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An Experimental Investigation into the Effect of Ceramic Fiber on the Fatigue Cracking of Stone Matrix Asphalt

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Abstract

Fatigue cracking of the asphalt mixture is a process whereby micro-cracks in the asphalt–aggregate interface propagates into extensive coordinated cracks under repeated loads. This process is the main cause of failure in flexible pavement and reduces its serviceability. Fiber reinforcement has received significant attention in the last two decades for finding viable solutions to increase the fatigue resistance of stone matrix asphalt (SMA). Accordingly, ceramic fiber (CF) as an asphalt binder modifier was used in this study to evaluate the fatigue behavior using mechanical and rheological tests. For this purpose, asphalt binder samples with different percentages of CF were subjected to short term and long-term aging according to the rolling thin film oven (RTFO) and pressure aging vessel (PAV), and dynamic shear rheometer (DSR) test was performed at mid temperature. Also, the fatigue life test was performed by indirect tensile fatigue test at two temperatures and five stress levels on asphalt mix samples made with controlled and modified asphalt binders. Based on the results, it is observed that asphalt binder modified with CF have higher and lower complex shear modulus and phase angle, respectively, compared to control asphalt binder. Also, the results of fatigue test show that using CF up to 5% increases fatigue life of mixtures. In addition, with enhancing temperature and stress level, fatigue life decreased in all samples, with a lower rate in CF modified samples.

Keywords

fatigue failure, ceramic fiber, dynamic shear rheometer, SMA, aged asphalt binder, indirect tensile fatigue test

1 Introduction

Asphalt concrete is a frequently used construction material in highway projects because of its durability and reparability. Fatigue cracking caused by successive tensile strains as a consequence of repeated traffic loading is a major type of distress in asphalt pavements [1, 2]. To overcome this type of damage, several studies have been conducted in recent years, indicating that different mixture properties, e.g. type and also amount of asphalt binder, air voids content, and gradation of mixture, affect the fatigue life of asphalt mixtures [3, 4, 5]. In this case, the structure of the stone matrix asphalt (SMA) differs from that of conventional asphalt since it contains high amount of optimum asphalt binder and has gap graded aggregates, resulting in better durability characteristics as well as a high fatigue resistance [6, 7]. Therefore, due to its advantages, it has been widely used all around the world. Despite its strong points, the drain down of mastic (asphalt binder + filler), high cost of SMA (due to high amounts of optimum asphalt binder content), risk of different types of fat spots appearing on the surface, etc. are the drawback of SMA [6]. In the course of investigation for overcoming the mentioned weaknesses and improving its advantages, especially fatigue resistance, it was shown that using additives can make the mechanical properties of SMA mixtures much more better. In this regard, fiber is conventionally utilized as an additive or stabilizer in the construction of SMA pavements [8, 9]. This stabilizer was used in the SMA pavement to reduce the drain down of the mastic and improve the performance connected with fatigue life [10]. The effective role of fiber is because of its influence on the interconnection between aggregates. Consequently, fibers strengthen the material against additional strain energy

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before the emergence of any crack, which is a prerequisite for achieving a long-life and safe pavement [8].

Many studies have been conducted on the beneficial effect of fiber in SMA. The result of a research conducted by Tapkin [11] demonstrated that Marshall stability values increased and flow values decreased in asphalt mixtures. Moreover, his investigation on fatigue life illustrated that it could be increased up to 27% by adding fibers (polypropylene). Mahrez et al. [12] found that the addition of glass fiber enhances the fatigue life of SMA by increasing its resistance to cracking. In another study, the effect of using glass macro-fibers on the performance of asphalt mixtures was evaluated. The results showed that adding macro-fibers improves fatigue life and reduces the rutting potential up to 50% [13]. Results of a similar research indicated that the use of natural and pelletized fibers has positive effects on asphalt binders' drain down and improves the fatigue resistance of SMA [10]. Furthermore, results of another research indicate that not only is the drain down of asphalt binder in SMA reduced by adding fiber (from 0.21% to 0.42%), but also the resilient modulus is increased [14]. Mohammadzadeh Moghaddam et al. [15] pointed out that the acrylic, polyester (synthetic type), and viscose (cellulose type) fibers obtained from waste streams effectively oppose the excessive drain down of SMA mixtures. It was also reported that the drain down properties of SMA mixture could be significantly enhanced by adding fibers obtained from waste tire and carpet [16]. This study also compared the performance of SMA mixtures containing waste fibers with mixes made with commonly used cellulose and other polyester fibers. The results showed that rutting potential and moisture damage in mixtures containing waste fibers compared to cellulose or polyester is similar. But, the tire, carpet, and polyester fibers impressively enhanced the toughness of the mixtures compared to the cellulose fibers. In another study, the effect of fiber type and its amount on the rutting potential of SMS was evaluated. In this research two different types of fiber (cellulose and mineral) with various contents (0.1 to 0.5%) of the total weight of the SMA were utilized. The results showed that specimens made with 0.3% cellulose fiber have resulted to highest value of ITS and least amount of permanent deformations. Also, taking into account the risk of rutting, optimum content for cellulose fiber was 0.3% and mineral fiber was 0.4% [17].

Herráiz et al. [18] used a new natural fiber called Posidonia oceanica to evaluate the performance of asphalt mixtures. In this study, algae fiber was used as an asphalt binder modifier in SMA at 0.3, 0.5, 1, 1.5, 2, 3, 4, 5 % and its results were compared with mixtures containing 0.3% cellulose fiber (as control mixture). The results show that mixtures containing algae fibers have a similar performance to mixtures containing cellulose fibers. In a similar vein, other studies revealed that ceramic fiber affects SMA properties positively while also being free from damaging effects on the environment, an effect which may be produced by other types of fiber. Moreover, in addition to environmental benefits, its utilizing in the asphalt mixture, reduces the percentage of asphalt binder due to the smooth surface, resulting in economic advantages compared to other fibers [19, 20].

1.1 Statement of the present study and objectives

In this study, the effect of ceramic fiber as asphalt binder modifier on fatigue behavior of SMA was evaluated. For this purpose, DSR and Indirect Tensile Fatigue Test (ITFT) experiments were used to determine fatigue potential in asphalt binder and asphalt mixture samples, respectively. In summary, the objectives of the present study are:

1. Modification of control asphalt binder with different amounts of ceramic fiber.
2. Implementation of DSR test on control and modified asphalt binder samples to determine fatigue factor.
3. Determination of fatigue life of different asphalt mixtures and the effect of CF on modified specimens.
4. Comparison the effect of CF modification on the fatigue life based on rheological test of asphalt binder and performance test of asphalt mixtures, and presenting fatigue model based on different parameters and determining the most effective parameter.

2 Experimental procedure

2.1 Materials

2.1.1 Aggregates and filler

In order to reach a test model similar to actually utilized materials, granite aggregate particles were procured from Safar Abad village in Iran. Iran Sayol Company has used this type of gap-graded aggregate in the Qom-Tehran highway project. Aggregate gradation and the mineralogical properties of aggregates are illustrated in Fig. 1 and Table 1, respectively. Since, filler plays an important role in the asphalt mixtures strength, hydrated lime was employed in this research as a filler [21, 22].

The determining role of mechanical and chemical properties of aggregates on the strength of SMA requires a thorough analysis of coarse and fine aggregates. In this regard, several tests have been performed, with the results given in Table 2.

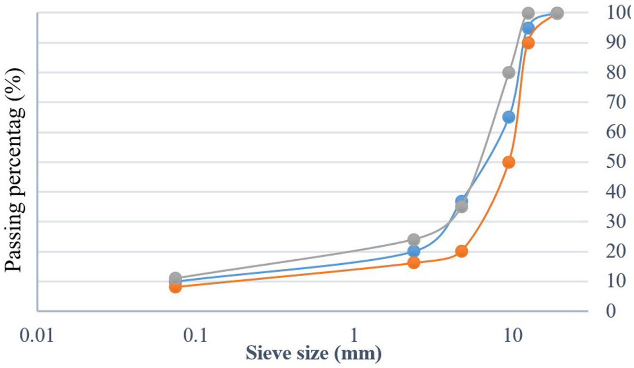

Fig. 1 SMA aggregate gradation

of about 0.1 mm. This type of material is widely used in asphalt pavements because it creates an interconnection between fibers and aggregates due to the absorption of light molecules of asphalt binder such as saturates on the surface of fiber [12, 20, 25]. Ceramic fiber (CF) plays a key role in the improvement of asphalt properties due to its capacity to withstand high temperatures, its flexibility along with high tensile strength, its low price in comparison to other types, and so on.

CF is manufactured by chemical vapor deposition, melt drawing, spinning, and extrusion. Three common types of CF that are classified based on the percentage of used material are: 1) standard CF, 2) CF with high alumina content, and 3) CF with high zirconia content. In this research, high zirconia CF made by Sepid Ceramic Fibers Company in Semnan was employed and is illustrated in Fig. 2.

Table 1 Some mineralogical properties of the aggregates (%)

Aggregates	Silicon dioxide SiO_2	Aluminium oxide Al_2O_3	Ferric oxide Fe_2O_3	Magnesium oxide MgO	Calcium oxide CaO
Granite	52.19	6.05	7.08	2.92	31.75

Table 2 Basic properties of coarse and fine aggregates

	No.	Test	Specifications	Standard	Granite aggregate
Coarse aggregates	1	Los Angeles abrasion	Max 30	ASTM C131	19
	2	Water absorption of aggregates	Max 2	ASTM C127	1.1
	3	Soundness of aggregates by using sodium sulfate in five cycles	Max 15	ASTM C88	12.1
	4	Soundness of aggregates by using magnesium sulfate in five cycles	Max 20	ASTM C88	15.8
	5	Percentage of fractured particles: Two-face One-face	 100 90	 ASTM D5821 ASTM D5821	 100 99
	6	Percentage of flat and elongated particles: 3 to 1 5 to 1	 Max 20 Max 5	 ASTM D4791 ASTM D4791	 7.9 3.3
Fine aggregates	7	Soundness of aggregates by using sodium sulfate in five cycles	Max 15	ASTM C88	12.9
	8	Soundness of aggregates by using magnesium sulfate in five cycles	Max 20	ASTM C88	18
	9	Liquid limit	Max 25	ASTM D4318	16
	10	Plastic limit	non-plastic	ASTM D4318	NP
	11	Sand equivalent value	Min 50	ASTM D2419	78

2.1.2 Asphalt binder

The PG 64–16 asphalt binder was employed in this study, and its chemical and mechanical properties are listed in Table 3. As noted earlier, the risk of 'asphalt binder drain down' is higher in SMA than HMA. Therefore, in order to curb this risk, 0.3% of total mixture weight Styrene Butadiene Styrene (SBS) is suggested to be added to asphalt binder [23, 24].

2.1.3 Ceramic fiber

In general, fiber is defined as a thin thread of herbal, mineral, or polymeric material with an outside diameter

2.2 Sample preparation

In order to fabricate the desired samples, SBS-asphalt binder was modified with fiber-stabilizer (ceramic fiber) by the drying process at the amount of 1, 3, and 5% of the total weight of asphalt binder. For ensuring the uniform

Table 3 Properties of asphalt binder

Test		Standard	Control asphalt binder (AC 60/70)	Modified asphalt binder		
				1 % CF	3 % CF	5 % CF
Penetration (100 g, 5 s, 25 ºC), 0.1 mm		ASTM D5–73	68	65	60	58
Ductility (25 ºC, 5 cm/min), cm		ASTM D113–79	114	126	>150	>150
Softening point, ºC		ASTM D36–76	51	53	57	59
Flash point, ºC		ASTM D92–78	265	271	282	285
Viscosity, mPas	115 ºC	ASTM D2171–07	0.729	0.735	0.754	0.763
	135 ºC		0.311	0.323	0.337	0.344
	150 ºC		0.156	0.169	0.183	0.188

Fig. 2 The used ceramic fiber

dispersion of fibers in asphalt binder, the SEM test was implemented at Tarbiat Modares University (Iran) using a Phenom-ProX device with a gold coating. These microscopes produce the image of the object surface by radiating electrons on the sample surface in vacuum conditions. As shown in Fig. 3, the CF is homogeneously distributed. To create suitable conditions, CF was heated in an oven at for 24 h. CF was dispersed in the asphalt binder by a mixer for 45 min at 160 °C and 1500 rpm. Then, in order to prepare SMA mixtures, the samples were prepared at 6.5% optimum neat asphalt content based on Marshall stability test. Subsequently, SMA asphalt mixtures with the resulting optimum asphalt binder content were created by CF-modified asphalt binder, since the difference in samples should solely result from the percentage of CF, not from a difference in asphalt binder content.

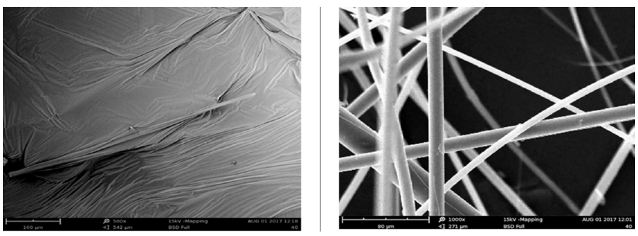

Fig. 3 SEM image of ceramic fiber surface

3 Tests

3.1 Rolling thin-film oven test

The rolling thin-film oven (RTFO) test is performed based on AASHTO T240 to ensure similar short-term aging conditions in the fatigue-related test of SMA. In this test, the films of asphalt binder are exposed to air and heat by rotating a bottle carriage. The rate of airflow should be kept at 4000 + 200 ml/min, and the temperature should be maintained at 163 °C. Moreover, the described rotating process should be performed at the rate of 15 rpm and in 85 min. Based on the mentioned protocol, this method has the following advantages: 1) All parts of the asphalt binder are uniformly and continuously exposed to heat and airflow due to rotation; 2) Contrary to the TFO test in which the asphalt binder is not in motion, this test does not allow the formation of surface crust which prevent the aging process; and 3) Compared to the TFO test that requires five hours to be implemented, this test needs only 85 min [26, 27].

3.2 Pressure aging vessel test

This method was developed by the SHRP-A-002A research group to simulate the long-term natural aging of asphalt binders in pavements obtained from the RTFO test (in-service oxidative asphalt binder in the field). Some advantages that have made the pressure aging vessel (PAV) test more reliable in recent years include: 1) restriction of the wasted emulsion; 2) acceleration of oxidation process without the mediation of high temperature; and 3) possibility of aging an adequate amount of asphalt binder for the next experiment. To perform this test, in the beginning, 50 g of asphalt binder is placed in a pan 140 mm in diameter. Then, the pan is positioned on sample rack cages. Finally, the samples are exposed to compressed air with a pressure of 2.1 mPa at temperatures between 90 and 110 °C for 20 h. The schematic view and overall picture of the PAV device are depicted in Fig. 4 [26].

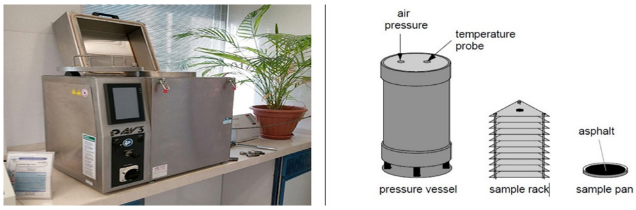

Fig. 4 Overall and schematic view of the PAV device

3.3 Dynamic shear rheometer

The dynamic shear rheometer (DSR) test is performed to analyze the elastic and viscous behavior of asphalt binders at intermediate and high service temperatures. In order to investigate the fatigue failure of SMA, the DSR test was performed at intermediate temperatures (22, 25, and 28 °C) based on AASHTO TP5 protocols. According to this standard, shearing force is applied to a thin asphalt binder that is placed between a fixed plate and a spindle. Based on Fig. 5, to simulate the shearing situation, the spindle oscillates back and forth at a frequency of 1.59 Hz in three stages:

1. From point A to point B,
2. From point B to point C (by crossing Point a)
3. From point C back to point A [26].

During this process, the DSR setup measures the shear strain of asphalt (γ) that is produced by shear stress (τ). There are some relations between material rheological properties and reaction patterns. If the asphalt were assumed to be a fully viscous material, the response (γ) would have a delay with respect to the applied force (τ), and the time lag would not be ignorable. On the other hand, a fully elastic material would not have a considerable time lag. Asphalt binder shows a viscoelastic behavior at functional temperatures of the pavement under traffic. In the DSR, asphalt as a viscoelastic material in service condition reacts according to a stress-strain diagram (Fig. 6). Based on this test, elastic and viscous behaviors are simulated through the resulting stress-strain relationship, and it would be possible to calculate two essential asphalt binder properties – complex shear modulus) G^*(and phase

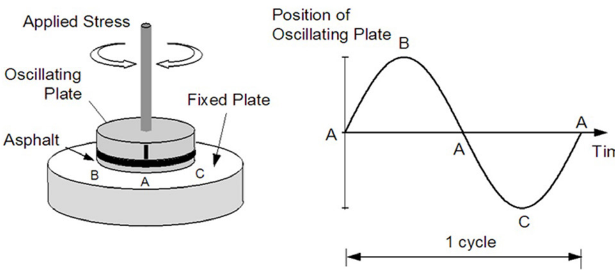

Fig. 5 Schematic view of the applied stress trend

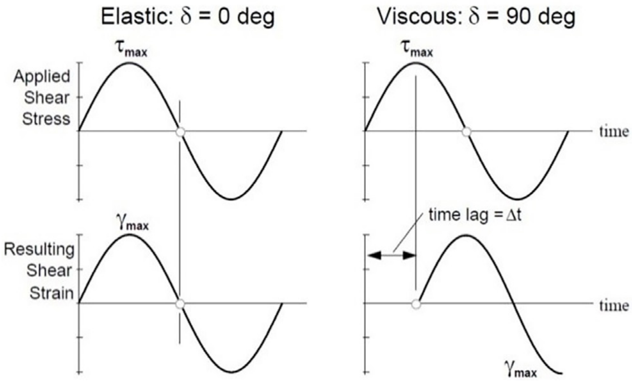

Fig. 6 Schematic representation of the applied stress and the resulting strain

angle (δ)-in DSR [26]. These two important parameters are illustrated below:

$$G^* = \frac{\tau_{\max}}{\gamma_{\max}}, \tag{1}$$

$$\Delta t = \text{timelag} \Rightarrow \delta. \tag{2}$$

In the above equations, G^* is the ratio of maximum τ to maximum γ, and δ represents the time lag obtained between the applied stress and the emerged strain.

Fatigue cracking mostly occurs in thin asphalt pavements. Therefore, in this type of pavement, fatigue is viewed as a phenomenon with controlled strain. Due to the higher incidence of cracks in the thin asphalt layer, SHRP researchers regarded this failure as a phenomenon with controlled strain in order to determine fatigue parameters with the aid of complex shear modulus and phase angle [27]. From a mathematical viewpoint, the work dissipated in each cycle in constant strain is defined according to Eq. 3.

$$W_c = \pi\varepsilon_0^2 \left[G^* \times \sin\delta\right]. \tag{3}$$

In the above equation, W_c indicates the amount of work dissipated in each cycle, ε denotes the amount of strain, and other factors have already been described.

This equation shows that more work is dissipated by increasing G^* and δ or both of them in each cycle. Indeed, with decreasing the G^*, asphalt binder stiffness is decreased and, consequently, the asphalt binder would be prone to deformation without accumulating a high amount of stress. In addition, the asphalt binder with less amount of δ has more elastic properties and, therefore, returns to its initial conditions without dissipating work. The less the work dissipated in each cycle, the less the possibility of failure. Hence, the $G^* \times \sin\delta$ parameter in Superpave specification was chosen to limit the total amount of energy dissipation, thereby minimizing fatigue cracking [28].

3.4 Indirect tensile fatigue test

Nowadays, asphaltic materials are subjected to short-term loading during a large number of vehicles passing in their service life, and this process decreases the rigidity of asphaltic materials. As a consequence of this process, fatigue failure occurs after a period of time. The indirect tensile fatigue test is the best experiment for analyzing this type of failure. The Nottingham Asphalt Tester is employed to evaluate the fatigue life of asphalt mixtures. Loading process in this test is usually done in two different ways: 1) constant stress, and 2) constant strain. In the first method, the strain is increased by loading pulses and, in the second method, the stress is decreased by loading pulses. It is noteworthy to mention that the first method is usually used to evaluate thick pavements [29].

In order to evaluate the resistance of SMA samples to fatigue by means of the ITFT test, all asphalt samples were formed in a 40 cm height along with a 10.1 cm diameter. These samples were separately tested at 5 and 20 °C with the stresses of 100, 200, 300, 400, and 500 kPa based on BS EN12697-24 standard [30]. Next, the sinusoidal loading of 1 Hz with a load duration of 0.1 s and a rest period of 0.4 s was applied to the samples, and the fatigue life of the samples was measured. The vertical movement of 8 mm was considered as the sample fatigue criterion because of device limitations. In Fig. 7, the position of the sample and loading process in the Nottingham Asphalt Tester is demonstrated for performing the fatigue test via the indirect tensile method.

4 Results and discussion

4.1 Dynamic shear rheometer

In order to decrease fatigue cracking, the binder needs to be flexible and elastic at intermediate temperatures. As mentioned before, this could be determined by viscoelastic parameters (phase angle and shear modulus). Results of the DSR test on the PAV-aged SBS-containing asphalt binder for each percentage of CF content are presented in Figs. 8–10. Evidently, the variation of phase angle indicates that the use of CF reduced the defined parameter. Decreasing the phase angle means improving the elastic response of asphalt binder, especially at low frequencies. As a result, asphalt binder samples with lower δ values are able to obtain their initial conditions without losing work. Asphalt pavement work can be wasted in many forms, such as heat, cracking and crack propagation. Therefore, it is expected that CF improves the cyclization of asphalt mixtures by increasing the elastic behavior of the modified asphalt binder.

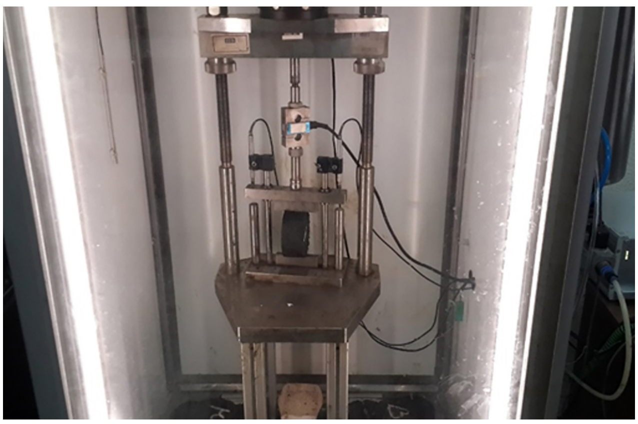

Fig. 7 The loading process of ITFT

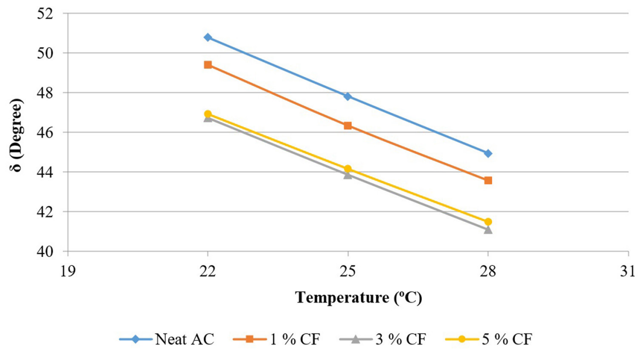

Fig. 8 Phase angle values in control and modified asphalt binders

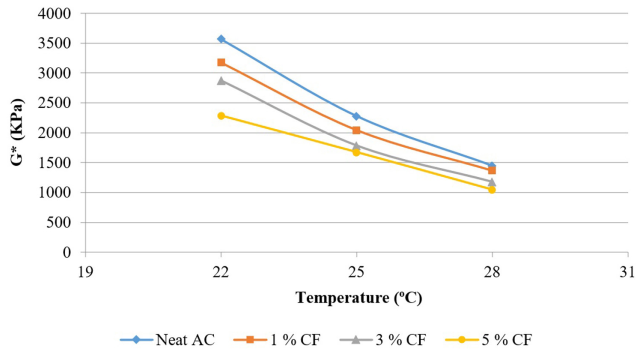

Fig. 9 Complex modulus values in control and modified asphalt binders

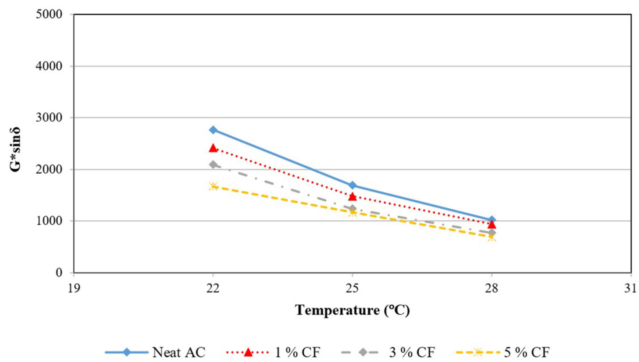

Fig. 10 Fatigue parameter values in control and modified asphalt binders

Increasing the complex shear modulus that will increase the stiffness of the asphalt binder samples, can lead to an increase in the fatigue life of the asphalt mixtures in the stress control test. Since the fatigue test using constant stress method is used in this study, increasing asphalt binder stiffness and as a result, asphalt stiffness reduces deflections and tensile stresses under the asphalt layer. The value of 5000 KPa has been suggested by SHRP researchers as the upper limit for $G^* \times \sin\delta$ in asphalt cement subjected to accelerated aging in the PAV. However, the highest amount of this value in this research was close to 3032 kPa, which is less than the maximum Superpave criteria for fatigue cracking (5000 kPa).

4.2 Indirect tensile fatigue test

Figs 11 and 12 demonstrate the fatigue resistance of PAV-aged SBS-containing SMA mixtures at 5 and 20 °C with the stress level of 100, 200, 300, 400, and 500 kPa. Results show a significant increase in the number of cycles for fatigue failure upon the addition of CF. Indeed, the figures show the higher the amount of CF, the more resistance to fatigue failure at both temperatures. Because a high-level of interface interaction between the absorbed asphalt binder and the CF surface can be formed [31]. Particularly, in 5% of CF, the highest number of cycles was achieved.

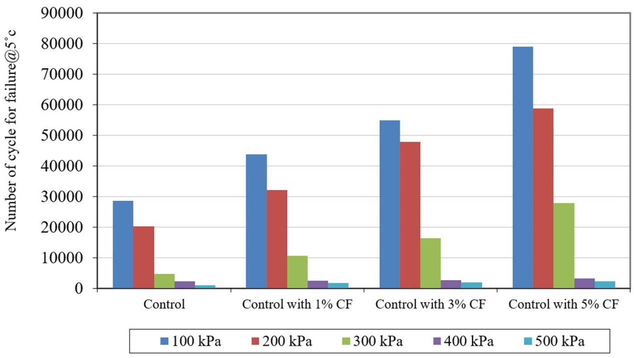

Fig. 11 Number of cycles for failure at 5 °C at different levels of stress

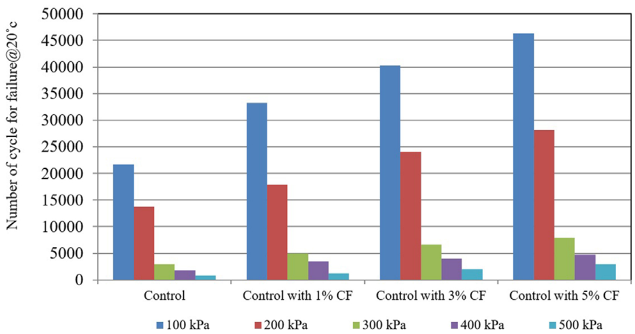

Fig. 12 Number of cycles for failure at 20 °C at different levels of stress

On the other hand, fatigue life decreases with increasing stress level in all asphalt samples. As the level of stress increases, the occurrence of deformation in the asphalt samples accelerates and the resistance of the specimens decreases. Also, by increasing the temperature to 20 °C, the fatigue life of the specimens decreases. This behavior is due to the high sensitivity of asphalt binder to temperature changes and the decrease of asphalt binder and viscosity at high temperatures. However, the results of this study show that CF modified samples are less sensitive to temperature changes. In other words, the fatigue life decreasing due to the temperature gradient for the modified asphalt sample is lower than that of the control sample.

It is also depicted that, in most cases, with a low amount of stress level, the addition of CF is more effective at low temperatures, and vice versa (with a high amount of stress, the addition of CF is more effective at high temperatures). In the sample with the stress level of 100 kPa at 5 °C, the number of cycles for failure was increased up to 175% by adding 5% CF and, at 20 °C, this number was increased only up to 113%. On the contrary, in the sample with the stress level of 500 kPa at 20 °C, the number of cycles for failure was increased up to 274% by the addition of 5% CF and, at 5 °C, this number rose only to 121%. It can be concluded that the effectiveness of CF is dependent on stress level and temperature as well.

In order to determine the role of effective factors on fatigue life, statistical analysis was performed (Tables 4–6). To this end, temperature, level of applied stress, and amount of CF were considered as independent (constant) variables, and the fatigue life (number of cycles for failure) was regarded as the dependent variable.

The results of the analysis of variance are shown in Table 4. The value of parameter F determines whether the presented model can generally describe the dependent variable. The value of F for the above model must be compared with the critical value obtained from the distribution function F. Given the value of 0.05 for the confidence level and degrees of freedom equal to 3 and 36 respectively, for

Table 4 ANOVA Output on the effect of CF

	Model	Sum of squares	df	Mean square	F	Sig.
1	Regression	1.200E10	3	4.000E9	45.433	0.000[a]
	Residual	3.169E9	36	8.803E7		
	Total	1.517E10	39			

[a] Predictors: (constant), CF, stress, temperature

Table 5 The coefficients of the rutting prediction model[a]

Model	Unstandardized coefficients		Standardized coefficients	t	Sig.
	B	Std. error	Beta		
1 (Constant)	51306.249	4608.634		11.133	0.000
Temperature	–582.957	197.803	–0.225	–2.947	0.006
Stress	–110.701	10.490	–0.804	–10.553	0.000
CF	3114.276	772.552	0.307	4.031	0.000

[a] Dependent variable: cycles

Table 6 Model summary

Model	R	R Square	Adjusted R square	Std. error of the estimate	Mean absolute error
1	0.889	0.791	0.774	982.61	713.2

regression and residuals on the distribution function F, the critical area value is defined as (11):

$$F \geq F_{(0.05)}(3.36) = 8.43. \quad (4)$$

Given that the difference in F value calculated in this study (45.433) is large compared to the critical value equal to 8.43, it is acceptable to assume that the regression and residual variances are inequalities. As a result, the model has been able to predict the laboratory values of the asphalt mixtures with relatively good accuracy.

According to these prerequisites, Eq. 5 derived from Table 5 was obtained as a model for predicting fatigue life in SMA. An indirect relationship between fatigue cracking and temperature and stress was obtained from this model (A high stress and temperature entail a lower rate of fatigue cracking). A direct relationship between fatigue cracking and CF was also resulted (A higher CF results in a higher fatigue cracking). According to Table 6, stress, temperature, and CF as independent variables significantly affect fatigue failure because of low amounts of Sig., i.e. < 0.05.

$$Y = 51306.249 - 582.957\ T - 110.701\ S + 3114.276\ CF, \quad (5)$$

where Y is the fatigue life, T is the temperature (ºC), CF is the ceramic fiber content (%), and S is the stress levels (kPa).

RMSE, MAE and R^2 parameters were used in this study to evaluate the performance of the model, the values of which are presented in Table 6. Based on the null hypothesis, if a model with minimum error values (using RSEM and MAE parameters in this study) and a coefficient of determination greater than 0.8 is considered as a very good model, it will be able to predict laboratory values with high accuracy [32, 33]. The results presented in Table 6 show that the proposed model is capable of predicting the fatigue life of asphalt mixture samples with good accuracy.

5 Conclusions

This research analyzed the suitability of using ceramic fiber in PAV-aged SBS-containing SMA mixture in order to improve its performance. A fatigue prediction model was also proposed. The following conclusions are drawn:

1. The higher CF contents in the asphalt binder leads to a smaller phase angle and higher stiffness. This is tantamount to an enhancement of the adhesion and elastic property of the modified asphalt binder at high temperatures.
2. The results of the fatigue test show that with increasing CF, the life of asphalt mixtures increases due to the elastic behavior of asphalt binder and distribution of stress throughout of the samples which reduce the stress concentration
3. Increasing temperature and stress levels decrease the fatigue life of control and modified asphalt mixtures, but the reduction process occurs at lower rates in modified samples.
4. The results of statistical analysis indicate that the stress level has more influence on the fatigue life of the asphalt mixtures than the temperature.
5. Predictive model of life span despite its simplicity, it has been able to predict laboratory values with good accuracy.

Finally, having considered the undeniable positive effects of CF on the fatigue performance of asphalt pavement, its utilizing is strongly recommended in the real field. In this regard, the optimized percentage of CF is of special importance that should properly be considered. Then, the rate of distribution of fiber in the mixture in both batching and drum process must be monitored for having a well-distributed network of CF and consequently better load distribution.

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