Abstract: Reinforcement consists of incorporating certain materials with some desired properties within other material which lack those properties. The concept of using fibres to improve the behaviour of materials is not new. The modern developments of fibre reinforcement started in the early 1960s. A multitude of fibers and fiber materials were introduced and are continuously being introduced in the market.

Stone Mastic Asphalt pavement surfaces have been used successfully in Germany on heavily trafficked roads. In recognition of its excellent performance a national standard was set in Germany in 1984. Since then SMA has spread and gained acceptance all over the world, because of its excellent performance characteristic the use of SMA increased in popularity amongst road authorities and asphalt industry.

This paper presents the characteristics and properties of glass fiber reinforced Stone Mastic Asphalt, which may have the benefit of improving the performance of road pavement. To evaluate the effect of the fiber content on the bituminous mixes, laboratory investigations were conducted on the samples with and without fibers. The testing undertaken in this research comprise the marshall test, indirect tensile test, creep test and resistance to fatigue cracking by using repeated load indirect tensile test.

The use of Glass fiber showed consistent results and it was found the addition of fiber does affect the properties of bituminous mixes, by decreasing its stability and an increase in the flow value as well the voids in the mix. 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. On the whole, the results showed that the addition of glass fiber will be beneficial in improving some of the main properties of the flexible pavement.

**Key words**: Modified Bitumen, Reinforcement, Fiber, Creep, Deformation, and Fatigue.

### 1. INTRODUCTION

#### 1.1 Introduction

Scientists and engineers are constantly trying to improve the performance of asphalt pavements. Modification of the bituminous binder is one approach taken to improve pavement performance. Since 1960s, Stone Mastic Asphalt pavement surfaces have been used successfully in Germany on heavily trafficked roads. In recognition of its excellent performance a national standard was set in Germany in 1984. Since then SMA has spread and gained acceptance all over the world, because of its excellent performance characteristic the use of SMA increased in popularity amongst road authorities and asphalt industry.

Stone Mastic Asphalt is a gap graded bituminous mixture containing a high proportion of coarse aggregate and filler, with relatively little sand sized particles. It has low air voids with high levels of macrotexture when laid resulting in a waterproof layer with good surface drainage (BCA 9808).

Since Stone Mastic Asphalt relies on stone-to-stone contact to provide its strength and a mastic mortar rich in binder, stabilising additives are needed in the mastic in order to prevent the binder from draining down from the mix. Research and experience has shown that fibers tend to perform better than polymers in reducing draingdown, thus fibers are recommended (BCA 9808).

Reinforcement generally consists of incorporating certain materials with some desired properties within other material which lack those properties. Fiber reinforcement was used as a crack barrier rather than a reinforcing element whose function is to carry the tensile loads as well as to prevent the formation and propagation of cracks (Maurer et al., 1989).

It is thought that the addition of glass fibers to asphalt mixtures enhances material strength and fatigue resistance while adding ductility. Because of their excellent mechanical properties, glass fibers might offer an excellent potential for asphalt modification.

The concept of using fibres to improve the behaviour of materials is not new. The modern developments of fibre reinforcement started in the early 1960s. 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 et al.,1996).

The principal functions of fiber as reinforcement material is to provide additional tensile strength in the resulting composite. This may increase the amount of strain energy that can be absorbed during the fatigue and fracture process of the mix.
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 et. al, 1968). Metal wires have also been proposed but they were susceptible to rusting with the penetration of water (Tons et. al, 1960). Asbestos was also used until it was determined as a health hazard (Kietzman, 1960; Marais, 1979).

This study investigates on the characteristics and properties of glass fiber reinforced Stone Mastic Asphalt, which may have the benefit of improving the performance of road pavement.

1.2 Literature Review

From the literature review fiber reinforced bituminous mixes has shown mixed results. It was noticed that relatively few published information concerning fiber modified asphalt is available. Most studies that included fibers in asphalt mixtures had a limited number of trials, and investigating the effects of fiber modification was in many cases secondary to the main purpose of the studies.

Some fibres have high tensile strength relative to bituminous mixtures, thus it was found that fibres have the potential to improve the cohesive and tensile strength of bituminous mixes. They are believed to impart physical changes to bituminous mixtures by the phenomena of reinforcement and toughening (Brown et. al, 1990). This high tensile strength reinforcement may increase the amount of strain energy that can be absorbed during the fatigue and fracture process of the mix. Finely divided fibres also provide a high surface area per unit weight and behave much like filler materials. Fibres also tend to bulk the bitumen so it will not run off the aggregates during construction.

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.

However, due to lack of understanding on the reinforcing mechanisms as well as ways of optimising fiber properties (e.g., fiber diameter, length, surface texture etc.) performance enhancement of asphaltic mixtures reinforced by theses fibers was found to be marginal. Depending on the characteristics of fibers, the effect of fiber addition to asphalt concrete can be very different. For example, if the fibers are too long, it may create the so called “balling” problem (i.e., some of the fibers may lump together) and the fibers may not blend well with the asphalt concrete. If the fibers are too short, then the fibers may not provide any reinforcing effect and may just serve as an expensive filler in the mix.

Previous researches showed that the addition of the fiber into bitumen increased the stiffness of the asphalt binder resulting in stiffer mixtures with decreased binder drain-down. The fiber modified mixtures showed improved Marshall properties by increasing the stability values and decrease in the resulting air void content compare to the control mix. Fibers appear to have the potential to improve fatigue life and deformation characteristics by increasing rutting resistance. The tensile strength and related properties of mixtures containing fibers was found to improve in some cases and not in others.
In terms of workability, mixtures with fiber showed a slight increase on the optimum binder content compared to the control mix. This is similar to the addition of very fine aggregates. The proper quantity of bitumen needed to coat the fibres is dependent on the absorption and the surface area of the fibres and is therefore affected not only by different concentrations of fibres but also by different fibre types (Button et. al, 1987). In addition, the degree of homogeneity of dispersion of the fibres within the mix will also determine the strength of the resulting mixtures (Mills et. al, 1982).

The results obtained from the different field studies showed that the addition of fiber have a benefit since it will help to produce more flexible mixtures and thus one that is more resistant to cracking (Jiang et al., 1993).

2. LABORATORY INVESTIGATION

2.1 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 as shown in Figure 1, Portland cement filler and the glass fiber.

![Figure 1. Aggregate Gradation for the SMA20](image)

2.2 Experiments

The basic experimental approach of this research is focused on the investigation of the properties of glass fiber modified bituminous binder as well as glass fiber reinforced bituminous mixes.

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 (SHELL BOOK) and repeated load indirect tensile test
(fatigue test). Testing were conducted using the standard Marshall apparatus and the MATTA equipment respectively.

Creep and fatigue tests were done at temperature of 40ºC, while IDT test was done at temperature of 25ºC.

2.3 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%, 0.4% and 0.5% by weight of mix. The optimum binder content for the original mix was 5.5% by weight of the mix, while the modified mixtures were prepared using the optimum binder content (5.6%, 5.7%, 5.8%, 5.9% and 6%) corresponding for each fiber content (0.1%, 0.2%, 0.3%, 0.4% and 0.5%) 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 as specified by the Malaysian standard (JKR 05-06) for heavily trafficked roads. The temperatures for mixing and compaction were designated at 160ºC and 140ºC, respectively.

Specimen for creep test was cut smoothly by cutting machine for both diametral surfaces to 50 mm. Then, capping by using grease and powder applied at the surface. This would minimize the friction with loading plates and thus ensure a uniaxial stress condition.

3. RESULTS AND DISCUSSION

3.1 Marshall Stability Results

Figure 2 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.

3.2 Flow Values Results

Figure 3 shows that the increase of fiber content in the mix does not necessarily increase the flow values. The increase of the fiber content in mix decreases the stability value and the more fiber you add the lower is the stability, but this is not the case for the flow value. The increase of fiber content in the mix increases the flow value and when the fiber content in the mix is higher than 0.30% (i.e. 0.4% and 0.5%) the flow values began to decrease.
3.3 Voids in the Mix (VIM) Results

The Figure 4 showed consistent results concerning the effect of fiber content on the VIM. Results showed that the increase in fiber content in the mix is followed by 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.
3.4 Resilient Modulus Results

The results obtained show that the resilient modulus increases with the increase of fiber content up to 0.3% and began to decrease when the fiber content increases above 0.3% (means 0.4 % and 0.5%).

The increase in resilient modulus 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 the 0.3% 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.

It was noted that with the inclusion of 0.3% of fiber content the resilient modulus noticeably increased by about 14% as compared to the original sample.

3.5 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 6 the permanent strains noticeably decreases by the increase of fiber content up to 0.3% and then it increases back with the further inclusion of fiber content.

Generally, the creep test results indicates that the addition of small amount of glass fiber (≤ 0.3%) into original bituminous mixes will improve reasonably well its deformation behaviour as compared to the original bituminous mix which might deform more easily under the same loading and temperature conditions. In contrast high amount of glass fiber (≥ 0.3%) incorporated into the mix might deteriorate its deformation properties due to the same reasons cited in the previous sections.
It was noted that the lowest values of permanent strain in the mixes indicate that these mixes are less prone to permanent deformation.

![Figure 5. Resilient Modulus Results For Different Fiber Content](image1)

![Figure 6. Permanent Strain Results For Different Fiber Content](image2)

### 3.6 Repeated Load Indirect Tensile Test Results

Laboratory fatigue testing indicated that the use of glass fiber significantly improved fatigue performance. Results show that mixes reinforced with glass fiber are considerably more fatigue resistant than the original mixes.
Fatigue life increases by about 28.2%, 37.2% and 44.4% with the addition of 0.1%, 0.2% and 0.3% glass fiber, respectively, into original bituminous mixes. 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.

![Fatigue Life Vs Fiber Content](image)

Figure 7. Fatigue Life Vs Fiber Content

3.7 Correlation between Fatigue Life with the stiffness and Deformation Properties of Glass Fiber Reinforced Bituminous Mixes

Figures 8 and 9 showed that fatigue life have good correlation with stiffness and permanent deformation properties, respectively, due to the addition of fiber to ordinary bituminous mixes.

The correlation factor between the fatigue life and stiffness was $R^2 = 0.98$, while a slightly lower correlation factor is obtained between the fatigue life and permanent deformation with $R^2 = 0.77$.

The fatigue life of the specimens showed a proportional correlation with the stiffness properties of the mixes, while there was an inverse correlation between the fatigue life and permanent deformations. In simple words the increase in stiffness properties of the specimens is followed by an increase in fatigue life of the specimens (Figure 8) and an increase in permanent deformation properties of the specimens is followed by a decrease in fatigue life of the specimens (Figure 9), and this is expected and understood.
4. CONCLUSIONS

The use of Glass fiber showed consistent results and it was found the addition of fiber does affect the properties of bituminous mixes, by decreasing its stability and an increase in the flow value as well the voids in the mix. The tests results indicated that the fiber has the potential to improve structural resistance to distress that occur in road pavement as result of increased traffic loading. Addition of fiber improves fatigue life by increasing the resistance to cracking and permanent deformation of bituminous mixes. It was noticed that the fiber content of 0.3% by weight of the total mix resulted in highest performance in terms of stiffness, resistance to permanent deformation and fatigue as compared to the ordinary mix, however a slight degradation in these properties when the fiber content exceeds 0.3%. On
the whole, the results showed that the addition of glass fiber will be beneficial in improving some of the main properties of the flexible pavement.

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