Performance Evaluation of Carbon Fiber Modified Asphalt

F. Moghadas Nejad & S. Baeetabar

Department of civil & environment engineering, Amirkabir University of Technology, Tehran, Iran

ABSTRACT: The aim of this research is to use fibers in distributed form throughout the mixture. These fibers had to be distributed in all directions in the mixture so as to prevent from production and expansion of crack for any reason- whether due to tensile stresses due to applied loads or due to thermal stresses. Although there are hypotheses and limitations in this area: One of these cases is the relatively viscous nature of asphalt, which is not capable of transferring the tensile stress to the fibers particularly when the applied load is permanent, and mixture's form will change with lapse of loading time. Another restriction in reinforcement of asphalt in this manner is to use fibers with favorite flexibility and remarkable thermal resistance against mixing time high temperature. For this purpose carbon fibers were preferred.

KEYWORDS: Asphalt, carbon fiber, permanent deformation, fatigue

1 BACKGROUND

So far different fibers have been used in asphalt mixtures. The experiments have been focused to use these fibers for reduction of reflection cracks in asphalt pavements and resistance against fatigue. A summary of the results of experiments on application of different fibers in asphalt mixture is presented here.

Propylene fibers have been studied as a factor to diminish reflection cracks in asphalt pavements in a research conducted by Jiang et'al in 1993. Although the intensity of cracks reduced in those parts of asphalt modified by fibers but no reduction or delay was observed in creation of reflection cracks (Jiang, McDaniel 1993).

The results of experiments conducted by Huang et'al in 1996 indicated that the samples modified with polypropylene fibers stiffened and their fatigue life improved. The most important problem in mixture of polypropylene fibers is the inherent nonconformity with hot asphalt due to low melting point of fibers (Huang, White 1996).

The results of Tapkin's research showed that by increasing the amount of polypropylene fibers, asphalt resistance and fatigue properties improves. When the fibers are increased by 1%, marshal resistance will increase by 58% and fatigue life will increase by 27%. Tapkin came to the conclusion that the influence of propylene fibers on the tar's elastoplastic and cohesion properties improves permanent deformations in asphalt mixture (Tapkin 2007).

Wu et al conducted a research in 2007 to study the influence of polyester fibers on characteristic behaviors of asphalt fatigue. When compared with the control asphalt mixture, the cycle numbers to fatigue failure of fiber modified asphalt mixture are increased with 1.9, 2.9 and 3.6 times at 0.5, 0.4 and 0.3 stress ratio, respectively (Wu et al 2007).

2 EXPERIMENTAL METHOD

2.1 Fatigue test

Fatigue properties of asphalt concrete mixtures were determined according to BS: DD ABF under the title "method of the determination of fatigue characteristics of bituminous mixture using indirect tensile fatigue test".

This experiment is a method to estimate resistance of asphalt mixtures against cracking. The asphalt sample used in this study is cylindrical with a thickness of 75 mm and diameter of 100 mm.

The sample failure is when it has a vertical movement of 9 mm above loading bar. Maximum tensile stress σ (x.max) in the sample center is calculated as follows:

$$\sigma_{(x,\max)} = \frac{2 \times P_L}{\pi \times d \times t} \qquad (1)$$

Where:
P_L is Applied Load(KN)
d is specimen diameter
t is specimen thickness

Loading, is made by mechanical actuator, which the applied load is applied vertically on the loading sample in the experiment for determining fatigue properties of asphalt mixtures by use of indirect tensile fatigue experiment. Actuator must be capable of loading in the form as displayed in fig1.

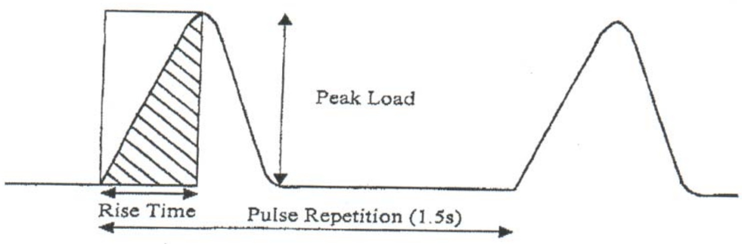

Figure 1: Loading form for fatigue test

Loading rise time is the time when loading begins from zero and reaches its maximum loading, is 124±4 ms. Maximum loading is adjusted based on the maximum required stress. Load's repetition time is 1.5±0.1 s.

Loading area coefficient, is the ratio of hachured area in fig.1 to the multiple of Loading rise time in the maximum load, which must be 0.6. Deformation is measured and recorded by two LVDTs with minimum displacement of 9 mm. The measuring system must be able to measure the experiment sample totally and provisionally. And measures the displacement based on measuring the distance between two loading plates

2.2 Indirect tensile stiffness modulus

Increased stiffness improves the rutting resistance of the mixture in hot climates and allows the use of relatively softer base bitumen, which in turn, provides better low temperature performance.(Behbahani et'al)

Indirect tensile stiffness modulus of asphalt concrete mixtures was determined according to BS: DD 213 under the title "determination of the indirect tensile stiffness modulus of bituminous mixture".

Loading system, incorporating a pneumatic load actuator, by means of which a load can be applied vertically across the diameter of the test specimen via the loading platens. The load actuator shall be capable of applying a load pulse, of the form shown in fig2, to the test specimen. The rise-time, measured from when the load pulse commences and which is the time taken for the applied load to increase from zero to its maximum value, shall be 124±4 ms. The peak load value shall be adjusted to achieve a peak transient horizontal diametric deformation of at least $5\mu m$.

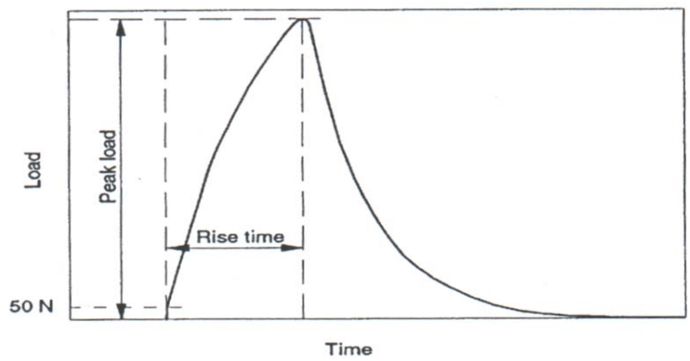

Figure 2: Loading form for indirect tensile stiffness modulus

Deformation measurement system must be capable of measuring peak transient horizontal diametric deformation of the test specimen, resulting from the load pulse across a diameter of the specimen, perpendicular to the direction of load pulse application. Measurement precision is 1μm and displacement area must be 1mm.

The suitable sample for conducting this experiment is the cylinder with a diameter of 100mm + 5mm and a thickness in the range 30 mm to 80 mm.

The experiment temperature has been recommended 30ºC although the experiment may be conducted in higher temperatures too. Axial strain ε_d measured based on the sample deformation after rest period of each loading and is calculated according to the following equation:

$$\varepsilon_{d(n,t)} = \frac{\Delta h}{h_0} \tag{2}$$

$\varepsilon_{d(n,t)}$ Axial strain after n repititatin of loading in t temperature

Δh Axial deformation (in mm)

h_{0} Initial distance between loading plates(in mm)

And indirect tensile stiffness modulus (S) in MPa calculated:

$$S_m = \frac{L}{(D \times t)} \times (\nu + 0.27) \tag{3}$$

L is the peak value of the applied vertical load(in N)
D is the peak horizontal diametric deformation resulting from the applied load (in mm)
t is the mean thickness of the test specimen(in mm)
ν is the value of Poisson's ratio for the bituminous mixture at the temperature of test

2.3 Permanent deformation

Cylindrical specimen with 1oomm ±5mm diameter is Suitable for this test. Axial strain that measured regarding to specimen deformation after rest period of loading cycle, calculated by equation (2) similar to indirect tensile stiffness modulus.

Loading is consist of 10kpa Preloading for 120 sec and 1800 cycle of loading witch each cycle include 1 sec of loading and 1 sec. rest. Peak lading is 100+-2 kpa.

3 LABORATORY EXPERIMENTS

3.1 Materials

Marshall specimen were prepared in the laboratory condition According to ASTM D1559-76.

Aggregate Materials: One type of crushed limestone aggregate with a nominal size of 19mm was used for preparing Asphalt concrete mixture in this study. The laboratory tests performed on aggregates were: Sieve Analyses, Specific Gravity, Water Absorption, Bitumen absorption.(Table 1&2)

Table 1: Sieve test result

Seive	Size (mm)	Passing (%)	Retained (%)
1	25	100	0
3/4	19	97	3
1/2	12.5	86.4	13.6
3/8	9.5	78.1	21.9
4	4.75	61.1	38.9
8	2.36	46.0	54.0
16	1.18	32.5	68.5
30	0.6	21.7	78.3
50	0.3	14.5	85.5
100	0.15	9.4	90.6
200	0.075	7.2	92.8

Bituminous Material: Asphalt binder 60/70 was used in this research. The laboratory tests performed to evaluate the bitumen properties were Penetration, Specific Gravity, Softening point and Fire Point.

Table 3 gives a summary of the result of some test performed on the asphalt cement.

Carbon fiber:The physical properties of carbon fiber used in this study are summarized in table 4.

Table 2. Aggregate Properties

Properties	Test Value	Standard
Bulk specific gravity, g/cm^3	2.625	ASTM-C127
Apparent Specific gravity, g/cm^3	2.645	ASTM-C128
Water absorption, %	0.29	ASTM-C127
Bitumen absorption, %	0.15	ASTM-C127

Table 3. Bitumen properties

Properties	Test Value	Standard
Peneteration at 25 C, 1/10 mm	62	ASTM-D5
specific gravity, g/cm^3	1.035	ASTM- D70
Softening point, C	57.8	ASTM-D36
Fire point, C	268	ASTM-D92

Table 4. Carbon fiber properties

Origin	Fiber Type	Diameter (μm)	SG (g/cm^3)	Tensile Stiifness (MPA)	Tensile Modulus (GPA)	Elongation (%)
Polyacrylonitrile	Carbon	8	1.75	3300	230	1.32

3.2 Preparation of material

Optimized content of bitumen is determined by evaluating four binder contents (4.5, 5, 5.5, 6) samples, using Marshall Stability and flow properties. All examined asphalt concrete mixtures were prepared in accordance with ASTM-D1559-89. Each samples compacted with 75-blow, using automatic compaction. The result indicated that optimum bituminous content was 5.5%.

The following blending sequence was used for the modified asphalt concrete sample

1. Bitumen was heated in an oven at a temperature of 145 c.
2. Carbon fiber witch submerge in water and then dry added to bitumen with mixture at Constant temperature at 140 c.
3. This mix added to aggregate that was heated in oven at a temperature at160 c.

For Determination of the optimized length and content of fiber, a control group (3 replicates) and six modified group (27 replicates) consist of fiber with three length(2, 2.5 and 3cm) and three content (0.020, 0.025, 0.030 percent of aggregate weight) were prepared and compared.

The test groups were made using the same aggregate and gradation and identical percent binder contents (measured by weight of total mix). The content of carbon fibers in the modified mixtures was measured as a percent by weight of aggregate.

At next step with Optimized content of fiber, three mechanical tests were planned for use in characterizing the behavior of the mixtures. The indirect tensile stiffness modulus was selected to compare the relative stiffness of mixtures and the creep test used to determine potential for rutting in each of modified an unmodified mixtures. Indirect tensile test would be used to examine the fatigue characteristics and the low temperature behavior of the mixtures.

4 RESULT AND DISCUSSION

4.1 Fatigue test

Fatigue properties of asphalt concrete mixtures were determined according to BS: DD ABF. Six carbon fiber modified asphalt (CFMA) and six control samples- that previously used in tensile modulus test- were used in this test. Note that the only difference in six samples is the applied stress.

Table 5. Fatigue test result

Control sample	Applied stress	Max. of horizontal strain	Num. of load repetition to failure
1	200	116.8	96600
2	250	194.5	27140
3	300	209.6	8740
4	400	261.9	5600
5	500	317.7	2350
6	600	373.7	505

Table 6. Fatigue test result

CFMA sample	Applied stress	Max. of horizontal strain	Num. of load repetition to failure
1	200	91.8	1595300
2	250	122.2	398740
3	300	175.5	30400
4	400	189.7	21000
5	500	258.6	8245
6	600	319.8	3600

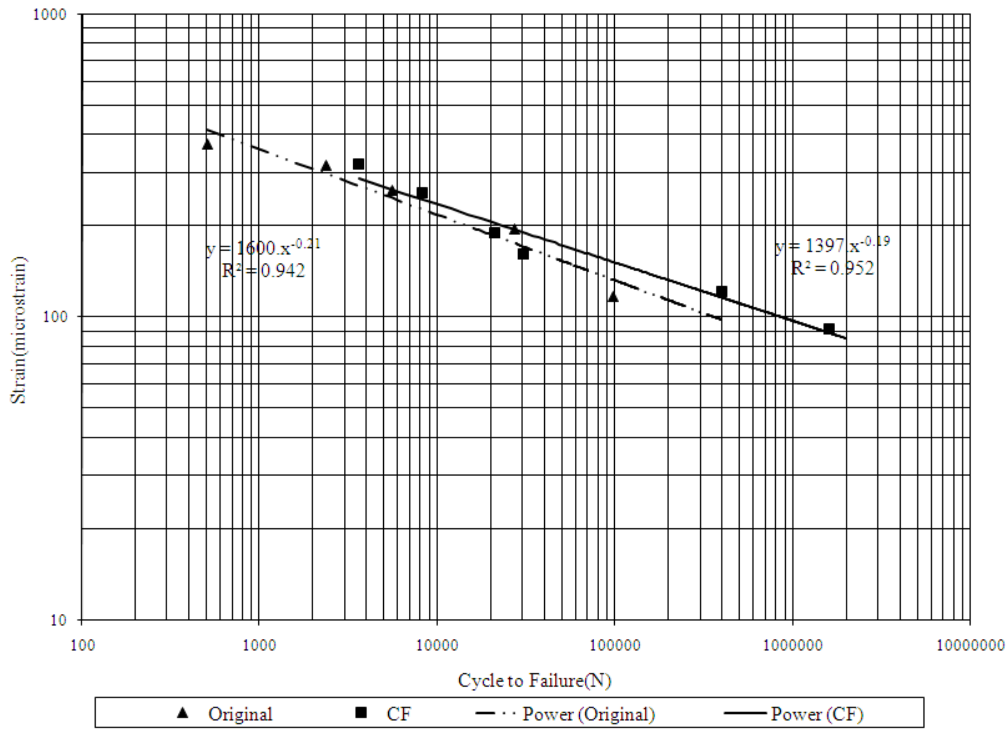

Figure 3. Strain verse cycle to failure

4.2 Tensile stiffness module

Tensile stiffness modules of CFMA and control samples are showed in table 7.

Table 7. Tensile stiffness module test result

Sample	CFMA	Control
1	4322	3510
2	3963	3145
3	3846	3130
4	3804	3226
5	4192	3290
6	4464	3440
Ave.	4098	3290

4.3 Permanent deformation

The permanent deformation under dynamic loading effect conducted according to BS:DD226 in 35ºC and 60ºC. Figure 4 shows the process of deformation in 4 condition of test. As seen decrease of CFMA's deformation relative to control samples is less in 60ºC. it's as predict because viscous property of bitumen and decrease in cohesion between fiber and bitumen

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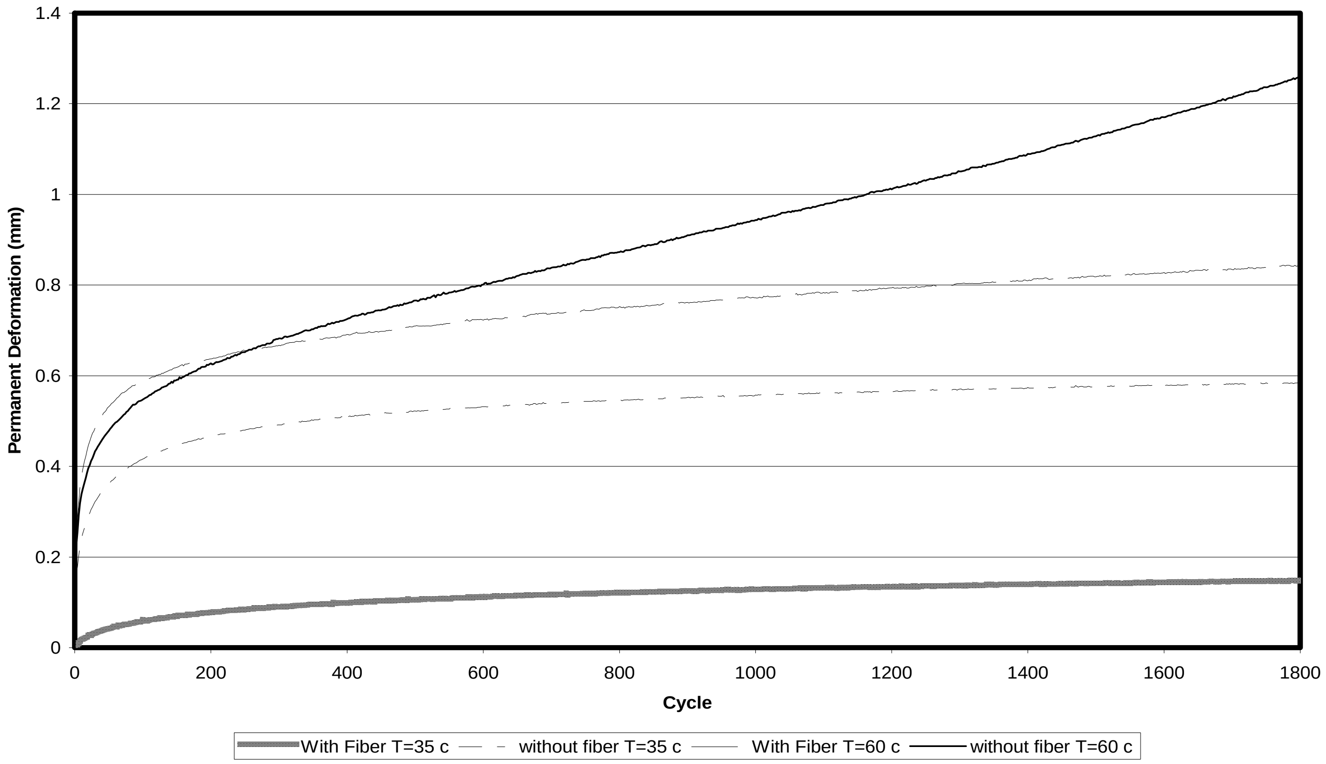

Figure 4. Permanent deformation of CFMA and control samples

5 CONCLUSIONS

1-Tensile stiffness module of the CFMA increased by 25% with regard to control samples. This show absorbing more energy by the CFMA in a specified strain amount.

2- Fatigue life of the CFMA was increased by 2.4 with regard to control samples that were determined by ABF BS: DD standard method. Increased fatigue life for propylene fibers was determined 27% with regard to control samples. Also cellulose fibers had no influence on increasing fatigue life (Stuart et al 1996).

3- Permanent deformation of CFMA declined 75% in 30º C temperature, and 34% in 60º C temperature with regard to control samples. As was expected, modified samples have better performance in lower temperature. Of course performance of these samples in 60C temperature was beyond expectation. As an important reason for this we can refer to suitable cohesion of carbon fibers and tar.

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