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Optimization of 5-component Fibers and Glass Fibers in Asphalt Mixtures Based on Functional Characteristics

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ABSTRACT

Nowadays, due to the increase in the amount of traffic and the number of axles, the use of additives in asphalt concrete has become common. In recent decades, one of the goals of engineers in asphalt technology has been to increase the bearing capacity and improve the tensile strength of asphalt mixtures. One of these effective additives in this matter is fiber. Fibers mainly contribute to the reinforcement of asphalt mixtures. Accordingly, in this research, the properties of asphalt mixtures reinforced with 5-component fibers and glass fibers have been investigated. 5-component fibers are added in 0.05, 0.075, and 0.01% of the weight of stone materials, and glass fibers are added in 0.1, 0.2, and 0.3% of the weight of stone materials in asphalt mixtures and finally, based on performance characteristics including Marshall resistance, indirect tension, moisture sensitivity, dynamic creep, and resilient modulus are the most optimal among the above percentages. According to the results of this research, 5-component fibers have the best results in many of the mentioned characteristics at 0.075 percent and glass fibers at 0.2 percent.

Keywords: 5-component fibers, glass fibers, optimization, performance characteristics, asphalt mixture.

1. INTRODUCTION

Due to being faced with traffic load (which is dynamic) and being affected by weather conditions, roads have a shorter useful life compared to other civil structures [1,2]. For this reason, solutions began in 1920, and in 1926, a woven fabric was used, which was not very effective [3]; until 1966, the use of various fabrics in road construction became common [4]. Zube recorded the first successful reinforcement of asphalt concrete [5]. In the 1960s, the use of cellulose fibers and asbestos in asphalt concrete was proposed, the first one was not suitable due to gradual decomposition in the structure, and the second one was not suitable due to its toxicity [6]. In the early 1970s, the European road industry felt the need for pavements resistant to rutting, abrasion, and various damages caused by heavy traffic loads and ice-breaking tires. In order to solve this problem, asphalt mixtures with bone mineralization (SMA) were developed. In these mixtures, due to the high contact surface of the coarse-grained materials, the incoming loads are better distributed, and if the underlying layers are strong enough, the SMA mixture will be more effective against heavy loads [7]. Another feature of this mixture is preventing the road surface from becoming slippery and not creating reflective cracks and cracks caused by fatigue. The high void space of coarse-grained materials, the relatively high consumption of bitumen, and the thick coating of bituminous stone materials in SMA mixtures are factors for bitumen spill and Extruding bitumen during its storage, transportation, and distribution. As a result, fibers were used as a kind of stabilizer to reinforce the asphalt mixture. At first, it was thought that the use of fibers (especially waste fibers) would not play a role in bearing the incoming loads and that these fibers would play the role of filler; But gradually, it became clear that the fibers play an effective and decisive role in improving the properties of the asphalt mixture and increase the tensile strength, fatigue life, final deformation and stabilization of bitumen in these mixtures [8]. Common types of fibers used in these mixtures are cellulose and mineral fibers. Brown and colleagues announced that some fibers have more tensile potential than bitumen and therefore have the ability to be used and improve the asphalt structure [9]. According to Maur et al.'s findings, it was found that fibers are more effective in reducing asphalt subsidence compared to polymer additives [10]. With the introduction of polymer bitumen in the market, it was believed that fiber would lose its place, but the high price of polymer bitumen caused the public interest to use these products to remain. Different types of fibers, including cellulose, mineral, and polymer, as well as unusual fibers such as recycled material fibers (newspaper, carpet fibers, and rubber fibers), can be used in asphalt mixtures. This wide range of fibers has advantages and disadvantages that make the use of one type of fiber preferable over another [11-20]. In the following, some of the research carried out regarding the use of fibers in asphalt mixtures have been examined. In research, Fu investigated the effect of glass fibers on the performance characteristics of asphalt mixtures. The results of this research showed that the use of 0.3% of glass fibers has significantly improved the cohesion between materials and has a positive effect on the functional properties of the mixtures [17]. Ameri et al. also concluded in the investigation of fibers such as basalt and glass fibers that the aforementioned fibers can cause an increase in marshal stability, resilient modulus, dynamic creep, and also indirect tension [18]. Simpson et al. investigated the effect of polypropylene and polyester fibers using tests such as Marshall resilient, indirect tensile strength, resilient modulus, and dynamic creep. The research results showed that asphalt mixtures containing polypropylene fibers showed higher tensile strength and resistance to cracking. It was also found that the mixtures containing polypropylene fibers were stiffer [21]. Fazaeli et al. investigated polyolefin fibers in semi-heated asphalt mixtures. The results of this research, which was accompanied by dynamic creep and resilient modulus tests, showed that the groove depth improved by 30% as a result of using these fibers [22]. Fakhri et al. investigated the properties of semi-warm asphalt mixtures containing glass fibers. The results of this research showed that the use of glass fibers could bring a slight improvement in creep resistance [23]. Accordingly, in this research, the functional characteristics of asphalt mixtures containing glass fibers and 5-component fibers have been investigated, compared, and evaluated.

2. MATERIALS AND METHODS

2.1. MATERIAL

In this research, asphalt mixtures reinforced with two types of glass fibers and 5 components of bitumen with a performance grade of 64-22 PG according to the characteristics presented in Table 1 have been used to evaluate the performance characteristics. Also, the stone materials used in this research are of limestone type and from the Asb Cheran mine located in Damavand city of Tehran province. The properties of stone materials used in the research are presented in Table 2.

Table 1. Specifications of bitumen

Features	Test Method	Consumable bitumen	Standard limits	
			upper limit	lower limit
Specific gravity at 25 degrees Celsius	ASTM D-70	1.03	1.06	**1.01**
Penetration degree at 25 degrees Celsius	ASTM D-5	64	70	**60**
Softening point (degrees Celsius)	ASTM D-36	54	56	**49**
The temperature is 25 degrees Celsius	ASTM D-113	102	--	**100**
flash point	ASTM D-92	305	--	**250**

The stone materials used in this research were weighed according to the standard of Iranian roads to grading number 4. The curve related to this granulation is presented in Figure 1. After granulation, the materials were kept for 24 hours at a temperature of 170°C, and finally, according to the expected sample, they were combined with the corresponding fibers, which characteristics are presented in Table 3. The fiber materials used in this research are two types of glass fibers and 5-component fibers, and the percentage of each of these fibers has been calculated according to previous research and their manufacturer's recommendations.

Table 2. Characteristics of stone materials

Description	Test Standard	Results	Permissible limits according to publication 234	
			surface	binder
Maximum abrasion according to the Los Angeles method (percentage)	AASHTO T96	22/3	30	**40**
Maximum flakiness coefficient (percentage)	BS 812	16	25	**30**
Minimum breakage on two sides on sieve No. 4 (percentage)	ASTM D5821	93	90	**80**
The maximum percentage of water absorption (coarse-grained materials)	AASHTO T85	2/2	2/5	**2/5**
Maximum percentage of water absorption (fine grain materials)	AASHTO T84	2/4	2/5	**2/8**
The actual specific gravity of coarse-grained stone materials	ASTM C127	2/59	–	–
The actual specific gravity of fine-grained stone materials	ASTM C128	2/32	–	–

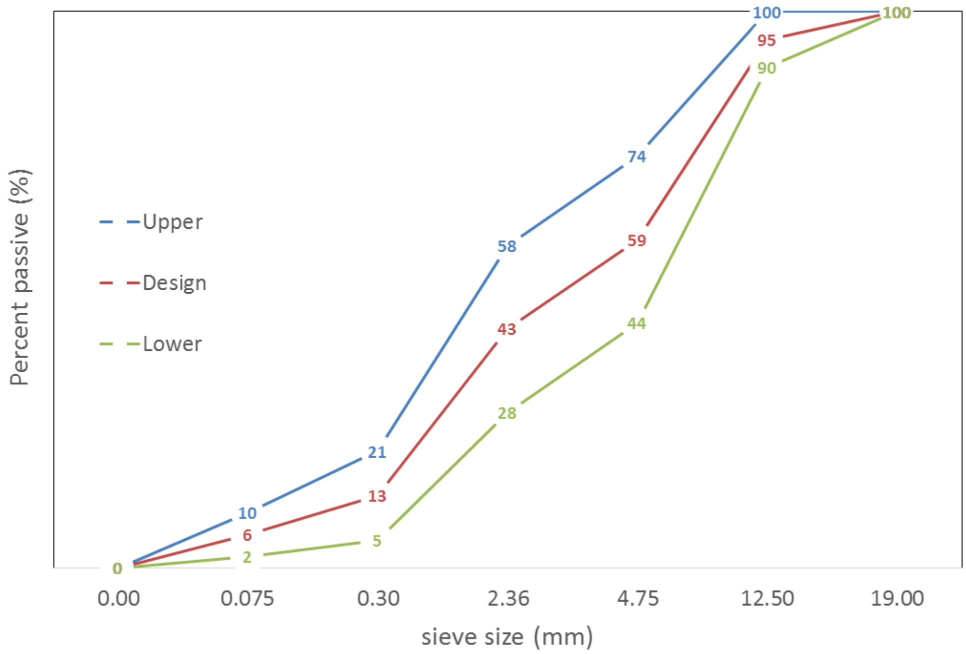

Figure 1. Granulation of applied materials

Table 3. Specifications of glass fibers and 5-component fibers

Specifications		glass fibers	5-component
color		white	**white yellow beige**
length	mm	6	**19**
density	gr/cm³	2.6	**1.44**
melting point	C°	1500	**450**
Tensile strength	MPa	3000	**3100**

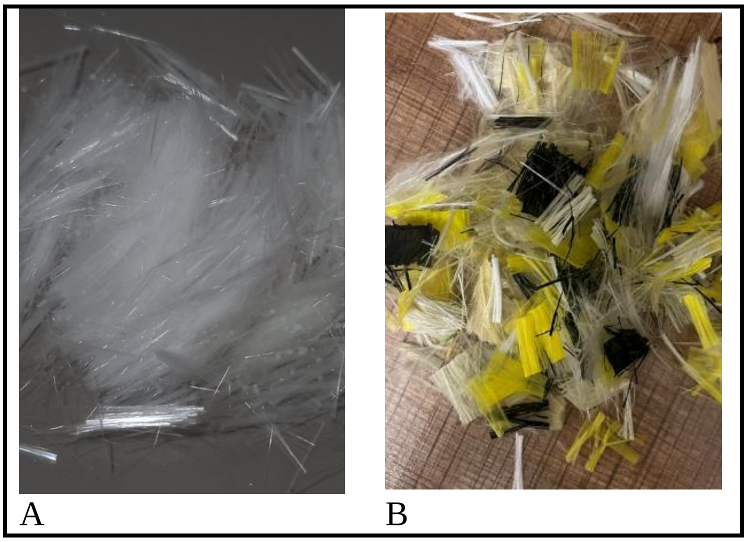

Figure 2. Fibers used in the research A. Glass fibers B. 5 component fibers

For the combination of bitumen and stone materials and fibers, first, the optimal bitumen of materials without fibers (control sample) was obtained through Marshall's mix design method, and according to this method, the optimal amount of bitumen equal to 5.1 was obtained for the control sample (without fibers). The same amount of bitumen has been used to check samples with fibers. The samples are classified into 3 general categories, the samples without fibers are placed in the first class, the samples containing different percentages of glass fibers are placed in the second class, and the samples containing 5-component fibers are placed in the third class. The classification of these samples, along with the abbreviations used, are presented in Table 4.

Table 4. Composition and naming of mixtures

Sample type	Percentage used	Abbreviations
control	0	CO
Reinforced with glass fibers	0.1	GLF1
	0.2	GLF2
	0.3	GLF3
Armed with 5 component fibers	0.05	PF5
	0.075	PF7.5
	0.01	PF10

2.2. MAKING SAMPLES

To make the samples, bitumen is first mixed with fibers and finally with aggregates. The mixture obtained according to the AASHTO R30 standard has been kept for 4 hours at the temperature of the track to apply the initial aging in accordance with the functional tests, and finally, the samples have been compacted according to the requirements of the final test.

2.3. MARSHALL STABILITY

The Marshall Stability test was performed at 60°C and following the ASTM D 1559 regulation. For the compression of the samples required to perform the Marshall Stability, a Marshall Compaction device was used with 75 blows to the sides [24]. The final samples with a diameter of 100 mm and a free space percentage of 4% have been tested.

2.4. RESILIENT MODULUS

The samples required for testing the resilient modulus with a diameter of 100 mm were made using a gyratory compaction device. The testing of these samples has been done at a temperature of 25 degrees Celsius and according to the ASTM D4123 standard [25].

2.4. INDIRECT TENSILE

The samples required to perform the indirect tensile test with a diameter of 100 mm and a percentage of free space of 0.5 ± 7% (6 to 8% of the regulations) were made in accordance with the AASHTO T283 standard and using a gyratory compaction device [26]. The samples of this test are classified into two groups of 3, and the first group was kept for 120 minutes at 25 degrees Celsius, and the second group samples were first saturated using a vacuum device to a saturation percentage between 55 and 80 percent, and then they were kept for 16 hours at -18 degrees and 24 hours at 60 degrees Celsius and finally they were kept at 25 degrees Celsius for 120 minutes and by applying once at a rate of 50 mm/min have been tested.

2.5. DYNAMIC CREEP

One of the methods of measuring the permanent deformation characteristic of asphalt mixtures is to apply several thousand repeated loads through a repetitive load test and record the change of permanent locations as a function of the loading cycle. In order to achieve such a goal, in this research, a dynamic creep test was performed with the UTM25 device with a stress level of 450 kPa and a temperature of 50 degrees. The diameter of the samples used for this test is 100 mm, and the height is 50 mm, which is compacted and ready for testing with a gyratory compaction device and with 5% void space according to AS 2891-12 standard.

3. RESULTS AND DISCUSSIONS

In this part of the research, the final results of the experiments are presented. These tests include resilient modulus, Marshall Stability, indirect tension, moisture sensitivity, and dynamic creep.

3.1. MARSHALL STABILITY TEST

Marshall Stability is significantly affected by the angle of internal friction of materials and the viscosity of bitumen at 60 degrees Celsius, and it can be evaluated from its results to check the endurance and ability of the asphalt mixture to resist rutting under heavy loads. The research samples, including asphalt mixtures containing different percentages of fibers, have been examined under the Marshall Stability test, and the results of this test are presented in Figure 3. As can be seen from the graph, the addition of 5-component fibers in all its percentages has improved Marshall's Stability. This improvement is most effective in the mixture containing 0.075% of 5-component fibers. The improvement observed in 5-component fibers can be attributed to the presence of SBS polymer in these fibers, which has increased the compressive strength of the sample by its partial dissolution. Regarding the samples containing glass fibers, it is clear that the addition of fibers up to 0.1% improves the Marshall Stability, and from this percentage onwards, it causes a drop in the Marshall Stability, so that in the sample containing 0.3% glass fibers, the Marshall resistance It reaches less than the Marshall resistance of the control sample. However, the differences regarding the sample containing glass fibers are not so great, and the reason for this issue can be attributed to the lack of power of glass fibers in compressive strength.

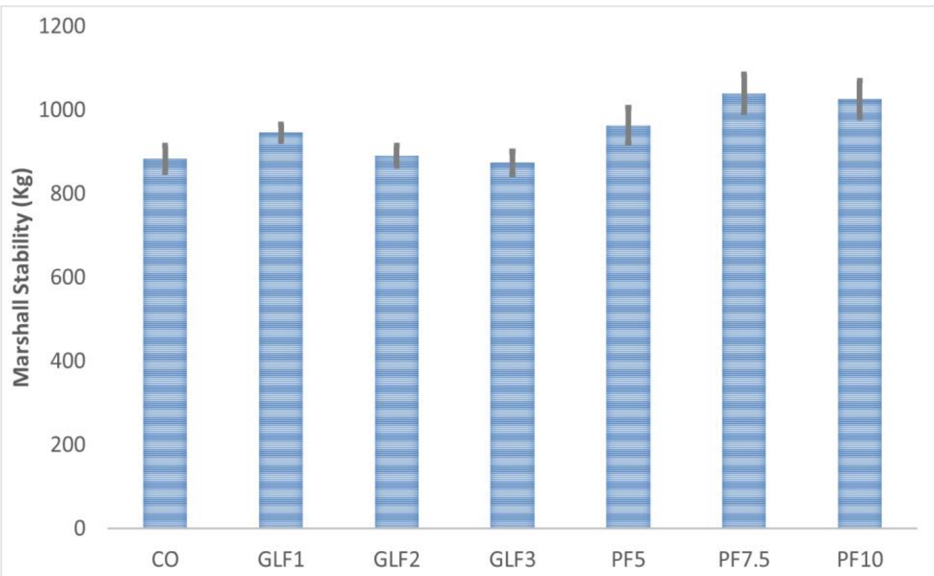

Figure 3. Results of the Marshall stability test

3.2. RESILIENT MODULUS

The tensile modulus test is a non-destructive test in which the loads applied to the sample are small. This test was done by a UTM device. The Modulus of resilience is represented by the symbol (MR), and the value that MR indicates is the maximum energy that the unit volume of the asphalt mixture can withstand without any permanent deformation, and when the mixture is loaded, it returns to its original state. Come back, the value of MR is obtained by integrating from the enclosed area of the stress-strain diagram. The results of the Resilient Modulus test for the samples of this research are presented in Figure 4. As it is clear from the graph, the addition of glass fibers partially in percentages of 0.1 and 0.2 and somewhat more significantly in the percentage of 0.3 has improved the Resilient Modulus and increased A. Regarding the results related to glass fibers, it can be argued that the addition of fibers has increased the hardness of the mixture due to its low plasticity.

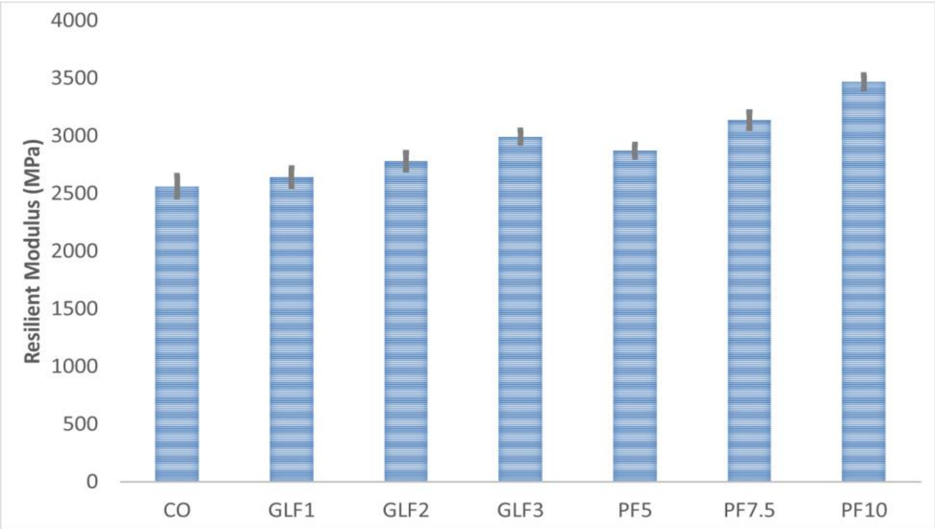

Figure 4. Results of the resilient modulus test

Regarding the results related to 5-component fibers, the results are different. As can be seen from the results, its addition has caused a significant increase in the Resilient Modulus of the mixture, which can be attributed to the partial dissolution of the SBS polymer in the fibers and the increase in the Resilient growth Modulus attributed to the presence of this material.

3.3. INDIRECT TENSILE STRENGTH

As mentioned in the previous section, the samples related to indirect tension have been tested in two groups. The results of this test are presented in Figure 5. As can be seen from the results, the addition of glass fibers did not change the dry indirect tensile strength much, but it increased the indirect tensile strength in the samples containing 0.1 and especially 0.2, and in the samples containing 0.3, there was a significant decrease in the tensile strength. It is observed more indirectly. Regarding the samples containing 5-component fibers, the amount of increase in indirect and dry tensile strength is significant, and these changes in the samples containing 0.005% and 0.075% fibers are increasing for both wet and dry states, but in the sample containing 0.01% 5-component fibers for the wet state almost do not show an increase compared to the sample containing 0.075%.

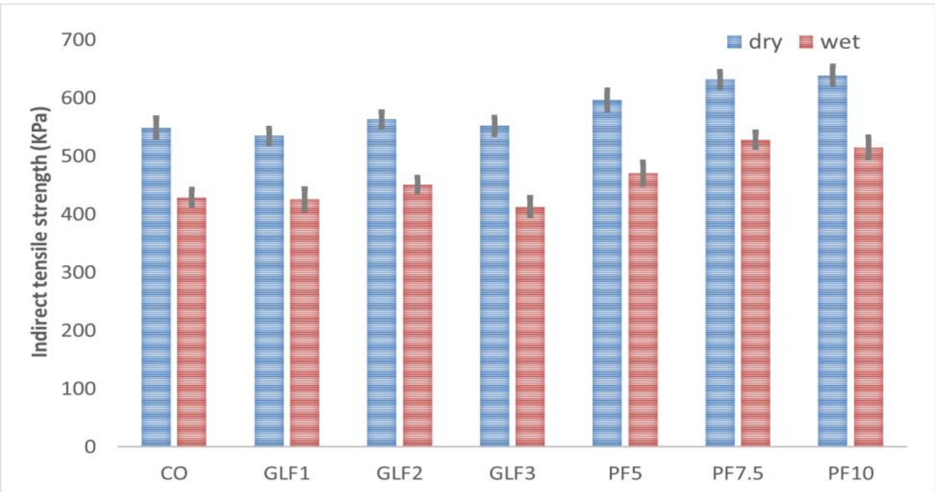

Figure 5. Indirect tensile strength

3.4. MOISTURE SENSITIVITY

Another specific case in the indirect tensile test is the TSR coefficient. This coefficient is one of the parameters for determining the moisture sensitivity of the mixture, the results of which are presented in Figure 6. The TSR parameter is expressed as a percentage from the division of indirect tension to dry indirect tension. Acceptable limits for TSR parameters in AASHTO T283 regulation are equal to 80%. As can be seen from the results, the control sample did not achieve this minimum value, and in terms of moisture sensitivity, it is among the mixtures prone to this damage. But for samples containing glass fibers up to 0.2% and samples containing 5-component fibers from 0.075% and more, they have obtained this amount and are considered resistant to this damage in terms of humidity.

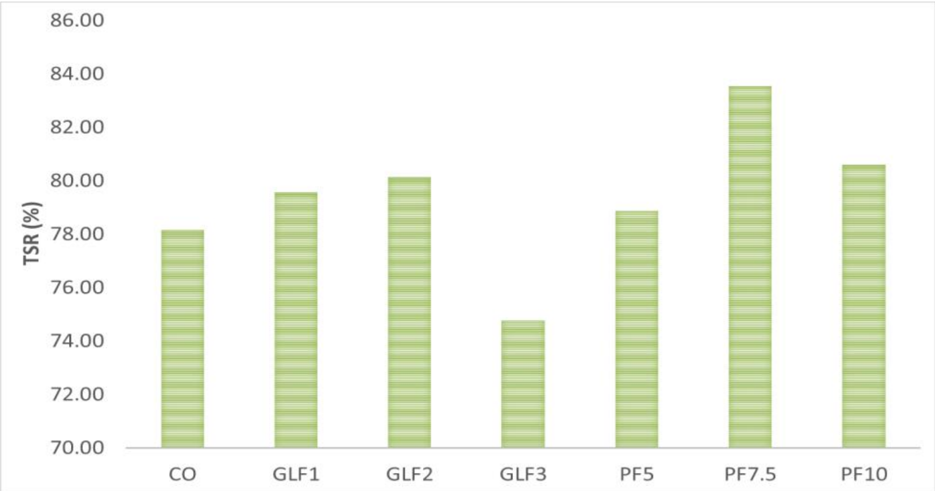

Figure 6. TSR results of the specimens

3.5. DYNAMIC CREEP

In this research, the slump test number based on the proposal of NCHRP Project 09-33 has been used to evaluate the rutting resistance of the asphalt mixture. The results related to the slump test number of the samples of this research are presented in Figure 7. As it is clear from the results, the addition of glass fibers has reduced the slump test number, and consequently, the resistance of the mixture against rutting has increased with the increase in the percentage of glass fibers in the asphalt samples. But in the samples containing 5-component fibers, a significant increase in rutting resistance is observed due to the presence of the SBS component. This improvement is associated with an increase in the percentage of 5-component fibers up to 0.075%, and from 0.075 to 0.01, there is almost a very slight decrease.

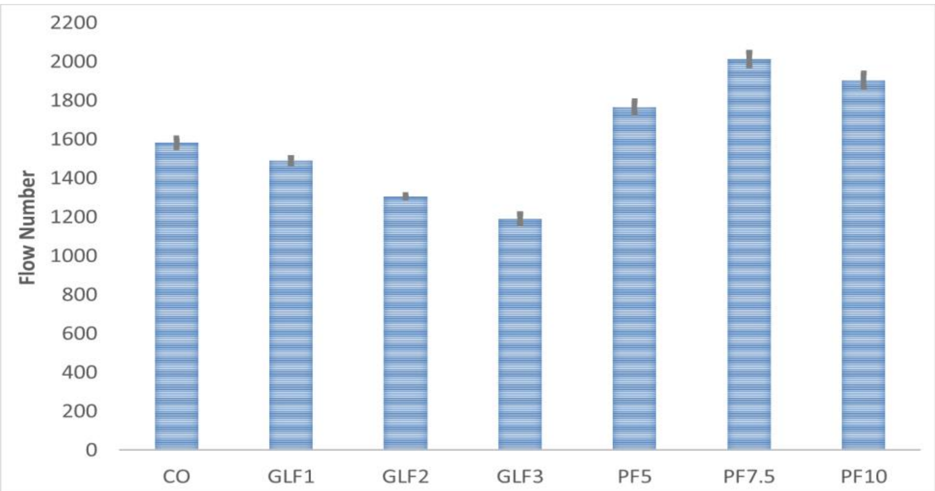

Figure 7. Results of the dynamic creep test

4. CONCLUSION

In this research, the functional characteristics of asphalt mixtures containing 5-component fibers and glass fibers have been investigated. Common performance tests, including Marshall Stability, resilient modulus, indirect and dry tensile strength, moisture sensitivity, and dynamic creep, have been performed on samples containing different percentages of these fibers. The main results of this research are: 1. The use of glass fibers causes a very slight change in the Marshall stability of the samples, but the 5-component fiber up to 0.075% has caused a more significant improvement in the Marshall stability of the samples. 2. The use of both fibers has improved the resilient modulus of the researched asphalt mixtures. This improvement is more evident in glass fibers at 0.3% and 5-component fibers at 0.01%. 3. The use of glass fibers has caused minor changes in the indirect tensile strength of the samples compared to the 5-component fibers. The dry indirect tensile strength of the sample containing 5-component fibers at 0.01% of use and the indirect tensile strength of the sample containing 5-component fibers at 0.075% have obtained the highest value in front of all the samples. 4. The humidity sensitivity of the samples containing glass fibers has obtained the best value in the sample containing 0.2%; in the sample containing 5-component fibers, the sample containing 0.075% has the best resistance to humidity sensitivity. 5. Tutting resistance of glass fiber samples is lower than the control sample in all percentages. For the samples containing 5-component fibers, this resistance is better than the control sample in all percentages and has its highest value at 0.075%. 6. Considering all percentages of both fibers, the most suitable percentage for 5-component fibers is 0.075%, and for glass fibers, 0.2% can be chosen.

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AUTHORS CONTRIBUTION

This work was carried out in collaboration among all authors.

CONFLICT OF INTEREST

The author (s) declared no potential conflicts of interests with respect to the authorship and/or publication of this paper.

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