Investigation of fatigue fracture in basalt fiber-reinforced asphalt beams

Esfandiyar Mardani[1], Sonia Moshfeghi[2,*]

[1]Associate Professor, Department of Engineering, Urmia University, Iran

[2]MSc. Of Roads and Transportation Engineering, Department of Engineering, Urmia University, Iran

[*]Sonia.moshfeghi@gmail.com

Abstract.

In this study, the effect of basalt fiber on asphalt beams is investigated for crack resistance to improve the performance with laboratory activity. Sample beams were prepared of local compressed asphalt containing polymer additives, especially basalt fibers. Asphalt specimens in dimensions of 20 cm*5 cm*5 cm in two cases without and with a volume of basalt fibers between 0 to 6 % of weight of used asphalt (0, 1, 2, 4 and 6 %) at temperatures of 5, 15 and 25 Celsius and loading frequencies of 1, 5 and 10 Hz are subjected to fatigue test. Fatigue test results show that reduction in the thickness of the specimens will show the asphaltic pavement potential for cracks. For all three mixtures reinforced with the basalt fiber, the thickness of the beam is maximal after 4 %, which means the minimum drop in the thickness of the beam under the fatigue test and indicates the optimal weight percentage of the basalt fiber executed in the beam layer. By increasing the percentage of asphalt mixing with basalt fiber from 0 to 4 percent, the drop in the thickness of the beam under the fatigue test decreases. But from 4 to 6 percent, the thickness of the beam increases. Thus, for 4 % basalt fibers, the drop in the thickness of the asphalt beam is less than fatigue testing, that is, the rate of cracking of asphalt reinforced with 4 % of the basalt fibers is minimal.

Keywords: Asphalt beam, Reinforced, Basalt fibers, Fatigue fracture, Vertical displacement

1. Introduction

Asphalts including asphalt binder, filler, and finer aggregate with fiber materials have showed a complex thermo-rheological behaviour at high temperatures [H Yao and S Zhou, S, 2016]. Asphalt binders can gain considerable advantages from adding fiber, particularly the stability, reinforcement, crack and fatigue resistance, and toughening effects of the fiber which improve the performances of asphalt beams [S. Shatnawi, 2008, P. Kumar and A. Gupta, 2010, Biro S and et al., 2009, Sengoz, B. and et al., 2009, El-Shafie and et al., 2012].

The improving effects of fibers on the performances of the asphalt mixtures have been studied in previous researches. Kumar et al. indicated that waste plastic fibers adding in asphalt mixtures can enhance some properties such as penetration, softening point, and ductility. Wu et al. demonstrated that polyester fibers in asphalt binders can improve the fatigue property, particularly at lower stress levels [X. Liu and S. Wu, 2011]. Serfass and Samanos proved that by adding fibers to asphalt mortar; thus, the asphalt beam and its contents can present high resistance in moisture, aging, and fatigue cracking [Hasan, Z. and et.al. 2012].

Lee et al. investigated the effect of nylon fibers on the fatigue cracking resistance of asphalt concrete, they used the pull-out test and the indirect tension strength test which showed that asphalt concrete samples reinforced with fibers of 1% and 12 mm causes 85% higher fracture energy than non-reinforced specimens [Hassan, A. and et al. 2014]. Liu et al. evaluated the mechanical properties of the asphalt concrete reinforced with carbon fibers with the indirect tensile test which resulted that the Marshall stability increased from 12.8 KN to 13.5 KN and residual stability from 91.1% to 92.7% [X. Zhang and et al. 2016].

Ye et al. defined basalt fiber (BF) as a high-performance fiber which made of basalt rocks and melted at approximately 1500 °C and produced as continuous fibres [Q. Ye and et al. 2009]. Some recent studies compared BF with other strengthening additives, such as polyester fiber, glass fiber, and lignin fiber, BF determined as a higher tensile strength, an elastic modulus, and a lower elongation rate [P. Kumar and A. Gupta, 2010, Y.P. Wei, 2012]. The high absorption rate of BF solves the bleeding and raveling problems of asphalt pavement under high temperatures. BF conserves 95% of its strength under 600 °C and repels water, acid, and alkalis. BFs considered as an excellent rectifier for asphalt high temperature resistance and good chemical stability [D. Wang and et al. 2013].

Recent researches and studies pinpointed the stabilizing and reinforcing effects of fibres on the performances of the components in asphalt beam is becoming a research hotspot [X. Gu and T. Xu, 2014, M.M. Wu and et al., 2015, Standard JTG, 2011, S. Liu and et al., 2009, S.M. Abtahi, 2010]. Although, the performances of fiber-reinforced concrete or asphalt mixtures through the macroscopic analysis of laboratory tests were the mutual point of most researches, few studies evaluted the reinforcing mechanism of the fiber on the asphalt behavior against damages and the correlation between properties and changes of asphalt beams. Therefore, the modifier role and beneficial effects of fibers on potential damages of asphalt pavements including fatigue fracture can be revealed by investigating reinforcing mechanism of fibers such as basalt fibers on asphalt beams.

2. Methodology

To investigate the role of basalt fiber in improving the performance of hot asphaltic mixtures, asphalt samples of 20 cm by 5 cm in 5 cm in two non-armed modes and armed with a volume of basalt fiber between 0 to 6 % by weight of asphaltic pavement Samples consisted of 0, 1, 2, 4 and 6 % at temperatures 5, 15 and 20 ºC, and loading frequencies of 1, 5 and 10 Hz were subjected to fatigue test. The reduction in the thickness of the specimens under fatigue test will show the asphaltic pavement potential for cracks, so that the sample that is lost during the fatigue test is more likely to leave the wheels faster than ever before.

For production of laboratory samples, pure 60-70 bitumen is used. The results of bitumen tests and physical properties of aggregates are presented in Tables 1 and 2. Gradation of Aggregates is as Table 3. Properties of basalt fiber are as Table 4. The figures of flexural fatigue device and basalt fiber are presented in figures 1 and 2.

Table 1: Results of bitumen tests

Test description	Results	Standards
Penetration degree at 25 ºC (0.1 mm)	60	ASTM-D5
Softening spot (°C)	45	ASTM-D36
Fire point (°C)	300	ASTM-D92
Specific gravity (g/cm3)	1	ASTM-D70
Ductility at 25 °C (cm)	96	ASTM-D113
Viscosity	65	ASTM-D2170

Table 2: Aggregates properties

Test description	Results (%)	Standards
Maximum Los Angeles Abrasion	3.2	ASTM-D96
Maximum water absorption of coarse aggregates	2.1	ASTM-D85
Maximum water absorption of fine aggregates	2	ASTM-D84
Maximum flat and elongated aggregates	8	ASTM-D4791

Table 3: Gradation of aggregates

Sieve size	Percent passing
3/8	100
# 4	75
# 8	53
# 16	45
# 30	28
# 50	19
# 100	15
# 200	7

Table 4: Properties of basalt fiber

Properties	Values
Sustained operating temperature (°C)	700
Minimum operating temperature(°C)	-3
Melting temperature(°C)	1430

Density (g/cm3)	3
Tensile strength (MPa)	2400
Elastic modulus (GPa)	85
Elongation at break (%)	3

Figure 1: Flexural fatigue device

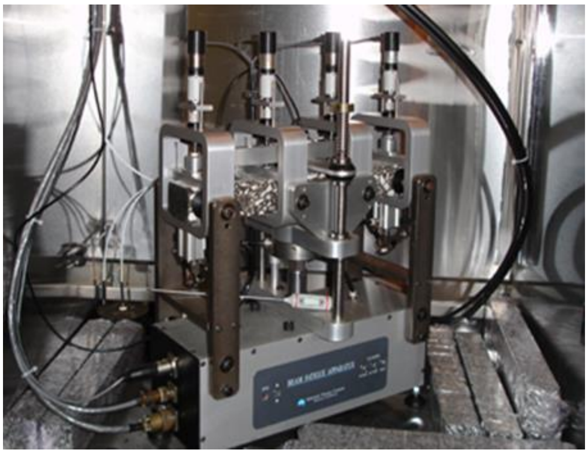


Figure 2: Basalt fiber

A series of tests were carried out to determine the optimum filler or polymer content. Asphalt specimens were produced using basalt fiber. 5 specimens were prepared for each bitumen percentage value, therefore a total of 20 asphalt specimens were prepared and used for Marshall Stability (MS) test in order to determine optimum basalt fiber content for the aggregate sample. For any given asphalt and aggregate asphalt beam, the durability is enhanced if adequate film thickness is attained. In terms of effective asphalt content, the film thickness will be greater if the aggregate gradation is coarser. This can most effectively be accomplished by decreasing or minimizing the percentage of fines. Establishing adequate

Voids in Mineral Aggregate (VMA) during mix design, and in the field, will help establish adequate film thickness without excessive asphalt bleeding or flushing.

3. Conclusion and discussion

Fatigue test results on non-armed asphalt mixtures with various percentages of polyethylene wax at temperatures of 5, 15 and 25 ° C and loading frequencies of 1, 5 and 10 Hz in the tables and charts following:

Table 5: Results of flexural fatigue test on unreinforced asphalt beam

Loading frequency (1/s)				
10	**5**	**1**		
4.31	4.43	4.54	**5**	**Temperature (°C)**
4.2	4.33	4.31	**15**	
4.18	4.21	4.28	**25**	

Table 6: Results of flexural fatigue test on 1 % basalt fiber-reinforced asphalt beam

Loading frequency (1/s)				
10	**5**	**1**		
4.24	4.49	4.56	**5**	**Temperature (°C)**
4.2	4.44	4.47	**15**	
4.11	4.23	4.42	**25**	

Table 7: Results of flexural fatigue test on 2 % basalt fiber-reinforced asphalt beams

Loading frequency (1/s)				
10	**5**	**1**		
4.29	4.43	4.59	**5**	**Temperature (°C)**
4.13	4.14	3.34	**15**	
4.03	4.09	4.22	**25**	

Table 8: Results of flexural fatigue test on 4 % basalt fiber-reinforced asphalt beams

Loading frequency (1/s)				
10	**5**	**1**		
4.32	4.47	4.61	**5**	**Temperature (°C)**
4.21	4.41	4.47	**15**	
4.13	4.23	4.41	**25**	

Table 9: Results of flexural fatigue test on 6 % basalt fiber-reinforced asphalt beams

Loading frequency (1/s)				
10	**5**	**1**		
4.40	4.54	4.68	**5**	**Temperature (°C)**
4.29	4.35	4.56	**15**	
4.22	4.40	4.43	**25**	

Figure 3: Results of flexural fatigue test on unreinforced asphalt beam

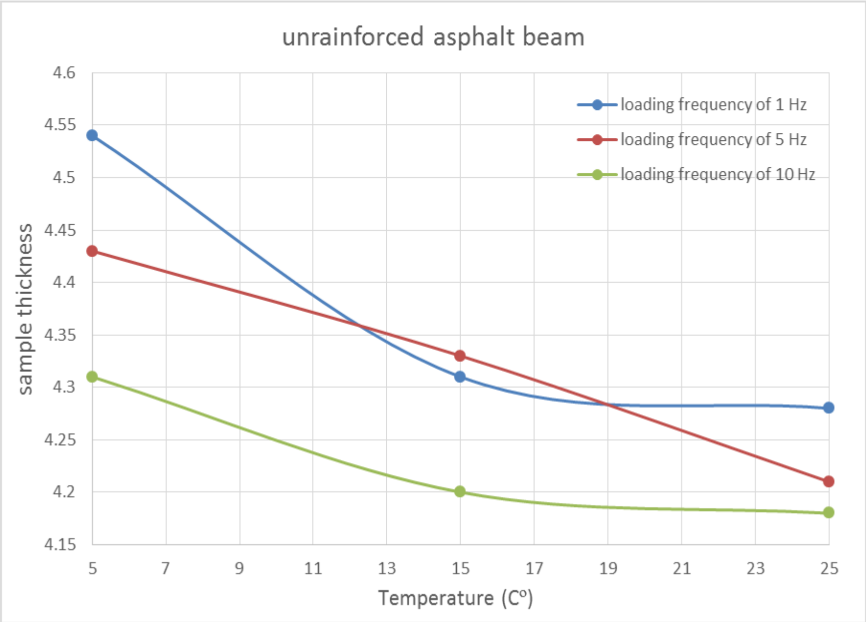


Figure 4: Results of flexural fatigue test on 1 % basalt fiber-reinforced asphalt beam

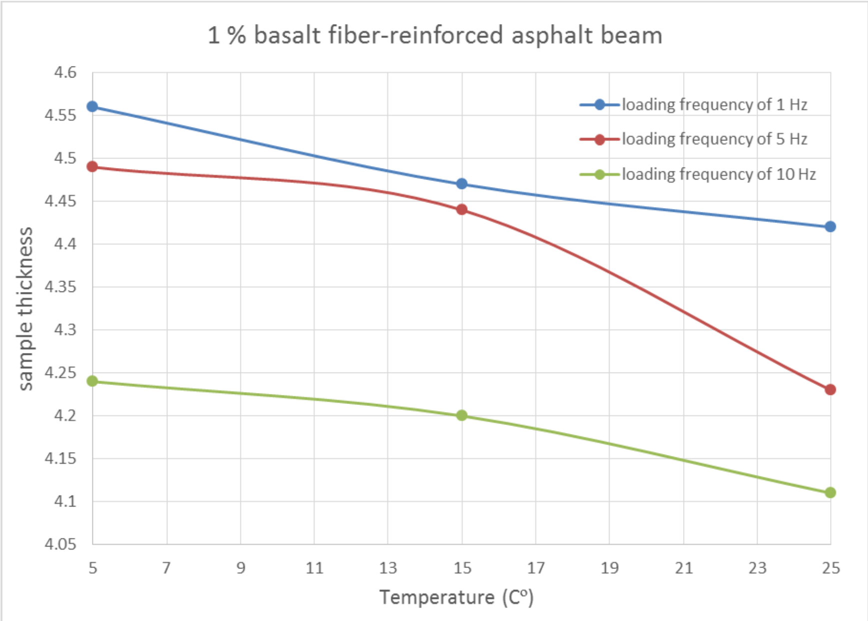


Figure 5: Results of flexural fatigue test on 2 % basalt fiber-reinforced asphalt beams

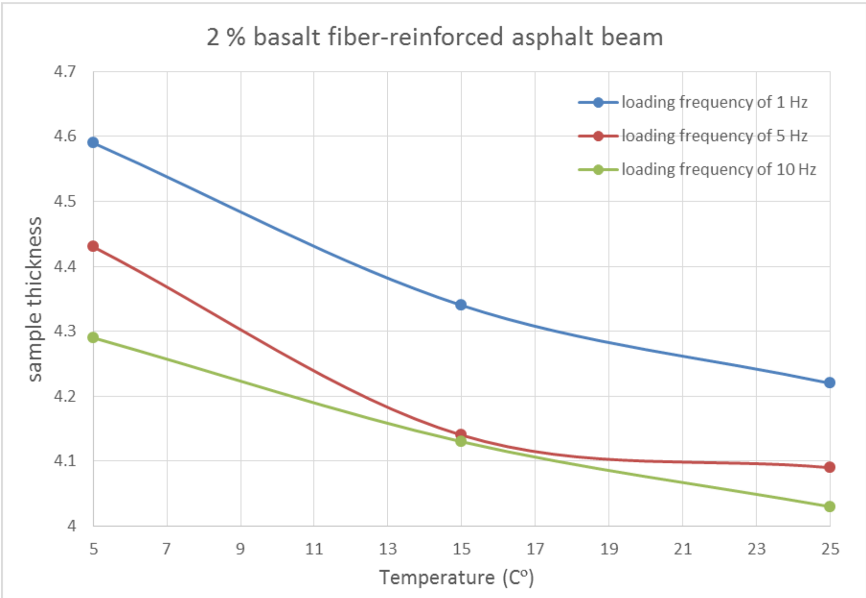


Figure 6: Results of flexural fatigue test on 4 % basalt fiber-reinforced asphalt beams

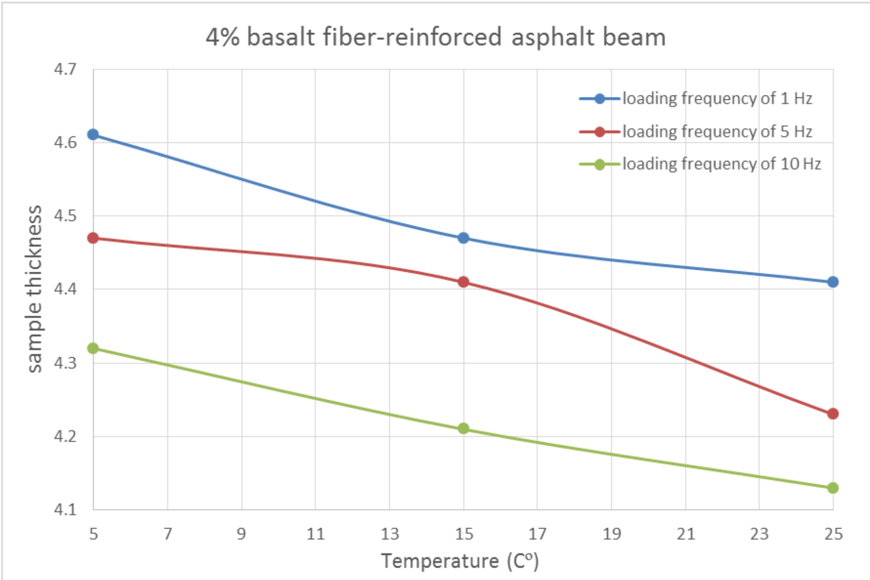
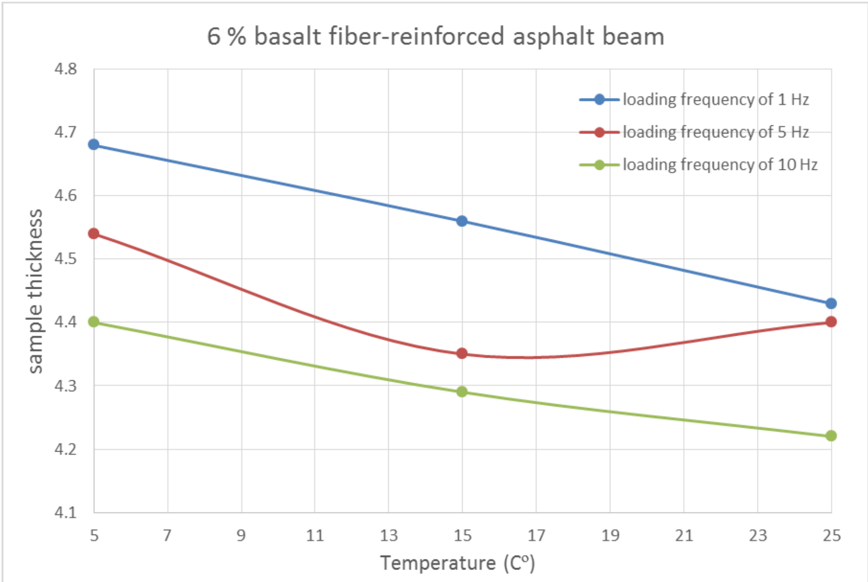


Figure 7: Results of flexural fatigue test on 6 % basalt fiber-reinforced asphalt beams



In this research, the amount of basalt fiber between 1 and 6% by weight of asphaltic pavement, including 1, 2, 4 and 6%, has been used. Fatigue test was carried out on asphalt mixtures at various temperatures of 5, 15 and 20 ° C, loading frequencies of 1, 5 and 10 Hz.

As the temperature and loading frequency increase, the thickness of the pavement under test increases, hence the thickness of the pavement after the test is reduced.

Comparing tables 5 and 6, no significant decrease observed in the sample thickness reduction of asphalt beams by adding 1% of basalt fibers, on the contrary, an increase in the thickness reduction was obtained by adding one percent of basalt fibers at high loading frequencies (10 Hz), however the thickness of asphalt beams has dropped gently since adding one percent of basalt fibers as shown in figure 4. By increasing the amount of added basalt fibers up to 2% according to table 7, a significant decrease in the thickness reduction of asphalt beams was resulted, while according to Figure 5, the process of thickness reduction has changed dramatically with increasing temperature, particularly at 5 Hz loading frequency, which has been improved by adding 4% of basalt fibers to asphalt beams and has become gradual according to Table 8 and Figure 6.

Although, according to Table 9, the decrease in the thickness reduction in asphalt beams with 6% of basalt fibers has continued, for two reasons it cannot be considered as the optimal value. Firstly, the use of excess amounts of basalt fibers is not economically justified and leads to higher costs in larger projects. Secondly, as shown in Figure 7, the thickness reduction at the 5 Hz loading frequency was sudden, which intensified the cracking of the asphalt beams.

Fatigue test results show that the pavement thickness is 4% after the test. That is, the drop in the thickness of the pavement is minimized by the fatigue test, and this represents the optimum weight percentage of the basalt fiber implemented in the pavement layer. As with the increase in the percentage of asphalt mix with basalt fibers from 1 to 4%, the decrease in the thickness of the pavement under the fatigue test decreases, but from 4 to 6%, the decrease in the thickness of the pavement increases. Therefore, for 4% basalt fiber reinforced mixes, the drop in the thickness of the asphalt pavement layer is less than the fatigue test, that is, the performance of the asphalt mix is reinforced with 4% basalt fiber optimum.

The argument is that considering the cost of producing basalt fibers and the more expensive the cost of implementing these reinforcements as coatings on the asphalt layer, is this application an economic boost? The answer is that considering the increase of the pavement lifetime by increasing the resistance of asphalt pavement to cracking and heavy costs of rebuilding or renovating asphalt pavements, the cost of implementing a layer of basalt fiber on the asphalt layer during the implementation of asphalt coatings is not costly. Although the results of this research can be exploited and by maximizing the performance capabilities of the asphalt mix, with the implementation of a 4% layer of basalt fiber layer thickness of the pavement layer, it can be assured that the cost for the implementation of the fiber layer Basalt on the asphalt layer is insignificant against economies of scale that are not arranged at the expense of repairing and rebuilding asphalt pavers.

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