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An evaluation of the usability of glass and polypropylene fibers in SMA mixtures

TMA karışımlarında cam ve polipropilen elyaf kullanımının değerlendirilmesi

Burak EVİRGEN[1*], *Altan ÇETİN*[2], *Asena KARSLIOĞLU*[3], *Ahmet TUNCAN*[4]

[1,3,4]Department of Civil Engineering, Faculty of Engineering, Eskişehir Technical University, Eskişehir, Turkey.
burakevirgen@eskisehir.edu.tr, asenakarslioglu@eskisehir.edu.tr, atuncan@eskisehir.edu.tr
[2]Department of Civil Engineering, Faculty of Engineering, Bartın University, Bartın, Turkey.
acetin@bartin.edu.tr

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Abstract

The use of stone mastic asphalt (SMA) is generally preferred to combat the undulation problem of roads due to wheel rutting, which is considered to be the most serious deterioration of road superstructure under heavy vehicle loads and thermal conditions. This type of mixture has a high level of aggregate interaction and interlocking effect with a high bitumen ratio in order to increase the lifetime of pavements. Commonly, polymer modified bitumen or cellulosic fiber additives involving a bitumen modification process is favored during the application. In this study, the usability of mixture modification was investigated by adding glass and polypropylene fibers directly into the dry mixture, unlike bitumen modification process that is requiring two mixing stages. In total, 169 specimens were prepared using a gyratory compactor according to the superpave design method. Of these specimens, 120 were fiber added samples with a ratio from 0.1% to 0.8% by dry weight aggregate. The draindown resistance, resilient modulus and water susceptibility including indirect tensile strength values, were improved by the addition of glass and polypropylene fibers according to experimental results within a range of 0.6% to 0.8% generally. However, calculated strain results show that satisfactory creep values could not be obtained in terms of static and dynamic uniaxial tests. Despite the fact that higher displacement occurred, reflecting cracks were eliminated owing to ductile behavior.

Keywords: Stone mastic asphalt (SMA), Glass fiber, Polypropylene fiber, Resilient modulus, Bitumen draindown, Permanent deformation.

Öz

Ağır taşıt yükleri ile ısıl şartlar altında yol üst yapısının en önemli bozulması olarak kabul edilen ve tekerlek izi nedeniyle meydana gelen ondülasyon problemiyle mücadele etmek için genellikle taş mastik asfalt (SMA) kullanımı tercih edilmektedir. Kaplama ömrünü arttırmak amacıyla bu tip karışımlar yüksek seviyede agrega etkileşimi ve kilitlenme etkisi ile yüksek bitüm oranı içermektedir. Uygulama sırasında çoğunlukla, polimer modifiye bitüm veya bitüm modifikasyonu uygulanmış selülozik elyaf katkıları tercih edilmektedir. Bu çalışmada, iki aşama gerektiren bitüm modifikasyonunun aksine cam ve polipropilen tipi elyaflar direkt kuru karışıma eklenerek karışım modifikasyonunun kullanılabilirliği araştırılmıştır. "Superpave" tasarım yöntemine göre yoğurmalı sıkıştırıcı kullanılarak toplam 169 numune hazırlanmıştır. Bu numunelerin 120 adedine kuru agrega ağırlığının %0.1'i ile %0.8'i arasında elyaf eklenmiştir. %0.6 ile %0.8 arasında değişen cam ve polipropilen elyaf katkılı deney sonuçlarına göre; süzülme direnci, esneklik modülü ve su hassasiyeti içeren dolaylı çekme dayanımı değerleri iyileştirilmiştir. Ancak, hesaplanan birim şekil değiştirme sonuçları statik ve dinamik tek eksenli testler açısından tatmin edici sünme değerlerinin elde edilemediğini göstermektedir. Daha yüksek deplasmanlar gerçekleşmesine rağmen, sünek davranış nedeniyle yansıma çatlakları ortadan kaldırılmıştır.

Anahtar kelimeler: Taş mastik asfalt (TMA), Cam fiber, Polipropilen fiber, Esneklik modülü, Bitüm süzülme, Kalıcı deformasyon.

1 Introduction

Stone mastic asphalt (SMA) mixtures are developed and used in many countries around the world against rutting caused by studded tires. SMA has been used in Turkey since 1999 as a wearing surface against heavy traffic effects [1]. This is one research area aimed at improving the performance of bituminous mixtures including new methods and design details [2]. SMA mixtures have high performance in terms of durability and rutting resistance due to their high content of coarse aggregate and filler ratio as well as bitumen modification [3],[4]. Design, production and application of SMA mixture increase cost compared to conventional bitumen mixtures. One fundamental reason for this increment is the high temperature requirement in bitumen modification and production processes. In addition, a number of difficulties are encountered during the spreading and compaction stages, as well as the additional cost requirement of cellulosic fiber usage to prevent the draindown effect [5],[6].

Although polymer modification is used as the most popular bitumen modification method, the favorable effects of fiber additives in asphalt mixture modification are reported in the literature. Studies on the behavior of fiber added asphalt mixtures show that a respectable amount of enhancement can be realized against permanent deformation and fatigue cracking [7],[8]. Certain fibers, which have high tensile strength, improve the adhesive properties and tensile strength of asphalt mixtures. Therefore, the fiber addition process increases the resilient modulus, modulus of rigidity, rutting strength, moisture susceptibility, and resistance against freezing thawing cycles of bituminous mixtures or pavements while reducing reflection cracks because of changes in the

*Corresponding author/Yazışılan Yazar

viscoelastic properties [9],[10]. Nowadays, glass and basalt originated fibers have been proposed instead of conventional polypropylene fibers. These new generation fibers have relatively high tensile strength, low elongation ratio and low working temperature requirements. Although the use of mentioned fibers is quite common in cement based concrete mixtures with the aim of increasing tensile strength and preventing crack formations, a limited number of studies have been found on the performance of SMA type of bituminous hot mixtures. Despite the fact that the use of fiber increases production costs in common mixtures, it is reasonable to use it as an alternative for expensive bitumen modification techniques. Using fibers in asphalt mixtures is more competitive compared with modified bituminous mixtures when considering technological development on fiber production and life span-performance relationships of asphalt pavements [11].

On the other hand, glass fiber addition to warm asphalt consisting of recycled asphalt pavement (RAP) improves the performance of mixtures against rutting and moisture susceptibility [12]. Aptahi et al. [13] studied the effect of hybrid use of polypropylene and glass fibers on the performance of asphalt concrete mixtures. The results show that hybrid modified mixtures can be confidently used in hot climate regions because of an increase in both voids and stability levels. Mahrez et al. [14],[15] state that resilient modulus and fatigue performance are greatly improved by increasing the amount of 20.0 mm long glass fibers. However, permanent deformations were negatively and unexpectedly affected under a dynamic creep loading test and Marshall Stability test. Another study shows that the addition of glass and polypropylene fibers according to different percentages, gives the best stability values among nylon, polyester, polypropylene and glass fiber [16]. Furthermore, glass fiber reinforcement improves the flexibility of mixtures without altering the optimum bitumen content and also prevents bleeding problems at high temperatures [17].

Fibers of basalt rock origin can be used to reinforce structural materials instead of carbon and glass fibers. In recent years, basalt fibers have been used to modify and reinforce asphalt mastic and asphalt mixtures [18],[19]. The addition of basalt fiber to the mastic directly increases the tensile strength, rigidity and fatigue resistance properties [20],[21]. Decreasing the length of fiber has positive effects on the rheological behavior of asphalt mixtures of constant fiber diameter due to the interaction area in the matrix [22]-[24].

Polypropylene fibers (PF) have been widely-used as an additive material to improve strength and to prevent crack formations in concrete [25],[26]. After studies were placed in the literature supporting the use of PP fibers in the modification of bitumen, a regulation for the use of PP fibers in high performance asphalt concrete was published in United States [27]. Previous studies suggest that the addition of PP fibers satisfies stability, while the other properties are kept within acceptable limits [28],[29]. An addition of thermoplastic materials, such as polyethylene (PE) and polypropylene inside bitumen, increases the rigidity and viscosity of a mixture around service temperature [30],[31]. The modification includes low density PE and PP and improves physical and rheological properties while decreasing penetration and viscosity [32],[33]. PP modified asphalt mixtures have a higher Marshall stability and indirect strength than non-modified asphalt mixtures generally [34]. Although fiber-modified mixtures are slightly stiffer, it is concluded that these have improved fatigue life, according to Huang and White [10].

In this study, it is investigated whether fiber modified SMA mixtures can be alternatively used instead of traditional design methods to especially improve rutting resistance. Different fiber types were used for this purpose, having high physical and mechanical properties, such as glass and polypropylene. Indirect tensile strength, stiffness, permanent deformation and moisture susceptibility tests were performed to evaluate the effects of the fiber content at an optimum bitumen rate, determined by the Superpave method. Fiber modified SMA mixtures were compared with traditional mixtures, for instance Styrene-Butadiene-Styrene (SBS) modified bitumen including specimens and cellulosic fiber added specimens. Moreover, design optimization was proposed for stone mastic asphalt mixtures modified by fibers.

2 Material properties

Aggregate, bitumen and filler are used as raw materials in ordinary asphalt mixtures. However, SBS modified bitumen or cellulosic fiber are generally used to provide resistance to draindown and to improve physical and mechanical behavior. Within this study glass fibers (GF) and polypropylene fibers (PF) were used in addition to the aforesaid materials.

2.1 Aggregate

Selected mix gradation of used aggregate is shown in Table 1, according to the limit values of Type-I gradation for wearing surface mentioned in related specifications [1]. The physical properties of crushed limestone aggregate taken from a quarry located in the Eskisehir region are shown in Table 2.

Table 1. Mix gradation.

Sieve size (mm)	Limit values (%)	Percent passing (%)
19.10	100.00	100.00
12.70	90.00-100.00	90.00
9.52	50.00-75.00	64.00
4.75	25.00-40.00	35.00
2.00	20.00-30.00	27.00
0.42	12.00-22.00	21.00
0.177	9.00-17.00	16.00
0.075	8.00-14.00	11.00

2.2 Bitumen

B50/70 bitumen class was used in the production stages of all the specimens since it is frequently chosen in many applications of hot mix bituminous binder due to the climatic conditions of Turkey. On the other hand, an elastomeric type of trademarked Styrene/Butadiene/Styrene (SBS) additive was used within the aim of polymer modified bitumen production for the preparation of traditional SMA samples providing the specified criteria in the standard [1]. SBS is considered the most suitable polymer for asphalt modification, although it has economic and technical limitations. The three-dimensional network of SBS enables the bitumen to maintain its elastic properties and performance criteria within a wide temperature range. Granular formed SBS was used, including combinations of 30.0% of polystyrene/polybutadiene blocks. The modified bitumen was produced in a laboratory by adding 4.0% of SBS by bitumen weight, as recommended by the manufacturer. A high shear mixing process was realized over a 45.0-minute period with 5000 rpm velocity at 175 °C according to the proposal of distributor firm and related studies [71].

The characteristic properties of SBS modified bitumen and ordinary bitumen with B50/70 penetration are shown in Table 3 for the completion of the fundamental experiments, including ductility, specific gravity and penetrometer Figure 1, Figure 2(a).

Table 2. Physical properties of aggregate.

Size of aggregate	Property	Standards	Specifications Limits	Results
19.00 - 4.75 mm	Los Angeles abrasion (%)	TS EN 1097-2 [35] ASTM C131 [36]	< 25.00	24.00
	Soundness (%)	TS EN 1367-2 [37] ASTM C88 [38]	< 14.00	2.90
	Flakiness index (%)	TS EN 933-3 [39]	< 25.00	11.00
	Polished stone value	TS EN 1097-8 [40]	≥ 50.00	53.10
	Stripping Resistance (%)	Tayebali et al. [41]	-	45.00 to 50.00
	Specific gravity	TS EN 1097-6 [42]	-	2.77
	Water absorption (%)	ASTM C127 [43]	≤ 2.00	0.86
4.75 - 0.075 mm	Specific gravity	TS EN 1097-6 [42]	-	2.78
	Water absorption (%)	ASTM C128 [44]	≤ 2.00	1.02
0.075 - 0.00 mm	Specific gravity	TS EN 1097-7 [45] ASTM C128 [44]	-	2.79

Table 3. Properties of SBS modified B50/70 bitumen.

Property	Related standards	Specifications Limits	Result	
			B50-70	SBS modified
Penetration at 25 °C (0.1 mm)	TS EN 1426 [46] ASTM D5 [47]	50.00-70.00	65.00	49.00
Softening point (°C)	TS EN 1427 [48] ASTM D36 [49]	46.00-54.00 >52.00	49.20	58.00
Flashing point (°C)	TS EN ISO 2592 [50] ASTM D92 [51]	>230.00	304.00	318.00
Specific gravity	TS EN 15326+A1 [52] ASTM D70 [53]	1.00 to 1.05	1.04	1.03
Loss on heating at 163 °C (%)	TS EN 12607-2 [54] ASTM D6 [55]	≤ 0.50	0.06	0.07

(a) (b) (c)

Figure 1. Basic experiments used for bitumen characteristics. (a): Ductility test. (b): Specific gravity test with pyknometer. (c): Needle penetration test.

(a) (b) (c) (d)

Figure 2. Used additives in mixtures. (a): SBS. (b): Bitumen impregnated cellulosic fiber. (c): Glass fiber. (d): Polypropylene fiber.

2.3 Fibers

GF and PF were used, in terms of cellulosic one, in order to evaluate the effect of fibers on the permanent deformation and crack resistance of SMA. A constant fiber length of 12.0 mm was selected considering standard sizes on the market and application steps in production. Cellulosic fiber Figure 2(b) is frequently used high performance fiber for the prevention of infiltration of bitumen as well as to increase elasticity and stability. In addition, glass fibers Figure 2(c) obtained from special glass content and petroleum based thermoplastic polymers, known as polypropylene fibers Figure 2(d), are generally used in a similar manner in the transportation industry. The physical and mechanical properties of the above-mentioned fibers are shown in Table 4, specified by the supplier.

Table 4. Physical and mechanical properties of fibers provided by the supplier.

Property	Type of fiber	
	Glass	Polypropylene
Operating temperature range (^{o}C)	-60.00 to 650.00	-55.00 to 140.00
Melting temperature (^{o}C)	1120.00	165.00
Thermal conductivity (W/m^{o}K)	1.20 to 1.35	0.030 to 0.038
Density (g/cm^3)	2.60	0.91
Filament diameter (μm)	13.00 to 15.00	22.00 to 28.00
Modulus of elasticity (GPa)	77.00	3.80
Tensile strength (MPa)	3400.00	400.00

3 Preparation of specimens

The requirements mentioned in TSH [1] were taken into consideration in the mixture design of the SMA. The bulk specific gravity of the compacted samples was determined according to the AASHTO T166 [56] method, while the AASHTO T209 [57] method was used during the calculation of the theoretical maximum specific gravity of the loose asphalt mixtures. Cylindrical samples of 100.0 mm diameter were prepared at bitumen ratios of 5.0%, 5.5%, 6.0%, 6.5% and 7.0% in the design of both control mixtures, including pure bitumen and SBS modified mixtures, individually using 0.6% bitumen-impregnated Viatop 66 type of cellulosic fiber for the bitumen stabilization. All of the specimens were prepared using a Gyratory compactor Figure 3 according to the Superpave mixing procedure proposed by NAPA [58] under 100 gyration, 600.0 kPa pressure and 4.0% amount of targeted air gap value.

The dry mixing method proposed by Abtahi et al. [59] was used to eliminate the high temperature requirement for melting fibers. The mixtures were prepared at an optimum bitumen ratio (6.5%) for all fiber added samples, as Morova [60] states that the addition of different fiber ratios with optimum bitumen content give similar results. After the determination of the optimum bitumen content, design mixtures were prepared with different fiber proportions of 0.1%, 0.2%, 0.4%, 0.6% and 0.8% by weight of the aggregate. Although the air void in the mixture (VA) and the voids in the mineral aggregate (VMA) are directly proportional to the amount of fiber content, void filled with asphalt (VFA) and density have an inverse proportion as shown in Table 5.

Figure 3. Gyratory compactor.

Table 5. Volumetric properties of control, SBS and fiber modified SMA mixtures.

Type of mixture	Amount of fiber (%)	VA (%)	VMA (%)	VFA (%)	Density (g/cm^3)
Control	-	4.01	16.30	75.4	2.509
SBS modified	-	4.00	16.57	75.9	2.501
GF	0.10	3.96	16.20	75.60	2.512
	0.20	4.07	16.31	75.10	2.509
	0.40	4.37	16.57	73.60	2.501
	0.60	4.99	17.10	70.90	2.485
	0.80	5.43	17.50	69.00	2.473
PF	0.10	4.10	16.34	74.90	2.508
	0.20	4.17	16.40	74.60	2.506
	0.40	4.26	16.48	74.20	2.504
	0.60	4.35	16.52	73.70	2.506
	0.80	4.55	16.73	72.80	2.496
Specification [1]	-	3.00 4.00	≥16.00	-	-

4 Test methods

The behavior of the SMA specimens were obtained using the uniaxial static creep test and the repeated creep test (cyclic compression test) using a Universal Testing Machine Figure 4, in order to determine the permanent deformation resistance of mixtures designed to prevent the formation of rutting on the surface. Moreover, a resilient modulus test (5 pulse indirect tensile modulus test), moisture susceptibility (water damage) test and draindown (bitumen infiltration or Schellenberger) test were performed to achieve resistance against external effects.

The most common problem concerning SMA surfaces is known as a draindown of bitumen from the mixture. The mechanical properties of the aforesaid pavement will deteriorate in this case, since aggregate is separately occurring inside the matrix without a required amount of binder. The Schellenberger bitumen draindown test [61],[62] was developed to minimize the infiltration of bitumen. In this test procedure, the mixture is poured into a beaker and placed in an oven for one hour after the prescribed temperature and mixing time has been applied. Then the sample is weighed again and the weight loss is expressed as a percentage in respect to the initial condition.

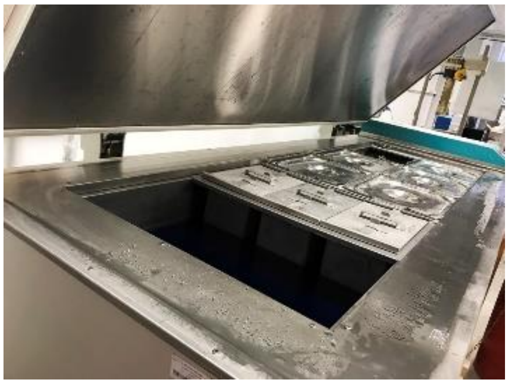
Figure 4. Universal testing machine for creep tests.

In general, a resilient modulus parameter is used with the aim of obtaining the deformation characteristics of asphalt pavements under external loading conditions. This parameter is calculated using the five pulse indirect tensile modulus test [63]. The resilient modulus value is determined at the end of the five conditioning pulses and five load pulses having 2000.0 ms and 3000.0 ms periods, respectively. Since the samples are not damaged in this experiment, the same specimens are used in the static creep test.

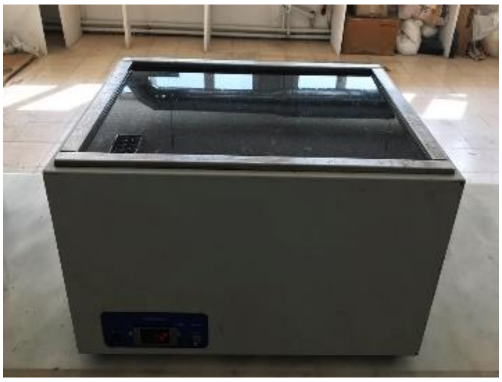
The uniaxial static creep test is known as a practical method to achieve permanent deformation and creep rigidity of asphalt samples. After the application of preliminary compression pressure has had a sinusoidal behavior along the normal direction, actual external pressure is applied between 5.0% and 25.0% of the ultimate value to create a creep phenomenon. The modulus of elasticity can be determined due to measured temporary deformation at this stage. These experiments are performed at 40 °C for 60 minutes under an axial load of 200.0 kPa within limitations [6],[64].

In addition, a uniaxial cyclic compression test was performed which has various loading and resting periods which simulates the load patterns caused under vehicular conditions. Test factors, such as uniaxial pressure, loading period and resting period, were selected around 200.0 kPa, 100.0 ms and 900.0 ms, respectively, to define the predefined wave form. The strain value and the repeated number of yields were determined at the point where the creep curve passes into the third region [65],[66].

Water can be harmful when penetrating into the asphalt mixture after it is deprived of bond effectiveness according to freeze thaw cycles [67],[68]. Therefore, a water susceptibility test was performed according to the procedure described in the AASHTO T-283 [69] standard that includes conditioned and unconditioned procedures. The conditioning process is defined by the following steps. A freezing temperature of -18.0 °C was applied for 16.0 hours Figure 5(a) and thereafter, the specimens were kept in a 60.0 °C water bath for 2.0 hours Figure 5(b). Lastly, the temperature of the water bath was adjusted to 25.0°C for an additional 2.0 hours before indirect tensile tests were conducted.



(a)



(b)

Figure 5. Conditioning process. (a): Freezing step inside the machine. (b): Heating step inside the water bath.

5 Results and discussion

The effects of glass and polypropylene originated fiber additives with amounts of 0.1%, 0.2%, 0.4%, 0.6% and 0.8% of the weight of the mixture are presented. On the other hand, the differences between them and the cellulosic fiber added traditional SMA results are also compared with the control specimens.

5.1 Draindown test

It can be seen that the amount of infiltration decreases with an increasing amount of fiber additive as expected, and as shown in Figure 6. Each fiber type has a unique draindown distribution due to the change in fiber content. Even though the same results were achieved up to a 0.4% fiber amount of glass fiber (GF) and polypropylene fiber (PF), bitumen infiltration values were differentiated in the higher additive rates. While the infiltration value of the glass fiber continues to decrease as of 0.6% fiber content, the polypropylene sample is partially reduced and then increased. This rise is derived from the adhesion of the partially melted polypropylene fiber to the glass beaker surface. The minimum draindown results for glass and polypropylene fiber additives were obtained for 0.8% and 0.6% rates, respectively. All of the fiber added specimens ensured the minimum draindown value (0.3%) recommended in the specification of the Schellenberger method [61],[62]. Despite the fact that cellulosic fiber (CF) has disadvantages in terms of its production and application stages, the greatest resistance against filtration was seen in this case due to its viscosity.

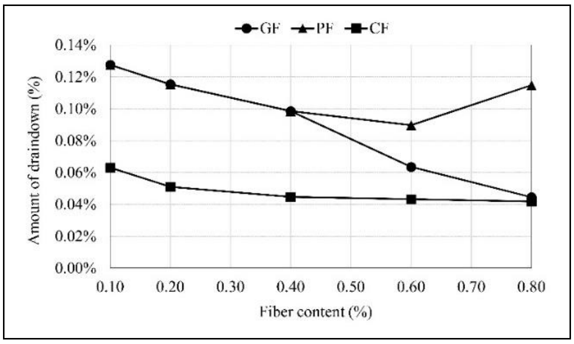


Figure 6. Draindown test results due to the change in fiber content.

5.2 Resilient modulus

The resilient modulus, which is calculated by dividing stress by recoverable displacement, provides valuable information about the elasticity properties of asphalt mixtures. An increasing trend is observed with an increase in the amount of glass fiber up to 0.8%, but in the case of polypropylene fiber addition, a bell curved distribution with a peak value of 0.4% is observed as shown in Figure 7.

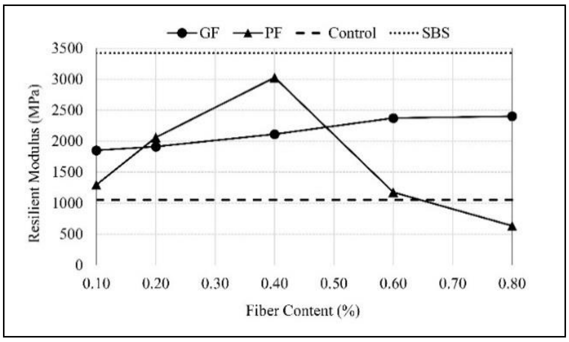


Figure 7. Resilient modulus results due to the change in fiber content.

Therefore, the optimum fiber content for GF can be selected at around 0.6% in terms of the resilient modulus parameter, because it is almost the same result as the 0.8% sample. On the other hand, an optimum PF value was obtained at around 0.4% fiber content, since it shows a sharp drop after this point. These peak resilient modulus values, corresponding to the previously mentioned fiber contents, are greater than the control specimens with a 2.25 and 2.87-fold increase for GF and PF, respectively. However, lower results were attained with a level of 30.6% and 11.5% within the same order if they are compared with SBS added samples.

5.3 Static creep test

The fiber modified specimens show much more ductile behavior than both the control and the SBS modified samples related to a significant increase in axial strain values Figure 8. However, this deformation behavior above expected levels creates high strain rates at low load steps rather than having a positive effect. Although a reduction is observed at a 0.4% GF addition after approximately 1700 seconds compared to the control sample, a noteworthy rise occurs in other cases during wide-ranging loading processes. It is determined that a sudden displacement increment occurs in the initial loading period after the addition of 0.1% for GF, even if it is usually seen after a 0.6% ratio in the case of positively affected additives, such basalt fiber. Mahrez and Karim [14] show that the increase in deformation is caused by the decrease in contact between aggregates due to the addition of glass fiber. This situation becomes more evident with large amounts of glass fiber.

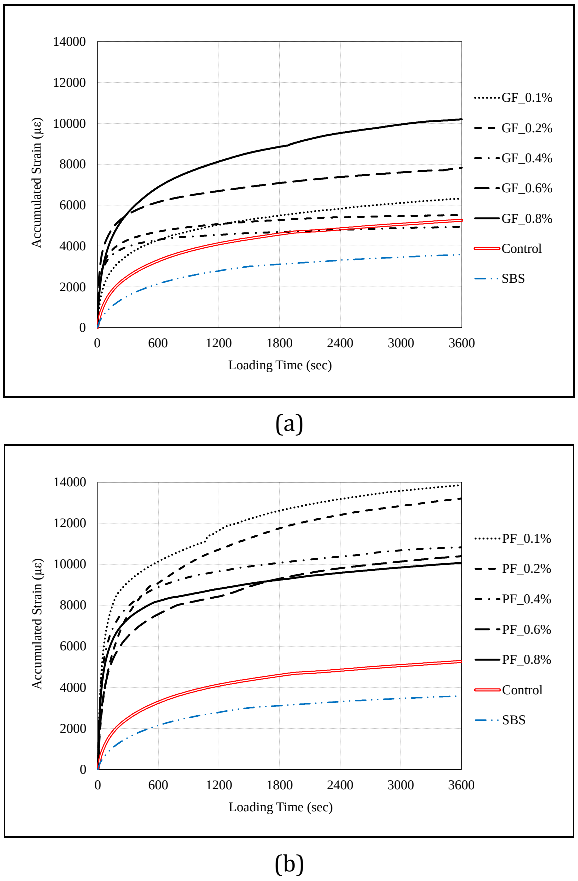
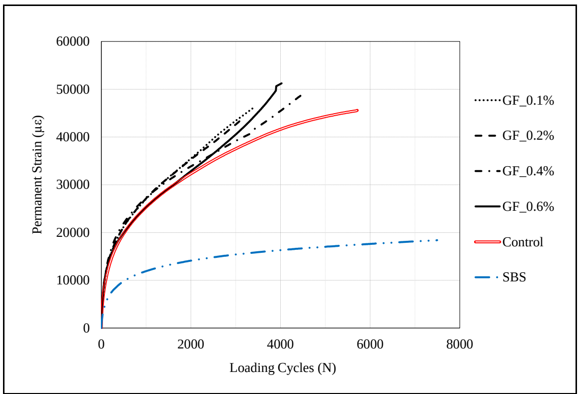


Figure 8. Static creep test results due to the fiber content. (a): Glass fiber. (b): Polypropylene fiber.

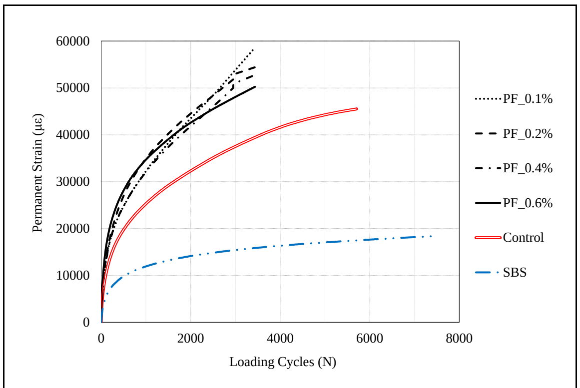
While the lowest axial deformation is obtained in the 0.8% PF ratio over a long period, the time-dependent strain curves are extremely close to each other. Therefore, it can be said that the static creep behavior of asphalt mixtures has not been seriously affected by the change in the PF ratio. The most noticeable difference between focused fiber types is the change in strain tendencies during the first loading period especially before 600 seconds. It can clearly be seen that PF added specimens cannot provide expected results within the fiber content increment. This problem is caused by the natural mismatch between the polypropylene fiber and hot asphalt binder, because of the low melting point requirement of fiber according to Huang and White [10].

5.4 Dynamic creep test

It can be stated that the fiber added samples have much more ductile failure behavior, since in the static creep tests all of them exhibit higher permanent strain than the SBS and control samples. However, this does not provide a positive effect on the expected level in terms of the creep loading reflecting long-term behavior due to the high level of displacement. This unexpected result can be attributed to two main reasons. Firstly, the bitumen passes through the viscous region because the temperature (50 °C) of the test is higher than the softening point of the bituminous binder. Secondly, fiber loses its enhancement effect in the matrix since the experiment was conducted under a uniaxial position without any confinement effect. This situation was effective in the case of the achieving higher deformation values at smaller load cycles. When the curves of all the GF added samples are examined, it can be clearly seen that the permanent strain values are close to each other and also to the control samples Figure 9(a). The results of the specimens consist of PF showing a greater deformation tendency at the lower load repetition numbers compared to those of the control Figure 9(b). These trends confirm the static creep test results, which are not affected by the amount of fiber additive.



(a)



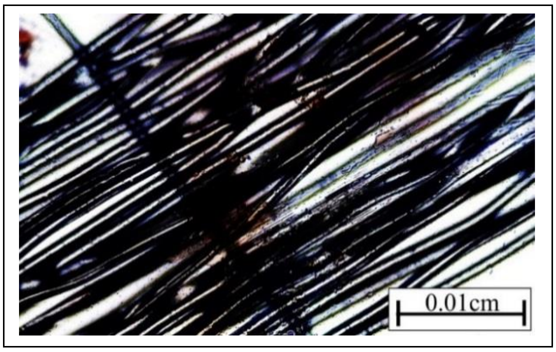
(b)

Figure 9. Dynamic creep test results due to the fiber content. (a): Glass fiber. (b): Polypropylene fiber.

On the other hand, as the softening point of the bitumen was not exceeded during the preparation of the SBS including samples, the related curve has seriously less permanent strain than all of the others. Moreover, it should also be noted that excessive displacement behavior was observed in the 0.8% fiber included specimens and that meaningless results were obtained in this case due to its heterogeneous matrix. As a result, the permanent deformation curves of the related specimen are removed in Figure 9.

A high degree of bond between the basalt fiber and asphalt binder forms an effective network structure along the micro pores as stated by Gao and Wu [70]. However, the adherence is reduced by the surface structure of the glass fiber and the partially weaker mechanical properties of the polypropylene inside the matrix, as can be seen in the microscopic images of fibers (Figure 10(a) and (b)). Therefore, high unit deformation behavior most likely occurs under both static and dynamic loading conditions due to these defects.

(a)



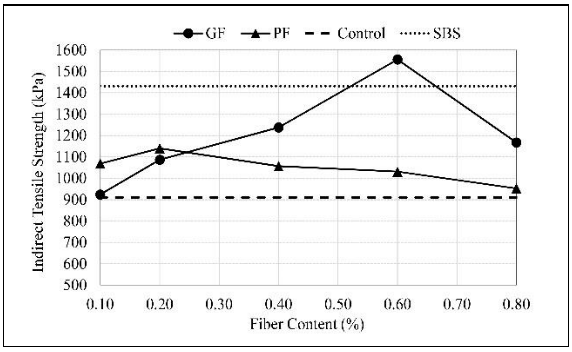
(b)

Figure 10. Microscopic images. (a): Glass fiber. (b): Polypropylene fiber (20x magnification factor).

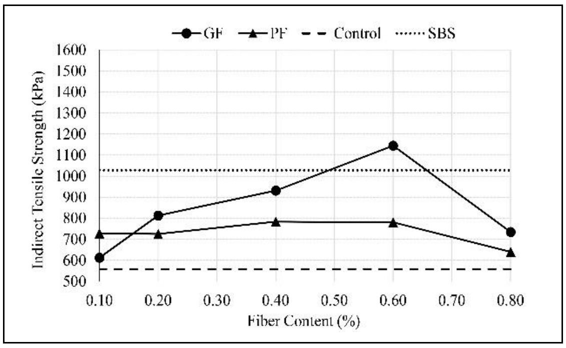
5.5 Moisture susceptibility test

The indirect tensile strength values of the fiber modified specimens are shown in Figure 11 within the scope of the moisture susceptibility test. In general, strength increased to a certain value and then decreased with an increase in fiber ratios. This reduction has a sharp transition in the glass fiber, but is soft in the polypropylene fiber. Although the maximum strength was obtained at around a 0.2% ratio for the PF added specimens in the unconditioned case, this peak value shifted to the 0.4% one. On the other hand, the ultimate values of the GF specimens were observed at around 0.6% in both cases. Most of the fiber modified specimens were located between the control specimens and the SBS specimen. Only 0.6% of the GF added sample provided great enhancement, even more than SBS sample. This suggests that the glass and polypropylene fibers are effective in reducing fatigue and low temperature cracking in terms of the tensile strength of the SMA mixtures. Similarly,

Previous studies [18],[19],[21],[22] conducted on modified mixtures indicate that tensile strength and low temperature crack resistance are significantly increased by the addition of fibers at low temperatures. While the change in amount of GF is consistent with the resilient modulus results, the PF fiber samples show a completely different trend contrary to the resilient modulus. This can be attributed to a loss of the form of PF in the asphalt mixture, due to its melting temperature and high temperature sensitivity.



(a)



(b)

Figure 11. Indirect tensile strength of specimens in the cases of; (a): Unconditioned process, (b): Conditioned process.

Moreover, the numerical index of resistance against water effect (TSR) was calculated with the ratio between indirect tensile strength (ITS) values of the conditioned and unconditioned specimens as given in Equation (1), Figure 12.

Although typical TSR values range from 0.70 to 0.90, the limitation of General Directorate of Highways of Turkey [1] cannot be reached. The results for all fibers with 0.4% and 0.6% additive ratios are extremely close to each other and the highest value is obtained in the 0.4% GF contained samples. This value is more than both control samples and the SBS modified samples with a ratio of 14.0% and 3.5%, respectively. These results show that a reduction in adhesion between the aggregate and bituminous binder arising from the effect of water can be minimized by the distribution of the appropriate fiber content in the bitumen matrix. However, if the aforesaid improvement is insufficient, it is important to investigate the design with stripping prevention agents.

$$TSR(\%) = ITS_{conditioned}/ITS_{unconditioned} \quad (1)$$

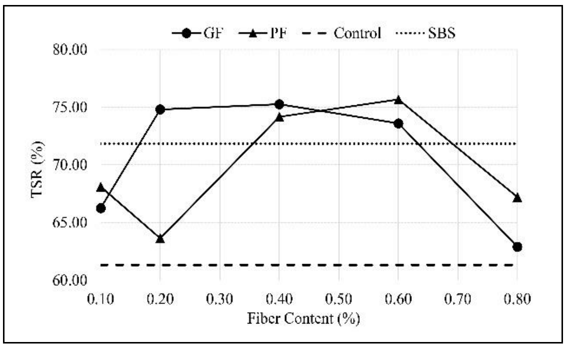


Figure 12. Tensile strength ratio (TSR) for asphalt mixtures of various fiber types and content.

6 Conclusions

This paper deals with the evaluation of glass fiber (GF) and polypropylene fiber (PF) usage within a mix modification by the dry mixing method instead of bitumen modification and cellulosic fiber usage. The following results can be drawn based on experimental studies concerning the design performance of SMA mixtures.

The draindown results of mixtures decrease with an increase in the amount of fiber, except for 0.8% PF. All of the fiber modified specimens are determined below a 0.3% value, which is the maximum infiltration ratio mentioned in the related specification. Therefore, it is appropriate to select an optimum fiber amount of between 0.6% and 0.8% rates. These fiber types can be confidently used as an alternative to cellulosic fiber in terms of resistance against any draindown effect.

When the fiber additive increases in the mixture, the resilient modulus values, that reflect the elasticity properties, tend to increase up to an optimum value and, thereafter, starts to decrease. These peak values of 0.6% for GF and 0.4% for PF are approximately 2.5 times higher than the control samples, although they are still lower than the SBS doped samples.

Only the 0.4% GF contained specimens provide an improvement of 10.0% in the final loading time according to the results of the uniaxial static creep test. For the others, it is not even close to the control sample and cannot be compared to the SBS modified ones. This unexpected result can be attributed to the following characteristics of the chosen fibers. A high level of axial deformations were seen in the initial loading period with respect to a decrease in the adhesion strength of the GF in the matrix due to the smooth surface structure. In addition, PF reduced the workability of the blends due to the melting temperature and high temperature sensitivity and cannot provide the expected effect by losing its form.

While the GF modified samples are close to the control sample results, the PF added samples tend to be a higher permanent strain in terms of dynamic creep behavior. However, these results are lower than the expected levels in either event. The reason for this can be that the fibers lose their effect in the matrix due to the softening point of bitumen and the absence of confinement pressure. On the other hand, as the softening point value of bitumen is not exceeded in the SBS added specimens, they show much less strain values in terms of creep tests.

Although the trends of the indirect tensile test, with respect to moisture effect and stiffness tests, change according to the amount of GF were compatible, the indirect tensile strength was not seriously affected by the amount of PF, unlike the resilient modulus test results.

When considering the tensile strength ratio, around 75.0% value (even above the SBS samples) was obtained for the GF and PF addition with the fiber content ranging between 0.2-0.4% and 0.4-0.6%, respectively.

Consequently, certain low-level results were encountered due to the brittle structure and surface properties of the GF, as well as the temperature sensitivity and partial low tensile strength of the PF. Therefore, bitumen modification is recommended for glass and polypropylene fibers instead of a mixture modification during the fiber addition process. Moreover, higher properties can be obtained by the use of fibers with much higher characteristics, such as basalt originated ones.

7 Author contribution statements

In the scope of this study, the Burak EVIRGEN and Asena KARSLIOĞLU in the formation of the idea, design, literature review, collecting data, assessment of obtained results and writing; Altan ÇETIN and Ahmet TUNCAN in the formation of the idea, writing and checking the article in terms of content were contributed.

8 Ethics committee approval and conflict of interest statement

There is no need to obtain permission from the ethics committee for the article prepared.

There is no conflict of interest with any person/institution in the article prepared.

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