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Full Length Research Paper

Fatigue characteristics of stone mastic asphalt mix reinforced with fiber glass

Abdelaziz Mahrez* and Mohamed Rehan Karim

Department of Civil Engineering, Faculty of Engineering, University Malaya, Kuala Lumpur 50603, Malaysia.

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Asphalt modification/reinforcement has received considerable attention as viable solutions to enhance flexible pavement performance. This is mainly prompted by the unsatisfactory performance of traditional road materials exposed to dramatic increases and changes in traffic patterns. This paper presents the characteristics and properties of glass fiber reinforced Stone Mastic Asphalt. Laboratory tests were conducted to evaluate such related properties of asphalt mixture with different fiber contents. The tests undertaken comprise the Marshall test, indirect tensile test, creep test and fatigue test using repeated load indirect tensile test. The results showed that the addition of fiber does affect the properties of bituminous mixes, by decreasing its stability and increasing the voids in the mix. Stiffness properties of reinforced SMA mix were enhanced by about 12% as compared to control mix. Mixes with more than 0.2% fiber content exhibited lower resistance to permanent deformation. The results indicated that the fiber has the potential to resist structural distress that occur in road pavement as result of increased traffic loading, thus improving fatigue life by increasing the resistance to cracking and permanent deformation especially at higher stress level.

Key words: Modified bitumen, fiber reinforcement, creep, fatigue property.

INTRODUCTION

Asphalt modification/reinforcement has received considerable attention as viable solutions to enhance flexible pavement performance. The introduction of this technology to the transportation industry was mainly prompted by the unsatisfactory performance of traditional road materials exposed to dramatic increases and changes in traffic patterns, a need that still exists. Since then various types of modifiers for asphalt mix were considered among and one of these is the use of fibers.

The concept of using fibres to improve the behaviour of materials is not new. The modern developments of fibre reinforcement dates back to the mid sixties with conflicting views as to their usefulness and effectiveness. A multitude of fibers and fiber materials were introduced and are continuously being introduced in the market as new applications such as polyester fiber, asbestos fiber, glass fiber, polypropylene fiber, Carbon fiber, Cellulose fiber, etc (Serfass and Samanos, 1996).

Fibers have been used in asphalt mixtures to improve performances of pavements. Previous researchers have reported fiber’s reinforcing effects in asphalt mixtures and pavements. Fiber can stabilize asphalts to prevent asphalt leakage especially for the open-graded-friction-course (OGFC) and stone–mastic–asphalt (SMA) mixtures during the material transportation and paving (Hassan et al., 2005; Serfass and Samanos, 1996; Peltonen, 1991). Fiber changes the viscoelasticity of mixture (Huang and White, 2001); improves dynamic modulus (Wu et al., 2007), moisture susceptibility (Putman and Amirkhanian, 2004), creep compliance and rutting resistance (McDaniel, 2001; Chen et al., 2004) and reduces the reflective cracking of asphalt mixtures and pavements (Tapkin, 2007; Maurer and Malasheskie, 1989).

The principal functions of fiber reinforcement in

*Corresponding author. E-mail: aziz112@hotmail.com. Tel: +603 79674445/5339. Fax: +603 79552182.

bituminous mixes are to provide additional tensile strength in the resulting composite and increasing strain energy absorption of the bituminous mix to inhibit the formation and propagation of cracks that can reduce the structural integrity of the road pavement. The idea was based on the general concept that if HMA is strong in compression and weak in tension, then reinforcement could be used to provide needed resistance to tensile stresses (Al-Qadi et al., 2003; Bushing et al., 1970).

Fibers reinforced bituminous mixture is widely used specially in stone mastic asphalt (SMA). SMA is hot mixture asphalt consisting of a coarse aggregate skeleton and a high binder content mortar. It was developed in Germany during the mid-1960s and it has been used in Europe for more than 20 years to provide better rutting resistance and to resist studied tyre wear (Scherocman, 1991). The original purpose of SMA was to provide a mixture that offered maximum resistance to studded tyre wear. SMA has also shown high resistance to plastic deformation under heavy traffic loads with high tyre pressures, as well as good low temperature properties (Brown et al., 1997; Cooley and Brown, 2003). SMA is characterized by a gap-graded aggregate gradation and high stone content. This high stone content ensures stone-on-stone contact after compaction. The gap-graded aggregate mixture provides a stable stone-to-stone skeleton that is held together by a rich mixture of asphalt mastic, which is a mixture of bitumen, filler, sand and stabilizing additives. Stabilizing additives can be organic or mineral fibers, or less often, polymers. They stabilize the asphalt mortar and tend to thicken or bulk the bitumen to prevent binder run-off from the aggregate. Thus, they ensure the homogeneity of the mixture. Aggregate interlock and particle friction are maximized and gives the structure its stability and strength (Susanne, 2000).

Attempts of using non-synthetic fibers in pavement have been reported in the literature. Cotton fibers and asbestos fibers were used but these were degradable and were not suitable as long term reinforcement (Bushing and Antrim, 1968). Metal wires have also been proposed but they were susceptible to rusting with the penetration of water (Tons and Krokosky, 1960). Asbestos was also used until it was determined as a health hazard (Kietzman, 1960; Marais, 1979).

With new developments the production of glass fiber reinforced bituminous mixtures can be cost competitive as compared with modified binders. The use of glass fiber reinforced bituminous mixes may increase the construction cost, however this may reduce and save the maintenance cost.

This research study seeks to identify the characteristics and properties of glass fiber reinforced stone mastic asphalt with specific emphasis on the fatigue properties of fiber reinforced SMA. This may have the benefit of understanding the reinforcing mechanisms and might provide ways of optimising fiber properties for performance enhancement of road pavement.

MATERIALS AND EXPERIMENTAL METHODOLOGY

Materials

The materials used in this research include an 80/100 penetration grade bitumen, aggregates with SMA 20 gradation characterised by 20 mm nominal size aggregates given in Table 1, Portland cement filler and the glass fiber.

Experiments

Standard laboratory tests for this research were used, namely, Marshall test (ASTM D1559-89), indirect tensile modulus test (IDT) (ASTM D4123-82), dynamic creep test performed according to the Shell procedure (AAMAS 338)) and repeated load indirect tensile test (BS EN12697-24:2004) in which three different stress levels were applied (1, 2 and 3 kN). Creep and fatigue tests were conducted at temperature of 40ºC, while indirect tensile test (IDT) was conducted at temperature of 25ºC.

Sample preparation

Bituminous mixes were prepared by mixing the SMA graded aggregates with 80/100 penetration grade bitumen and glass fibers. The dry blending method was used in which the glass fibers were blended with hot aggregate and the filler before the binder was added. The filler content is 2% by weight of mix. The glass fiber content in this research was varied between 0.1, 0.2, 0.3 and 0.4% by weight of mix. The optimum binder content for the original mix was 5.2% by weight of the mix, while the modified mixtures were prepared using the optimum binder content of (5.3, 5.4, 5.7 and 5.8%) corresponding for each fiber content (0.1, 0.2, 0.3 and 0.4%) respectively. The fiber length in the mixture was preserved as constant parameter with a value equal to 20 mm.

Specimens were prepared using a Marshall compactor machine. The number of compaction was 75 blows for top and bottom side of the specimens. The temperatures for mixing and compaction were designated at 160 and 140ºC, respectively.

RESULTS AND DISCUSSION

Marshall test results

Figures 1 and 2 present the stability and voids in the mix (VIM) results, respectively, for different fiber contents. Figure 1 shows that there is a decrease in stability values as the fiber content increases in the mix, this is due to the big amount of fiber within the mix, which affect the goal of SMA by having contact points between aggregates therefore resulting in a lower value of stability. Figure 2 shows that the increase in fiber content in the mix results in an increase in the VIM. This is probably due to the greater surface areas (aggregates and fibers) that need to be wetted by the binder failing which would lead to an increase in the voids in mix. In addition, mixes with higher fiber content might experience lower compact ability; therefore higher air voids value might be obtained.

Table 1. Selected aggregate gradation for the SMA20.

Sieves [mm]	20	14	10	6.3	2.36	0.3	0075
Passing [%]	100	95	75	50	26	13.5	8

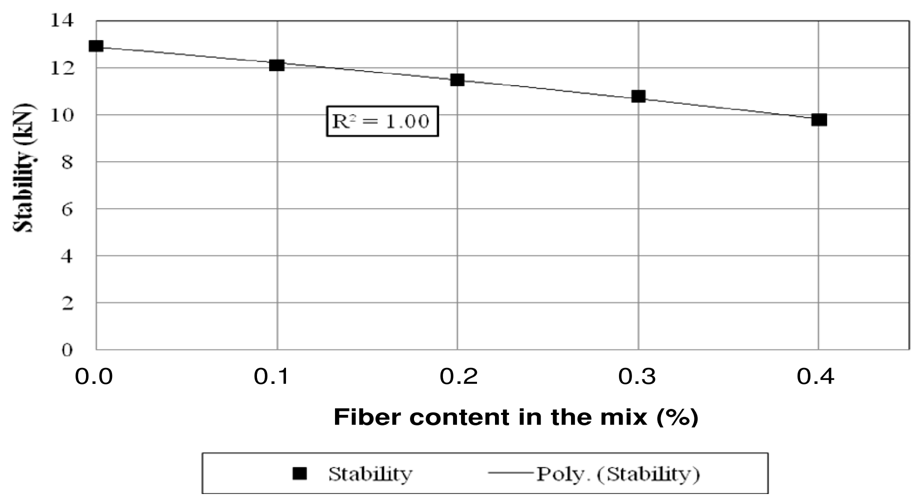

Figure 1. Stability results for different fiber content.

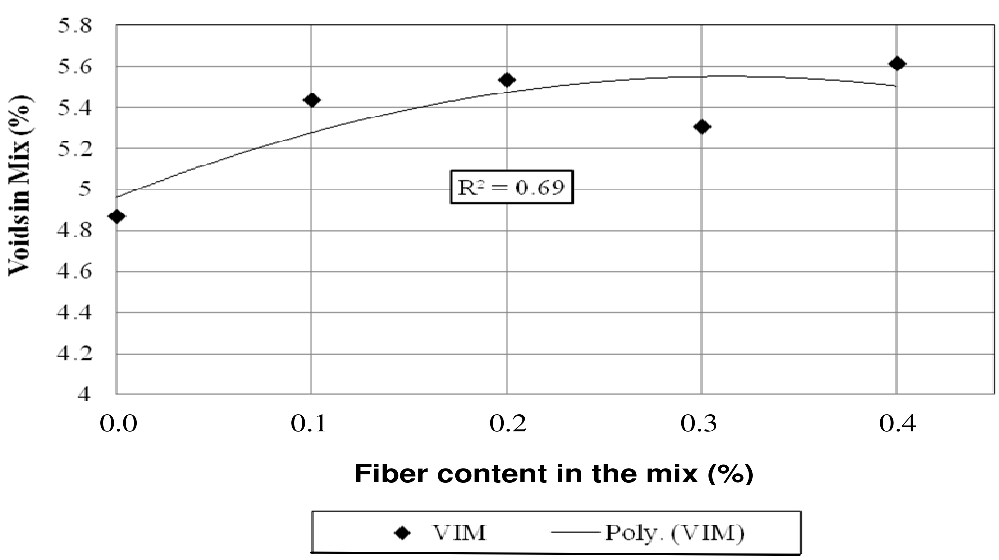

Figure 2. Voids in the mix results for different fiber content.

Resilient modulus results

The stiffness properties of the reinforced SMA mixes at their optimum bitumen content are presented in Figure 3. The results showed that the mixes with different fiber contents had slightly a higher stiffness value as compared to control mix. The results trend displayed an increase in stiffness modulus of the mix as the fiber contents increases up to an optimum value (0.2% fiber content) then it decreases back with further increase of fiber contents. The increase in resilient modulus due to the increase in fiber content was not large and ranged between 4 to 12% as compared to control mix depends on the fiber content. Mix with 0.2% fiber content exhibited slightly higher stiffness modulus as compare to other mixes.

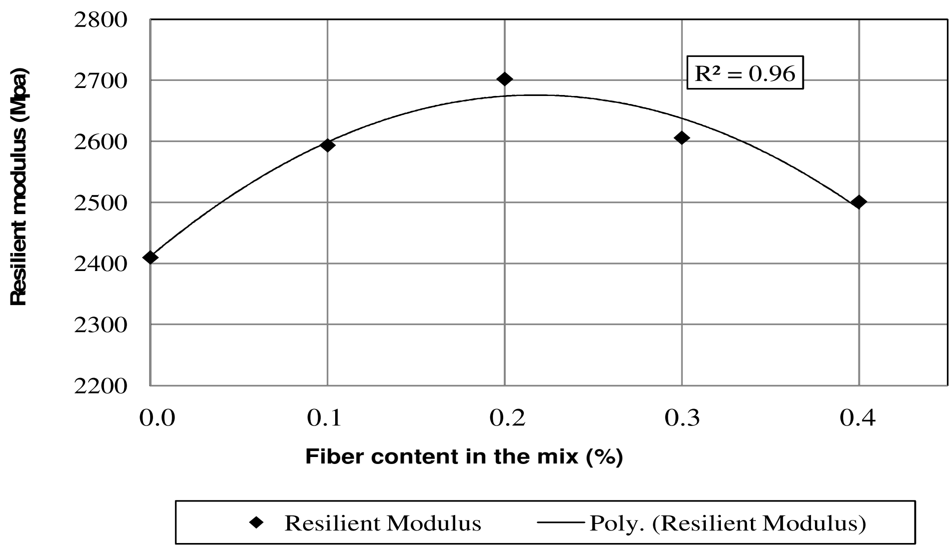

Figure 3. Resilient modulus results for different fiber content.

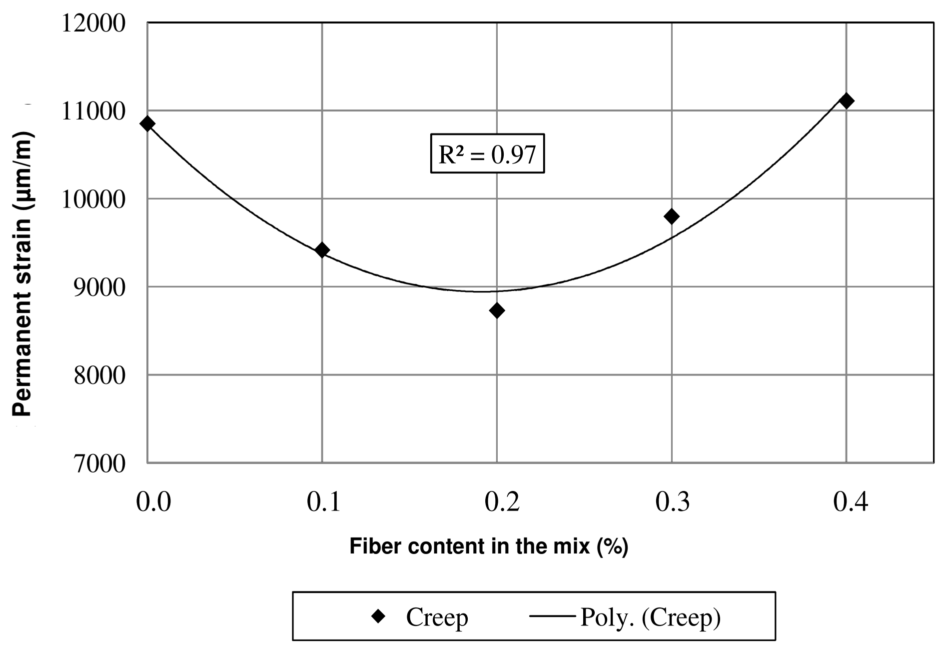

Figure 4. Permanent strain results for different fiber content.

The increase in resilient modulus of the modified mixes is probably due to the higher modulus of elasticity and very low ability of extension of glass fiber and its random orientation in different direction in the sample. The fibers firmly bind the aggregate particles inside the matrix and prevent them of movement, which makes the mix stiffer. However the decline in resilient modulus beyond a certain value of fiber content is probably due to high inclusion of fiber, thus higher surface area to be coated by bitumen is generated; consequently the aggregate particles and fiber will not be fully coated with the bitumen and thereby looser and less stiffer mix is obtained.

Dynamic creep test results

The creep test results presented in the form of permanent strain indicated that the fiber content affects the creep properties of the bituminous mixes. As illustrated in Figure 4 the permanent strains noticeably decreases with the increase of fiber content up to an optimum value then it increases back with the further inclusion of fiber content. Mix with 0.2% fiber content resulted in lowest permanent strain. The addition of 0.1, 0.2 and 0.3% fiber content to the mix reduced the strain value by about 13, 20 and 10% as compared to the control mix. It was noticed that mix with 0.4% fiber content increased the strain value by about 2% as compared to the control mix.

Generally, the dynamic creep data indicates that at the optimum condition the addition of small amount of glass fiber (≤ 0.2%) into original bituminous mixes will improve reasonably its deformation property as compared to the unmodified bituminous mix if tested under the same loading and temperature conditions. In contrast high amount of glass fiber incorporated into the mix will results in strain value that could be higher as compared to the control mix, causing a detrimental effect to the reinforced mix by lowering its resistance to permanent deformation.

Note that the lowest values of permanent strain in the mixes indicate that these mixes are less prone to permanent deformation.

Repeated load indirect tensile test results

The fatigue characteristics relating the accumulated strains with the number of cycles to failure for the mixes are presented in Figure 5 (a - c), respectively, for stress level 1, 2 and 3. All the figures showed that the addition of glass fiber into mixtures improved the fatigue life and reduced the accumulated strain. Mixture with 0.2% fiber content resulted in the highest fatigue life and hence lower strain value. The figures also showed that the higher the stress level the lower the fatigue life and the higher the accumulated strain, in fact this is understood and expected.

At stress level 1 and 2, fatigue life increases by about 28% (18% for stress level 2), 45, 21 and 10% with the addition of 0.1, 0.2, 0.3 and 0.4% glass fiber, respectively, whereas at stress level 3, the fatigue life increases by about 24, 79, 45 and 24% with the addition of 0.1, 0.2, 0.3 and 0.4% glass fiber, respectively. This is probably due to chopped glass fiber that are well distributed in different directions of bituminous matrix highly resist the shear displacement and firmly prevent aggregate particles from any movement, thus increasing fatigue life by efficiently delaying crack propagation once the crack had been initiated. Furthermore, the improvement in fatigue life due to the addition of fiber is more considerable at higher stress level as compared to low stress level. Meaning that the enhancement of glass fiber reinforced bituminous mix as fatigue barrier is more significant and useful when heavy trafficked road is concerned rather than normal trafficked road. This is good and practically acceptable since the normal trafficked road are less prone to fatigue, thus if the reinforcement in this case provides some improvements but in the same time it will increase the cost, however at heavy trafficked roads which are more prone to fatigue failure the reinforcement with glass fiber provide great improvements in fatigue life and therefore the reinforcement here might be more cost effective by reducing the maintenance cost in the same time being able to extend the service life of the pavement. Noticed that the higher is the stress level the lower is the correlation coefficient (R^2) between the number of pulses and the accumulated strain.

In order to obtain more realistic representation of the fatigue relation, the regression models for the natural logarithms of fatigue life and accumulated strain due to different fiber contents was developed for all mixtures and presented in Figure 6. The regression equations for each stress level along with the regression parameters for each relationship are summarized in Table 2. The basic fatigue life model, confirms the aforementioned effects of fiber contents and stress levels on fatigue life. A look at fatigue models coefficients may provide some guidance. As evidenced, the high R^2 values are reasonably indicative of good models' accuracy.

Conclusions

Based on this study the following conclusions can be deduced: (1) The addition of fiber does affect the properties of bituminous mixes, by decreasing its stability and increasing the voids in the mix. (2) The resilient modulus can be significantly enhanced by the addition of fibers depending on the fiber content in the mixture. An increase in stiffness properties of reinforced SMA mix by about 12% was obtained as compared to control mix. This increment in stiffness might be insufficient but this is good enough in the sense that reinforced mixes are stiffer and will not be too rigid. (3) Mixes with fiber decreased the permanent strain up to certain value than it increases back with further inclusion of fiber content. Since larger permanent strain value is an indication of deformation susceptibility of the mix, thus based on the trend of the plotted creep data one can argue that at the optimum condition the addition of more than 0.2% fiber content will cause a detrimental effect to the reinforced mix by lowering its resistance to permanent deformation. (4) Addition of fiber improves fatigue life by increasing the resistance to cracking and permanent deformation of bituminous mixes. Mixes reinforced with glass fiber exhibited higher fatigue life as compared with the original mix. This improvement in fatigue life is more considerable at higher stress level as compared to low stress level. Therefore the enhancement of glass fiber reinforced bituminous mix as fatigue barrier is more significant and useful when heavy trafficked road is concerned. (5) Regression models of fatigue life and accumulated strain showed strong relation with the fatigue parameters due to different fiber contents and different stress levels. High

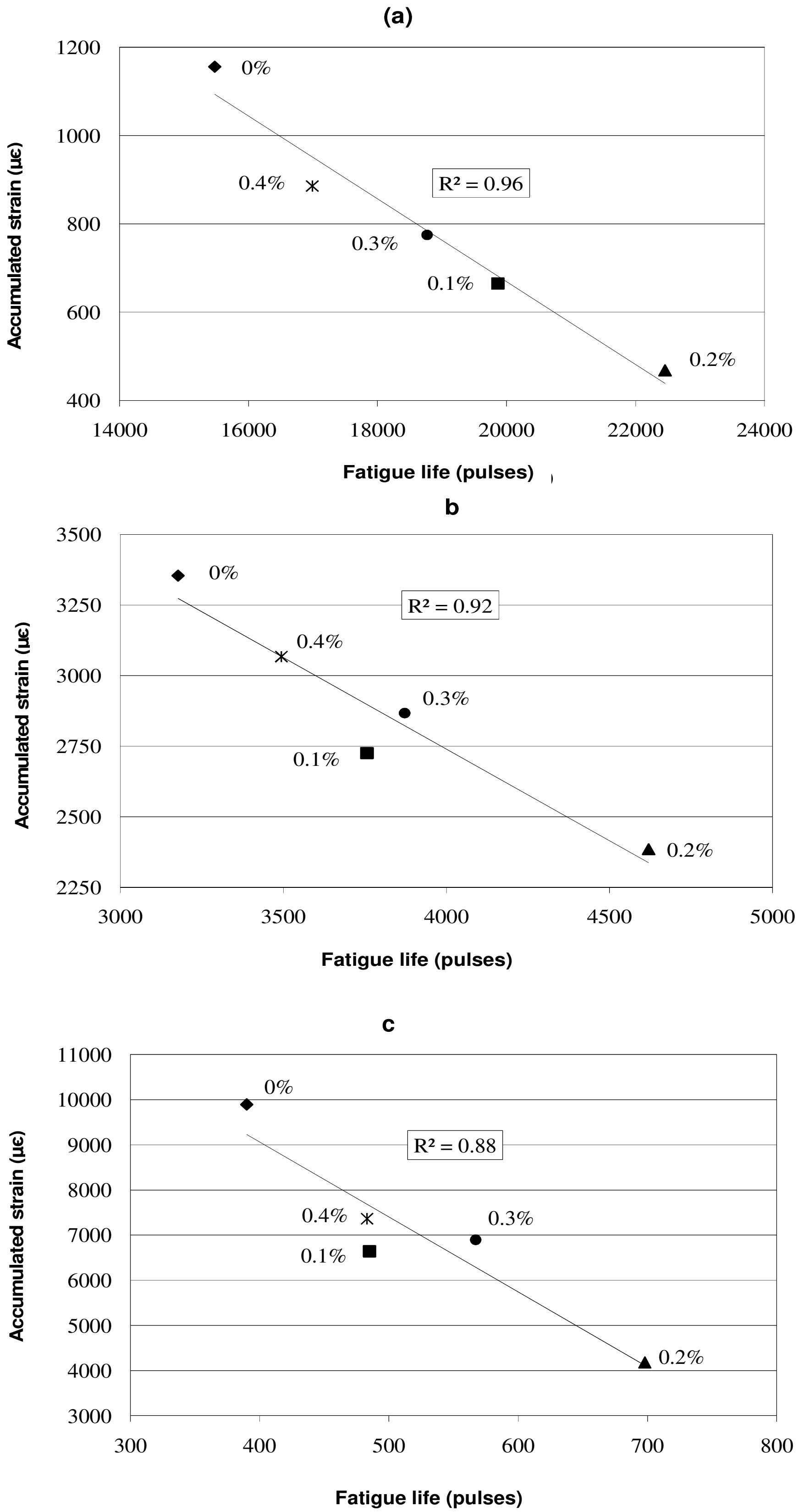

Figure 5. (a) Fatigue life versus accumulated strain at stress level 1. (b) Fatigue life versus accumulated strain at stress level 2. (c) Fatigue life versus accumulated strain at stress level 3.

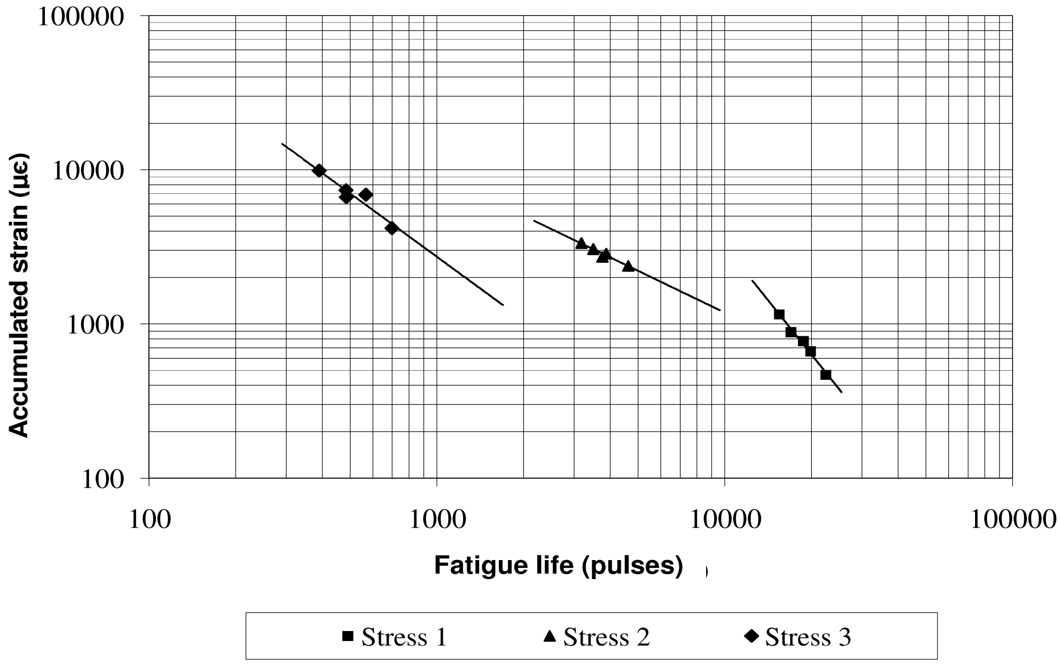

Figure 6. Fatigue characteristics versus accumulated strain for different stress levels.

Table 2. Regression equations for fatigue life and accumulated strain due to the variation of fiber contents along with regression parameters.

Stress levels*	Fatigue equation	k_1	k_2	R^2
Stress 1	$N_f = 3.188 \times 10^5 \left(\frac{1}{\varepsilon}\right)^{0.429}$	3.188×10^5	0.429	0.98
Stress 2	$N_f = 2.624 \times 10^7 \left(\frac{1}{\varepsilon}\right)^{1.112}$	2.624×10^7	1.112	0.95
Stress 3	$N_f = 3.322 \times 10^5 \left(\frac{1}{\varepsilon}\right)^{0.734}$	3.322×10^5	0.734	0.90

(*) Stress 1 < Stress 2 < Stress 3.

models coefficients (R^2) values are reasonably indicative of good models' accuracy. (6) Overall at optimum binder content, mix with 0.2% fiber content resulted in highest performance in terms of stiffness, resistance to permanent deformation and fatigue.

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