Teknik Dergi, 2018 8515-8535, Paper 510

Experimental Study Concerning Iron Wire Fiber Reinforced Asphalt Concrete

Sevil KÖFTECİ[1]

ABSTRACT

The usability of low-cost iron wire fiber for reinforcement of hot asphalt mixtures was investigated with experiments in this study. Five mixtures having different fiber content of 1%, 3%, 5%, 7%, 9% and control mixtures were prepared. Characteristic properties of bitumen, aggregate and iron wire used in the mixtures were determined by thermogravimetric analysis (TGA), conventional bitumen tests, conventional aggregate tests, and metal tensile tests. After optimum bitumen rate was determined Marshall Stability Test, Cantabro Tests were performed in order to measure the performance of the mixtures. Additionally, moisture susceptibility of samples was determined with indirect tensile strength test. As a result of indirect tensile strength tests, indirect tensile strength (St) and indirect tensile strength ratio (ITSR) values were calculated. The results of the investigations indicate that the addition of low-cost iron fiber in the amount of 1%-3% improved performance of asphalt mixtures. When the used fiber rate was increased over 3%, clustering created by fibers was observed through stereo-microscope observations. Consequently, air voids were increased and bitumen-aggregate interaction decreased. Increasing fiber ratio especially, at 7-9 percent caused compressing, durability and stability problems in the mixture.

Keywords: Reinforced asphalt concrete, iron wire fiber, Marshall stability, moisture susceptibility.

INTRODUCTION

A large rate of transportation activities in the world are performed through highways. Asphalt mixtures are the most widely used construction material in road building throughout the world. Bitumen and aggregates used in asphalt mixtures are sensitive materials especially against repetitive traffic loads and temperature. Therefore, highway pavements deteriorate before their preplanned service life. Primary means to avoid this deterioration is to enhance the structural properties of the mixture by using additives. Additives can be introduced into asphalt pavements using two methods. Polymer-based additives can be applied to the bitumen / mixture [1] or fibers can be added to the mixture.

Note:

- This paper has been received on November 08, 2017 and accepted for publication by the Editorial Board on April 17, 2018.
- Discussions on this paper will be accepted by September 30, 2018.

- DOI: 10.18400/tekderg.350135

1 Akdeniz University, Department of Civil Engineering, Antalya, Turkey - skofteci@akdeniz.edu.tr

Fiber additives have been used to improve properties of the composite materials for many years. Fibers such as steel fiber, polymer fiber, natural fiber etc. are frequently used for the reinforcement of concrete and mortars, and there are various studies regarding this particular topic in related literature [2-4]. Fibers are usually used in Stone Mastic Asphalt (SMA) which has a gap-graded configuration and porous asphalt which has an open-graded configuration, in order to prevent draining of bitumen between aggregates [5, 6]. However, in recent years, as well as concrete, in order to improve resistance to cracking and rutting of the asphalt mixtures, fibers have been generally utilized as additional constituents. Some fibers have higher tensile strength as related to asphalt mixtures, thus it was observed that fibers have the potential to improve cohesion and tensile strength of bituminous mixes [7].

A wide variety of fiber types has been used in asphalt mixtures, including cellulose, mineral, synthetic polymer, and glass fibers, as well as some less common fiber types. Recycled fiber materials-such as newsprint, carpet fibers, and recycled tire fibers-have also been used [8]. There are numerous studies in the literature regarding strengthening of asphalt concrete with fibers. [9-11]. Guo [12] used a steel fiber in order to improve the mechanical properties of asphalt concrete. In this article, analyzing the test results such as rutting test, low temperature bending test, freeze-thaw splitting test and comparing stability of mixtures in high temperature, anti-cracking performance in low temperature and comparing water stability of steel fiber asphalt concrete with ordinary asphalt concrete, it is concluded that adding steel fibers into asphalt concrete can significantly improve the performance of the road surface. Al-Ridha et al [13] conducted a study on the effect of steel fibers on the performance of hot mix asphalt with 5% asphalt content at different temperatures and compaction levels. According to the test results, it is recommended use of steel fibers in the layers that are under the surface layer, such as the binder course, in the amount that is less than or equal to 0.2%. Garcia et al [14] investigated the use of steel wool fibers in dense asphalt concrete to improve mechanical properties. Additionally, fibers (steel wool) distribution and their effect on the porosity and electrical conductivity of asphalt mixtures was investigated. Experimentally obtained results indicated that short and thick fibers disperse very well in mixtures. The study recommended that fiber content in the asphalt mixture must be 6% or higher in order to attain satisfying results. Serin et al. [15] examined the effect of fibers in asphalt concrete mixtures. The study concluded that fiber additions can be used in the binder course of flexible pavements because of its positive impact on stability. Based on the results, it is recommended to use fiber 0.75% in weights in order to obtain best results.

In the current study, due to the high costs of steel fibers, use of low-cost iron wire is currently being considered as asphalt concrete additive. For this purpose, Marshall Stability (MS) test, Cantabro test and Indirect Tensile Strength Test (ITS) were performed. Iron fiber was obtained from the building site at the Akdeniz University campus. Depending on the results of these experiments, impacts and usability of low-cost iron fiber in hot mix asphalt were investigated regarding stability, raveling, flexibility as well as moisture susceptibility effects.

2. MATERIALS AND METHODS

2.1. Materials

2.1.1. Bitumen

The bitumen 50/70 penetration grade was obtained from Aliağa/İzmir Refinery of the Turkish Petroleum Refineries Corporation (TUPRAS). Conventional bitumen tests on the aged and unaged bitumen such as penetration, softening point etc and thermogravimetric analysis (TGA) were performed in order to determine the properties of the bitumen. Temperature-dependent deterioration of bitumen binder used in the study was determined by thermogravimetric analysis (TGA) method. This temperature value was calculated by using the proportional reduction in weight. In the TGA test, reduction of weight proportions was measured under nitrogen atmosphere at 10 ^{0}C/min heating rate. While the test was performed, temperature range was measured in the range of 250 ^{0}C to 600 ^{0}C. Figure 1 shows the TGA test results.

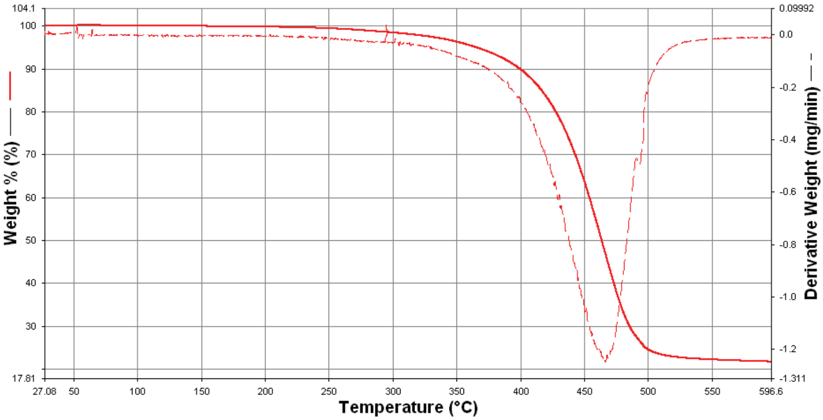

Figure 1. TGA result of bitumen used in the study

Table 1. Characteristic properties of the bitumen

Test	Specification	Results	Specification limits
Penetration (25 °C; 0.1mm)	TS EN 1426	64	50-70
Softening point °C;)	TS EN 1427	490C	46-54
Penetration index(PI)	-	-0,88	-
Ductility (25 C0;5 cm/min)	TS 119	>100	-
Flash point, 0C (Cleveland open cup)	TS ISO 2592	298 0C	230 (min)
Thin Film Oven Test (TFOT) (163 0C; 5h)	TS EN 12607-2		
Change of mass (%)		0.04	0.5 (max)
Change of softening point (°C;)	TS EN 1427	2,2	9 (max)
Retained penetration (%)	TS EN 1426	56	50 (min)
Specific gravity	TS 1087	1.033	-

With increasing temperature, weight was not affected until 240 ^{0}C. After this temperature, weight decreased with increasing temperature. This meant that the bitumen binder started to deteriorate. Reduction of the total weight was determined as 78 %. Table 1 gives a summary of the results and their conformity with the relevant test methods of conventional tests performed on the 50/70 penetration grade bitumen.

2.1.2. Aggregates

Limestone aggregates were used for the preparation of samples. Aggregates were obtained from the quarries around Antalya. Limestone aggregates are generally used in Antalya for making of bituminous hot mixtures. In order to determine aggregate properties, aggregate tests were performed on coarse as well as fine aggregates and fillers. Results of tests were evaluated according to various specifications which are stated in the Turkish Highway Specifications 2013 [16]. Table 2 gives a summary of the results and their conformity with the relevant test methods of aggregates.

Table 2. Characteristic properties of the limestone aggregates

Aggregate type	Test	Specification	Results	Specification limits
Coarse aggergate	Volume specific gravity	ASTM C127	2,693	-
	Apparent specific gravity	ASTM C127	2,710	-
	Water absorption (%)	TS EN 1097/6	0,28	≤2,5
	Los angeles abrasion (%)	AASHTO T96	22,40	≤30
	Micro-Deval abrasion (%)	TS EN 1097-1	18,24	≤25
	Soundess of aggregate by use of Magnesiun Sulfate (%)	TS EN 1367-2	10,22	≤18
	Flakiness index (%)	BS 812	13,07	≤30
	Stripping resistance, (%)	TS EN 12697-11	85	≥60
Fine aggregate	Volume specific gravity (g/cm3)	ASTM C127	2,44	-
	Apparent specific gravity	ASTM C127	2,72	-
	Water absorption (%)	TS EN 1097/6	0,43	≤2,5
	Plasticity index (%)	TE 1900-1	N.P.	-
	Methylene blue, (g/kg)	TS EN 933-9	1,5	≤1,5
Filler	Apparent specific gravity	ASTM C127	2,69	-

Aggregates were brought to the laboratory in four groups. Mixture ratios were calculated according to binder course specifications based on the Turkish Highway Specifications 2013. Table 3 shows the mixture ratios used for mixture gradation.

Table 3. Mixture raitos

Sieve size	Mixture ratio
25 mm. - 19 mm.	26
19 mm.- 12,5 mm.	16
12,5 mm. – 4,75 mm.	20
< 4 mm.	38

Gradation of aggregates is very important for the design of mixtures. In order to prepare Marshall samples, aggregates were mixed by using the grading curve in Fig. 2.

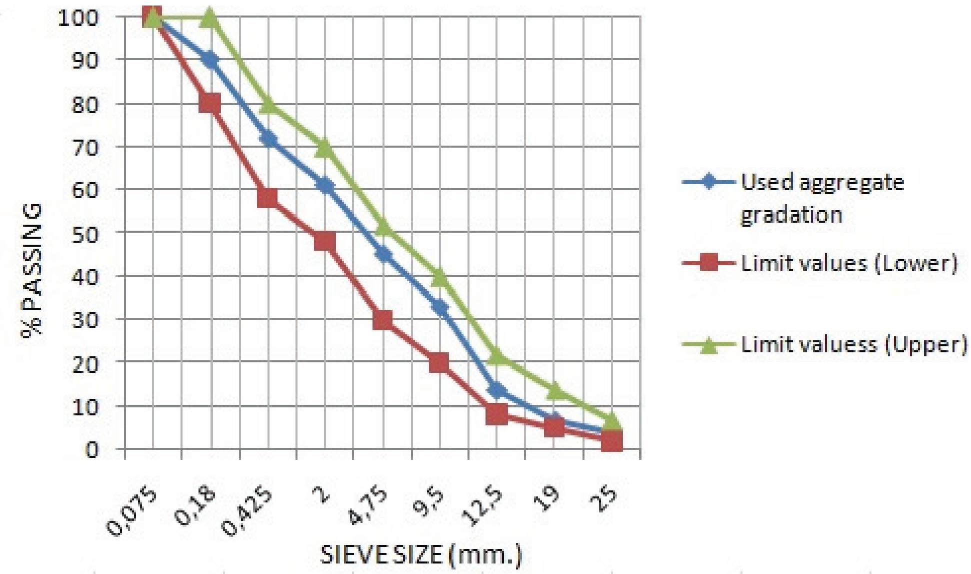

Figure 2. Aggregate grading curve

2.1.3. Iron Fiber

In this study, low-cost iron fiber which has the smallest diameter used in the construction industry was used. To this end, building site in the university was visited and iron wires were taken from the site in the shape of wire rolls. These iron fibers are very cheap and it can be found easily at every construction site. They are not specially produced steel fibers. In the road pavement laboratory, each wire coil was cut using hoof pliers. Length of wires varies in the range of 6 to 10 mm. Diameter of wires measured 1 mm. In the experiments, especially for the preparation of each sample, it was paid attention to the use of the fibers of approximately the same length. Fig 3 shows the wires used in the study.

Figure 3. Wire roll and cut iron pieces

In order to determine the strength of the iron fiber, metal tensile test was performed. According to test results, maximum stress and maximum strain values were measured as 444.599 N/mm^2 and 44.76% respectively. In view of values obtained from metal tensile tests, it can be said that iron fiber showed good performance in terms of strength. Figure 4 shows the metal tensile test results.

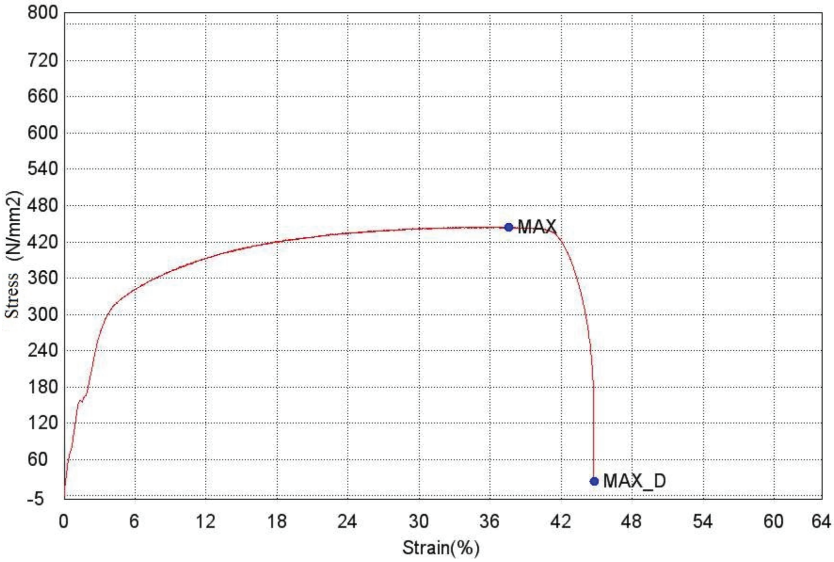

Figure 4. Curve of stress versus strain for iron fiber

2.2. Methods

2.2.1. Determination of Optimum Bitumen Content

In this study, the optimum bitumen content was determined using the Marshall mix design method described in AASHTO T 245-97. Mixtures with limestone aggregates weighing 1150 g. and 50/70 penetration bitumen were prepared for six different bitumen content

(3.0%, 3.50%, 4.0%, 4.50%, 5.0% and 5.50%). The sum total of the samples prepared for determination of optimum bitumen content was 18 (3 x 6). In the experiments, aggregates were heated at about 165 ^{0}C and bitumen was heated at about 150 ^{0}C. Both of them were heated at different ovens. Then they were introduced into the mixer and mixed for 120 seconds. The temperature of the mixture must be a minimum of 140 ^{0}C. For this reason, the temperature of the mixture was controlled continuously by using infrared thermometer during mixing. Prepared hot mixtures were placed in steel molds and compacted using Marshall compactor in order to obtain Marshall samples. Table 4 shows the hot mix asphalt design criteria for binder course according to the Turkish Highway Construction Specifications 2013.

Table 4. Hot mix asphalt design criterias

Features	Binder course		Specification
	Min.	Max.	
The number of blows to be applied making briquettes	75		TS EN 121697-30
Marshall stability, Kg	750	-	TS EN 121697-34
Voids volume, %	4	6	TS EN 121697-8
Voids filled with bitumen, %	60	75	TS EN 121697-8
Voids between mineral aggregates, %	13	15	TS EN 121697-8
Flow, mm (10-2inch)	2(8)	4(16)	TS EN 121697-34
Filler/Bitumen ratio	-	1,4	-
Bitumen (Weight percent)	3,5	6,5	TS EN 121697-1
ITSR ratio (% Min)	80		AASHTO T2 83

In the next step 18 samples were tested using the Marshall Stability Test machine. This test should be performed at 60 ^{0}C. To ensure this condition, samples were kept in a water bath at 60 ^{0}C for 40 minutes. Then samples were broken with a machine and Marshall stability, as well as Marshall flow values, were measured. Using these values, eight curves were plotted. These values were obtained from the curves; Bulk specific gravity (Dp) versus bitumen content, Marshall stability versus bitumen content; Marshall flow versus bitumen contents; percentage of air void (Vh)versus bitumen content; percentage of void filled with bitumen (V.F.A.) versus bitumen content; percentage of void in mineral aggregates versus bitumen content. Figure 5 shows the curves which are used for determining optimum bitumen content.

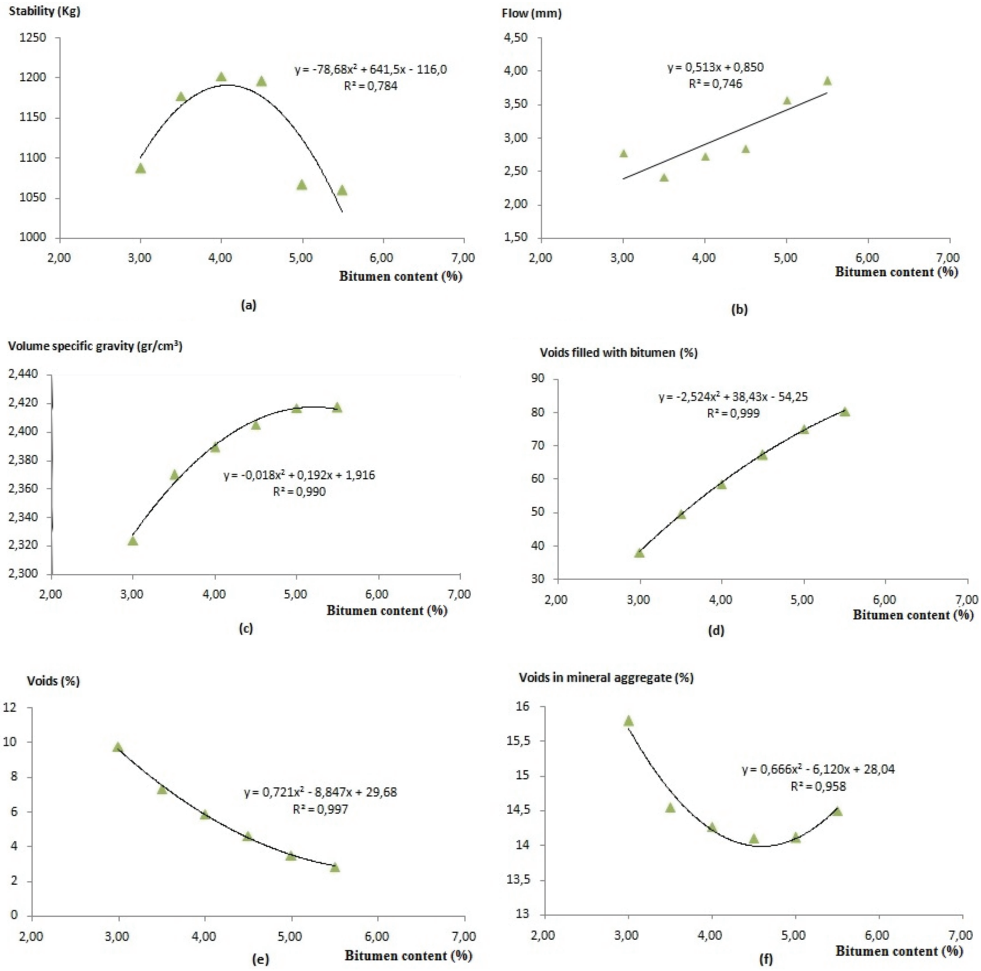

Figure 5. Graphs prepared according to bitumen content.

The optimum bitumen content was determined by taking into consideration four values which are obtained from the above curves. First value was determined from the stability curve which corresponds to maximum stability (a). The second value was obtained from volume specific gravity curve which corresponds to maximum volume specific gravity value (b). The third value was obtained from the voids graph (e). According to hot mix asphalt design criteria (seen from Table 4), the percentage of air voids should be between 4-6 % for the binder course. For this reason, average value of these limits was calculated and bitumen content corresponding to this value was determined. The last value was obtained from voids filled with bitumen graph (d). According to Table 4, the percentage of voids filled with bitumen should be between 60-75 % for the binder course. Average value of these limits was calculated and bitumen content corresponding to this value was determined. Considering these values, optimum bitumen content was calculated as follows:

$$\frac{4{,}10 + 5{,}0 + 4{,}2 + 4{,}3}{4} = 4{,}40$$

2.2.2. Preparation of Asphalt Mixtures Reinforced With Low-Cost Iron Wires

After optimum bitumen ratio was determined, iron fibers were added in different ratios (1%, 2%, 5%, 7%, 9%) by weight of the aggregates (1150) g. during mixing aggregates and bitumen. The samples used in the study were coded as below:

Control mix + 0% IWR – “CMIX”

Control mix + 1% IWR - “MIX-1-IWR”

Control mix + 3% IWR - “MIX-3-IWR”

Control mix + 5% IWR - “MIX-5-IWR”

Control mix + 7% IWR - “MIX-7-IWR”

Control mix + 9% IWR - “MIX-9-IWR”

2.2.3. Marshall Stability Test

After samples were prepared, weights of each sample in air and water, as well as heights for three-points were measured. By using these values and the other parameters such as bitumen and aggregate specific gravity, air voids (V_h), voids in mineral aggregate (VMA) and voids filled with bitumen (V_f) for each sample was drawn. Void in the bituminous hot mixture (V_h) is a small air gap between aggregates coated with bitumen. This value used in order to obtain durable pavements. V_h was calculated according to the following equation:

$$V_h = \frac{D_T - D_P}{D_T} x100 \qquad (1)$$

where $D_p$is the volume the specific gravity of compacted mixture, D_T is the max. specific gravity of the uncompacted mixture. V_f represents the thickness of the bitumen film. The following equation was used to calculate V_f [17]:

$$V_f = \frac{VMA - V_h}{VMA} x100 \qquad (2)$$

where VMA represents the voids in mineral aggregates, V_h indicates voids in the bituminous mixture. VMA is defined as gaps between aggregates in compacted hot mixtures. In other words, VMA includes the air voids and V_f (not absorbed). VMA proportion is very important in order to determine adequate film asphalt film thickness around each aggregate grain. This value is closely related to the durability and stability of mixtures. VMA was calculated as follows [17]:

$$VMA = 100 - \frac{D_p}{G_{sb}} x \frac{100}{100 + W_a} x100 \tag{3}$$

where D_p is the volume specific gravity of the compacted mixture, G_{sb} is the volume specific gravity of the aggregates, W_a is the bitumen ratio. Strength and flow values were determined by using a fully automatic Marshall stability test machine. The strength of the mixture is measured in terms of Marshall stability value. Compressive loading was implemented on the Marshall sample at a loading rate of just about 51 mm/min. until sample brakes. This test is performed at 60 ^{0}C which represents an favorable temperature according to specifications. The flow value shows the flexibility properties of the hot mixtures. This value measured by the change in diameter of the sample from the start of the loading until the stability values begin to decrease. Both stability and flow values are determined by using the Marshall stability device.

Marshall Quotient (MQ) represents the ratio of load to deformation. This value can be used to give an indication of the mixture's stiffness. This value is usually used by European agencies and is also known as the Marshall rigidity [18]. MQ which is well known as a form of pseudo stiffness is recognized as a measure resistance of materials to shear stresses, permanent deformation and hence rutting [19]. Arabani and Tahami [20] investigated the use of rice husk ash as modifier in asphalt mixture and calculated MQ, as well as rutting parameter ($G^*/\text{Sin } \delta$), were G^* is the complex modulus and Sin δ is the phase angle of pure and modified samples. The study concluded that MQ can be using as an indicator of rutting resistance of the asphalt mixture. Gibreil and Feng [21] examined the effects of high-density polyethylene and crumb rubber powder as modifiers on properties of hot mix asphalt. Results showed that samples of which MQ values were calculated higher than the others showed higher resistance to rutting. The type of gradation significantly affects the validity of the MQ results. Conventional dense graded mixes normally combine high stability with low flow values and hence high MQ values, indicating a high stiffness mix with a greater ability to spread the applied load and resist creep deformation [22]. Tayfur et al.[23] evaluated the rutting performance of asphalt mixtures containing polymer modifiers by using MQ values and other performance tests. Results showed that Marshall Quotient may not be a good indicator of measuring permanent deformation for stone mastic asphalt mixtures. Similarly, Sengul et al. [24] evaluated the BS modified stone mastic asphalt pavement performance. They stated after MQ evaluation that MQ may not be a good indicator of measuring permanent deformation for stone mastic asphalt mixtures.

2.2.4. Cantabro Test

Asphalt mixtures are subjected to wearing effects continuously due to traffic loads. For this reason, mass loss of pavements occur. The most common method for determination of mass loss is the cantabro test. Cantabro test is usually used for the OGFC (Open-Graded Friction Courses) mixtures such as porous asphalt [25-27]. However, there are numerous studies in the literature which are related to usage of these methods for dense gradations [28-32]. In this study, cantabro test was carried out according to the Turkish standard TS EN 12697-17. In this test, Marshall samples of different types of mixtures were tested by using the Los Angeles drum. During the test, weights of samples were measured (M_1). Then samples were placed in the drum without steel spheres. The drum was rotated 300 times with a speed of 30-33 rpm. Finally, weights of damaged samples were measured again (M_2). The following equation was used to calculate the percentage of mass loss (K):

$$K = 100 \text{ x } \frac{M_1 - M_2}{M_1} \tag{4}$$

In this study, cantabro test was performed on aged and unaged samples. In order to prepare aged samples, samples were placed in the forced draft oven at 60 ^{0}C for seven days. Unaged samples were kept at room temperature. Then both groups of samples were tested according to the procedure described above.

2.2.5. Indirect Tensile Strength Test and Moisture Sensitivity

Moisture-induced damage in asphalt mixtures, better known as stripping, is one of the primary causes of distress in the asphalt pavement layers [33]. For this reason, moisture susceptibility of the samples was investigated. The moisture susceptibility of the samples at optimum asphalt content was prepared and evaluated according to AASHTO T283. The results of these tests are the indirect tensile strength (St) and the indirect tensile strength ratio (ITSR). Mixtures were prepared for each additive percentage. Maximum theoretical specific weight, bulk specific gravity and volume values of each sample were calculated. Samples were divided into two groups according to average air void and defined as unconditioned and conditioned. Unconditioned samples were placed in sealed plastic bags and they were kept at room temperature. Conditioned samples were saturated with water by use of a vacuum desicator to obtain 70%-80% saturated samples. Then, they were wrapped with stretch film and they were placed in plastic bags with 10 ml. water. In the next step, conditioned samples were placed in a deep freezer at (-18) ^{0}C for 16 hours. After 16 hours, conditioned samples were immersed in a water bath at 60 ^{0}C and plastic bags were taken out from samples instantly. After 24 hours, plastic bags were taken out from the unconditioned samples and both conditioned and unconditioned samples were kept in a water bath at 25 ^{0}C for 2 hours. Finally, all samples were broken vertically at a loading rate of just about 51 mm/min with Marshall tester to determine indirect tensile strength values (P). Diameters (D) and heights (T) of samples were measured. The units of determined values were converted from kg to kg/cm^2 by using Eq5. ITSR was calculated by using Eq6 St_1 and St_2 are the arithmetic mean of indirect tensile strength values of unconditioned and conditioned samples respectively.

$$S_t = \frac{2.P}{\pi.T.D} \tag{5}$$

$$\text{ITSR} = \frac{S_{t2}}{S_{t1}} \tag{6}$$

3. RESULTS

3.1. Marshall Stability Test Results

The stability values determined following stability tests are shown in Figure 6. These values were obtained for control and reinforced samples which were prepared using iron wire of 1%, 3%, 5%, 7% and 9%. Marshall stability values of all samples were measured higher than 750 kg which is the lower limit value according to the Turkish Highway Construction Specifications 2013. Fig. 6 indicates that the stability of mixtures increased with increasing additive content initially.

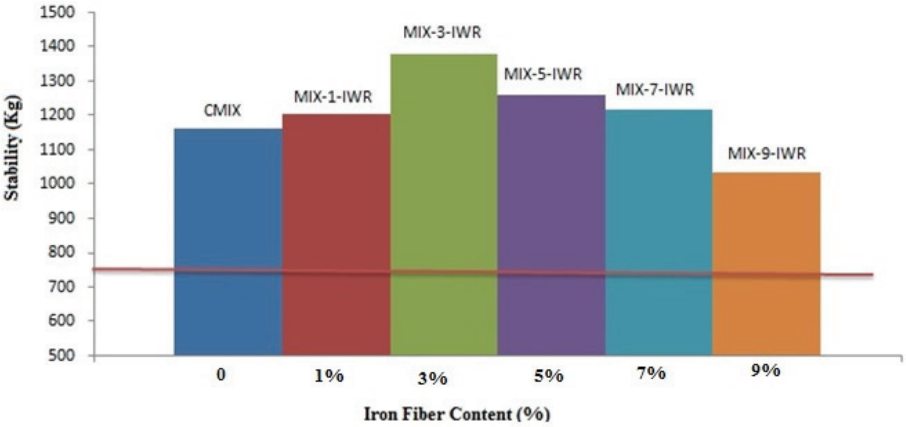

Figure 6. Stability values for each fiber content used in the experimental study

Maximum stability was obtained at 3% fiber content. Then stability values decreased. When the underlying reason is questioned, it can be seen that fibers may not distribute homogeneously in the mixture. Generally, applied loads are taken by the aggregate mass by means of contact points in Marshall samples. Because fibers created clustering in the mixture, contact between aggregate particles may be lost, and hence the stability of mixtures decreased at high fiber contents. In order to observe distribution fibers in the mixture, stereo images of mixtures were taken. According to Figure 7, it can be stated that all fibers were not dispersed in the mixture homogeneously at high fiber rates especially. Undistributed images of fibers in the mixture supports these conclusions. But these images also show us that, iron fibers in the mixtures worked properly without exhibiting any segregation and/or agglomeration from the mixture.

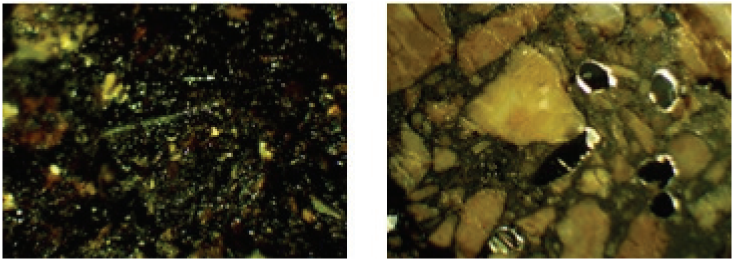

Figure 7. Stereo microscope image analysis results of mixtures prepared with iron fiber

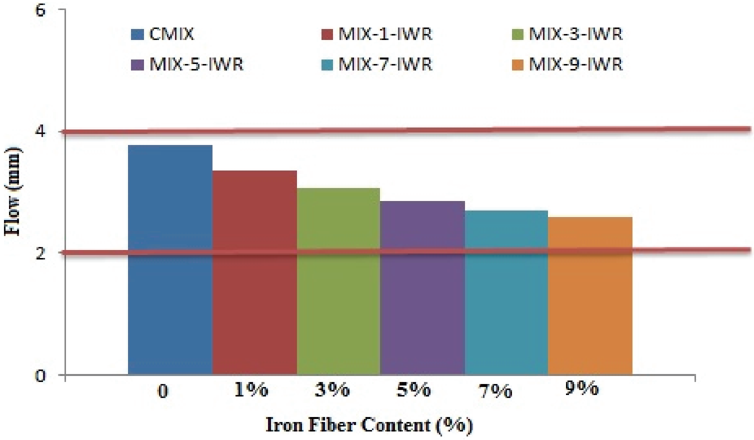

Figure 8. Flow values for each fiber percent used in the experimental study

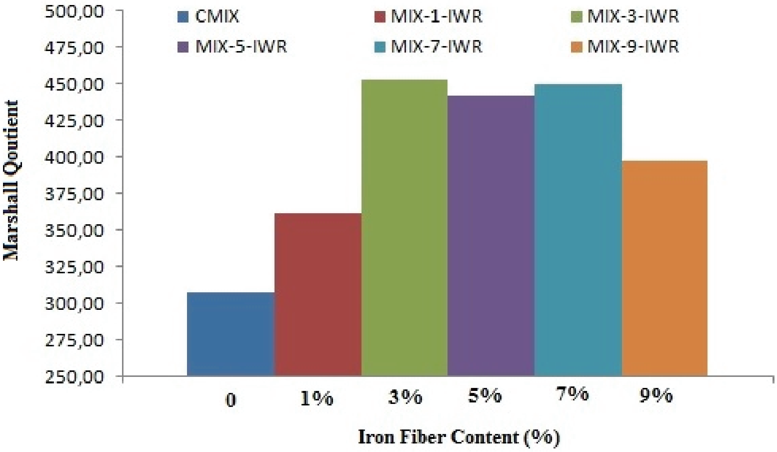

Figure 9. Marshall Quotient for each fiber percent used in the experimental study

The flexibility of mixtures was measured in terms of flow value. Figure 8 shows the flow values. When flow values were examined, it was observed that with increasing amounts of fiber, flow values decreased. This means that, as the amount of the fiber increased, the mixture became less flexible owing to the stiffness of fibers. Nevertheless, flow values were measured between required specification ranges of 2 to 4 mm.

MQ values were determined by using the ratio of stability to deformation value of mixture. The results obtained calculating MQ are shown in Figure 9.

According to Figure 9, it is evident that use of iron wire fiber as an additive in the mixture improved the MQ values. The iron wire fiber addition at the rate of 3% raised MQ value of control mixture from 306, 98 kg/mm to 452, 34 kg/mm which is almost equal to 1,5 times the MQ of the control mixture. It can be said that, adding at the rate of 3% provides rigidity, so it provides better strength against permanent deformation. This means that the mixtures gained additional stiffness with the addition of iron fibers. When the fiber contents were increased above 7%, fragility was observed in the samples. Obtained MQ results, supports the MQ approach with dense gradation mixtures as explained above.

Figure 10 shows the air voids values of samples. According to the Turkish Highway Construction Specifications 2013, air void amount should be within the range of 4% to 6% for the binder course. An evaluation of Fig 10 indicated that, with the exception of the MIX-5-IWR, MIX-7-IWR, and MIX-9-IWR, other samples were measured between required specification ranges. Too much air voids would result in low durability of the mixture, i.e. the performance would become worse. However, increasing air void value is important for pavements design in hot regions where the asphalt is suspected to flushing and bleeding. Increased void ratio can be a solution for these problems. It is important that, air voids should be within the specification limit values. As can be seen from Fig 10 the air void values increased with increasing amounts of iron fiber. The increase in air void values means that compressing the mixtures becomes more difficult with increasing fiber content.

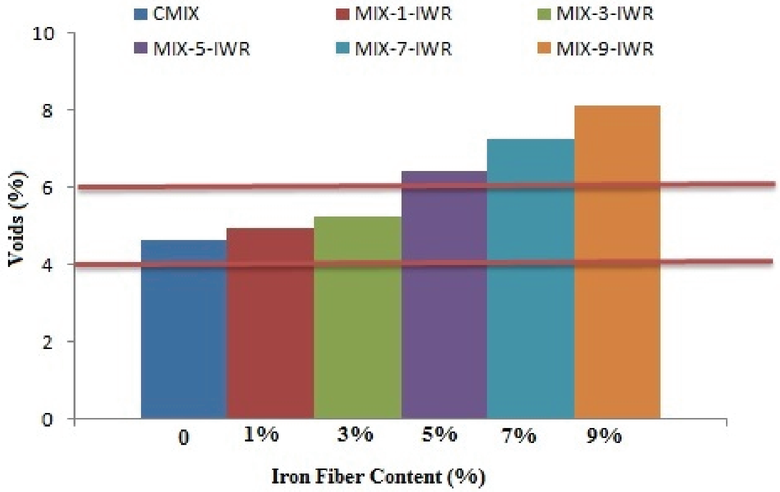

Figure 10. Air void values for each fiber percent used in the experimental study

Increasing the additive content decreases V_f values as shown in Fig 11. All samples were prepared with the same bitumen content. When fiber content was increased in the mixtures, voids filled with bitumen decreases because the amount of the bitumen in the mixture becomes insufficient.

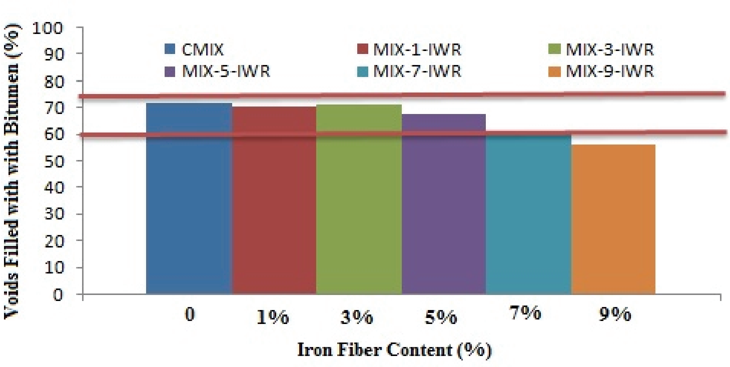

Figure 11. Voids filled with bitumen values for each fiber percent used in the study

In order to obtain enough durable and stable mixtures, VMA value should be within the range of 13% to 15% for binder course according to the specification. According to Figure 12, it can be said that VMA values of samples except for the MIX-5-IWR, MIX-7-IWR and MIX-9-IWR were determined between required specification ranges. This means mixtures with 5%, 7% and 9% iron wire content require an uneconomical amount of binder which may cause stability problems. The decrease in stability value supports this conclusion.

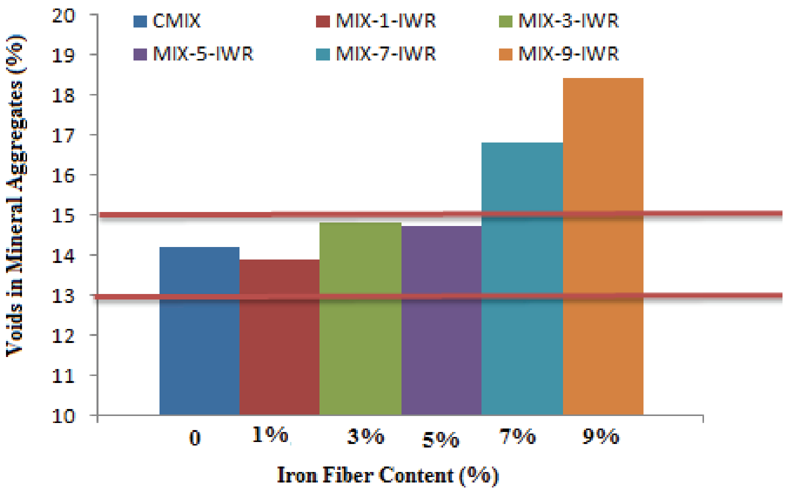

Figure 12. Voids between mineral aggregate values for each fiber percent used in the study

3.2. Cantabro Test Results

Cantabro tests were performed on aged and unaged samples for evaluating the quality of the bitumen/aggregate bond. Figure 13 shows the results of the tests. According to Figure 13, it can be said that the unaged samples exhibit lower mass loss during tests. This was expected since the samples were battered as a result of the aging process. This figure indicates that, at higher percentages of additive for both aged and unaged samples, mass loss values were significantly increased. However, when the mass loss values of unaged samples are examined, it will be seen that these values obtained for the samples defined as MIX-1-IWR, MIX-3-IWR and MIX-5-IWR correspond to rather low mass losses comparable to those obtained for the samples defined as MIX-7-IWR and MIX-9-IWR. Moreover, the similar situation was observed for the aged samples with the exception of MIX-1-IWR.

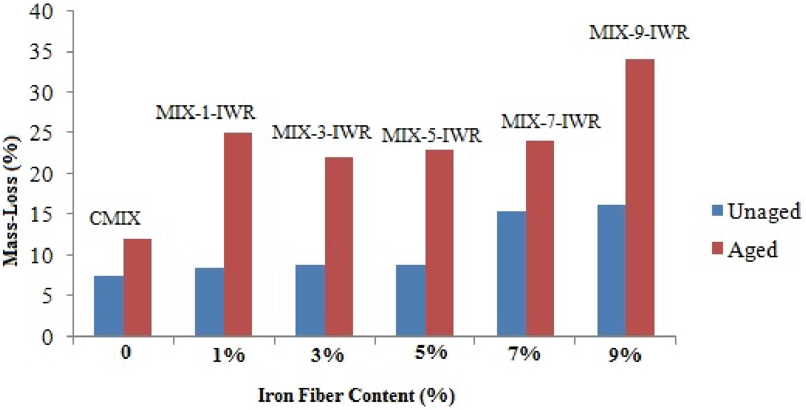

Figure 13. Mass-Loss values for each fiber percent used in the experimental study

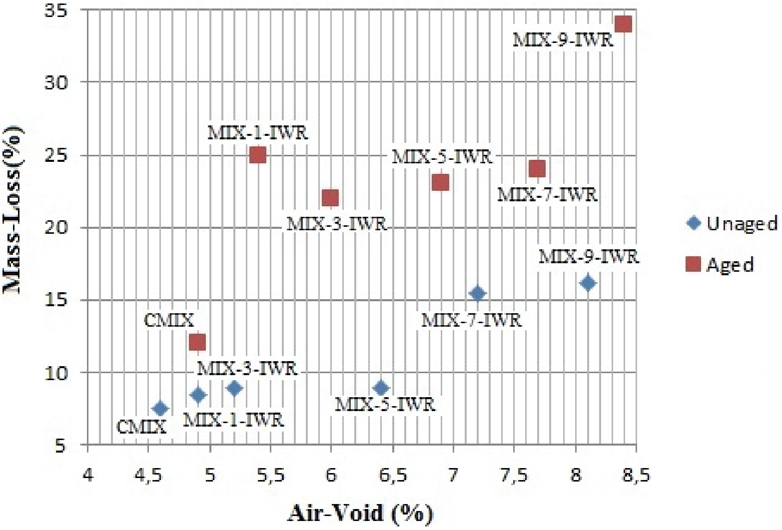

Figure 14. Change of mass loss according to air void for each fiber content

In order to better evaluate the influence of the air voids in the wear resistance of each sample, the air void-mass loss graph for the aged and unaged samples was drawn. This graph is given in Figure 14. According to Figure 14, it can be said that mass loss increases with the increase of air void content in the mixture. This means that gaps between aggregates caused decrease of the bond between bitumen and aggregate.

3.3. Moisture Susceptibility

In order to evaluate performance of low-cost iron wires iron reinforced asphalt mixtures in regards to moisture susceptibility, S_t and ITSR values were determined. Figure 15 shows the average S_t values for three samples at 25 ^{0}C for both wet and dry groups at optimum bitumen content for each additive input. Both dry and wet S_t values remained approximately the same up to 5% additive content. At higher percentages of additive, the S_t values decreased gradually. Maximum dry average S_t value was obtained with 5% additive while max. wet average S_t value was obtained from control samples. The higher this parameter, the more resistant is the sample against vertical loads. This means that, due to the air voids increased with increasing amount of fiber, gaps between aggregates of saturated samples were filled with water. Also, because samples were in the freeze-thaw cycle during the test, this water caused weakening of samples against loading.

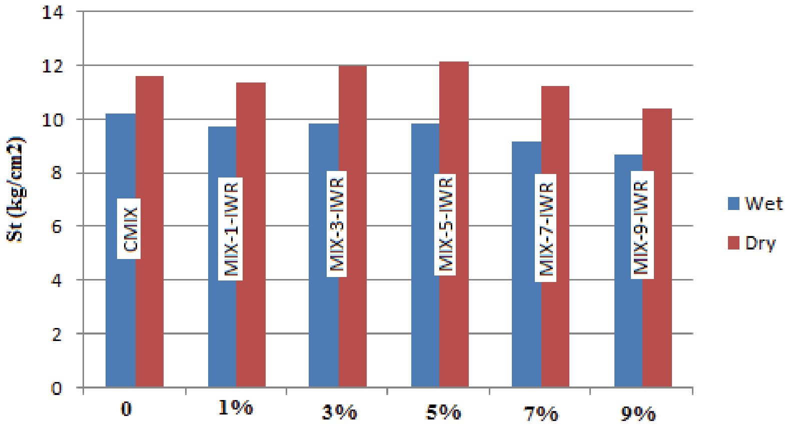

Figure15. S_t values for the each additive content

Moisture susceptibilities of each additive percentage were determined according to ITSR values, as shown in Fig 16. According to the Turkish Highway Construction Specifications 2013, the minimum ITSR value should be 80%. As seen in Fig 16, all samples provide this limit. However, control samples showed most resistance against moisture damage. ITSR value of these samples calculated as 88,02%. So, when the ITSR values examined, one can see that fiber additives could not improve the moisture susceptibility of the mixtures.

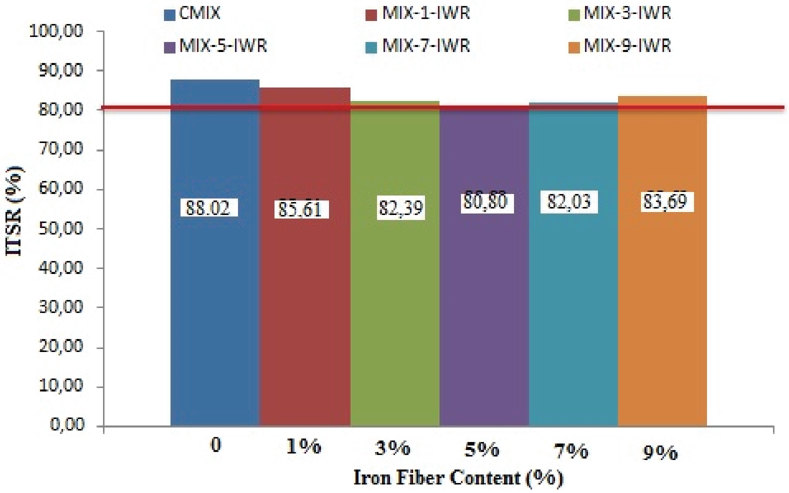

Figure 16. ITSR values for the each additive content

4. CONCLUSIONS

The asphalt mixture should be strengthened especially for heavy traffic conditions. Using low-cost iron fibers instead of other expensive reinforcing additives in the asphalt mixture presents a benefit to the community from an economic point of view. The aim of this study is to determine properties of the reinforced asphalt mixtures with low-cost iron fiber.

The optimum bitumen content for the mixtures was determined as 4.40% by weight of aggregate. Marshall stability test results showed that stability values increased up to 3% by additive. Using additive more than 3% in the mixture affected the samples adversely. When the reason of decreasing stability especially at high ratios was investigated by using stereomicroscope, it was seen that fibers were not distributed in the mixture homogeneously and that they created clustering. Although all samples were prepared with the same number of blows in the Marshall compactor, it was observed that mixtures showed less flexibility with increasing amount of fiber by reason of clustering. Measured flow values support this conclusion. Compressing the mixtures becames more difficult as well especially at high fiber ratios. Air void values were increased at high fiber ratios and consequently, samples required an uneconomical amount of binder which could cause stability problems. Additionally, air void values at samples with more than 5% additive exceed specification limits. Such a high rate air void in the mixture caused durability problems of mixtures as well. Cantabro test was performed in order to evaluate bitumen-aggregate bond for aged and unaged samples. Mass-loss percent of aged samples were measured higher than unaged samples. The Indirect tensile strength values of both wet and dry samples remained approximately the same up to 5% additive. Using additive higher than 5 percent led to a sudden and dramatic increase in indirect tensile strength values. On the other hand, although indirect tensile strength value of samples calculated higher than 80% which is the specified limit, fiber additives could not improve the moisture susceptibility of the mixtures at all.

When all of these results are considered together, it can be concluded that in strengthening of asphalt concrete with the low-cost iron fibers, best results were obtained at the rate of 3% additive. In addition, it should be explained that, adding of steel fibers to surface layers of flexible pavements may cause discomfort for drivers and they reduce safety on the road, which may cause accidents, therefore, it is recommended to use it in the below the surface layers such as the binder course. In view of improving stability effect of fiber on a mixture, further research is needed to determine the stability results of either stone mastic asphalt mixture strengthed with iron wire fiber or dense graded asphalt mixture strengthened with the powder form of iron wire. Because of stone mastic asphalt has a gap-graded gradation; high air voids caused by fibers may not cause compressive strength problems in the mixture.

References

[1] Ahmedzade P.,The investigation and comparison effects of SBS and SBS with new reactive terpolymer on the rheological properties of bitumen, Construction and Building Materials 2013; 38: 285-291

[2] Emon, M.A.B., Manzur, T., Yazdani, N., “Improving performance of light weight concrete with brick chips using low-cost steel wire fiber”, Construction and Building Materials 106 (2016), 575–583.

[3] Facconi, L., Minelli, F., Plizzari, G.,” Steel fiber reinforced self-compacting concrete thin slabs – Experimental study and verification against Model Code 2010 provisions”, Engineering Structures 122 (2016), 226–237

[4] Caratelli A., Imperatore, S., Meda, A., Rinaldi, Z., “Punching shear behavior of lightweight fiber reinforced concrete slabs”, Composites Part B 99 (2016), 257-265

[5] Putman, B.J., Amirkhanian, S.N., “Utilization of waste fibers in stone matrix asphalt mixtures”, Resources, Conservation and Recycling 42 (2004) 265–274

[6] Wu, S., Liu, G., Mo, L., Chen, Z., Ye, Q. “Effect of fiber types on relevant properties of porous asphalt” Transactions of Nonferrous Metals Society of China, 16(2006): 791-795

[7] Abtahi, S.M., Sheikhzadeh, M., Hejazi, S.M., “Fiber-reinforced asphalt-concrete – A review”, Construction and Building Materials 24 (2010) 871–877

[8] Transportation Research Board (TRB):NCHRP Synthesis Report 475, “Fiber Additives in Asphalt Mixtures”, 2015, Washington D.C.

[9] Park, P., El-Tawil S., Park, S., Naman, A., “Cracking resistance of fiber reinforced asphalt concrete at -20 ^{0}C”, Construction and Building Materials 81 (2015), 47–57

[10] Fazaelli, H., Samin, Y., Pirnoun, A., Dabiri, A.S., “Laboratory and field evaluation of the warm fiber reinforced high performance asphalt mixtures (case study Karaj – Chaloos Road)”, Construction and Building Materials 122 (2016) 273–283

[11] Ferotti, G., Pasquini, E., Canestrari, F., “Experimental characterization of high-performance fiber-reinforced cold mix asphalt mixtures”, Construction and Building Materials 57 (2014) 117–125

[12] Guo, J.F., “The Effect of Steel Fiber on the Road Performence of Asphalt Concrete”, Applied Mechanics and Materials, 584-586 (2014), 1342-1345

[13] Al-Ridha A.S.D., HAmeed, A., Ibrahim, S.K., “Effect of steel Fiber on the Performance of Hot Mix Asphalt with Different Temperaturesand Compaction”, Australian Journal of Basic and Applied Sciences, 8(6) ,2014: 123-132

[14] Garcia, A., Norambuena-Contreras, J., Parti, M.N., Schuetz, P., “Uniformity and mechanical properties of dense asphalt concrete with steel wool fibers”, Construction and Building Materials 43 (2013) 107–117

[15] Serin, S., Morova, N., Saltan, M., Terzi, S., “Investigation of usability of steel fibers in asphalt concrete mixtures”, Construction and Building Materials, 36(2016), 238-244

[16] General Directorate of of Highways,“Highway Construction Specifications”, Ankara, General Directorate of Highway Press, 2013 (in Turkish)

[17] General Directorate of of Highways, “Bituminous mixtures laboratory manual”, Ankara, Turkey, General Directorate of Highway Press, 2012 (in Turkish).

[18] Lavin, P. (2003), “Asphalt pavements: A practical guide to design, production and maintenance for engineers and architecs”, CRC Press.

[19] Whiteoak D, The Shell bitumen handbook, UK: Shell Bitumen; 1991.

[20] Arabani, M., Tahami, S.A.,” Assessment of mechanical properties of rice husk ash modified asphalt mixture”, Construction and Building Materials, 149 (2017), 350-358

[21] Gibreil, H.A.A., Feng, C.P., “Effects of high-density polyethylene and crumb rubber powder as modifiers on properties of hot mix asphalt”, Construction and Building Materials 142 (2017) 101–108

[22] Zoorob, S.E., Suparma, L.B., “Laboratory design and investigation of the properties of continuously graded Asphaltic concrete containing recycled plastics aggregate replacement (Plastiphalt)”, Cement & Concrete Composites 22 (2000) 233-242

[23] Tayfur, S., Ozen, H., Aksoy, A., “Investigation of rutting performance of asphalt mixtures containing polymer modifiers”, Construction and Building Materials 21 (2007) 328–337.

[24] Sengul C.E., Oruc, S., Iskender, E., Aksoy, A., “Evaluation of SBS modified stone mastic asphalt pavement performance”, Construction and Building Materials 41 (2013) 777–783

[25] Arrieta, V.S., Maquilon, J.E.C., “Resistance to degradation or cohesion loss in Cantabro test on specimens of porous asphalt friction courses.”, XVIII Panamerican Conference of Traffic and Transportation Engineering and Logistics (PANAM 2014), Procedia - Social and Behavioral Sciences 162 (2014) 290 – 299

[26] Shirini, B., Imaninasab, R., “Performance evaluation of rubberized and SBS modified porous asphalt mixtures”, Construction and Building Materials 107 (2016), 165–171

[27] Chiu, C., “Use of ground tire rubber in asphalt pavements: Field trial and evaluation in Taiwan”, Resources, Conservation and Recycling 52 (2008) , 522–532

[28] Celauro, C., Bernardo, C. Gabriele, B., "Production of innovative, recycled and high-performance asphalt for road pavements", Resources, Conservation and Recycling 54 (2010), 337–347

[29] Lin, J., Guo, P., Wan, L., Wu, S., "Laboratory investigation of rejuvenator seal materials on performances of asphalt mixtures", Construction and Building Materials 37 (2012,) 41–45

[30] Colonna P, Berloco N., Ranieri V., Shuler S.T., "Application of Bottom Ash for Pavement Binder Course", SIIV - 5th International Congress - Sustainability of Road Infrastructures, Procedia - Social and Behavioral Sciences 53 (2012), 962 – 972

[31] Pereira, S.M.S., Oliveira, J.R.M., Freitas, E.F., Machado, P., "Mechanical performance of asphalt mixtures produced with cork or rubber granulates as aggregate partial substitutes", Construction and Building Materials 41 (2013), 209–215

[32] Contreras, J.N., Gaecia, A., "Self-healing of asphalt mixture by microwave and induction heating", Materials and Design 106 (2016), 404–414

[33] Liang R.Y., "Refine AASHTO T283 Resistance of compacted bituminous mixture to moisture induced damage for Superpave " , U.S. Department of Transportation Federal Highway Administration Report, Report No: FHWA/OH-2008/1, 2008

[34] Tapkın, S., "The effect of polypropylene fibers on asphalt performance", Building and Environment 43 (2008) 1065–1071