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LABORATORY INVESTIGATION OF USABILITY OF SLATE WASTE POWDER AS FILLER IN HOT MIX ASPHALT CONCRETE

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Abstract

The main objective of this experimental research was to investigate the effect of slate waste powder (SWP) as filler material in hot mix asphalt concrete. In the study, the use of slate collected during the shaping process of slate blocks in bituminous hot mixtures as mineral filler was investigated. For this purpose, four different serial asphalt concrete samples were produced using limestone (LS) in different proportions (4%, 5%, 6%, and 7%) as mineral filler. In this context, specimens were produced and tested under Marshall Stability (MS) Test, and the optimum bitumen content (OBC) value for the aggregate samples to be used was determined. Choosing the series of asphalt having 5% filler which has given the highest stability SWP was changed with LS filler in the rate of 25%, 50%, 75%, and 100%. After that MS and Indirect Tensile Strength (ITS) tests, comparatively was conducted on the produced samples and the results were evaluated. As a result, it has come in view that SWP can be used as mineral filler in bituminous mixtures.

Key Words: Asphalt concrete, Slate, asphalt mixture, hot-mix asphalt

ARDUVAZ TOZ ATIKLARIN SICAK KARIŞIM ASFALT BETONDA FİLLER OLARAK KULLANILABİLİRLİĞİNİN DENEYSEL OLARAK İNCELENMESİ

Özet

Bu çalışmanın amacı atık arduvaz tozlarının sıcak karışım asphalt beton yollarda kullanılabilirliğinin deneysel çalışmalarla araştırılmasıdır. Arduvaz bloklarının kesilmesi ve işlenmesi esnasında meydana gelen toz artıklarrın bitümlü sıcak karışımlarda kullanımları araştırılmıştır. Bu amaçla kireçtaşı kullanılarak dört farklı (4%, 5%, 6%, and 7%) seride asphalt numuneler hazırlanmıştır. Numeler Marshall Stabilite testine tabi tutularak optimum bitüm içerikleri tayin edilmiştir. En yüksek marshall stabilite değerini veren 5% filler içerikli asfalt serisi seçilerek kireçtaşı filler oranı 25%, 50%, 75%, and 100% oranlarında arduvaz filler ile yer değiştirilerek numuneler hazırlanmış ve bu numunelere Marshall Stabilite ve inderekt çekme deneyleri uygulanmıştır. Sonuç olarak arduvaz toz atıkların sıcak karışım asfalt betonununda filler malzemesi olarak kullanılabileceği sonucuna varılmıştır.

Anahtar Kelimeler: Asfalt beton, Arduvaz, Asfalt karışımlar, sıcak karışım asphalt beton

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1. Introduction

Hot mix asphalt (HMA) concrete is a combination of aggregate and asphalt cement. The aggregate acts as the structural skeleton of the pavement and the asphalt cement as the glue of the mixture. The mineral aggregate, including coarse and fine particles in asphalt paving mixtures, encompasses approximately 90% of volume of HMA. The properties of the aggregate have direct and significant effect on the performance of asphalt pavements [1,2,3]. Asphalt concrete is the most commonly used material in pavement due to its superior service performance in providing driving comfort, stability, durability and water resistance [2,3,4,5]. But pavement engineers were leaded to an alternative materials and techniques because of economical dimension of materials, good evaluation of energy and sources[5].

One hundred million tons of aggregate is used each year in road construction in Turkey. The most important qualities of these aggregates are mechanical strength, service life, and safety and environmental aspects in road pavement layer construction [4].

Turkey, like Portugal, Spain, Italy, Greece, Iran and Pakistan, has an important place in natural stone production. The types of natural stone in Turkey number more than 250. Approximately 100 of these stones are well known and regularly in demand in the international market [4,6].

Research studies showed that the strength of hot mix asphalt (HMA) depends on different factors such as filler and aggregate type, and bitumen grade. Among these, filler material plays a major role in various properties of HMA, especially those related to mixture compatibility and aggregatebitumen adhesion. Furthermore, it also affects several HMA properties such as workability, moisture sensitivity, stiffness, durability, fatigue behavior and long term characteristics of HMA. Fillers vary in physical and chemical properties, shape and texture, size, and gradation. Therefore, selection of suitable filler is very vital for ideal performance of HMA. Nowadays due to environmental and economic concerns the use of recycled waste materials in road pavements has considerably extended. In this regard, several research studies have been performed by environment and transportation organizations which relate to using recycled waste materials as filler in pavement applications [7].

A great deal of natural stone or waste material for use as aggregate or filler in hot mix asphalt concrete has been investigated: rice husk ash [2], andesite [4], asphaltite [5], coal waste powder [7], basalt [6,8], hydrated lime [9], recycled fine aggregates powder [10], waste ceramic materials [11], coarse recycled aggregates [12], recycled waste lime [13], cleaned oil-drill cuttings [14], marble dust [15], and granite sludge [16].

Nowadays, the use of recycled compounds in building materials is of current interest as one of the researching lines proposed to integrate sustainability criteria in construction. Recycled compounds that can be included in building materials come mainly from building demolition, mineral wastes, urban wastes and industrial wastes and by-products.

Slate is a natural metamorphic stone mainly used in buildings for roofing or flooring purposes. Slate has a mineralogical composition formed by quartz, phyllosilicates like chlorite and muscovite, illite, and other minor components [17].
Like any natural material, slate deposits are heterogeneous and not all the raw material can be manufactured, due to the different properties that present. Low quality deposits, particularly

those of such low strength stone as slate, are usually dismissed. Besides, large quantities of waste are produced either in the extraction or in the processing plants where slate blocks are transformed into usable thin sheets. The amount of residuals also increases due to the cutting and manufacturing processes and, indeed, this has become an important problem for slate producers [17].

In this study, the effect of the use of slate as mineral filler in hot-mix asphalt pavements was investigated. The study consist of two main stages. Firstly, four different proportions of Filler Rate (FR) (4%, 5%, 6% and 7%) were chosen on the basis of max and min FRs determined by General Directorate of Highways. Step by step optimum bitumen contents were determined for every filler rates with the test results on Marshall Samples prepared using determined filler rates.

2. Materials

2.1. Aggregates and gradation

In this study, four different serial asphalt concrete samples were produced using LS in different proportions (4%, 5%, 6%, and 7%) as mineral filler. The amount of optimum bitumen and the value of MS were determined with MS test for the samples. After choosing the series of asphalt having 5% filler which has given the highest stability, usability of slate as filler was examined. Crushed LS aggregates were used in asphalt mixtures. The nominal maximum aggregate size is 19.5 mm, and the binder course design method was used for the mixtures. Aggregate material tests were carried out based on American Standards, in order to obtain the physical and mechanical characteristics of the materials to be used in the mixtures. Crushed LS (aggregates) used in the study were supplied from asphalt construction site of municipal of Isparta. Sieve analyses were carried out and available grading curve for the aggregate used in the study was close to binder layer course as shown in Fig. 1.

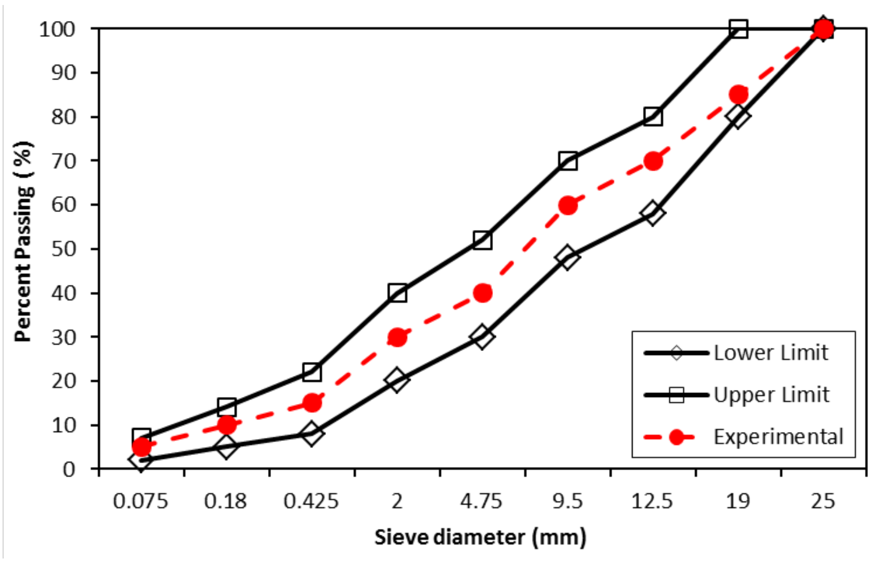

Fig. 1. Gradation limits of the aggregates used in the study.

2.1.1. Limestone

The aggregate properties are given in Table 1 [2,3,4]. In the study, aggregate grading curves for asphalt mixtures were selected in convenience with Turkish Highway Construction Specifications [18].

Table 1. Properties of aggregate used in the tests

Sieve Diameters	Properties	Standard	LS Aggregate
4.75-0.075mm	Specific gravity (g/cm^3)	ASTM C 127-88 [19]	2.660
	Saturated specific gravity		2.652
	Water absorption (%)		0.130
25-4.75mm	Specific gravity (g/cm^3)	ASTM C 128-88 [20]	2.329
	Saturated specific gravity		2.428
	Water absorption (%)		2.800
	Abrasion loss (%) (Los Angeles)	ASTM C 131 [21]	20.38

2.1.2. Slate

In the study, The size of the slate stones obtained after breaking process was not enough for using them in asphalt concrete as filler. Therefore, slate aggregates were sieved to pass through the 200µ.

Slate stone (Fig. 2) was provided by Uşak region, (Turkey). The characteristics of the slate were given in Tables 2 and 3.

a) b)

Fig. 2. Slate (aggregate) (a) and slate (filler) (b)

Table 2. Physical properties of Slate [27].

Pozzolan	Particle Diameter Range (mm)	Specific Gravity (g/cm^3)
Slate waste powder (SWP)	0.075-0.150	2.664
	0.150-0.180	2.658
	0.180-0.425	2.651
	0.425-0.600	2.647
	0.600-1.180	2.643
	1.180-2.360	2.640
	2.360-4.000	2.637

Table 3. Los Angeles and water absorption test results of slate [27].

Properties	Slate Aggregate
Abrasion loss (%) (Los Angeles)	14.71
Water absorption (%)	0.0665

2.2. Bitumen

In order to prepare the Marshall samples, 60–70 penetration asphalt cement was used. Variety of standard tests was examined in order to determine properties of bitumen. For instance, ASTM D5 [22] "Standard Test Method for penetration of bitumen materials", ASTM D70

[23] “Standard Test Method for density of semi-flexible bitumen materials”, ASTM D36 [24] “Standard Test Method for softening point of bitumen (ring and ball apparatus)”, ASTM D92 [25] “Standard Test Method for combustion and flash point with Cleveland open cup test apparatus”, ASTM D113 [26] “Standard Test Method for ductility of bitumen materials” were used and assessed respectively. Test results were summarized in Table 4.

Table 4. Bitumen characteristics

Characteristics of Bitumen		
Test Name	Average Values	Standard
Penetration (25 ºC)	60-70	ASTM D5 [22]
Flash Point	180ºC	ASTM D92 [25]
Fire Point	230 ºC	ASTM D92 [25]
Softening Point	45.5°C	ASTM D36 [24]
Ductility (5 cm/minute)	>100 cm	ASTM D113 [26]
Specific Gravity	1.030	ASTM D70 [23]

3. Methods

3.1. Marshall stability test

Asphalt mixtures were prepared in accordance with the technical specifications required by Highway General Directorate of Turkey [18].

A flowchart summarizing the experimental study was given in Fig. 3. As seen from figure, asphalt concrete samples were prepared for four different filler proportions (4%, 5%, 6% and 7%) and seven different bitumen content (3.5%, 4%, 4.5%, 5%, 5.5%, 6% and 6.5%) and these samples were tested with MS for determining the amount of optimum bitumen. Three samples were prepared for each of fractions. 84 (4 x 7 x 3) samples were totally prepared and MS, flow value, void volume values (Vh), void percentages (Vf) and voids in mineral aggregate (VMA) values were determined [2].

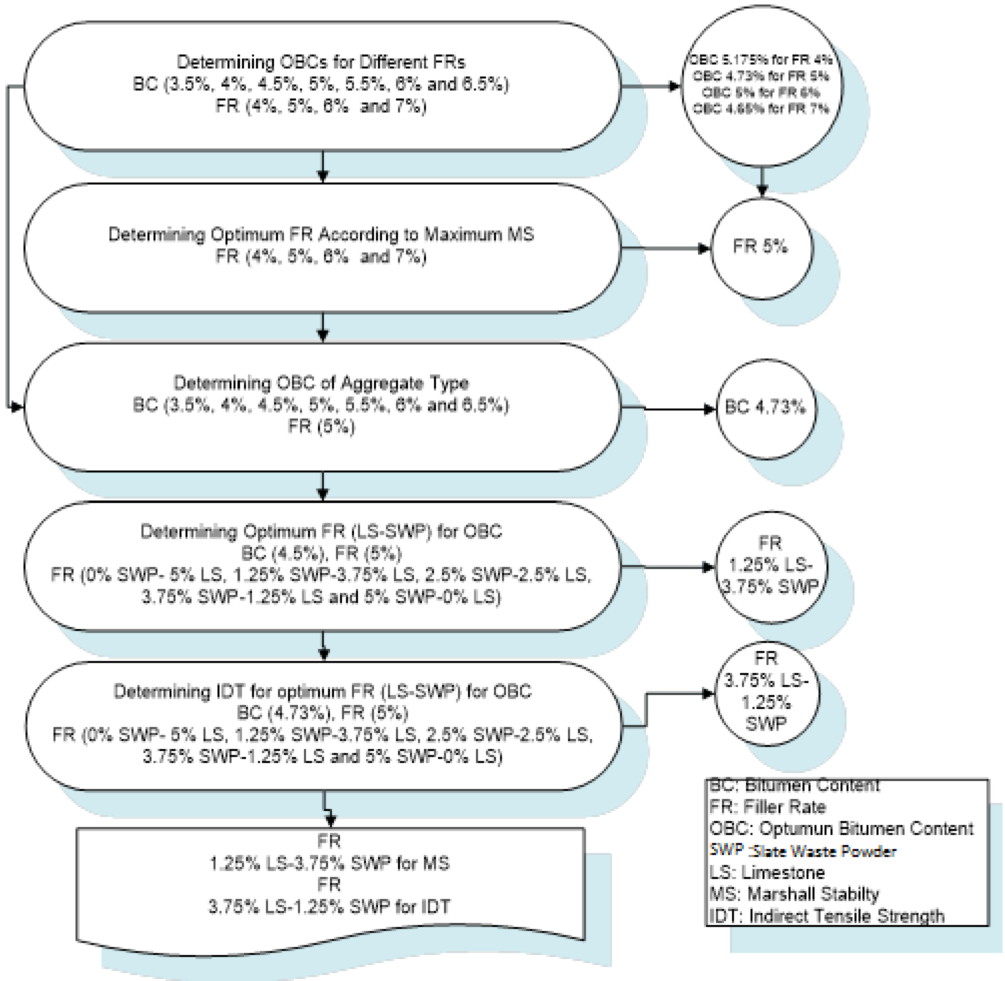

Fig. 3. Flow chart of laboratory Works

3.2. Indirect Tensile (ITS) Strength Test

One commonly used parameter to evaluate asphalt mixtures is tensile strength which can be used to quantify the effects of moisture and to determine the fracture resistance of an asphalt mixture. Typically, the tensile strength can be accurately determined from an ITS strength test carried out in accordance with AASHTO TP9-02 [28,29].

The ITS strength test is a simple test that proposes to use currently available equipment in most laboratories, being MS machine and a water bath set at 45 ^{0}C.

Loading configuration develops a relatively uniform tensile stress perpendicular to the direction of the applied load and along the vertical diametral plane, which ultimately causes the specimen to fail by splitting along the vertical diameter. Ensuring the test was carried out in a consistent manner, a testing procedure of the ITS Strength test was prepared [29,30].

In this study prior to the testing, the pats were measured according to the procedure and were placed in the water bath for a period of conditioning of 30 to 40 minutes at a temperature of 45 ^{0}C. The test temperature of 45 ^{0}C was selected as it represented the strength of asphalt at the high temperature range but below the softening point of standard bitumen. Thus the working of the binder with the aggregate structure was being tested, rather than just the aggregate structure itself as for MS test which tests at 60^0C. The specimens were then placed into the resilient modulus style loading jig which is placed within the MS machine to commence a load of the constant speed to give a rate of travel of platen of 50 mm/minute.

The ITS Strength test is provided in the test procedure which includes the calculation for ITS Strength. Calculation of ITS Strength [29,30]:

$$S_t = \frac{2000F}{3.14x(hd)}$$

Where;

St = Indirect tensile strength, KPa

F = Total applied vertical load at failure, N

h = Height of specimen, mm.

d = Diameter of specimen, mm.

4. Results and discussion

4.1. Marshall stability test results

MS values depending on the bitumen ratio were given in Fig. 4. As seen from the figure, maximum MS value was obtained for 5% Filler Rate (FR).

According to the Technical Specifications of General Directorate of Highways (HTS), the stability value must be minimum 750 kg for binder course.

Fig. 5 shows that flow values for all bitumen contents. All flow values ranged between 2 mm and 7.5 mm. It was appeared that maximum flow value is 7.53 mm with 7% FR and minimum flow value is 2.26 mm with 7% FR [2].

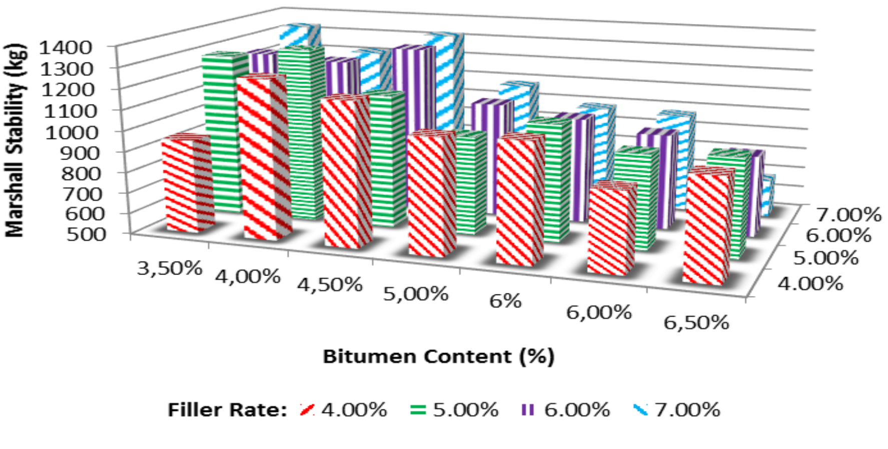

Fig. 4. The MS values.

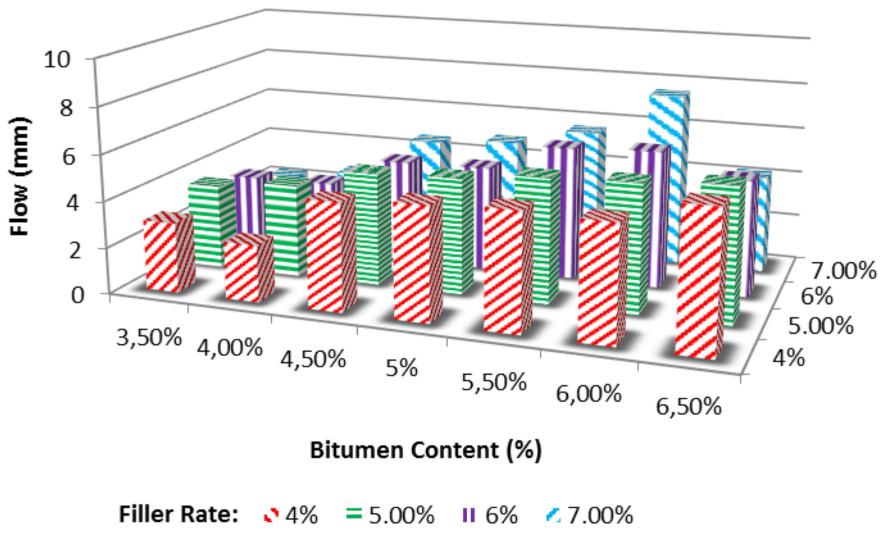

Fig. 5. Flow values.

According to Technical Specifications of General Directorate of Highways, the flow value limit must be minimum 2 mm and maximum 4 mm for binder course. Fig. 6 shows that the voids in mineral aggregate (VMA) of all specimen groups. VMA values of mixture change between 18.1% and 14.2% and maximum VMA values are between 4% FR and 3.5% bitumen content. Minimum VMA value is also seen 14.2% value for 4.5% bitumen content. According to the Technical Specifications of General Directorate of Highways, minimum VMA value should be determined based on the nominal D_{max} value. The value should be taken as diameter of sieve passing 90% on gradation curve of aggregate mixture. If considered that nominal D_{max} value of mixture used in the study is 19 mm (3/4"), the corresponding minimum VMA value is 14% [2].

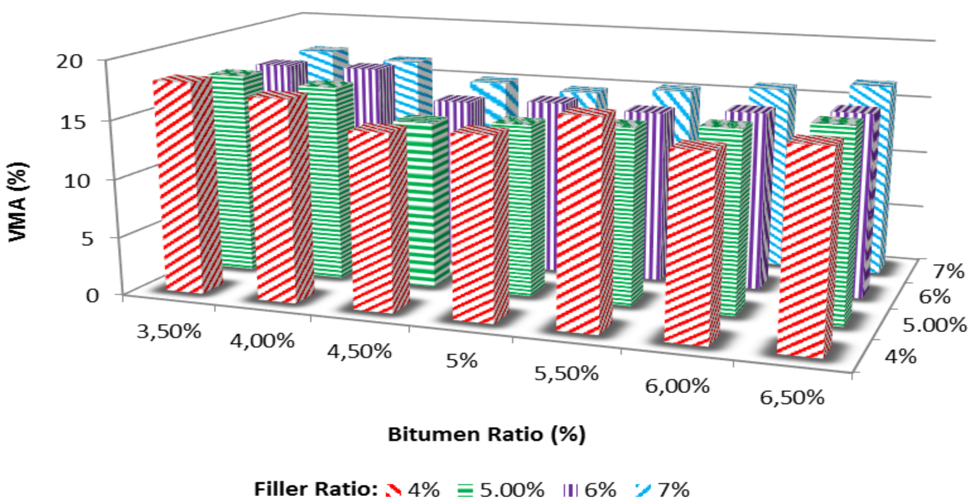

Fig. 6. Changes in VMA for different bitumen contents.

Fig.7 shows that the void percentage (Vf) values for all bitumen contents. Vf value is maximum 94.02% and minimum 42.61%. Also, according to Technical Specifications of General Directorate of Highways, the Vf value limit must be maximum 75% and minimum 65% for binder course [2].

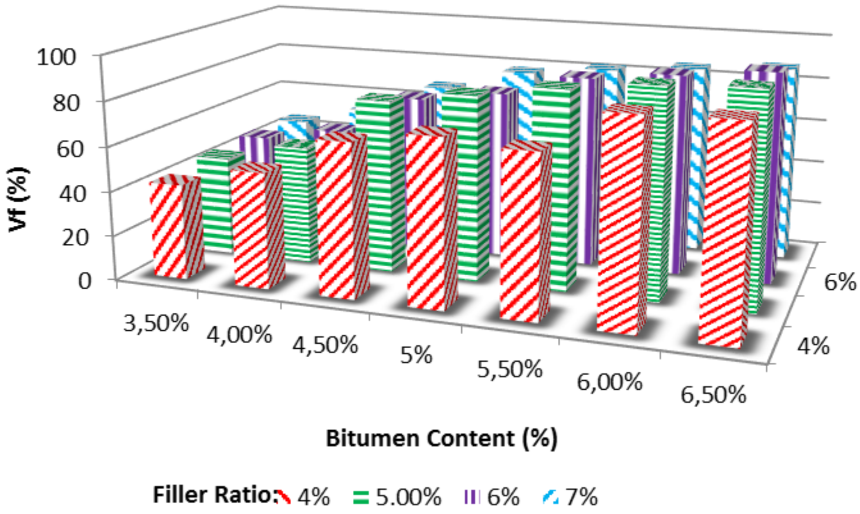

Fig. 7. Changes in Vf for different bitumen contents.

Fig. 8 shows the void volume values (Vh) change depending on bitumen content. Vh values change between 0.98% and 10.39%. Maximum Vh value is on 3.5% bitumen content, 4% FR and 0.98% which is minimum Vh value was seen on 6.5% bitumen content and 5% FR. According to the Technical Specifications, the Vh values must be maximum 6% and minimum 4% [2].

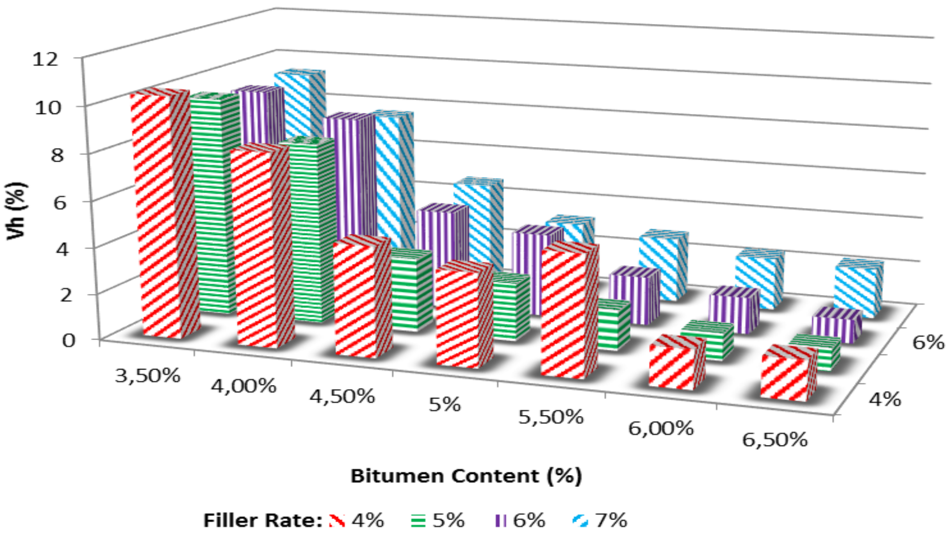

Fig. 8. Changes in Vh for different bitumen contents.

The optimum bitumen content for the mix design was determined by taking the average value of the following three bitumen contents taken from the above graphs.

1. Bitumen content corresponding to maximum stability

2. Bitumen content corresponding to maximum bulk specific gravity

3. Bitumen content corresponding to the median of designed limits of percentage air voids in the total mix (i.e. 4%)

4. Bitumen content corresponding to the median of designed limits of percentage voids filled with bitumen in the total mix (i.e. 80 %)

Limestone aggregate optimum bitumen content for %5 FR:

$$\frac{4.8+4+4.6+5.5}{4}=4.73$$

The flow value corresponding to this ratio is 2.51, which is below the maximum values in the specification [18].

On the basis of determined amount of optimum bitumen, SWP was tested with MS by changing with limestone in proportion as 25%, 50%, 75%, and 100% and the results were evaluated (Figs. 9–13).

Different FRs and mixture percentages were given in Table 5. The obtained asphalt concrete samples with SWP were denominated by using SWPAC abbreviation, formed by the initials of "Slate Waste Powder Asphalt Concrete". The samples were numbered from SWPAC 1 to SWPAC 4 based on percentage values, starting from 25%, and with 100% SWP.

Table 5. Asphalt concrete mixtures prepared by using different filler rates

Samples Name	Aggregates %			Limestone (%)	SWP (%)
	25-4.75 mm	4.75-0.075 mm	Filler (LS+ SWP) (%)		
Control Sample	60	35	5 (100%)	5 (100%)	0 (0%)
* SWPAC 1	60	35	5 (100%)	1.25 (25%)	3.75 (75%)
SWPAC 2	60	35	5 (100%)	2.5 (50%)	2.5 (50%)
SWPAC 3	60	35	5 (100%)	3.75 (75%)	1.25 (25%)
SWPAC 4	60	35	5 (100%)	0 (0%)	5 (100%)

*SWPAC: Slate Waste Powder Asphalt Concrete

The physical and mechanical characteristics obtained for all mixtures were given in Figs. 9–13. Maximum MS value (1340 kg) obtained from 4.73% bitumen content and 75% SWP addition (SWPAC 1). After these values, it was seen a decrease for the other samples.

While 1340 kg which is the highest MS value has seen on samples prepared with 1.25 % LS and 3.75% SWP of FR,1080 kg which is the lowest MS value has seen on samples prepared with 2.5% LS ve 2.5% SWP. When the samples prepared with 5% LS of FR taken as a reference MS value decreased by percentage of 5.38 in samples prepared with 3.75% LS and 1.25% SWP and decreased by percentage of 5.77 in samples prepared with full with SWP filler. While the percentage of 0.77 increase on MS value has seen on samples prepared with 1.25% LS and 3.75% SWP according to the reference, 16.92% which is the most significant decrease has seen on samples prepared with 2.5% LS and 2.5% SWP filler.

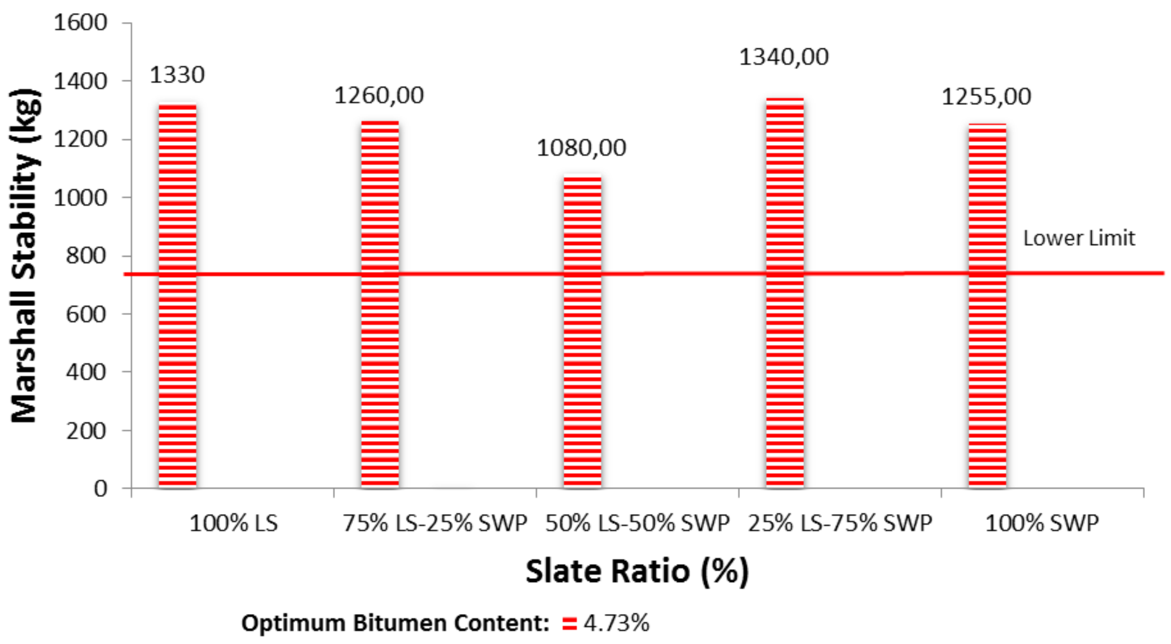

Fig. 9. Comparison of MS values for different bitumen amounts and for constant filler rates.

As seen from flow values, obtained bitumen content and the filler rate (2.81 mm), the max. stability remains at the specification limits (Fig. 10). When considering flow charts lowest flow value was obtained at the point of 2.39 mm corresponding to prepared full with SWP filler. and highest flow value was obtained at the point of 4.11 mm corresponding to 2.5% LS ve 2.5% SWP.

When comparing mixtures full with LS flow value has 22.90% decrease for samples prepared full with SWP filler of FR, 9.35% decrease for samples prepared with 1.25% LS and 3.75% SWP, 24.84% increase for samples prepared with 3.75% LS and 1.25% SWP and 32.58% increase for samples prepared with 2.5% LS ve 2.5% SWP filler.

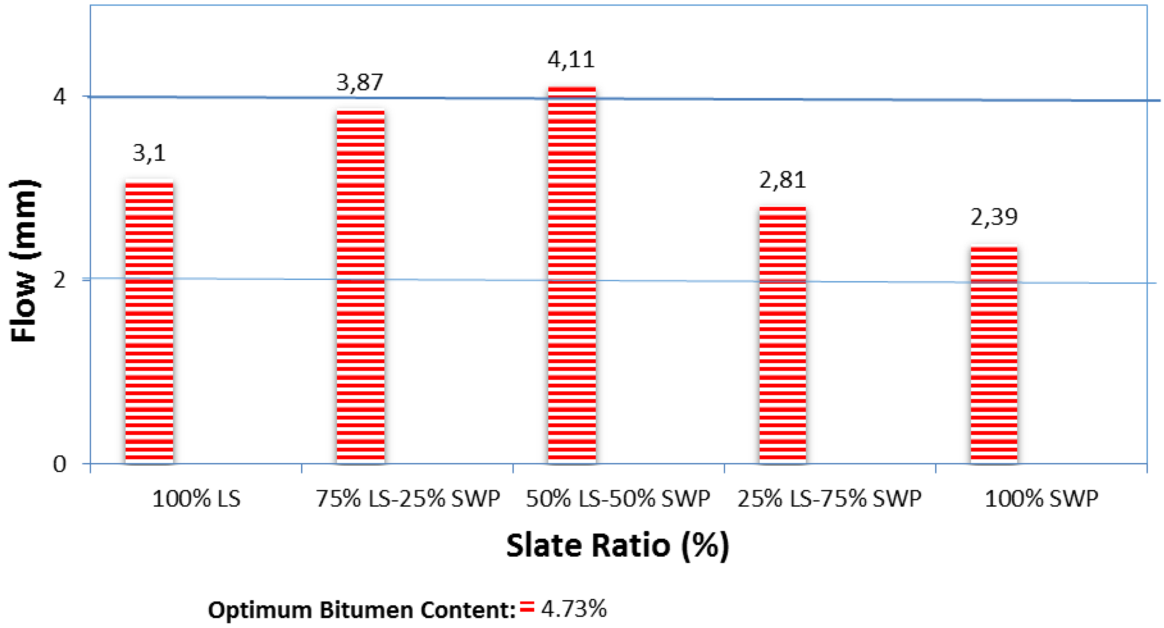

Fig. 10. Flow values for different bitumen contents and for certain filler rates.

While the VMA value is 16.36% for asphalt samples prepared with 3.75% LS and 1.25% SWP, with the increase in substitution proportion there is an increase in VMA values and the max value of VMA which is 17.91% was obtained from asphalt samples prepared with 2.5% LS and 2.5% SWP. There is max 38.97% increase of VMA value according to the reference samples.

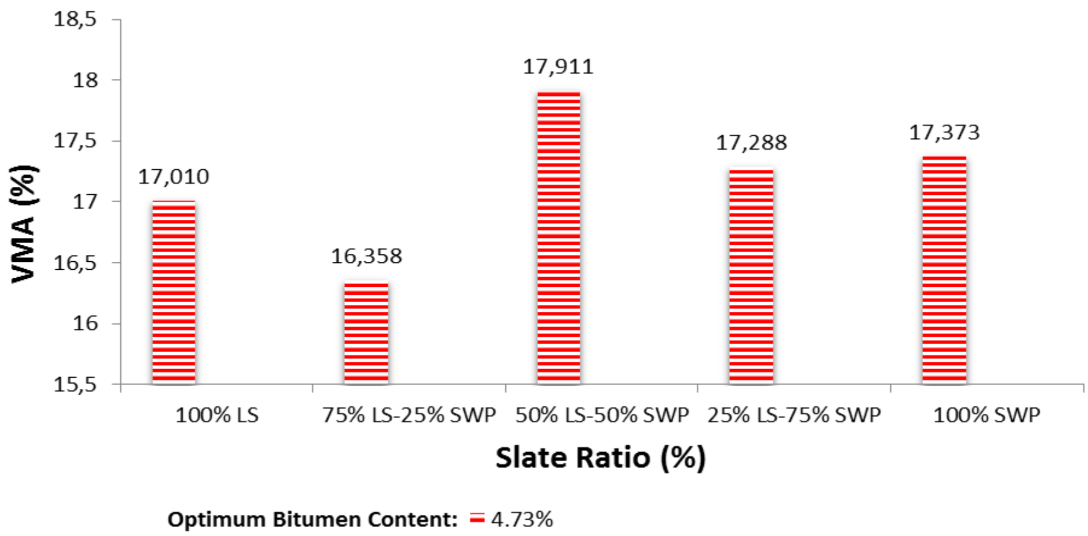

Fig. 11. Change in VMA for different bitumen contents and for certain filler rates.

While 9.24% which is the highest Vh value has seen on samples prepared with 3.75% LS and 1.25% SWP of FR, 6.45% which is the lowest Vh value has seen on reference samples. When the samples prepared with 5% LS of FR taken as a reference Vh value increased by percentage of 29.77 in samples prepared with 2.5% LS and 2.5% SWP and increased by percentage of 20.93 in samples prepared with full with SWP filler. While the percentage of 19.07 increase on Vh value has seen on samples prepared with 1.25% LS and 3.75% SWP according to the reference, 43.26% which is the most significant increase has seen on samples prepared with 3.75% SWP and 1.25% SWP filler.

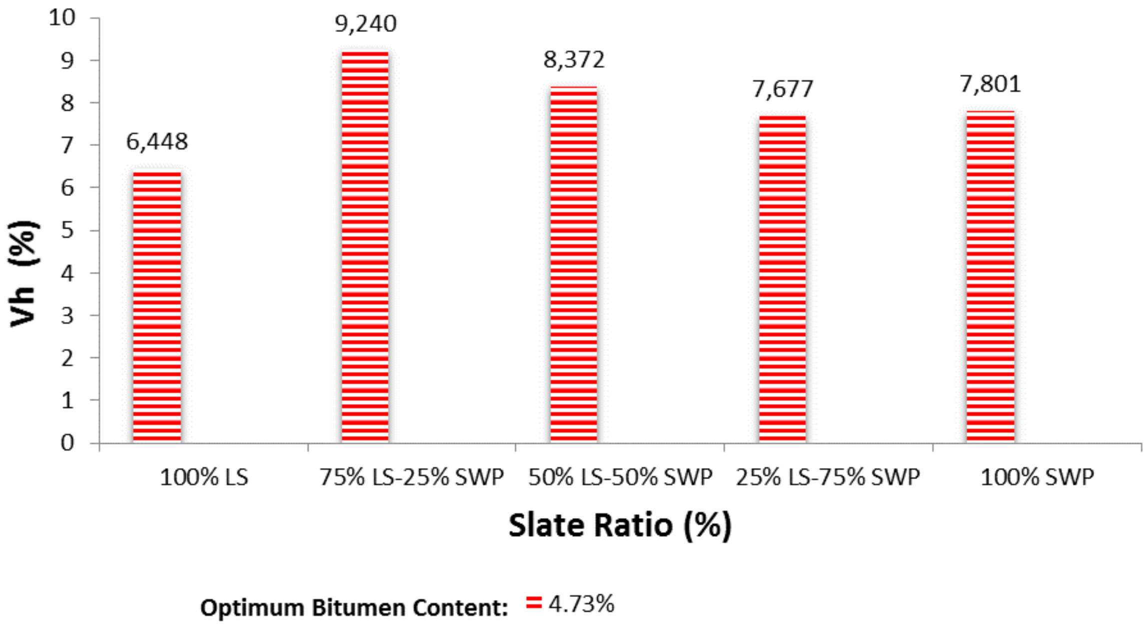

Fig. 12. Change in Vh for different bitumen contents and for certain filler rates.

While 65.08% which is the highest Vf value has seen on samples prepared with 3.75% LS and 1.25% SWP of FR, 58.33% which is the lowest Vf value has seen on samples prepared with 2.5% LS and 2.5 SWP. When the samples prepared with 5% LS of FR taken as a reference Vh value increased by percentage of 4.53 in samples prepared with 3.75% LS and 1.25% SWP and decreased by percentage of 2.78 in samples prepared with full with SWP filler. While the percentage of 2.2 decrease on Vf value has seen on samples prepared with 1.25% LS and 3.75% SWP according to the reference, 6.31% which is the most significant decrease has seen on samples prepared with 2.5% LS and 2.5% SWP filler.

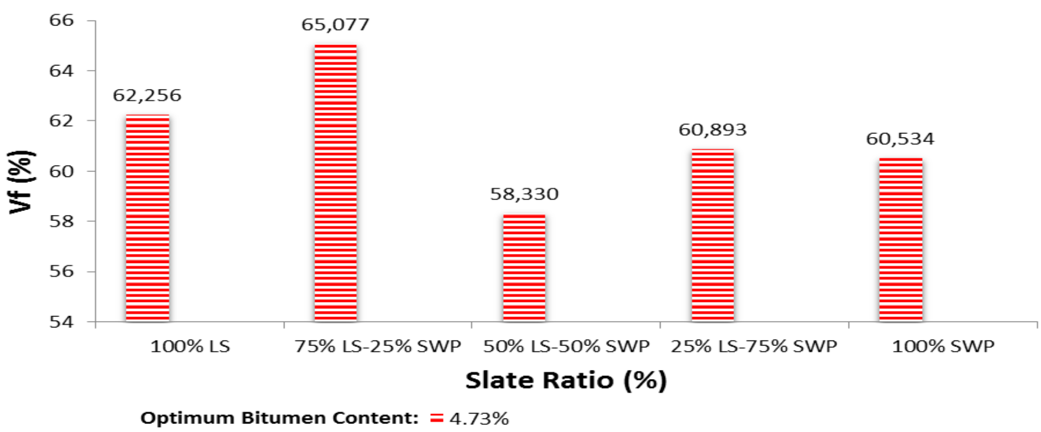

Fig. 13. Change in Vf for different bitumen contents and for certain filler rates.

4.2. Indirect tensile (ITS) strength test

Indirect tensile strength test samples were produced using optimum bitumen content obtained after Marshall Stability test procedure. As seen from Figs. 14 and 15, 75% LS and 25% SWP samples gave 11% higher indirect tensile strength value than the control samples.

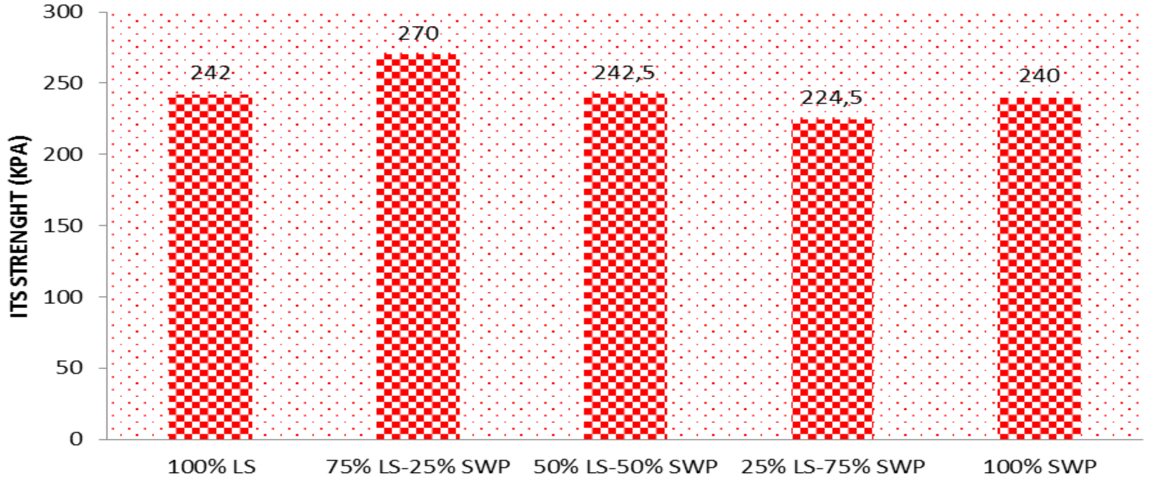

Fig. 14. Comparison of ITS values for different bitumen amounts and for constant filler rates

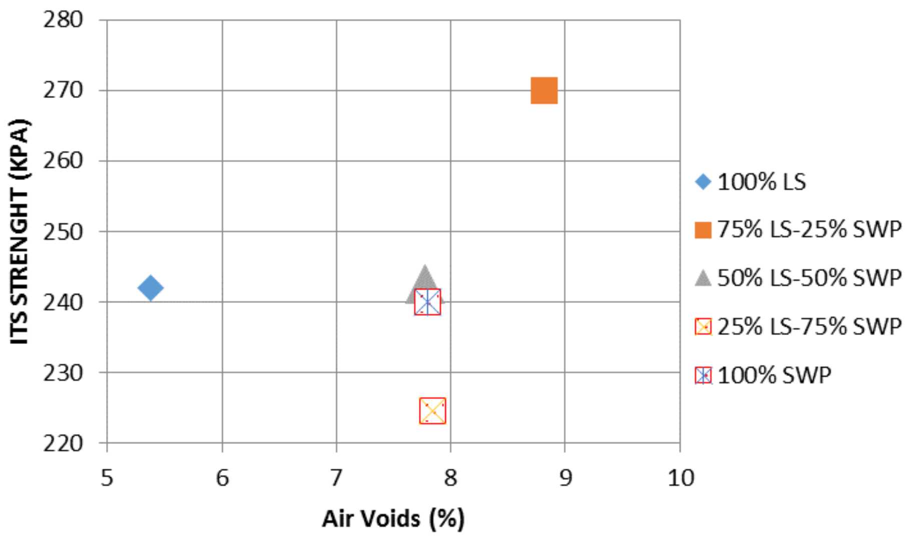

Fig. 15. ITS Strength vs Air Voids for limestone and SWP addition samples

5. Conclusions

First part of this study, four different Fiber Rate (FR) (4%, 5%, 6% and 7%) were chosen on the limits of FR determined by General Directorate of Highways Turkey. The optimum bitumen contents (OBC) were determined as 5.175% for 4% FR, 4.73% for 5% FR, 5% for

6% FR and 4.65% for 7% FR. This paper has two main sections. In the first section, Marshall samples were prepared with determined OBC and comparative charts were generated. Results have showed that the 4.73% OBC prepared with 5% FR which have given the most successful result.

In the second section of the study SWP obtained by during the shaping process of slate blocks were changed with determined 5% FR Limestone (LS) in proportion of 25%, 50%, 75% and 100% and the optimum SWP substitution ratio was determined by comparing the results.

Test results have showed that mixtures that used 75% SWP and 25% LS of FR (FR 1.25% LS and 3.75% SWP) have had the best Marshall Stability (MS) when evaluated in terms of MS. It was seen clearly from the MS chart MS values increases up to a point and decreases after that point. Also, Indirect tensile (ITS) strength test results showed that 25% SWP and 75% LS of FR (FR 3.75% LS and 1.25% SWP) mixtures had best ITS values.

As a results, all samples having slate waste powder meet Turkish Highway Specification. Also, it was concluded that SWP waste can be used in hot mix asphalt concrete as mineral filler.

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