Mühendislik Bilimleri ve Tasarım Dergisi
7(4), 906 – 912, 2019
e-ISSN: 1308-6693

Journal of Engineering Sciences and Design
DOI: 10.21923/jesd.553502

Araştırma Makalesi Research Article

INVESTIGATING THE UTILITY OF SISAL IN HOT MIX ASPHALT AS A FIBER

Şebnem KARAHANCER[1*], Ekinhan ERİŞKİN, Mehmet SALTAN[2], Serdal TERZİ, Onur SARIOĞLU[2], Dicle ÖZDEMİR KÜÇÜKÇAPRAZ[3]

[1] Isparta University of Applied Sciences, Faculty of Technology, Civil Engineering Department, Isparta, Turkey
[2] Suleyman Demirel University, Faculty of Engineering, Civil Engineering Department, Isparta, Turkey
[3] Suleyman Demirel University, Faculty of Engineering, Textile Engineering Department, Isparta, Turkey

Keywords

Sisal, Agave Sisalana, Fiber, Indirect Tensile Strength, Tensile Strength Ratio.

Abstract

Hot mix asphalt (HMA) is very common as a highway construction material. Although investment costs are lower than other pavements, HMA needs maintenance and rehabilitation (M&R) more often because of environmental conditions. The time needed for M&R can be extended by using fibers in the mixture. In this study, utility of sisal (Agave Sisalana) plants' fibers are investigated in HMA. Initially, optimum bitumen content according to best aggregate gradation is determined using Superpave volumetric mix design process. Then, fiber is prepared as short (~3 cm) and long (15 – 100 cm) pieces. Prepared fibers are added into HMA mixtures at different ratios (1, 2 and 3‰ by weight of mixture) based on optimum bitumen content. 1‰ short sisal fiber added specimen gave the best unconditioned indirect tensile strength values, and also long fibers gave best tensile strength ratios.

SISALIN BİTÜMLÜ SICAK KARIŞIM İÇERİSİNDE LİF OLARAK KULLANILABİLİRLİĞİNİN ARAŞTIRILMASI

Anahtar Kelimeler

Sisal, Agave Sisalana, Fiber, İndirekt Çekme Dayanımı, İndirekt Çekme Oranı.

Öz

Bitümlü Sıcak Karışımlar (BSK) karayolu inşasında yaygın olarak kullanılmaktadır. Diğer üstyapı türlerine göre yatırım maliyetinin düşük olmasına rağmen, sıklıkla çevresel koşullardan dolayı bakım ve rehabilitasyona (B&R) ihtiyaç duymaktadır. B&R için ihtiyaç duyulan süreyi uzatmak için BSK içerisinde lif kullanılabilmektedir. Bu çalışmada, sisal (agave sisalana) ağaçlarının liflerinin BSK içinde kullanılabilirliği incelenmiştir. İlk olarak Superpave karışım tasarımı kullanılarak en iyi agrega gradasyonuna göre optimum bağlayıcı içeriği belirlenmiştir. Daha sonra, lifler kısa (~3 cm) ve uzun (15 – 100 cm) olmak üzere iki uzunlukta hazırlanmıştır. Hazırlanan lifler optimum bağlayıcı içeriğine bağlı olarak farklı oranlarda (‰1, ‰2 ve ‰3, ağırlıkça) karışıma eklenmiştir. En iyi şartlandırılmamış indirekt çekme dayanımı ‰1 kısa sisal lif eklenen karışımlarda elde edilmiş, en iyi indirekt çekme oranı ise uzun liflerle elde edilmiştir.

Alıntı / Cite

Karahancer S., Eriskin E., Saltan M., Terzi S., Sarioglu O., Ozdemir Kucukcapraz D., (2019). Investigating the Utility of Sisal in Hot Mix Asphalt as a Fiber, Journal of Engineering Sciences and Design, 7(4), 906-912.

Yazar Kimliği / Author ID (ORCID Number)	Makale Süreci / Article Process	
S. Karahancer, 0000-0001-7734-2365	**Başvuru Tarihi / Submission Date**	13.04.2019
E. Erişkin, 0000-0002-0087-0933	**Revizyon Tarihi / Revision Date**	28.05.2019
M. Saltan, 0000-0001-6221-4918	**Kabul Tarihi / Accepted Date**	16.07.2019
S. Terzi, 0000-0002-4776-824X	**Yayım Tarihi / Published Date**	19.12.2019
O. Sarıoğlu, 0000-0001-6754-7105		
D. Özdemir Küçükçapraz, 0000-0003-0209-8323		

[*] Corresponding Author/İlgili Yazar: sebnemsargin@isparta.edu.tr, +90-246-211-80-04

1. Introduction

Hot mix asphalt (HMA) is common worldwide as a construction method for roads. HMA is consist of aggregates and bitumen which is a petroleum product. But pavement professionals are focused on alternative materials because of high construction costs (Yilmaz et al. 2011). So, they are looking for some alternative materials which decreases the bitumen rate in the HMA while maintaining or increasing the parameters which affects the structural performance of the HMA.

There are many studies about establishing the necessary structural performance parameters and increasing the performance such as modifying bitumen (Khattak et al. 2012; DuBois et al. 2014; Cardone et al. 2014), using different aggregates in the mixture (Abo-Qudais S. and Al-Shweily 2007; Airey et al. 2008; Yilmaz et al. 2011) and adding additives into the mixture (Hassan et al. 2005; Serin et al. 2012; Morova et al. 2016; Ondurucu and Karacan 2018; Atav and Namirti 2011; Kacar 2018).

A big part of the world use fibers for many decades to reinforce paving materials. A very common use of fibers is adding them into open graded mixtures or porous asphalt to avoid drain down of bitumen from aggregates. However, use of fibers in dense graded mixtures for increasing the stability or improving cracking resistance is less common. Fibers were reportedly used to provide; increased tensile strength results, increased fatigue resistance, increased rutting resistance, increased abrasion resistance, increased durability, and potential lower life cycle costs (Lottman 1982).

Sisal (Agave Sisalana) fibers (SF) are one of the best fibers in natural fiber classification. Fibers are obtained by removal of fiber bundles from dried sisal plant leaves which are growing in tropical environments. Cross section of a SF has hollow area which is encompassed by thin polygonal walls. SF have high strength and rigidity because of the high cellulose rate (~%78-88). In addition, SF have good elasticity by having high moisture absorption capability because of hollow structure of the fiber, and large amount of hydroxyl groups in chemical bonds. SF are used to produce technical textiles since ancient times. Usage areas of SF can be listed as; traditional textiles (twine, ropes, string, carpets, etc.), reinforcing composites (as to reinforce plastics in automobiles, boats, furniture, etc.) and also be used to add strength in construction elements (insulation material due to the low density and good welding specific properties). Near having good mechanical performance of this eco-friendly fiber, it is also cheaper than synthetic fibers which are used for technical textiles (Cook 1984; Mukherjee and Satyanarayana 1984; Joseph et al. 1999; Li et al. 2000; Oladele et al. 2014). When the advantages are considered, SF is useable material for reinforcing the dense graded pavement.

In this study, sisal fiber (SF) has been used in HMA for wearing course as a fiber and studied the improvements of the mixture. Therefore, optimum bitumen rate and aggregate gradation from volumetric mix design have been obtained. Samples with different SF rates are prepared according to the optimum bitumen and aggregate rates. At the beginning, it is thought to add 1, 3 and 5‰ SF to the HMA by weight. But samples with 5‰ SF was incompressible so the rates have been revised as 1, 2 and 3‰ by weight. In addition, the length of the SF is studied in this study by preparing samples with short SF (~3 cm) and long SF (15 – 100 cm). The prepared samples have been tested in accordance with AASHTO T283.

2. Materials

2.1. Aggregate

Limestone ($CaCO_3$) aggregate is used in this study. Properties of the aggregate is given in Table 1. Aggregate gradation curve used in this study for preparing mixtures are selected in convenience with aggregate gradation control points (Figure 1) (AASHTO 2001).

Table 1. Properties of aggregates

Sieve Diameter	Properties	Standard	Limestone Aggregate
4.75 – 0.075 mm	*Specific Gravity (g/cm³)*	*ASTM C 127-88*	*2.660*
	Saturated Specific Gravity		*2.652*
	Water Absorption (%)		*0.130*
25 – 4.75 mm	*Specific Gravity (g/cm³)*	*ASTM C 128 88*	*2.750*
	Saturated Specific Gravity		*2.428*
	Water Absorption (%)		*2.800*
	Abrasion Loss (%)	*ASTM C 131*	*20.38*

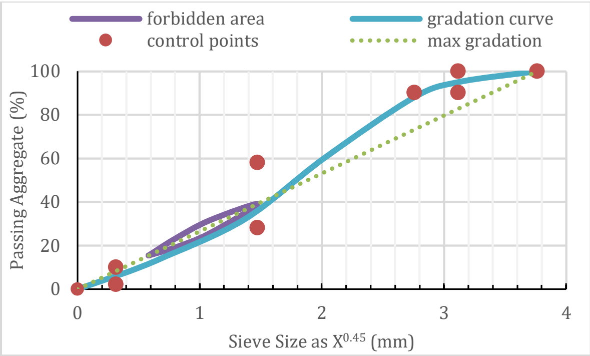

Figure 1. Gradation of the aggregates used in the study

2.2. Bitumen

Basic properties of bitumen are determined by standard bitumen tests. Test results are summarized in Table 2.

Table 2. Bitumen characteristics

Bitumen Tests	Average values	Standard
Penetration (25 °C)	50-70	ASTM D5
Flash Point	180°C	ASTM D92
Combustion Point	230 °C	ASTM D92
Softening Point	53.1°C	ASTM D36
Ductility (5 cm/min)	>100 cm	ASTM D113
Specific Gravity (g/cm³)	0.995	ASTM D70

Optimum bitumen content is obtained with four different bitumen contents (4.5%, 5%, 5.5% and 6%). HMA samples are prepared by Superpave Gyratory Compactor (SGC). The test results are given in Figure 2-5.

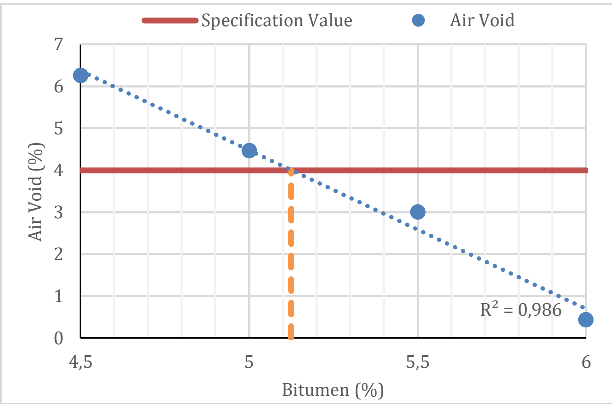

Figure 2. Change on air voids for different bitumen rate

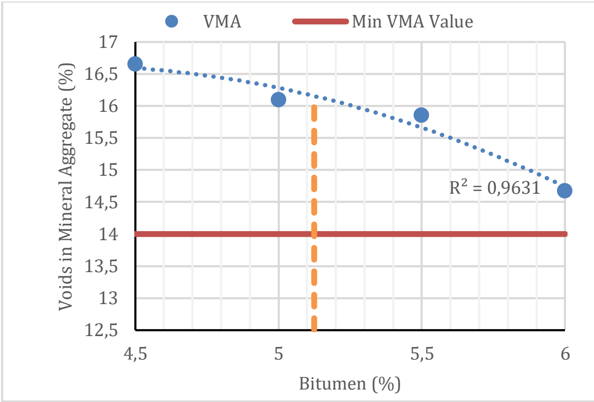

Figure 3. Change on voids in mineral aggregates for different bitumen rates

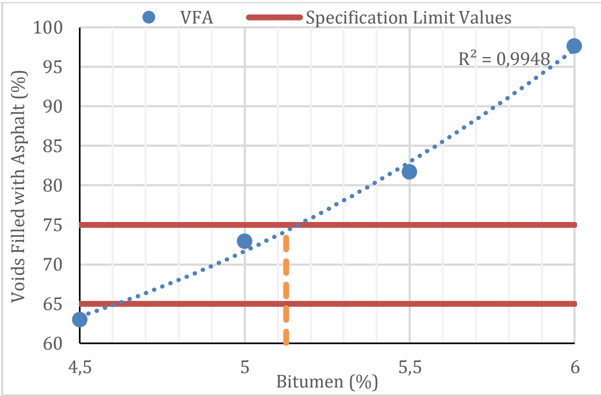

Figure 4. Change on voids filled with asphalt for different bitumen rates

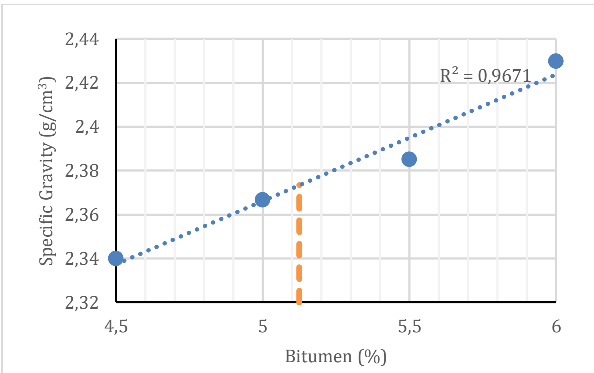

Figure 5. Change on specific gravity for different bitumen rates

Seen on Figure 2, air void content of 4% is ensured by 5.125%. Besides, the bitumen content ensures specification limits (14% min voids in mineral aggregate (VMA) (Figure 3) and 65 – 75% interval voids filled with asphalt (VFA) (Figure 4)). Also, specific gravity for different bitumen rates is given in Figure 5. Based on test results, the optimum bitumen content is used as 5.125%.

2.3. Sisal Fiber

Fibers, used in this study, are obtained from Sisal (Agave Sisalana) plants leafs. The most important parts of the characteristics of sisal fibers are given in Table 3. Photos of sisal fibers taken by light microscope are given in Figure 6.

Table 3. The features of sisal fiber (Mukherjee and Satyanarayana 1984; Joseph et al. 1999; Li et al. 2000; Oladele et al. 2014; Joseph and Thomas 1996; Mwaikambo and Ansell 2002)

Features	Value
Chemical composition of fiber (by weight)	%78-88 cellulose %8 lignin %10 hemi-celluloses %2 waxes %1 ash
Crystallinity (%)	70.90
Density (g/cm³)	1.45
Diameter of fiber (μm)	100-300
Tensile strength (MPa)	400-700
Elongation (%)	5-14
Electrical properties	Anti-static
Tensile strength ratio (wet to dry)	~1:2
Fire resistance	Good

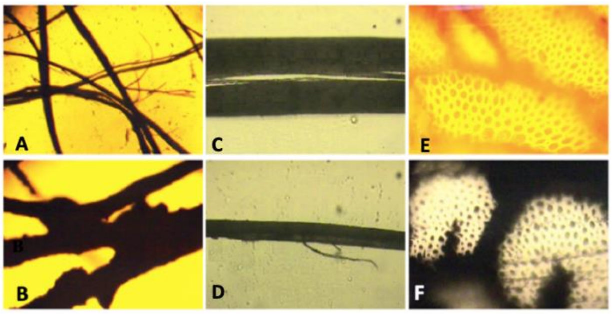

Figure 6. The Morphological analysis of sisal fiber bundles in different conditions

Photos shown in Figure 6 are taken with different magnifications. Photos of A and B are taken with 4x object lens, C and D with 10x object lens and for E and F 40x object lens. A group of basic sisal fibers can be seen from photo of A. A group of sisal fibers can be seen taken from the compacted specimens which are united with bitumen and fine aggregates from photo of B. Although C and D are taken with the same magnification, fineness difference between sisal fibers of different thicknesses can be easily seen. At E and F, cross sections of fibers are shown. E is the cross section of basic sisal fiber and F is cross section of sisal fibers taken from compacted specimens after loading.

3. Method

3.1. Indirect Tensile Strength Test

AASHTO T283 (2011) is adopted to determine the Indirect Tensile (IDT) strength of the prepared specimens. The ratio of the IDTC to IDTU is Tensile Strength Ratio (TSR). Moisture susceptibility is represented by TSR. A minimum TSR value should be 80%.

3.2. Tensile Strength Test for Sisal Fiber

Morphology and diameter of fiber bundles used in this study are examined by Motic Light Microscopy and image analyzer program. Diameter of the SF are determined by measuring 100 random SF and calculating the mean of the results. Tensile strength test is conducted on basic sisal fiber bundles, extracted sisal fiber bundles from the samples subjected to Indirect Tensile Strength Test, and sisal fiber coated with bitumen. The strength test is performed by Lloyd LR5 K Plus (CRE/The principle of constant elongation rate). 50 mm long SF bounded to 100 N load cell with a 0.005 kN preload were strained at a speed of 50 mm/min. Each SF samples have been tested for five times. Sisal could be effected by mixture preparing conditions like high temperature, moisture etc. as explained in introduction section. By applying this test, the potential differences between the SF samples are determined.

4. Results and Discussion

SF are used in this study to obtain the usability as fiber in hot mix asphalt. Therefore, fibers in leafs of sisal plant are extracted. Obtained fibers had different diameters so to determine an average value, hundred samples are randomly selected from the fiber bundle and measured with an electronic microscope. In Figure 7, the variation of diameters for the basic sisal fibers are shown.

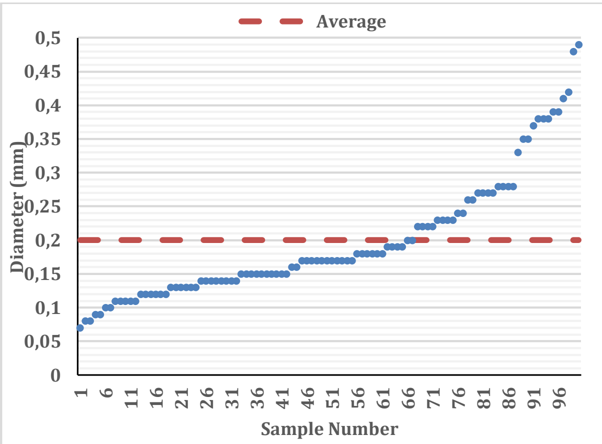

Figure 7. Diameter variation of random selected fiber samples

As seen on Figure 7, average diameter of the samples is obtained as 0.2 mm. Minimum diameter measurement was 0.07 mm and the maximum diameter have been 0.49 mm measured. There was a standard deviation of 0.092 between the diameter measurements.

In Figure 8, load versus elongation graph is shown for the single fiber in different conditions. Five strength analysis tests have been done for each fiber samples in different conditions, and the average values obtained from this test results are used for plotting Figure 8.

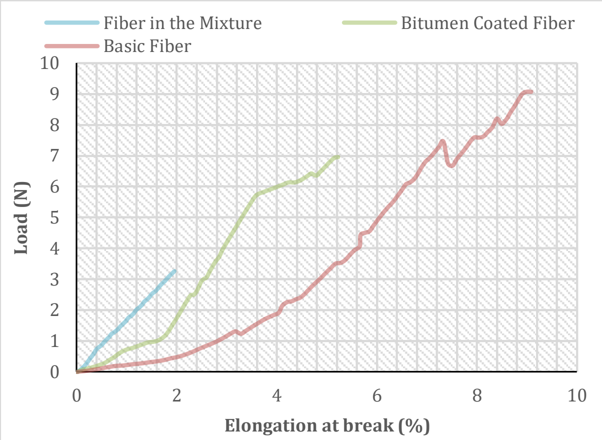

Figure 8. Load elongation graphics of sisal fibers in different conditions

As seen in Figure 8, results of fibers taken from mixture, fibers coated with bitumen and basic fibers are placed side by side. While basic fiber prolonged 9.07% with 9.08 N load at break, fibers taken from compacted specimens, and coated with bitumen had lower values. Minimum values are obtained from fibers taken from compacted specimens which are prolonged 2% with 3.3 N load. The reason that these fibers had the lowest values is that these fibers are damaged while trying to separate them from compacted specimens because of occurring of well attaching of fiber, bitumen and aggregate. Fibers which are coated with bitumen have only an elongation of 5.2% at 7 N load. The difference between basic fiber and fiber coated with bitumen can be explained with coating fiber with bitumen and restriction of elongation.

As seen on Figure 9, by increasing the SF ratio, surface area increases. As a result, bitumen doesn't bond around whole fiber surface.

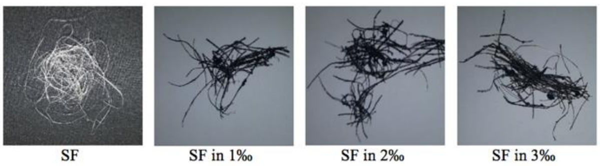

Figure 9. Reference sisal fiber and sisal fiber taken from compacted specimens

IDT values of SF added specimens are given in Figure 10. By adding short SF in the mixture, indirect tensile strength of the specimen decreases. Adding long SF gives lower unconditioned IDT results than reference specimen. However, the strength values for long SF specimens are close to each other. This situation could be explained with increased SF rates in the mixture increases the surface area so bitumen is not enough to bond with all fibers.

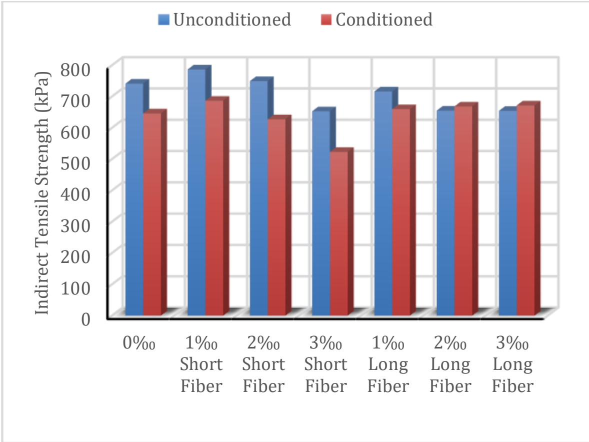

Figure 10. Conditioned and unconditioned IDT strength values for each specimen

Comparison of the conditioned and unconditioned IDT strength values are shown in Figure 11. As seen in Figure 11, 2 and 3‰ SF added specimens are nearest to the line of equality which gradient is one. That means that 2 and 3‰ SF added specimens almost isn't affected by the moisture. Although 1‰ added specimen is not close as 2 and 3‰ SF added specimens, specimens compacted with long sisal fibers are closer to the line of equality than the other specimens.

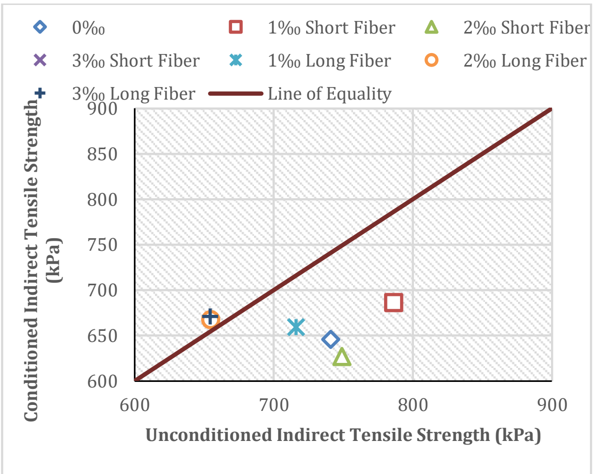

Figure 11. Comparison of the conditioned and unconditioned specimens' strength values

Tensile strength ratios (TSR) are shown in Figure 12. As seen in Figure 12, all specimens have greater TSR value than 80% which is minimum specification limit value. TSR results of short SF added specimens have a downward trend line, and 3‰ short SF added specimen is on the specification limit. However, long SF added specimens had a greater TSR value than reference specimen. So, none of the prepared specimen is moisture susceptible.

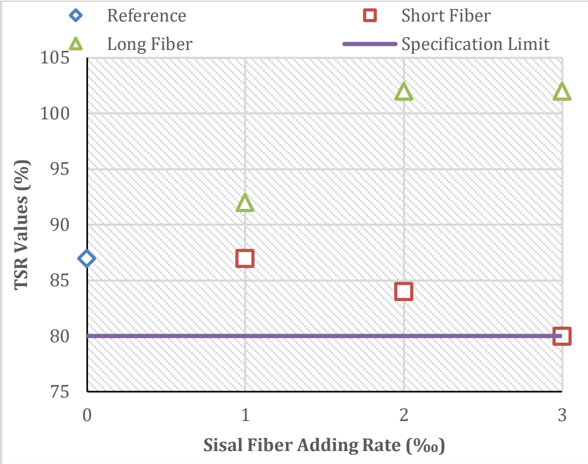

Figure 12. TSR values

5. Conclusion

The purpose of this study was to determine the usability of sisal fibers (SF) as a fiber material in dense graded hot mix asphalt (HMA) pavement. Optimum bitumen content for best suitable gradation is determined as 5.125% by weight of aggregate.

In this study, SF have been added into the HMA in six different conditions (1, 2 and 3‰ for both, short and long SF). IDT strengths of 1‰ short fiber added specimen is greater than reference specimen. Specimens compacted with long SF have lower IDTU strength values. However, IDTC strength values of specimens compacted with long SF are greater than reference specimens.

All specimens' TSR values are above 80%, minimum specification limit. Therefore, none of the specimens are moisture susceptible. By increase of short SF, the TSR values are decreasing. However, adding 1‰ long SF increases the TSR value approx. 5%. There is no difference between 2 and 3‰ long SF added specimens, and they are closest to one. So, they have most resistance against moisture.

After investigation of sisal fibers' morphologies in different conditions, single fiber of sisal which is coated by bitumen did not change but the outside of fiber degenerated because of high temperature of bitumen by mixing process. Obtained from both, during the mixing process observed and also as seen in morphological analysis, bitumen and aggregate attached very well because of the rough surface of bundles.

Conflict of Interest

No conflict of interest was declared by the authors.

References

AASHTO MP2, 2001. Standard specification for Superpave volumetric mix design, American Association of State Transportation and Highway Officials, Washington, D.C.

Abo-Qudais S., Al-Shweily H., 2007. Effect of aggregate properties on asphalt mixtures stripping and creep behavior, Construction and Building Materials, 21(9), 1886-1898.

Airey G. D., Collop A. C., Zoorob S. E., Elliott R. C., 2008. The influence of aggregate, filler and bitumen on asphalt mixture moisture damage, Construction and Building Materials, 22(9), 2015-2024.

Atav R., Namırtı O., 2011. İpek Liflerinin Dünü ve Bugünü, Mühendislik Bilimleri ve Tasarım Dergisi, Cilt:1, Sayı:3, s.112-119.

Cardone F., Ferotti G., Frigio F., Canestrari F., 2014. Influence of polymer modification on asphalt binder dynamic and steady flow viscosities, Construction and Building Materials, 71, 435-443.

Cook J. G., 1984. Handbook of Textile Fibers: Natural Fibers, Merrow.

DuBois E., Mehta Y., Nolan A., 2014. Correlation between multiple stress creep recovery (MSCR) results and polymer modification of binder, Construction and Building Materials, 65, 184-190

Hassan H. F., Oraimi S. A., Taha A., 2005. Evaluation of open-graded friction course mixtures containing cellulose fibers and styrene butadiene rubber polymer, Journal of Materials in Civil Engineering, 17(4), 416-422.

Joseph K, Filho R. D. T., James B., Thomas S, Carvalho L. H., 1999. A Review on Sisal Fiber Reinforced Polymercomposites, Revista Brasileira de Engenharia Agrícola e Ambiental, 3(3), 367-379.

Joseph K., Thomas S, 1996. Effect of Chemical Treatment on the Tensile Properties of Short Sisal Fiber-Reinforced Polyethylene Composites, Polymer, 37 (23), 5139-5149.

Kacar A., 2018. Atık Kağıt Katkılı Çimento Harçlarının Mekanik Özellikleri, Mühendislik Bilimleri ve Tasarım Dergisi, 6 (1), 1-6.

Khattak M. J., Khattab A., Rizvi H. R., Zhang P., 2012. The impact of carbon nano-fiber modification on asphalt binder rheology, Construction and Building Materials, 30, 257-264

Li Y., Mai Y. W., Ye L., 2000. Sisal Fiber and Its Composites: a Review of Recent Developments, Composites Science and Technology, 60, 2037-2055.

Lottman, 1982. R.P. NCHRP Report 246: Predicting Moisture-Induced Damage to Asphaltic Concrete—Field Evaluation. In Transportation Research Board, National Research Council. Washington, D.C.

Morova N., Serin S., Terzi S., Saltan M., Ozdemir Kucukcapraz D., Sargin Karahancer S., Eriskin E., 2016. Utility of polyparaphenylene terephtalamide fiber in hot mix asphalt as a fiber, Construction and Building Materials, 107, 87-94

Mukherjee P. S., Satyanarayana K. G., 1984. Structure and Properties of Some Vegetable Fibers Part 1 Sisal Fiber, Journal of Materials Science, 19, 3925-3934.

Mwaikambo L. Y., Ansell M. P., 2002. Chemical Modification of Hemp, Sisal, Jute, and Kapok Fibers by Alkalization, Journal of Applied Polymer Science, 84(12), 2222-2234.

Oladele I. O., Daramola O. O., Fasooto S., 2014. Effect of Chemical Treatment on the Mechanical Properties of Sisal Fiber Reinforced Polyester Composites, Leonardo Electronic Journal of Practices and Technologies, 24, 1-12.

Ondurucu A., Karacan A., 2018. Tabakalı Cam Elyaf/Epoksi Kompozitlerin Darbe Davranışının Deneysel Olarak İncelenmesi, Mühendislik Bilimleri ve Tasarım Dergisi 6 (3), 435 – 447.

Serin S., Morova N., Saltan M., Terzi S., 2012. Investigation of usability of steel fibers in asphalt concrete mixtures, Construction and Building Materials, 36, 238-244.

Yilmaz M., Kok B. V., Kuloglu N., 2011. Effects of using asphaltite as filler on mechanical properties of hot mix asphalt, Construction and Building Materials, 25, 4279-4286.