Journal of Civil Engineering and Materials Application
Journal home page: http://jcema.com

Received: 15 May 2023 • Revised: 19 June 2023 • Accepted: 14 August 2023

Research

doi: 10.22034/jcema.2023.179694

Analyzing the Functional Features of HMA Mixtures Containing Multi-Component Polymeric and Glass Fibers

Seyedeh Negar Zadparast , Mahmoud Ameri *

Iran University of Science and Technology (IUST), Tehran Iran.

*Correspondence should be addressed to Mahmoud Ameri, Iran University of Science and Technology (IUST), Tehran Iran. Tel: +9821 73228104; Email: ameri@iust.ac.ir.

ABSTRACT

Road engineers have always tried to enhance the tensile strength and rutting resistance of asphalt mixtures, and using various fibers is one way that helps them achieve this objective. Multi-component polymeric fibers consist of 5 components, two of which, that are quite important, are polymeric and dissolve when bitumen and materials are mixed. This research has used 0, 0.4, 0.8 and 1.2% multi-component polymeric fibers (by total weight of the mixture) to investigate and compare the performance features of asphalt mixtures containing multi-component polymeric and glass fibers. Results showed that using these fibers had positive effects, prevented main failure and highly improved the low temperature, rutting and stripping performance of asphalt mixtures.

Keywords: multi-component polymeric fibers, asphalt mixture failure, functional properties of asphalt

1. INTRODUCTION

As roads are vital infrastructures and their construction and maintenance annually impose much money on various countries, comprehensive research has been nonstop to increase their performance. The pavement is an important part of the road that highly affects its construction and maintenance costs, and since asphalt pavements are, for various reasons, among the most important and most used types, many researches have used different materials (recycled, nano, slag, etc.) and evaluated their effects on the rutting failure, low/medium temperature cracking, stripping and tensile strength [1-3].

Loads and temperature changes cause pavements to experience deformations on top and horizontal tensile stresses underneath, and one way to prevent this is to use such reinforcements as geo-grids and natural/synthetic fibers because they highly increase the tensile strength [4]. Researchers have shown that using fibers in pavements and asphalt mixtures has strengthening effects, and the world's major research centers are doing research on reinforcing with new fibers [5]. Fibers (e.g., steel, polypropylene, glass, etc.) are thin strands with specific lengths distributed in the asphalt randomly in all directions, and have different types, shapes and applications [6-8].

Fibers (especially the waste types) were first thought to be fillers with no roles in bearing the applied loads, but gradually they were shown to play effective and decisive roles in increasing the tensile strength, fatigue life and final deformation of asphalt mixtures and stabilization of bitumen in them [9].

Riccardi et al. [10] studied the effects of polyacrylonitrile fibers and high reclaimed asphalt pavement (RAP) contents on the mechanical properties of asphalt mixtures in bitumen-modified and base layers. While previous studies had not investigated the low-temperature performance, this was the first effort that evaluated the effects of high RAP contents on the mechanical bond of the fiber-reinforced asphalt mix (FRAM) composites; according to the results, adding polyacrylonitrile fibers reduced the moisture resistance, but improved the rutting, stiffness properties, fatigue performance and cumulative fatigue failure of mixtures with/without RAP. Using polyacrylonitrile fibers had no significant effects on low-temperature cracking resistance, but the crack propagation resistance was highly improved, concluding that these fibers generally improved the mixture's mechanical, especially the stiffness, response.

Previous researches have studied effects of fibers in asphalt mixtures, but ignored bamboo fibers that have good strength and toughness. Jia et al. [11] studied the mechanical properties of bamboo fiber-asphalt mixes and provided a reference for their engineering applications by evaluating the reinforcing effects of these fibers on the mechanical properties of bitumen-modified asphalt mixes under different loading/temperature conditions and showed that they increased their resistance against permanent deformation and cracking. They used dynamic shear Rheometer to do bending beam and reversal frequency tests to determine the properties of these asphalts with different fiber contents and showed that their medium-temperature stiffness and crack resistance was increased, but their high-temperature performance was not significant.

Eisa [12] used the Marshall mix-design method to prepare 5 samples for surface-wear tests and showed that the glass fiber (GF) improved the properties of the hot mix asphalt (HMA) mixtures.

Gupta et al. [13] used aramid fiber/pulp, glass hybrid fiber and cellulose fiber to improve the wear resistance and strength of porous asphalt mixtures while maintaining their performance characteristics, studied their effects through multi-criteria analyses, and showed that while glass hybrid fibers improved the ITS of the mixtures, the aramid pulp highly increased the wear resistance; hence, according to the proposed method, it was selected as the best fiber to improve the mechanical strength.

Wi´sniewski et al. [14] performed tests to evaluate the effects of aramid fibers on the mechanical properties of asphalt mixtures, compared their results with those of other research teams and showed that the effects were relatively low.

Fucheng [15] studied the effects of the fiber type, length and content on the asphalt mixture properties and performance and showed that the basalt type 6 mm in optimum length and 0.4% (by wt. of mixture) in optimum content was preferred because of its high temperature stability, sensitivity to water and low temperature crack resistance, all of which can be practically valuable for engineers and specialists.

Using polymer aramid-polyalphaolefin fibers in asphalt mixture, Jaskuła [16] studied their reinforcement effects on some selective properties responsible for low-temperature cracking and resistance to permanent deformation. The low-temperature crack sensitivity was evaluated by bending tests on semi-circular and rectangular beam specimens (with fix deformation rate) based on the fracture mechanics theory and the high-temperature performance was evaluated using main curves of the dynamic module; results showed that these fibers could improve the low-temperature pavement performance.

2. MATERIALS AND METHODS

2.1. Materials

This research has used limestone, the properties of which are given in Table 1, and graded according to the standard of Iran roads (Sieve No. 4), the curve of which is shown in Figure 1.

Table 1. Characteristics of limestone

Description	Test standard	Permissible limits (Publication 234)		Tests results
	Standard	Lining	Cover	
Max erosion, Los Angeles Method (%)	AASHTO T96	40	30	22.3
Max cleavage coefficient (%)	BS 812	30	25	16
Min fracture on two sides, Sieve No. 4 (%)	ASTM D5821	80	90	93
Max water absorption (coarse aggregates) (%)	AASHTO T85	2.5	2.5	2.2
Max water absorption (fine aggregates) (%)	AASHTO T84	2.8	2.5	2.4
Actual specific weight (coarse aggregates)	ASTM C127	-	-	2.59
Actual specific weight (fine aggregates)	ASTM C128	-	-	2.32

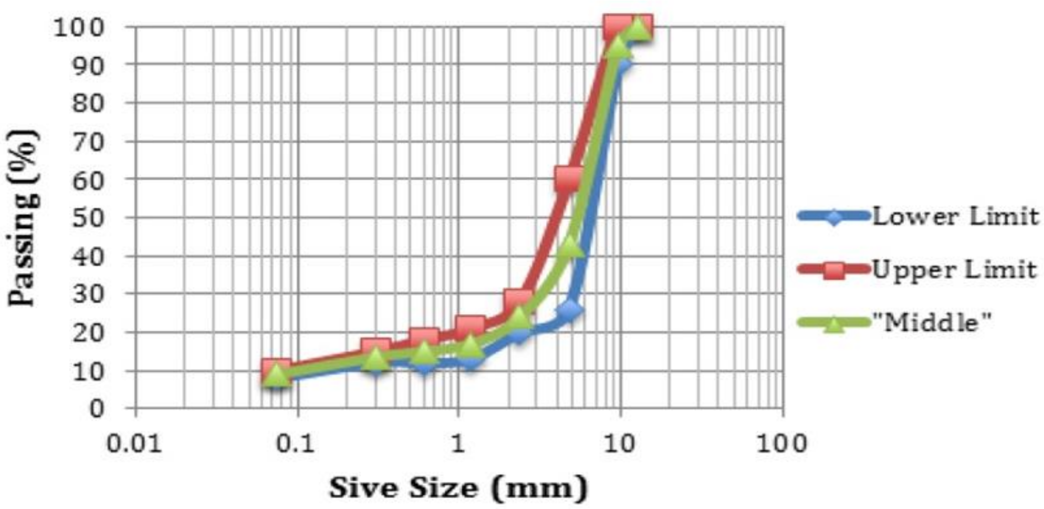

Figure 1. Limestone gradation

To evaluate the performance features of asphalt mixtures reinforced with multi-component polymeric and glass fibers, use was made of the 64-22 PG bitumen with characteristics shown in Table 2.

Table 2. Specifications of the applied bitumen

Properties	Test method	Standard limits		Bitumen
		Lower	Upper	
Specific weight at 25°C	ASTM D-70	1.01	1.06	1.03
Penetration rate at 25°C	ASTM D-5	60	70	64
Softening point (°C)	ASTM D-36	49	56	54
Ductility at 25°C	ASTM D-113	100	--	102
Flash point	ASTM D-92	250	--	3.5

After grading, the aggregates were kept at 170°C for 24 h, and then combined with the glass and multi-component polymeric fibers, the properties of which are listed in Table 3, and the percentage of which are according to previous researches and recommendations of the related manufacturers.

Table 3. Characteristics of the glass and multicomponent polymeric fibers

Multi-component polymeric fiber	Glass fiber	Features	
White, yellow, beige	White	Color	
19	6	mm	Length
1.44	2.6	gr/cm³	Density
450	1500	C°	Melting point
3100	3000	MPa	Tensile strength

To mix the bitumen, aggregates and fibers, the optimum bitumen was found by the Marshall mix-design method to be 5.4 for the control sample (no fibers), which was also used for the fibrous samples.

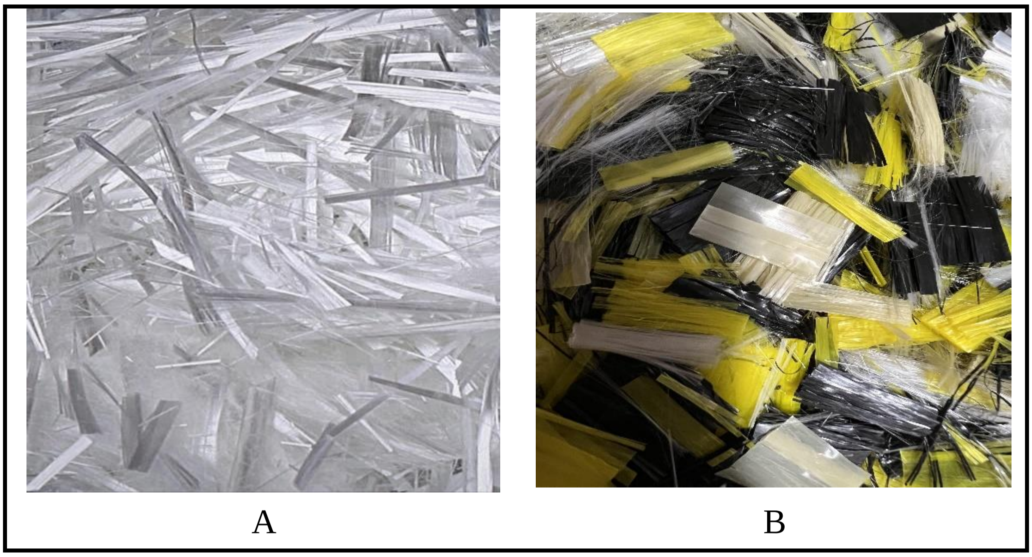

Figure 2. Fibers used in this research: a)Glass fibers, b) Multicomponent polymeric fibers

Table 4 classifies the samples (with their abbreviations) into those containing: 1) no fibers, 2) different percents of glass fibers and 3) different percents of multi-component polymeric fibers.

Table 4. Mixtures' names and compositions

Abbreviation	Percent used	Fiber
AC	0	Control (no fiber)
GF4	0.4	Glass
GF8	0.8	
GF12	1.2	
MPF4	0.4	Multi-component polymeric
MPF8	0.8	
MPF12	1.2	

2.2. Tests

2.2.1. Making samples

To make the samples, the bitumen was first mixed with fibers and then with aggregates and the mixture was kept for 4 h at the required temperature for initial curing, based on AASHTO R30 functional tests. Finally, the samples were compacted according to the tests' final requirements.

2.2.2. Marshall Resistance

The Marshall Resistance test was done at 60°C (ASTM D 1559), where the samples (100 mm in diameter and 4% void) were tested using a Marshall Compaction device that compacted the samples by applying 75 blows on their sides [17].

2.2.3. Fracture toughness

For the fracture toughness test, this research has used SCB samples that are obtained by cutting gyratory-compacted asphalt mixtures and are quite common in fracture mechanics testing. Cylindrical samples 7% void, 10 cm in diameter and 14 cm in height, were first made by a gyratory compactor, then cut by a cutting machine into four 2.5 cm-height semi-circular samples after cooling, then notched 10 mm-deep in the middle and, finally, used for Mode I (KIC) fracture toughness tests (AASHTO TP105-13) under different fiber percentages considered in this research. For the brittle failure, since tests should be done under negative temperatures, different SCB samples were kept at -12°C for at least 2 h in the chamber (10°C more than the lower limit of the bitumen) and then subjected to semicircular bending test under Mode I loading using the UTM-25 machine. Here, the distance of supports from the sample center (S) was 40 mm and loading rate was 5 mm/min, loads and displacements were recorded momentarily and load-displacement curves were drawn for each sample [18].

2.2.3. Indirect tension

For indirect tensile tests, the required samples, 7% void ± 0.5 (6-8% of the Code) and 100 mm in dia, (AASHTO T283) were made using a gyratory compaction machine [19] and classified into two 3-sample groups. Group 1 were kept under 25°C for 120 m and Group 2 were first saturated 55-80% by a vacuum device, then kept under -18, 60 and 25°C for, respectively, 16, 24 and 120 min and tested under a load at a rate of 50 mm/min.

2.2.4. Dynamic creep

One way to measure the permanent deformation of asphalt mixtures is to apply thousands of repeated loads in a repetitive load test and register the related variations as a function of the loading cycles. To this end, the present research used the UTM25 machine to do the dynamic creep test with a stress level of 450 kPa under a temperature of 50°C. In this test, the samples diameters and heights were 100 and 50 mm, respectively, and compaction was done with a gyratory device and 5% voids (AS 2891-12).

3. RESULTS AND DISCUSSION

This section presents the final results of the fracture toughness, Marshall Resistance, indirect tension, moisture sensitivity and dynamic creep tests.

3.1. Marshall Resistance test

The Marshall Resistance is highly affected by the materials' angle of internal friction and the bitumen viscosity at 60°C, and its values can be used to evaluate the resistance and ability of asphalt mixtures to resist rutting under heavy loads. In this research, samples containing various percent fibers were examined under the Marshall Resistance test, the results of which are presented in Figure 3.

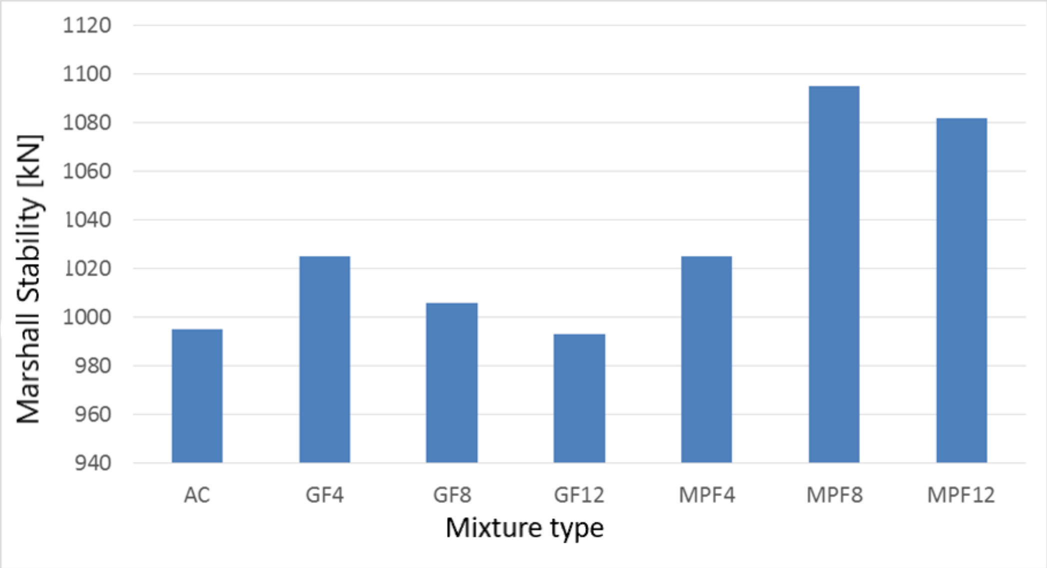

Figure 3. Results of Marshall Resistance tests

As shown, adding glass and multi-component polymeric fibers as reinforcements has highly changed the Marshall Resistance compared to the control sample. Glass fibers first increased this resistance, then more fibers reduced it and, finally, 1.2% fibers (glass fiber-to-total sample weight ratio) made it less than that of the control sample; samples with 0.4% glass fibers provided the most suitable results. Regarding the results of multi-component polymeric fibers, which are more important for this research, adding 0.4% fibers and increasing them up to 0.8% increased the resistance, but adding more fibers reduced it.

3.2. Low-temperature fracture toughness

The low-temperature fracture toughness is a common test, where KI is examined as a main variable. In the present research, this test was done at -12°C under Mode I loading and the output was the fracture toughness of each sample. Figure 4 shows the related results used to check the low-temperature behavior of the research samples.

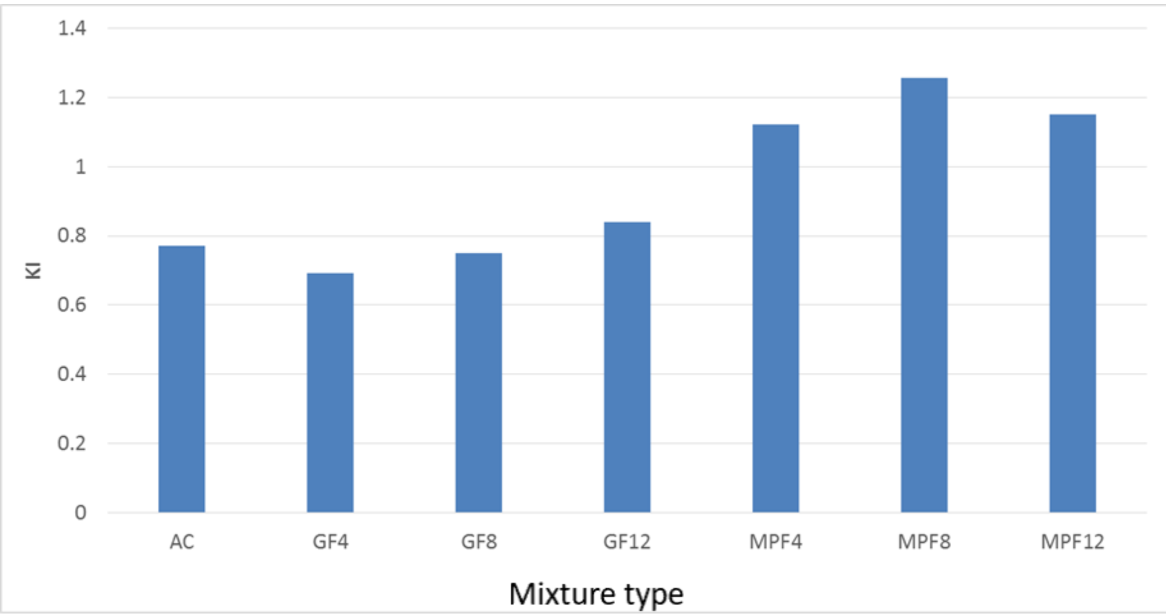

Figure 4. Fracture toughness test results

As shown, using 0.4 and 0.8% glass fibers affects the fracture toughness negatively, but 1.2% fibers have a slight positive effect on the fracture toughness of the asphalt mixtures of this research. On the other hand, multi-component polymeric fibers have improved the fracture toughness in all three mentioned percentages and the highest positive effect has been at 0.8% fibers.

3.3. Indirect tensile strength

As mentioned above, indirect-tension samples are tested for both glass and multi-component polymeric fibers, and the results are presented in Figure 5. As shown: 1) adding glass fibers first increases the dry indirect tensile strength slightly, adding them up to 8% increases the wet strength and adding them up to 1.2% reduces it, and 2) adding multi-component polymeric fibers has increasing effects in the dry state, adding them up to 0.8% has increasing effects in the wet state and above that starts decreasing.

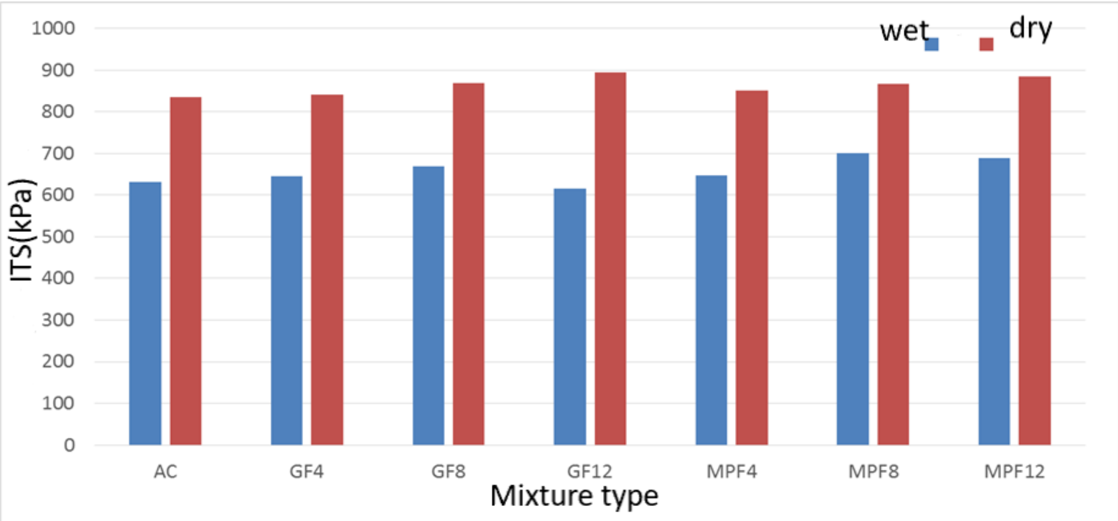

Figure 5. Indirect tensile test results

3.4. Moisture sensitivity

In the indirect tensile test, the TSR coefficient (Figure 6) is one of the parameters used to determine the mixture's moisture sensitivity. It is the wet-to-dry indirect tension ratio expressed in percents and its acceptable limit in AASHTO T283 is 80%. The stripping test results show that using 0.4 and 0.8% glass fibers improves the TSR (the difference is negligible), but using 1.2% of them highly reduce it, concluding that using this amount of fibers is not justified in terms of stripping and should not be used.

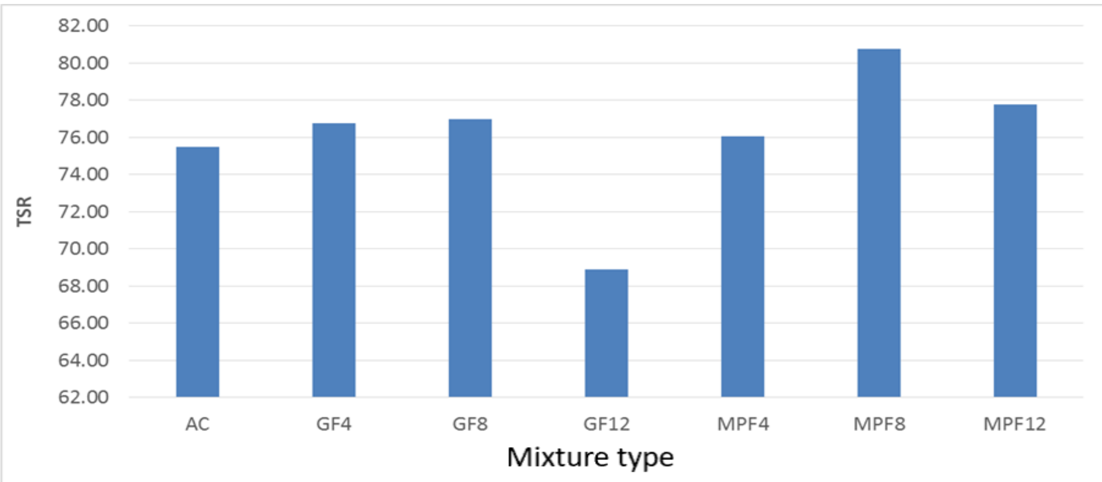

Figure 6. TSR parameter results

3.5. Dynamic creep

This research has found the flowability from the cumulative cycle-strain curve obtained from dynamic creep tests proposed by NCHRP Project 09-33, and has evaluated the rutting strength of asphalt mixtures by examining the three behavior zones calculated in the permanent deformation.

The curves in Figure 7 show, on the vertical axis, the flowability (for all tested asphalt mixtures), which is actually the number of loading cycles as soon as the shear displacement starts and permanent deformation occurs.

Results of this test show two totally opposite trends for the samples: 1) adding 0.4% glass fibers caused a relative increase in the flowability and adding more fibers reduced it; at both 0.8 and 1.2% fibers, flowability was less than that of the control example, and 2) adding multi-component polymeric fibers increased the flowability and adding more fibers increased it more; in this research, the highest flowability belonged to samples containing 1.2% of these fibers.

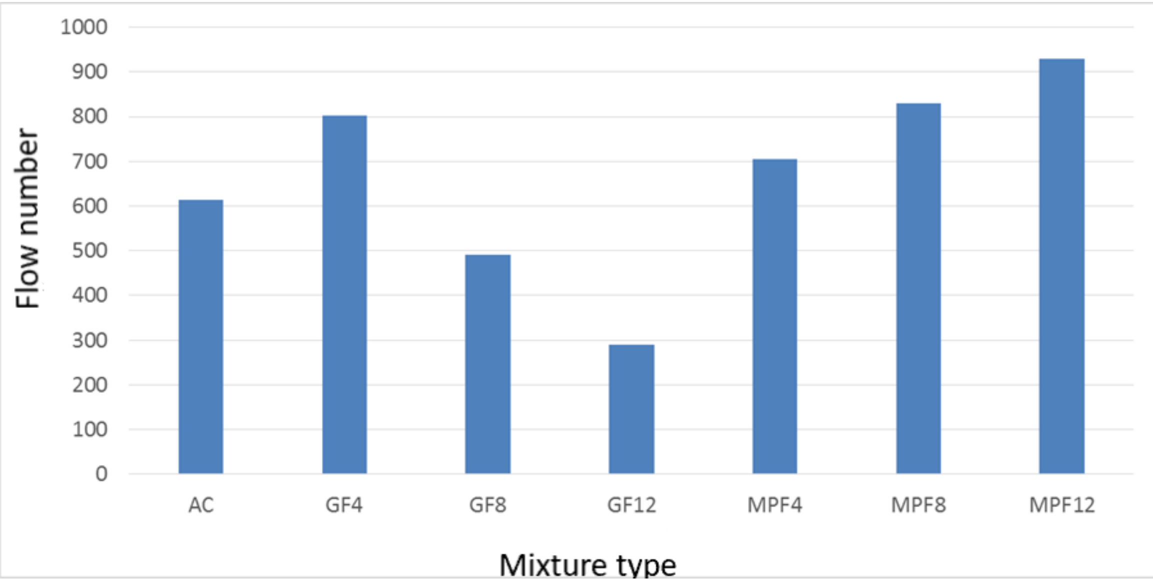

Figure 7. Dynamic creep test results

4. CONCLUSION

This research has used glass and multi-component polymeric fibers to reinforce asphalt mixtures, and has applied the Marshall Resistance, indirect tension, fracture toughness and dynamic creep tests to check the related results, which showed that:

1. 0.4 and 0.8% glass fibers increased the Marshall Resistance of asphalt samples, but 1.2% fibers reduced it; 0.4% fibers yielded the most appropriate result. Multi-component polymeric fibers, at all percentages, increased this resistance compared to the control sample, and the highest increase belonged to 0.8% fibers; this was the highest resistance among all the tested samples.
2. Dynamic creep test results showed that multi-component polymeric fibers improved the flowability, and an increase in fibers increased it more, but regarding glass fibers, the highest flowability belonged to 0.4% samples; in other samples, flowability was higher than that of the corresponding control sample.
3. The indirect tensile test results showed that glass fibers increased the dry-state ITS more than multi-component polymeric fibers, but in the wet state, the trend was reverse.
4. The ITS stripping results showed that both 0.8% glass and multi-component polymeric fibers yielded the highest stripping resistance; however, the results of the latter were better than those of the former.
5. The fracture toughness test results under Mode I fracture mechanics loading showed that glass fibers reduced the low-temperature fracture toughness, but multi-component polymeric fibers increased it.
6. Considering all the tests, 0.8% multi-component polymeric and 0.4% glass fibers can be introduced as the optimum values.

FUNDING/SUPPORT
Not mentioned any Funding/Support by authors.

ACKNOWLEDGMENT
Not mentioned by authors.

AUTHORS CONTRIBUTION
This work was carried out in collaboration among all authors.

ONFLICT 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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