EFFECT OF CARBON FIBER ON THE PERFORMANCE OF REINFORCED ASPHALT CONCRETE MIXTURE

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Hayder Kamil Shanbara
Department of Civil Engineering
Al-Muthanna University

E-mail : hayder.shanbara82@gmail.com
Tel : 964(0)7733297733

Abstract :

This paper presents characteristics and properties of carbon fibers reinforced asphalt concrete mixtures. The results showed that carbon fibers do improve the performance of the asphalt concrete mix. To evaluate the effects of carbon fibers contents on mixtures, in which one mix was reinforced with carbon fibers and the other mix was not. The testing undertaken in this research comprise the Marshall Test, Indirect Tensile Test, Creep Test, and Wheel Tracking Test. Carbon fibers exhibited consistency in results, and as such it was observed that the addition of fibers affects the properties of mixtures, i.e. an increase in its stability and a decrease in the flow value and increase in voids in the mix. The carbon fibers are able to block the propagation of cracks, reduce the rut depth or increase the strength of pavements to the rutting deformation.

الخلاصة:

يعنى هذا البحث في عرض استخدام الألياف الكربونية في تدعيم خليط الإسفلت بهدف تحسين أداء الطرق. وتبين نتائج هذا البحث إن الألياف الكربونية تحسن من أداء الخلطات الإسفلتية، وقد قمنا بإجراء تجارب مختبرية على الخلطات الإسفلتية التي تحتوي على هذه الألياف وأخرى لا تحتوي عليها وهذه التجارب هي : اختبار مارشال، واختبار قوة الشد غير المباشر، واختبار الزحف، واختبار العجلة المتحركة. وقد أدى استخدام ألياف الكربون إلى زيادة استقرار الخلطات الإسفلتية وتناقص في الجريان، كما أدى إلى زيادة الفراغات الهوائية في الخلطات الإسفلتية، وكذلك أظهرت النتائج إن الألياف الكربونية لها القدرة على تأخير ظهور التشققات على السطح الخارجي للطرق وكذلك تقلل من التخدد الذي يحصل في الطبقة السطحية للطريق أو بمعنى آخر زيادة مقاومة الطريق للتشوه الذي ينتج عنه التخدد.

1. Introduction :

Most of the hot mix asphalt produced were designed using the Marshall methods , with the rapid development of the economy in Iraq , traffic volumes have been increasing exponentially. The fast growth of heavy load traffic places a huge demand on the ration's highway network , which is covered primarily with hot mix asphalt concrete. Modifying the asphalt mix by adding additives to the bitumen or asphalt mix has proved to help improve the performance of asphalt pavements efficiently [1]. Today , many types of additives are used , including polyester fiber , asbestos fiber , glass fiber , polypropylene fiber , carbon fiber , cellulose fiber , etc [2]. Modifying hot mix asphalt with carbon fiber is thought to improve mechanical properties and extend pavement life [3]. It is widely believed that the addition of fibers to asphalt enhances material strength as well as fatigue characteristics while at the same time adding ductility. Likewise , carbon fiber may also offer excellent potential for binder modification due to their inherent compatibility with asphalt cement and superior mechanical properties. With new developments in production , carbon modified binder has become cost competitive with polymer modified binders. Further , it was expected that carbon fiber modified asphalt mixtures would increase stiffness and resistance to permanent deformation and , similarly , that the fatigue characteristics of the mixture would improve with the addition of discrete carbon fibers. Because of the high tensile strength of carbon fiber , cold temperature behavior of asphalt mixture was also expected to improve. Finally , carbon fiber modified asphalt could produce a higher quality asphalt mixture for pavements [4].

2. Literature Review :

Using fibers to improve the behavior of materials is not a new concept. Fibers are widely used as reinforcing agent in concrete, however , the modern ways of fiber reinforcement started in the early 1950 [4]. Based on result from other fiber modified composites , it was thought that the incorporation of carbon fiber into an asphalt cement mixture would enhance its tensile strength properties , resulting in a decrease in cracking due to cold temperatures and repeated loading at intermediate temperatures , while stiffening the mixture at high temperatures , increasing its resistance to permanent deformation. Modification of asphalt binder is on approach taken to improve pavement performance [5]. In 1996 , Serfass and Samanos investigated fiber modified asphalt using chrysotile , rock wool , glass wool , and cellulose fibers. There modified asphalt were subjected to a wide variety of tests on mastics (bitumen and fibers) , mortars (bitumen , fibers , and sand) , and asphalt concrete.

Common characteristics of all tested asphalt includes resistance to thermal cracking , ageing , shearing , and aggregate dislodgment. They concluded in their studies that the addition of fibers to asphalt concrete improved the fixation of the asphalt binder in the mix. This relates to less bleeding and improved skid resistance over unmodified mixtures of the same design. Fiber modification also allowed for an increase in film thickness , resulting in less aging and improved binder characteristics. The addition of fibers also resulted in the reduction of temperature susceptibility of asphalt mixtures. Adding fibers enables developing mixtures rich in bitumen (asphalt binder) , and therefore displaying high resistance to moisture , aging , fatigue , and cracking [6].

A two-phase study by [5] , investigated the behavior of carbon fiber modified asphalt mixtures. The first phase focused on determining the feasibility of achieving improvements in mechanical behavior with the addition of carbon fiber. The second phase focused on investigating the factors that contribute to the new behavior. Carbon fiber were found to create improvements in high temperature and low temperature behavior. Hot mix asphalt samples containing 0.5% to 0.8% weight carbon fibers in the asphalt cement binder showed a respective improvement in resistance to repeated load deformation ranging of 38% to 82%. Fibers length taken after a pug mill field trial by the research sponsor revealed a reduction in average final carbon fiber length from 2.54cm to between 0.2mm and 0.65mm. Potential problems identified by this study were final. Fiber length even distribution of fibers and initial asphalt quality [5].

Aren's [5] study formed the foundation for this current study due to the need to improve carbon fiber length in the final asphalt cement by protecting it during mixing. An estimate was made of a final length of 6mm for improved mechanical properties , enough to arrest microcracks and reduce creep.

3. Materials :

The materials used in this research include an (40 – 50) penetration grade asphalt with 5.19% optimum asphalt content by weight of mixture , aggregate with 3/4" (19mm) maximum size (1/2" (12.5mm) nominal size) according to (SCRB) [7] as shown in figure (1) , Portland cement filler and carbon fiber. Table (1) indicates the properties of the carbon fiber.

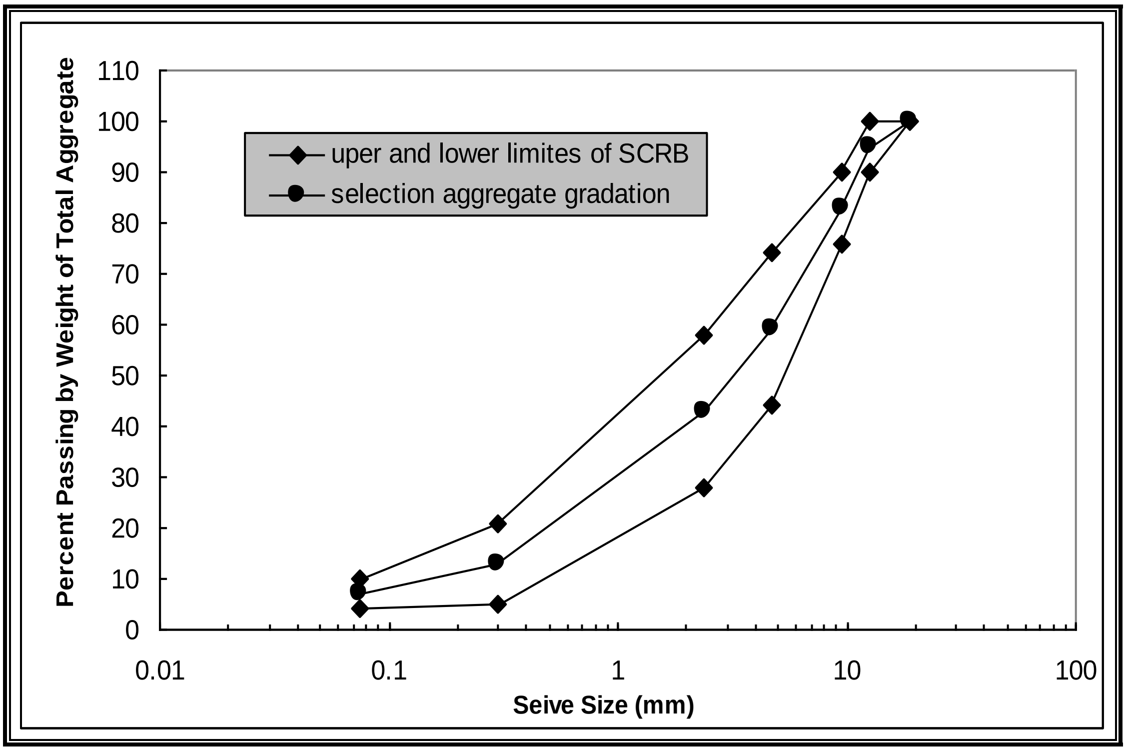

Figure (1)

Table (1) Properties of Carbon Fiber

Diameter	7.5 – 7.8 µmm
Tensile Modulus of Elasticity	200 Gpa
Tensile Strength	3.2 Gpa
Failure Strain	> 2%
Base	Polyacrylonitrile
Temperature of Carbonization	1400°c
Cost	15 – 35 $/kg

4. Experiments :

The basic experimental approach of this research is focused on the investigation of the properties of carbon fiber reinforced asphalt mixtures. Standard laboratory tests for this research were used , Marshall test (ASTM D1559) [8] , Indirect Tensile Strength test (ASTM D4123) , Creep test , Wheel Tracking test. Indirect tensile strength test was performed at temperature 40°c while creep test was performed at 25°c.

5. Sample Preparation :

Asphalt mixes were prepared by mixing the aggregates at 160°c with (40 – 50) penetration grade asphalt at 150°c , the carbon fiber was blended with hot aggregates (160°c) , fiber content were selected arbitrarily and without optimization. Previous researchers however had selected fiber content between 0.3% - 0.8% by weight of mixture [4] , In this research contents were 0.2% , 0.3% , 0.4% , 0.5% , and 0.6% by weight of mixture. The fiber length in the mixture was kept constant at two length of equal the maximum size of aggregate (19mm) , and nominal size (12.5mm).

5-1. Preparation of Asphalt Mixture Sample for Wheel Tracking Test:

The asphalt mixtures were heated to 150°c , mixed and put in the compaction mold beam 50cm (length) , 10cm (width) , 5cm (thickness) , to obtain the required beam density as Marshall specimens bulk density , static compaction is used by compression machine with 310kN loads at the rate of 2.5mm per minute and the load was applied for the five times. The compacted beams were demolded the next day , and allowed to cure at room temperature for seven days. The wheel tracking machine has speed of electric motor driving wheel is 53 rounds per minute (any point on the asphalt concrete beam passed by the tire is 106 cycles per minute , distance of the tire passed was 40cm , and the speed of the tire is equivalent to 2.54Kph.

6. Results and Discussion :

6-1. Marshall Stability :

Marshall stability and flow tests are performed on each specimen according to the method described by ASTM D1559. The cylindrical specimen (2.5"(63.5mm) height × 4" (101.6mm) diameter) is compressed on the lateral surface with a constant rate of 50.8mm/min (2in/min) until reaching the maximum load. The maximum load resistance and the corresponding flow value are recorded. Three specimens for each combination are prepared and the average results are reported. The stability values were then adjusted with respect to sample height. The height of the samples were measured and specimens were immersed in a water bath at 60°c for (30 – 40) minutes. Specimens were removed from the water bath and quickly placed in the Marshall loading head.

Figure (2) shows an initial increase in stability values once the fibers content increased in the mixture , but it also decreases with higher fibers contents. To increase stability , it seems that there is an optimum percentage of fibers content. A large amount of fibers in the mixture produces lower contact points between aggregates , hence resulting in lower stability. The above decrease also shows that the fiber length has little effect on mixture stability.

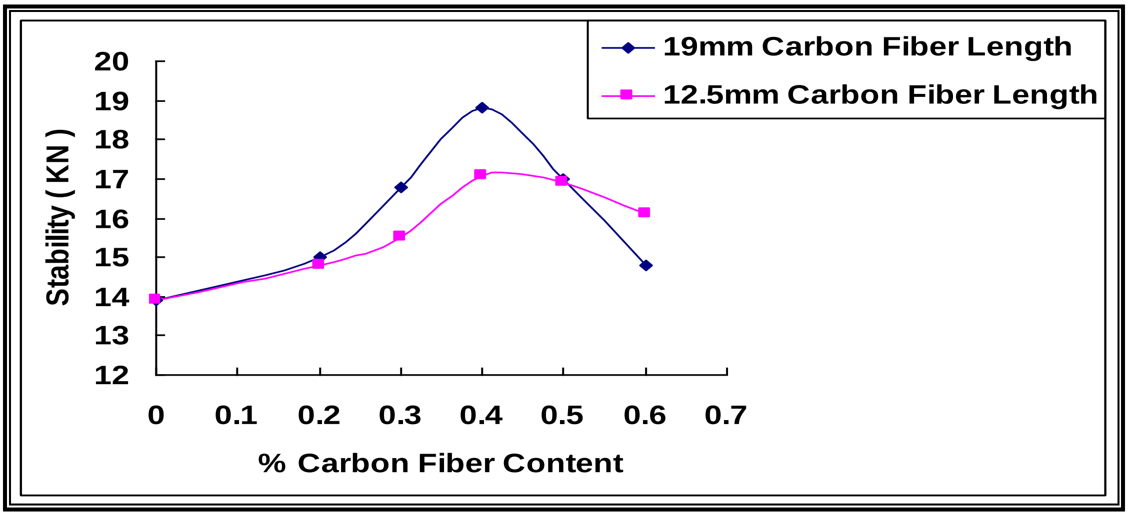

Figure (2)

6-2. Flow Values :

Figure (3) shows that an increase in fibers content decreases the flow value and as such , when the fiber content is higher than (0.4%) the flow values start to increase. The effect of fibers length on flow is more pronounced than on the stability.

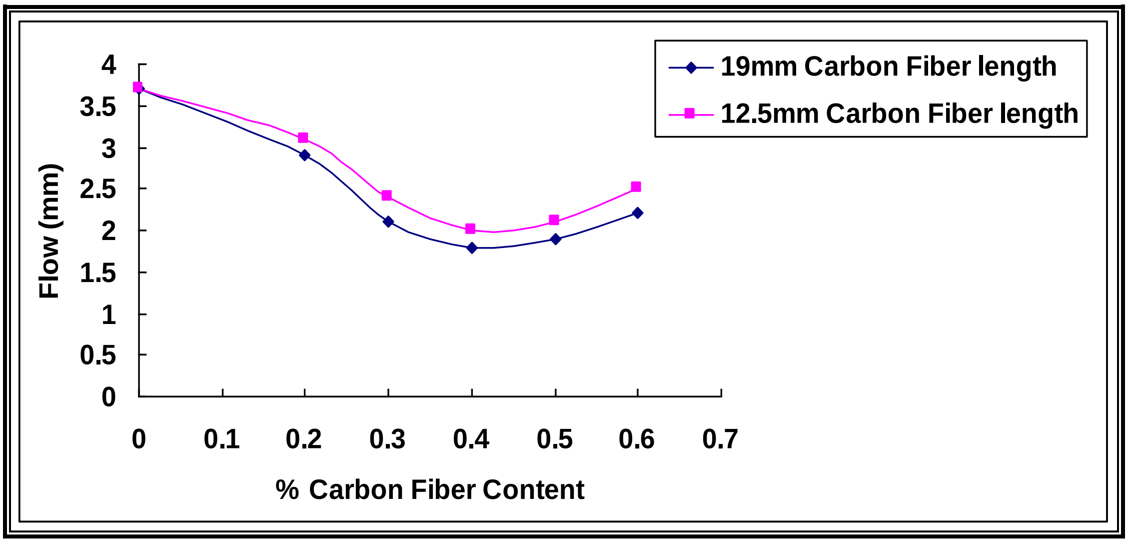

Figure (3)

6-3. Bulk Density :

Figure (4) shows that the bulk density decreases when the fibers content and length are increased. The increase in fibers content may separate the coarse aggregate particles and hence decrease the density.

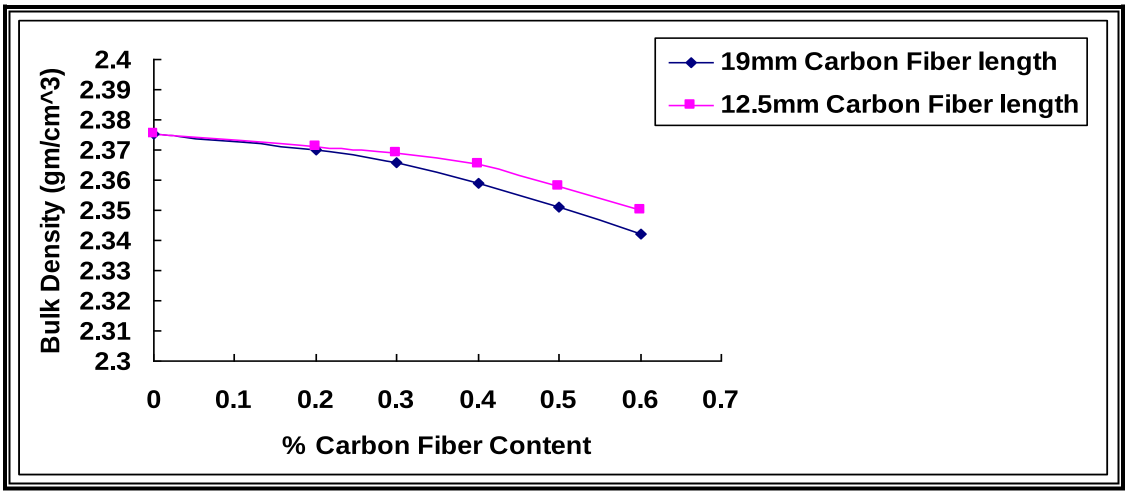

Figure (4)

6-4. Air Voids :

Figure (5) shows consistent results concerning the effect of carbon fiber

content and length on the air voids. This figure shows that the increase in fibers content and length in the mix is followed by an increase in the air voids. This is probably due to the greater surface area (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.

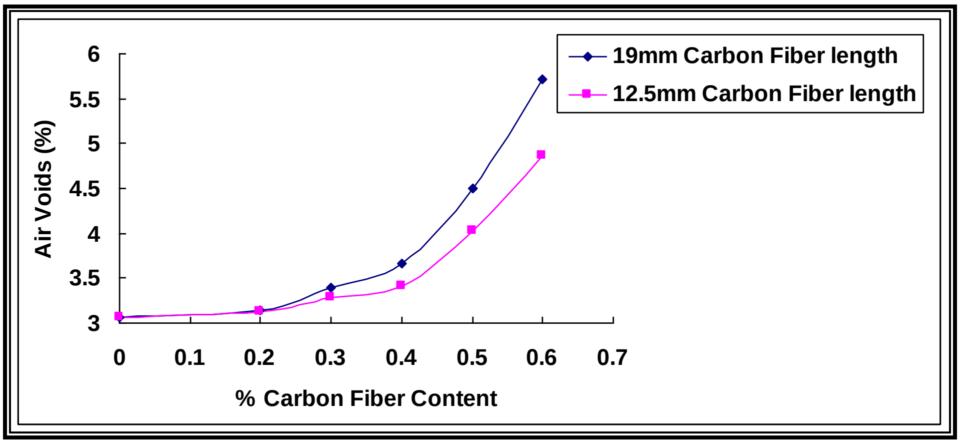

Figure (5)

6-5. Marshall Stiffness :

The Marshall stiffness is calculated as the ratio between Marshall stability and corresponding flow for the different mixtures.

Increased values of Marshall stiffness have been obtained by increasing Marshall stability (with the same value of flow) or decreasing flow (with the same value of Marshall stability). Marshall stiffness can be increased by using harder asphalt grade and compaction efforts, compaction temperature , mixing temperature high enough and within the acceptable limits of specification.

Figure (6) presents the effect of carbon fiber content on Marshall stiffness for the two carbon fiber lengths. This figure shows that the Marshall stiffness increased when the carbon fiber content increased up to 0.4% and then Marshall Stiffness decreased (The optimum content of carbon fiber for Marshall Stiffness is 0.4%).

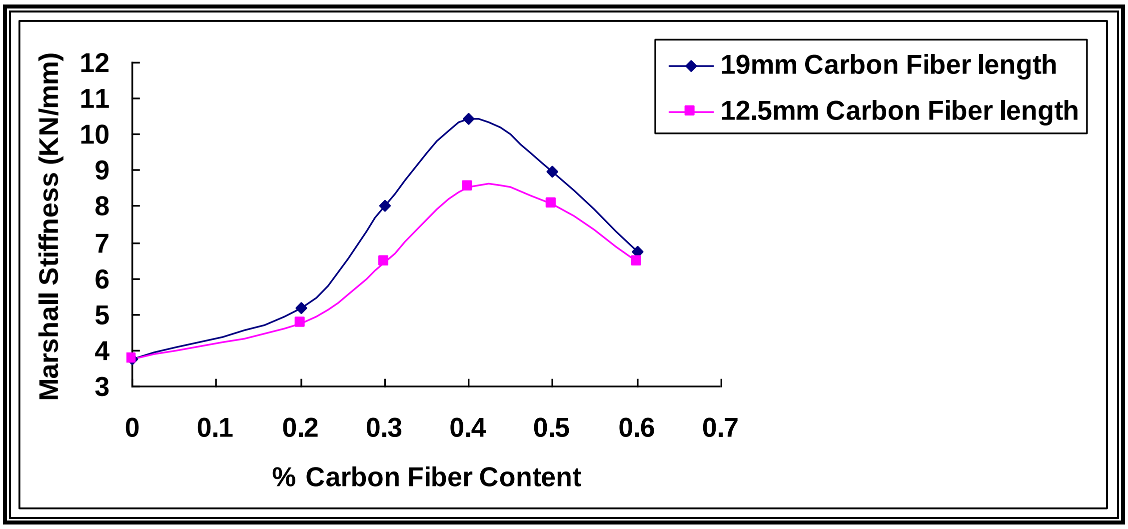

Figure (6)

6-6. Indirect Tensile Strength Test :

Figure (7) shows that the increase in carbon fiber content leading to increase in tensile strength. From the below mentioned figure , it is obvious that an increase in the indirect tensile strength value can appear due to the increase in carbon fiber in the mix until 0.5%.

Modification of the asphalt binder is one of many approaches which can be considered to improve the pavement performance. The addition of fibers to asphalt enhances material strength and fatigue characteristics. Fatigue characteristics of the mixture were expected to improve with the addition of carbon fibers , because of the high tensile strength of carbon fiber and of their inherent compatibility with asphalt cement and excellent mechanical properties , carbon fiber might offer an excellent potential for asphalt modification. The indirect tensile strength (ITS) is calculated , as follows :

$$ITS = 2P_{ult} / \pi td \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad (1)\ [8]$$

ITS : Indirect Tensile Strength (Kpa)

P_{ult} : Ultimate applied load at failure (KN)

t : Thickness of specimen (m)

d : Diameter of specimen (m)

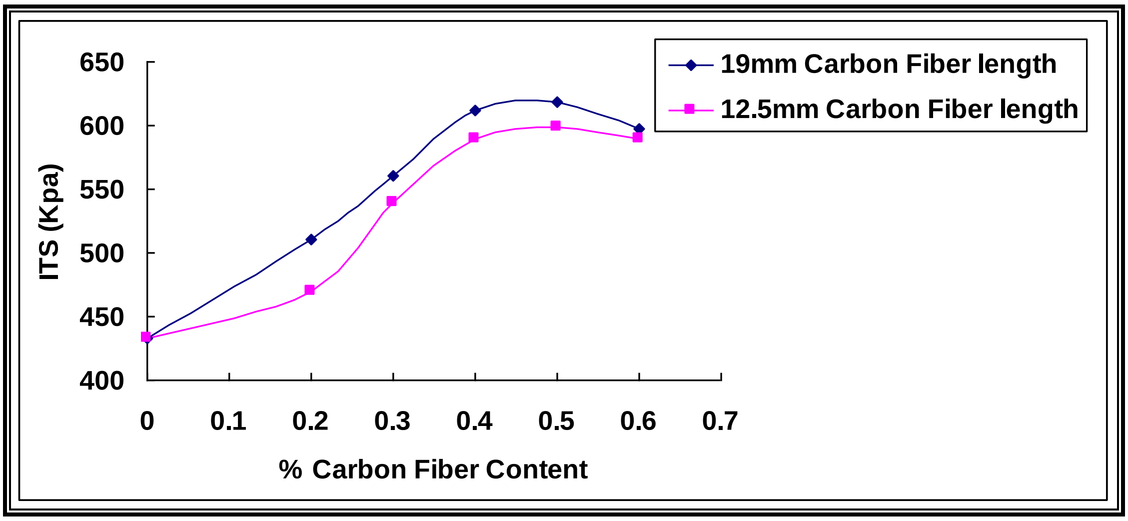

Figure (7)

6-7. Creep Test Results :

The creep test is performed on Marshall specimen at corresponding optimum asphalt content without carbon fiber and with (0.2 , 0.4 , 0.6) % carbon fiber additives and 19mm length under constant stress of 0.1 Mpa , 25°c test temperature for one hour loading followed by one hour unloading.

Figure (8) shows the effect of adding carbon fiber on resisting creep , it indicates that increasing carbon fiber content leads to lower strain and as a result to more resistance to permanent deformation. Carbon fiber modified asphalt mixtures were expected to show an increased stiffness and resistance to permanent deformation.

The values of strain are calculated as follows :

$$\varepsilon t = \Delta H / D_{\circ} \text{ (mm/mm)} \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad (2)\ [8]$$

εt : Strain after (t) minutes of loading (mm/mm)

ΔH : the total measured vertical deformation at a certain loading time (mm)

$D_{\circ}$: the original diameter of specimen (mm)

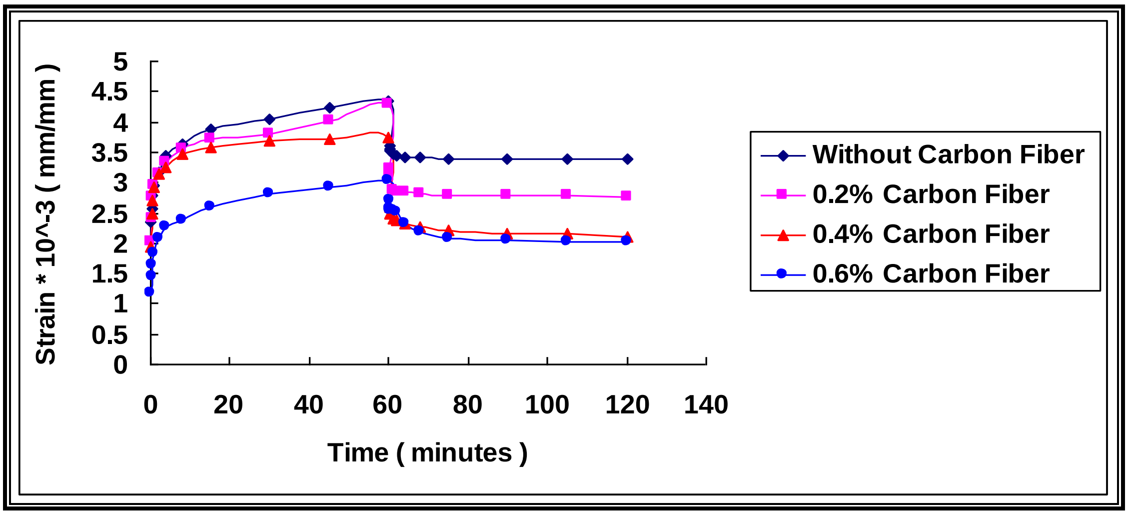

Figure (8)

6-8. Stiffness Modulus :

The stiffness modulus of the mix (S_{mix}) is defined as the ratio of stress to strain at a particular temperature and loading time , as follows :

$$S_{mix}(t) = \sigma / \varepsilon t \quad (\text{N/mm}^2) \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad (3)\ [8]$$

$S_{mix}(t)$: Stiffness modulus after (t) minute of loading (N/mm^2)

σ : Applied stress. (N/mm^2)

ε_t : Strain after (t) minutes of loading (mm/mm)

This modulus can be used to describe the mechanical properties of viscoelastic materials , where the strain is a function of the time of loading (t).

Figure (9) presents the values of stiffness modulus for 19mm of carbon fiber length with selected loading time for applied stress 0.1 Mpa and at 25°c test temperature.

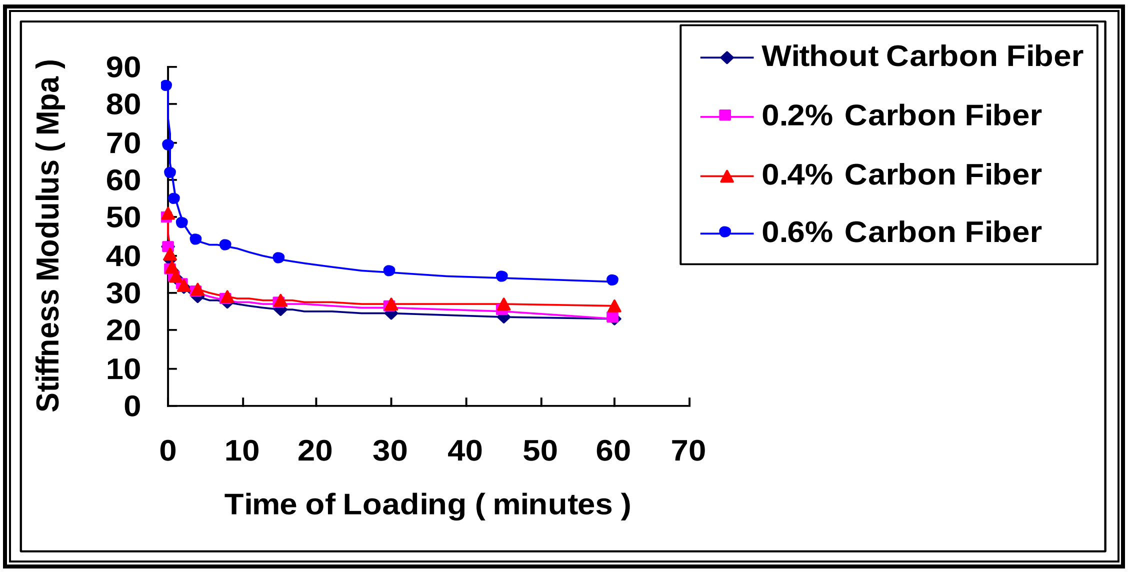

Figure (9)

6-9. Wheel Tracking Test :

The results of the wheel tracking test are displayed in table (2). It can be seen that the carbon fiber modified asphalt mixtures show the highest reduction in rut depth as compared with the unmodified reference mixtures. When the length of carbon fiber additives and content are increased shows highest reduction in rut depth.

Table (2) Rut depth (mm)

Carbon Fiber %	At 5000 Cycles		At 10000 Cycles		At 15000 Cycles	
	12.5 mm	19 mm	12.5 mm	19 mm	12.5mm	19 mm
0	11	11	18	18	22.5	22.5
0.2	9.5	9	12.5	11.5	15	12.5
0.4	7	5.8	9.3	9	11.5	10
0.6	6.5	5.5	9	8.5	10	9

7. Conclusions :

1. The use of carbon fiber showed consistent results and it was found the addition of fibers does affect the properties of asphalt mixes.
2. The use of carbon fiber increases stability and air voids and decreases the flow value in the mix.
3. The carbon fibers have the potential to improve structural resistance to distress that occurs in road pavement as result of increased traffic loading.
4. Addition of carbon fiber improves fatigue life and rutting by increasing the resistance to cracking and permanent deformation of asphalt mixes.
5. The fibers content of 0.4% by weight of the asphalt mixture resulted in highest performance in terms of Marshall test , stiffness , resistance to permanent deformation , rutting , and fatigue as compared to the ordinary mix.
6. The length of the carbon fiber is a critical factor affecting the performance of carbon fiber modified asphalt mixtures , it must be ensured that individual fibers keep their linear configuration intact after the mixing process.
7. The results indicated that 19mm fibers length shows better mechanical behavior than the longer fibers , which may lead to a " balling " phenomenon in the mix and there by lose its beneficial effects.

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