Gradation of mixture passing, %	Weight, g
Inch	mm			
		%	%	gr
3/4"	19	100	100	0
1/2"	12.5	88 – 100	94	69
3/8"	9.5	72 – 90	81	149.5
No.4	4.75	42 – 52	47	391
No.10	2.00	25 – 35	30	195.5
No.40	0.425	10 – 20	15	172.5
No.80	0.180	7 – 14	10.5	51.75
No.200	0.075	3 – 8	5	63.25
Filler	-	-	0	57.50
Total		100 %	100 %	1150

Table 2. Physical and mechanical properties of aggregates

Samples	Apparent specific gravity, g/cm^3	Bulk specific gravity, g/cm^3	Water absorption, %	Standard
>Sieve number: 4 (coarse aggregate)	2.711	2.686	0.40	ASTM C127
Sieve number: 4-sieve number: 200 (fine aggregate)	2.715	2.662	0.60	ASTM C128
Filler of limestone	2.729	-	-	-
Aggregate tests	Value	Limit		Standard
Abrasion loss value, %	22	≤ 27		ASTM C-131-89
Percent fractured faces, %	100	≥ 100		ASTM D5821
Polish value	54	≥ 50		ASTM C 3319
Flatness index, %	19.1	≤ 25		ASTM D 4791

2.2. Bitumen

Bitumen with a penetration of 50 – 70 (it was found to be 58 in this study) was used while preparing the asphalt concrete samples. Various conventional bitumen tests such as penetration, softening point, burning point, specific gravity, flash point have been carried out to determine the basic properties of the bitumen binder. The physical properties of the bituminous binder used in the study are given in Table 3.

2.3. Waste phonolite

The PW used in the study was taken from the natural stone processing factory of Isparta municipality (Fig. 1 a). PW was obtained from phonolite processing wastewater formed during the shaping of phonolite stone blocks (Fig. 2). The PW material was sieved using No.40 (0.425 mm), No.80 (0.180 mm), and No.200 (0.075 mm), sieves. In the sieve analysis results, it was seen that 100 % of the PW passed through No.40 sieve, 98.3 % through

No.80 sieve and 83 % through No.200 sieve. These grain sizes showed that PW could be used as filler material.

Table 3. Physical properties of the asphalt binder

Characteristics of Bitumen / Source Aliağa/Türkiye		
Test	Average values	Standard
Penetration grade	50 – 70	-
Penetration, 25 ºC	59	ASTM D5
Flash point, ºC	290 ºC	ASTM D92
Softening point, ºC Loss on heating, %	51 °C 2.0	ASTM D36 ASTM D6
Ductility (5 cm/minute at 25 ºC)	> 100 cm	ASTM D113
Specific gravity at 25 °C	1.033	ASTM D70
Viscosity at 135 °C	0.408 Pa·s	ASTM D4402-06

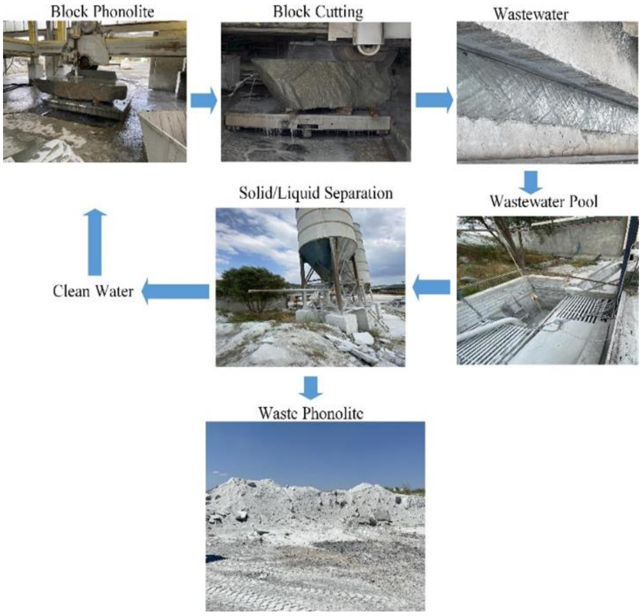


Fig. 2. Phonolite processing plant flow chart

Scanning Electron Microscopy (SEM) images of LS and PW samples are given in Fig. 3. It is seen that the LS and PW samples have a similar granular structure. It has been observed that the grain sizes of both materials are similar to each other and the PW grains are angular. It is known that the angular structure of the aggregate in hot bituminous mixtures increases the interlocking [14]. Therefore, the angularity of PW supports the use of fillers in hot mixes.

The chemical properties of the phonolite material were obtained from the natural stone processing factory of Isparta municipality, where the PW was supplied. The chemical properties of the PW and LS used as fillers in the study are given in Table 4.

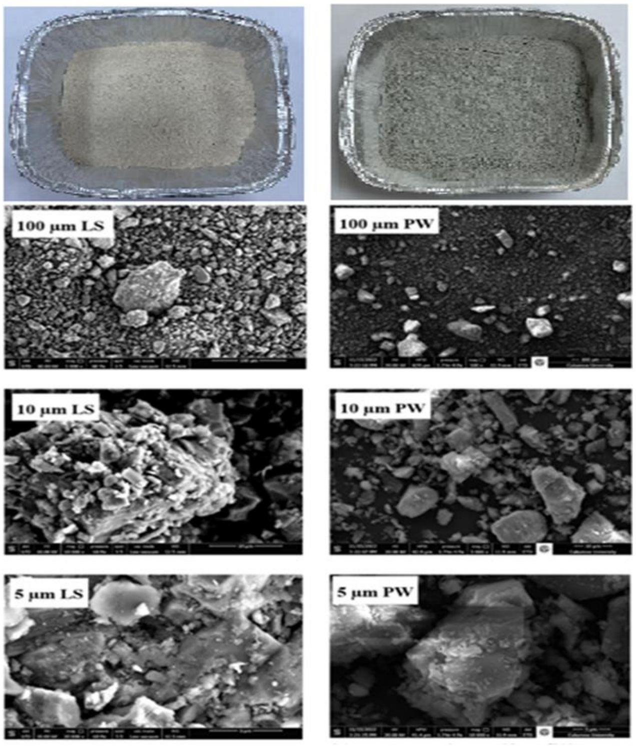
Table 4. Chemical properties of phonolite [31] and limestone [31]

Chemical analysis (phonolite), %							
CaO	MgO	Fe_2O_3	SiO_2	Al_2O_3	Na_2O	K_2O	SO_3
3.90	1.20	6.29	55.02	18.86	5.59	5.48	0.06

Chemical analysis (limestone), %					
CaO	MgO	Fe_2O_3	SiO_2	Al_2O_3	LOI
55.41	0.001	0.002	0.001	0.001	44.54

3. METHOD

To investigate the usability of PW as fillers in HMA concrete, hot mix samples were prepared using the Marshall design method according to ASTM D1559.



a b

Fig. 3. SEM analysis results: a – LS samples; b – PW samples

The flow chart showing the experimental work is given in Fig. 4. According to this, samples were prepared with four different filler ratios (4 %, 5 %, 6 % and 5 % LS) and bitumen content in six different ratios (3.5 %, 4 %, 4.5 %, 5 %, 5.5 % and 6 %) and submitted to the Marshall experiment. has been subjected. Three samples were created for each ratio and a total of 72 (4 × 6 × 3) samples were prepared. The Marshall design test, Retained Marshall stability (*RMS*), Marshall stability (*MS*) and flow tests after the F-T cycle, indirect tensile strength (*ITS*), and moisture damage resistance tests were performed. The optimum bitumen content of different aggregate mixtures is found by the Marshall design test. After the aggregates are heated to 165 °C and the bitumen to 160 °C, the materials are combined and mixed in a controlled manner. The mixture placed in the mold is compacted 75 times (represents that it is under heavy traffic) with the Marshall hammer. After the samples are prepared, stability, flow, density and void analysis are performed using MS and a flow tester [17].

While calculating the OBR for the mixture design, the average is taken using the four bitumen contents given below in the light of the graphics above. The optimum bitumen ratio for the limestone aggregate was calculated using Eq. 1. While calculating the OBR for the mixture design, the average is taken using the four bitumen contents given below in the light of the graphics above.

The optimum bitumen ratio for the limestone aggregate was calculated using Eq. 1.

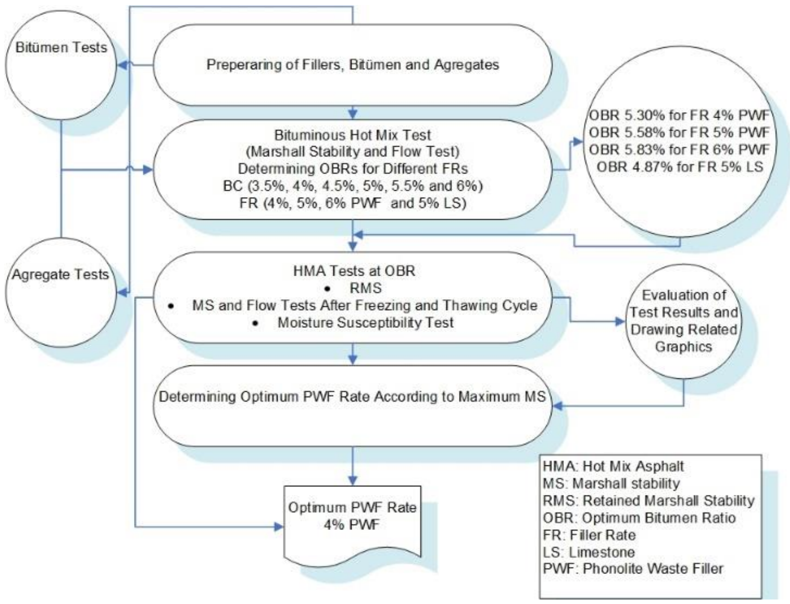


Fig. 4. Flow chart of laboratory works

1. The amount of bitumen giving the maximum practical specific gravity;
2. Bitumen amount corresponding to 4% void percentage;
3. Bitumen content corresponding to 70% voids filled with bitumen;
4. Bitumen content giving maximum stability.

LS aggregates *OBR* for 5 %filler rate:

$$\frac{4.79 + 5.25 + 4.77 + 4.68}{4} = 4.87. \quad (1)$$

The flow value corresponding to this ratio is 3.44, which is below the maximum values in the specification [30].

The Marshall Quotient (*MQ*) value, which is accepted as an indicator of the hardness and resistance to deformation of hot bituminous mixtures, can also be calculated with the Marshall test. *MQ* is obtained by dividing the stability value by the flow value [33, 34].

The *RMS* test is a test applied to determine the resistance of hot bituminous mixtures against moisture damage. In the experiment, the samples are kept in a water bath at 60 ± 1 °C for 24 hours and then subjected to the Marshall test. The *RMS* value is determined by proportioning the stability value of the samples kept in these conditions to the normal stability value. Mixtures with high RMS values are expected to have high resistance to moisture damage [33, 34].

The RMS was then found through the average stability of each group using the following Eg. 2:

$$RMS = \frac{MS_{cond}}{MS_{uncond}} * 100, \quad (2)$$

where *RMS* is retained Marshall stability; MS_{cond} is average *MS* for conditioned specimens, kg; MS_{uncond} is average *MS* for unconditioned specimens, kg.

During the service life of asphalt pavements, freezing-thawing, drying-wetting, cold-hot, snow, etc. is subject to many influences. As a result of these effects, reductions in the mechanical properties of the flexible pavement may occur over time, resulting in the deterioration of the flexible pavement. In the study, Marshall samples were subjected to five freeze-thaw (F-T) cycles in the air-conditioning cabinet as recommended in the AASHTO T283-2008 standard, and then the MS test was performed on the samples. A cycle consists of two stages. In the first stage, the sample was frozen at -18 °C for 16 hours, and in the second stage, it was left to thaw at 60 °C for 24 hours [35].

The *ITS* is a method used to determine the strength of cylindrical specimens by subjecting them to compressive loads along the vertical diametral plane using Marshall loading equipment. This results in uniform tensile stresses perpendicular to the direction of the applied load and along the vertical diametral plane, leading to the splitting of the specimen along the vertical diameter upon failure. The *ITS* value is calculated by determining the maximum load that the specimen can withstand before failure, using Eq. 3 [36]. The *ITS* test is conducted at a temperature of 25 °C and a loading rate of 50.8 mm/min, utilizing the Marshall apparatus, as per the ASTM D6931-17:2017 Standard Test Method for Indirect Tensile (*IDT*) Strength of Asphalt Mixtures.

$$ITS = \frac{2P_{max}}{\pi t d}, \quad (3)$$

where *ITS* is the indirect tensile strength, kPa; $P_{\max}$ is the ultimate applied load required to fail specimen, kN; *t* is the thickness of the specimen, mm; and *d* is the diameter of specimen, mm.

Moisture sensitivity refers to the resistance of plastic coatings to internal moisture movement enclosure damage after contact with water. The presence of water or moisture in the coating weakens the bond between the bitumen and aggregate and causes deterioration in the coating. Moisture sensitivity in hot mix coatings is determined by the AASHTO T283 standard. According to the standard, hot mix samples are evaluated by dividing them into two groups as “unconditioned” and “conditioned”. Unconditioned samples are kept in a water bath at 25 °C for 2 hours. Conditioned samples, on the other hand, are subjected to vacuum treatment so that the air spaces of the samples are filled with 60 – 80 % water. After that, the samples are wrapped with cling film and kept in the freezer at -18 °C for 16 hours, and at the end of the time, these samples are kept in a water bath at 60 °C for 24 hours. At the end of the time, the samples taken from the bath are kept in the bath at 25 °C for 2 hours. After these procedures, unconditioned (ITS_{dry}) and conditioned (ITS_{wet}) samples are subjected to the *ITS* test using the Marshall device. As a result of the test, the indirect tensile strength ratio (*TSR*) values of the mixture samples are calculated with the help of Eq. 4. *TSR* values of HMA samples are required to be more than 80% in terms of their resistance to moisture damage caused by water [37].

$$TSR = \frac{ITS_{wet}}{ITS_{dry}} * 100, \quad (4)$$

where ITS_{wet} is the indirect tensile strength for soaked specimens kPa; ITS_{dry} is the indirect tensile strength for dry specimens, kPa.

4. EXPERIMENTAL RESULTS AND ANALYSIS

4.1. Results of the Marshall stability and flow test

Three different ratios of PWF (4 %, 5 %, 6 %) and HMA samples were prepared, with 5 % LS as the control sample. Marshall designs were made on each prepared HMA sample. HMA samples were prepared to remain within the gradation limits specified in the specification for the wear layer. Three samples were formed at the bitumen ratios of 3.5 %, 4.0 %, 4.5 %, 5.0 %, 5.5 % and 6.0 % and from each ratio.

MS test was carried out by measuring the weight of the samples in water, weight in air and saturated surface dry weight. *OBR* was calculated separately for each filler ratio. The *OBR* values for 4 %, 5 % and 6 % phonolite and 5 % LS fillers were found to be 5.30, 5.58, 5.83 and 4.87 %, respectively. The relationship between *MS* and bitumen is given in Fig. 5.

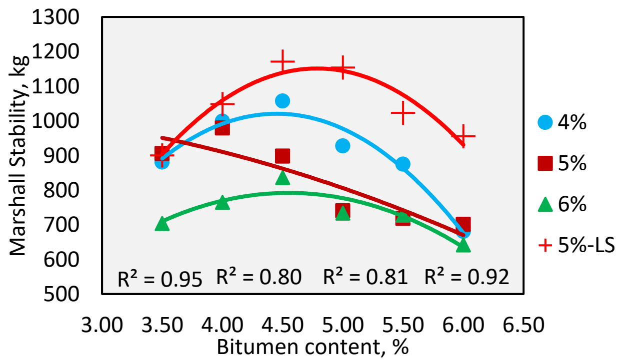


Fig. 5. Relationship between *MS* and percentage of asphalt

According to *MS* test results, *MS* values decreased as the amount of phonolite waste filler by weight in the mixture increased. Especially at the rate of 6 % of phonolite filler waste, significant decreases are observed in the stability values. The most important reason for this is that when the amount of filler is 6 %, it increases the bitumen absorption, which reduces the *MS* value. Maximum stability values for 4 %, 5 %, 6 % and 5 % LS series at optimum bitumen rates were obtained as 1057, 979, 836 and 1171 kg, respectively. Except for samples containing 6 % PWF, the stability values of the samples were higher than the minimum stability limit value recommended for the wear layer in the specification (900 kg). The highest stability value in the samples produced with phonolite waste fillers was obtained at 4 % phonolite filler content. However, the stability value of the control sample (5 % – LS) was higher than the stability value of all samples.

The maximum MS values showed a proportional relationship with the filler content. According to the findings, the maximum stability value of the mixture with the ratio of 5 % LS filler was obtained as 1171 kg (Fig. 6).

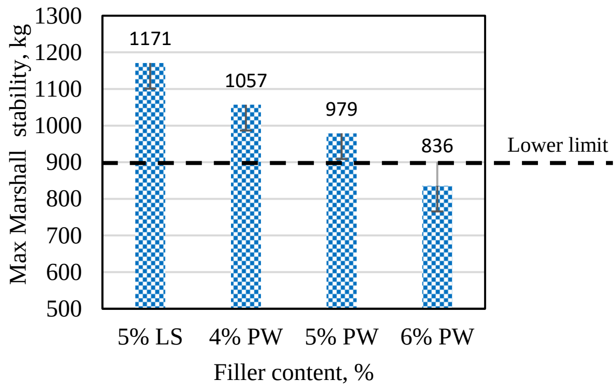


Fig. 6. Relationship between maximum stability and filler content

Another important property of HMA is density. Fig. 7 shows the percent bulk specific gravity of bitumen. As the density of HMA increases, various physical properties such as the strength and stability of asphalt concrete also improve.

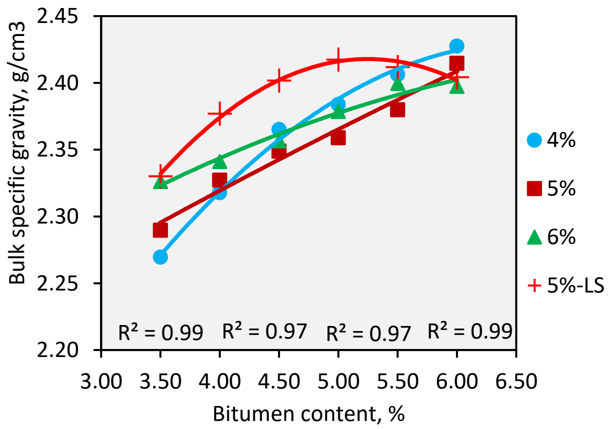


Fig. 7. Relationship between bulk specific gravity and percentage of asphalt

The highest specific gravity was obtained from samples containing 4 % and 5 % PWF. The maximum specific gravity of the samples containing 4 %, 5 %, and 6 % PW and 5 % LS were found to be 2.404, 2.428, 2.407 and 2.309 g/cm^3, respectively. It was observed that the density value increased as the filler ratio increased (Fig. 8).

Maximum specific gravity values were obtained in the samples produced using 4 % and 5 % phonolite waste. Specific gravity values of 5 % LS control sample and samples containing 4 %, 5 % and 6 % phonolytic waste fillers; 2.404, 2.428, 2.407 and 2.309 g/cm^{3}respectively (Fig. 8).

When the results are examined, it is seen that the density of the samples containing 4 % and 5 % phonolite fillers is higher than the control sample. When the samples produced using PWF were examined, it was determined that the highest density value was reached at the rate of 4 % PW.

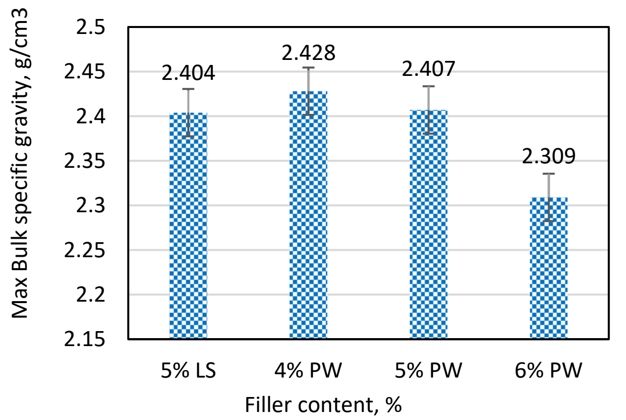


Fig. 8. Relationship between maximum bulk specific gravity and filler content

According to the results obtained, it was revealed that there are strong relationships between maximum specific gravity and phonolite fillers. When 4 % phonolite filler was added to the HMA sample as material, the maximum mass specific gravity value was found as 2.428 g/cm^3. Fig. 8 shows the filler added to the mix as 4 %, the denser bituminous mix was obtained. If the PW filler ratio is set as 4 %, improvements in the resistance of asphalt concrete against deterioration are predicted [1].

Vfa plays an active role in the plasticity, friction coefficient and strength of the mixture and ensures that the aggregates are covered with a bitumen film around them. If the Vfa is low in the mixture, there is a decrease in the strength of the HMA [1]. It has been checked whether the OBR meets the specification limit (≤ 75 %).

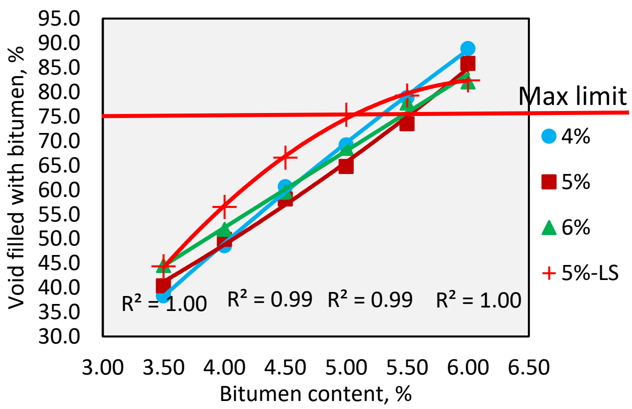


Fig. 9. Relationship between Vfa and percentage of asphalt

The Vfa values of the samples containing 4 %, 5 % and 6 % PW filler material were found to be 75.45, 75.81 and 80.61 %, respectively. The Vfa value of the mixture containing 5 % LS filler was calculated as 72.8 %. The percentage of bitumen corresponding to 70 % of Vfa was used while determining the *OBR*. According to HTS, the Vfa value in the wear layer should be below 75 % [30].

The lower and upper limits for Vh are specified in the specification. If it exceeds the upper limit, a decrease in the stability of the HMA or early deterioration of the pavement may occur [38]. The Vh values of the mixtures with 4 %, 5 %, 6 % PW and 5 % LS were determined as 3.52, 3.7, 2.93 and 3.78 %, respectively. It is seen that with the increase of the PWF amount, the voids are filled with more filler material and the void value falls below the specification values in the samples produced with 6 % PWF.

According to HTS, the Vh value for the wear layer should be between 3 % and 5 % (HTS, 2013). If filler material is added to the HMA, it becomes easier to settle the fine aggregates in the mixture. As a result, the Vh value of the mixture decreases. Fig. 10 shows the relationship between each Vh percentage and the bitumen ratio. Looking at the results, it was seen that all Vh percentages except 6 % PW were within the specification limits.

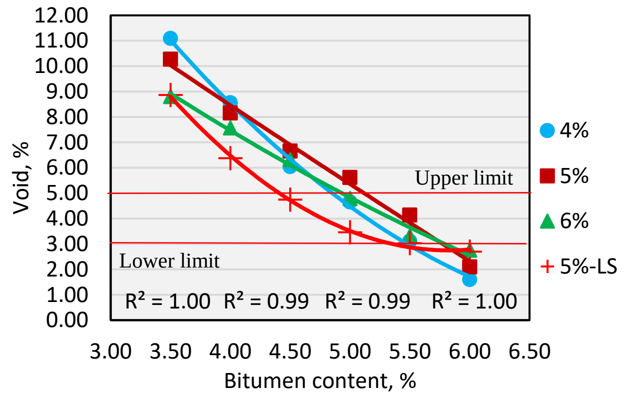


Fig. 10. Relationship between the percentages of Vh and asphalt

VMA consists of bitumen and Vh volume in mix aggregates. The void ratio in aggregates is of great importance in terms of interlocking and strength of the grains [38].

In mixes including 4 %, 5 %, 6 % and 5 % LS filler, the percentage of void in mineral aggregate in relation to the optimum level of bitumen were found to be 14.64, 15.35, 15.15 and 14.04 %, respectively. It is seen that all mixtures have values in accordance with the HTS. The relationship between the percentage of void in mineral aggregate and bitumen content is shown in Fig. 11.

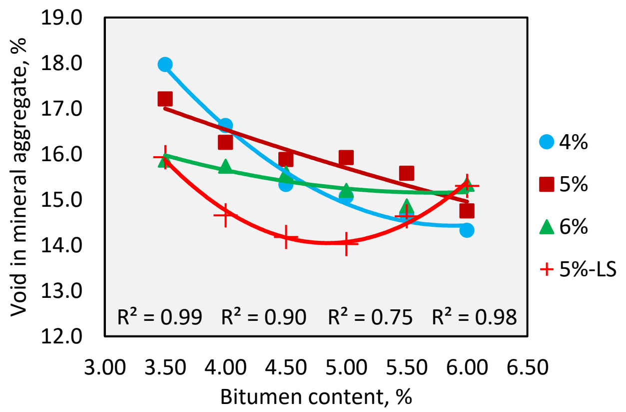


Fig. 11. Relationship between the percentages of VMA and asphalt content

Marshall flow value provides information on the plasticity and flexibility of HMA samples [1]. The flow value corresponding to the load that causes deformation and fracture of the compressed Marshall specimens is an indicator of internal friction in bituminous mixtures. There is an inverse and linear correlation between flow and internal friction values. In the Marshall method, the flow value represents the deformation of the sample [39]. The relationship between the flow values and the percentage of asphalt is given in Fig. 12.

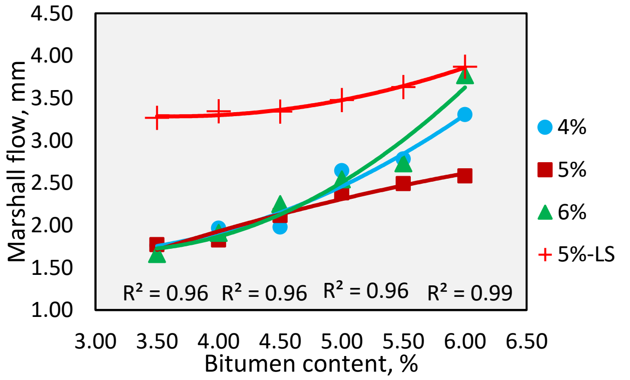


Fig. 12. Relationship between the percentages of flow and asphalt content

The flow values of the mixtures containing 4 %, 5 %, 6 % PW and 5 % LS fillers prepared according to *OBR* were found to be 2.68, 2.49, 3.40 and 3.44 mm, respectively. The flow value for the wear layer is in the range of 2 – 4 mm according to HTS. The *OBR* value corresponding to 3 mm flow was found to be 5.69 %.

MQ is used as a measure of HMA resistance to permanent deformation throughout its service life [40]. The relationship between *MQ* and the asphalt percentage is given in Fig. 3. *MQ* values for optimum asphalt percentage were determined as 3.51, 2.87, and 1.98 kN/mm for 4 %, 5 %, and 6 % phonolite wastes, respectively. The *MQ* value was found to be 3.28 kN/mm for the 5 % LS control samples.

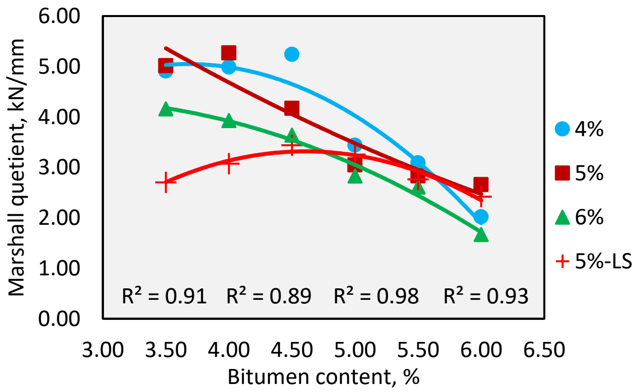


Fig. 13. Relationship between the percentages of *MQ* and asphalt content

MQ values decreased with the increase in the amount of PW. Compared to the control sample (5 % LS), an increase of 6.6 % and a decrease of 12.5 % and 39.6 % were detected, respectively, in *MQ* values. Compared to the control series, it is seen that the highest increase occurs in the samples produced with 4 % PWF. Therefore, it is understood that the most resistant mixtures against shear stresses are the mixtures containing 4 % PWF.

4.2. Retained Marshall stability test results

In the study, to determine the effects of PW mineral filler on moisture damage resistance of hot mixtures, the *RMS* values of the mixture samples were determined and given in Fig. 14.

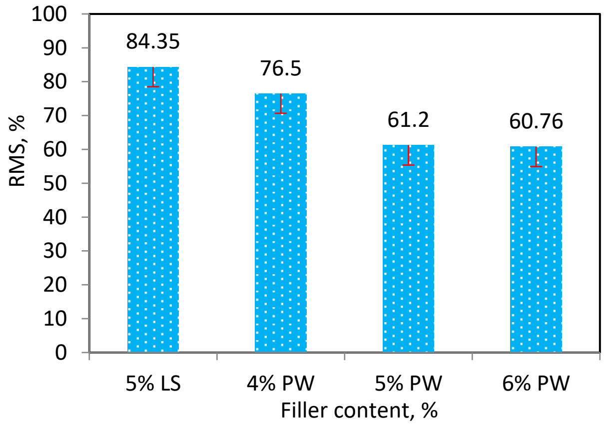


Fig. 14. RMS test result

When Fig. 14 is examined, significant changes occurred in the RMS values of the mixtures compared to the control sample, with the increase of the filler ratio in the samples produced with PWF. Compared to the control sample prepared with LS, these changes were decreased by 9.3 %, 27.44 %, and 27.9 %, respectively. The fact that the RMS values of the control samples are above 80 % indicates that they are suitable in terms of moisture damage resistance. When the samples prepared with PWF are examined, the highest resistance against moisture damage is seen in the samples containing 4 % PW. It is seen that the resistance of the samples against moisture damage decreases as the amount of PWF increases. The reason for this is thought to be the weakening of the adhesion force between the aggregate and the bitumen with the increase in the amount of PW.

4.3. Effects of the freeze-thaw cycle on the HMA samples

The service life of HMA pavements is affected by many factors such as freezing-thawing, rain, and snow. These factors may result in the loss of certain mechanical properties of HMA pavements. Some researchers reported that the amount of water-induced damage was increased in HMA samples with the increased number of F-T cycles [35]. The test results of the current study showed that the lowest loss of MS was observed in the control sample containing 5 % LS. According to the test results, losses in MS values in samples prepared with PW were 6 %, 7.3 %, and 8.8 %, respectively. It was determined that the samples that gave the MS loss closest to the control sample occurred in the samples prepared with 4% PW. It was determined that the losses in MS values increased with the increase in the amount of PWF. The loss of MS in all samples after the F-T cycle is given in Fig. 15.

4.4. Indirect tensile strength and moisture damage resistance test results

In the study, the *ITS* test was applied to conditioned and unconditioned PWF added and control samples, and their resistance to coating deterioration caused by water was determined. *ITS* and *TSR* values are given in Fig. 16 and Fig. 17, respectively.

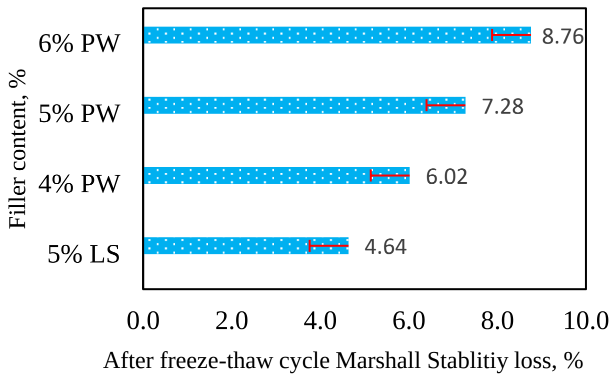


Fig. 15. Loss of *MS* after the F-T cycle

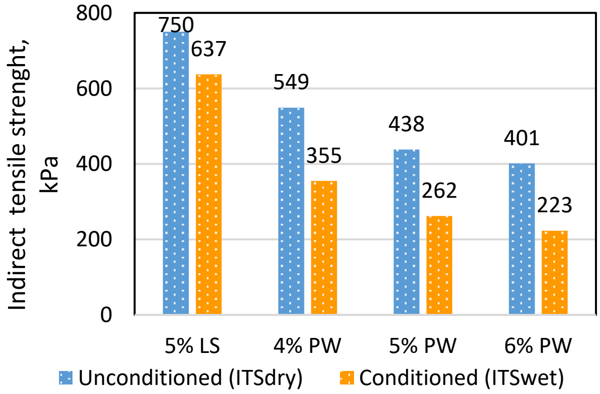


Fig. 16. ITS values of the control and PWF asphalt mixtures

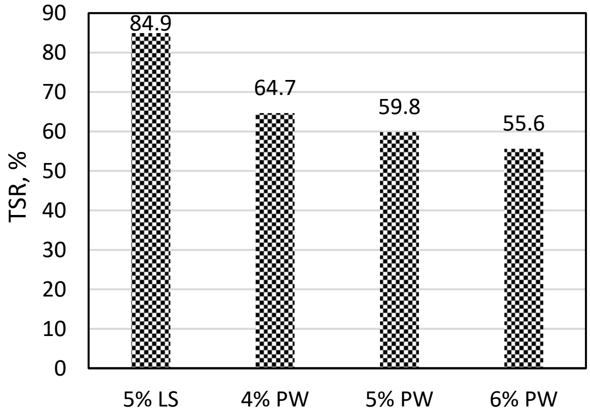


Fig. 17. Tensile strength ratio results

To determine the effects of samples produced with waste phonolite fillers on moisture resistance, the *ITS* test was applied to samples of mixtures containing conditioned and unconditioned limestone and phonolite fillers.

When Fig. 16 is examined, changes occurred in the indirect tensile strength values of ITS_{wet} mix samples with the increase in the ratio of waste phonolite fillers. These changes are 44.2 %, 58.8 %, 64.9 % reductions, respectively, compared to the pure mixture (5 % LS). The changes in the indirect tensile strength values of the ITS_{dry} mix samples are respectively 26.8 %, 41.6 % and 46.5 % reductions compared to the pure mix. The decrease in the ITS_{wet} and ITS_{dry} values of the mixture samples with the increase in the waste phonolite filler ratio indicates that the resistance of the bituminous hot mix coatings exposed to traffic loads against tensile stresses under load decreases.

In Fig. 17, it is seen that the *TSR* values of the mixtures decreased by 23.9 %, 29.6 % and 34.5 %, respectively, with the increase of the PWF ratio compared to the pure mixture (5 % LS). According to these results, the highest TSR value was observed in 5 % LS mixtures. The fact that the *TSR* values of the mixtures containing PWF are below 80 % indicates that PWF does not have a positive effect on water-related deterioration.

5. CONCLUSIONS

In this study, the usability of phonolite wastes as fillers in HMA concrete was investigated. For this purpose, hot mix samples were prepared with the addition of three different phonolite waste fillers by weight. To compare the results obtained from the samples prepared with phonolite waste, samples were prepared using LS, which is frequently used in the manufacture of flexible pavements. In the experimental study, the following results were obtained.

1. According to *MS* test results, it was observed that the *MS* of the bituminous hot mixtures in which PW was used as filler decreased by 40 % and the lowest stability value was obtained from the mixtures containing 6 % waste phonolite filler. However, although a decrease of 10.8 % was observed in *MS* in samples produced with 4 % waste phonolite, it was determined that the stability value was above the limit value determined for the wearing course of the HTS.
2. According to the *MQ* results, the highest *MQ* value was obtained from the mixture with 4 % PW additive and thus the additive of PWF provided an improvement in the resistance of the flexible pavement against shear stresses.
3. It was observed that the lowest stability loss after the F-T cycle occurred in the control series produced with 5 % LS filler. It has been determined that as the amount of PW increases, the loss of stability also increases.
4. According to the *RMS* results, it was observed that the resistance of hot mixes to moisture effects decreased with the addition of PWF, and the highest resistance was obtained from the control series mixes produced with 5 % LS filler. It was observed that the most resistant samples to moisture damage among the filler series with the addition of phonolite were in the series with 4 % waste filler. It was determined that the moisture sensitivity of the mixtures decreased as the amount of PWF increased.
5. According to the *TSR* results, it is seen that the waste phonolite filler material does not have a positive effect against the deterioration caused by water.
6. When the flow results are examined, it is seen that there is a decrease in all series with the addition of PWF compared to the control sample, but it is within the limit values specified in the HTS. For this reason, it is thought that all PWF added series will exhibit a resistant behavior against plastic deformation formation.

7. It is known that the enterprises in the industry want to get rid of these wastes that occupy unnecessary space in open areas or large warehouses and that these enterprises do not expect any financial income from the waste in general. On the other hand, a similar problem in phonolite wastes occurs during the disposal of wastes. In this study, these waste materials, which can generate both economic gain and environmental and visual pollution, are evaluated by considering the use of phonolite wastes in HMAs and road pavement design and manufacturing, taking into account the transportation cost.
8. A significant amount of aggregate is needed in the manufacture of flexible pavements. Waste materials harm the environment. It is thought that hot bituminous mixtures with low traffic volumes can be used as mineral fillers in wear layers to eliminate the environmental damage caused by PW. It is thought that the use of PW in hot mixes will also be beneficial from an economic point of view.

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