Introducing Two Simple Models for Predicting Fiber-Reinforced Asphalt Concrete Behavior During Longitudinal Loads

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ABSTRACT: Scientists and engineers are constantly trying to improve the performance of asphalt pavements. Modification of the asphalt binder is one approach taken to improve pavement performance. The idea of using fibers to improve the behavior of materials is an old suggestion, so different researchers reported the results of adding a large variety of fibers to asphalt concrete (AC) as fiber-reinforced asphalt concrete (FRAC). However, there are few comments about the mechanism of reinforcement and fiber performance in the inner structure of AC and/or exposing some models to predict fiber recital as a modifier in FRAC. So this article is going to introduce two simple models for predicting FRAC behavior during longitudinal loads. The former is called ''Slippage Theory'' and the latter is ''Equal Cross-Section.'' Finally, four types of fibers (glass, nylon 6.6, polypropylene, and polyester) were used in AC to evaluate the two theories. ''Marshall Test,'' as stability and flow outcomes, and ''Specific Gravity'' were carried out on specimens in the next stages followed by an artificial neural network (ANN), which was developed in the system to recognize important fiber parameters effective in the FRAC specifications. In the end, the two theories predicted each fiber performance in FRAC as well as ANN. © 2008 Wiley Periodicals, Inc. J Appl Polym Sci 109: 2872–2881, 2008

Key words: fiber; asphalt concrete; reinforcement; neural network

INTRODUCTION

Scientists and engineers are constantly trying to improve the performance of asphalt pavements. Modification of the asphalt binder is one approach taken to improve pavement performance.[1]

Zube[2] published the earliest known study on the reinforcement of asphalt mixtures. In this research, various types of wire mesh placed under an asphalt overlay were evaluated. This was performed with an attempt to prevent reflection cracking. The research concluded that all types of wire reinforcement prevented or greatly delayed the formation of longitudinal cracks.

The use of fabrics in asphalted paving systems began in 1966. Since then, their performance has been monitored and evaluated to provide a basis for better design and installation procedures.[3]

The idea of using fibers to improve the behavior of materials is an old suggestion, as reported by Hongu and Philips; their use can be traced back to a 4000-year-old arch in China constructed with a clay earth mixed with fibers or the Great Wall built 2000 years ago.[4] However, the modern developments of fiber reinforcement started in the early 1960s. Metal wires were used as fiber-reinforced asphalt concrete (FRAC) by Tons et al.[5] Bushing et al. employed cotton and asbestos fibers in asphalt mixes.[6] But these fibers were degradable and were not suitable for long-term reinforcement, and not to mention the dangerous application of asbestos fibers, environmentally.

Brown et al.[7] played an important role in the development of research. They found that some fibers have the potential to improve the cohesive and tensile strength of asphalt concrete (AC) because of more tensile strength compared with bitumen. It is believed that some fibers cause physical changes to modifiers, which had a better effect on drain-down reduction than polymer modifiers.[8,9]

In a separate study, a fracture mechanics approach was used to evaluate the effects of fiber reinforcement on crack resistance.[10] Polyester and polypropylene fibers were used to modify mixtures that were then tested for modulus of elasticity, fracture energy, and tensile strength. Fracture energy in modified samples increased by 50–100%, i.e., increased

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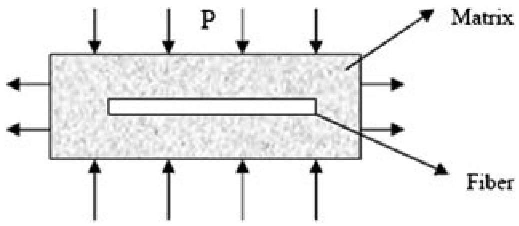

Figure 1 A fiber in a matrix and AC as a matrix under the compressive load P.

toughness, but elasticity and tensile strength results were not significantly affected.

In 1996, Serfass and Samanos[11] investigated fiber-modified asphalts using Chrysotile, rock wool, glass wool, and cellulose fibers. These modified asphalts were subjected to a wide variety of tests on mastics (bitumen and fibers), mortars (bitumen, fibers, and sand), and AC. Common characteristics of all tested asphalts included resistance to thermal cracking, ageing, shearing, and aggregate dislodgment. The importance of dispersion of fibers in the mix was noted as a key factor.

Lee et al.[12] investigated the influence of nylon fibers on the fatigue cracking resistance of AC. The tests were the single fiber pull-out and the indirect tension strength. Through pull-out tests of single nylon fibers, the critical fiber embedded length was determined to be 9.2 mm. Another test illustrated that the use of fibers of 1 vol % and 12 mm results in 85% higher fracture energy than non-reinforced samples.

Fiber modification of asphalt mixtures has shown mixed results. Fibers appear to increase the stiffness of the asphalt binder resulting in stiffer mixtures with decreased binder drain-down and increased fatigue life. Mixtures containing fibers showed less decrease in void content and increased resistance to permanent deformation. The tensile strength and related properties of mixtures containing fibers was found to improve in some cases and not in others.[13]

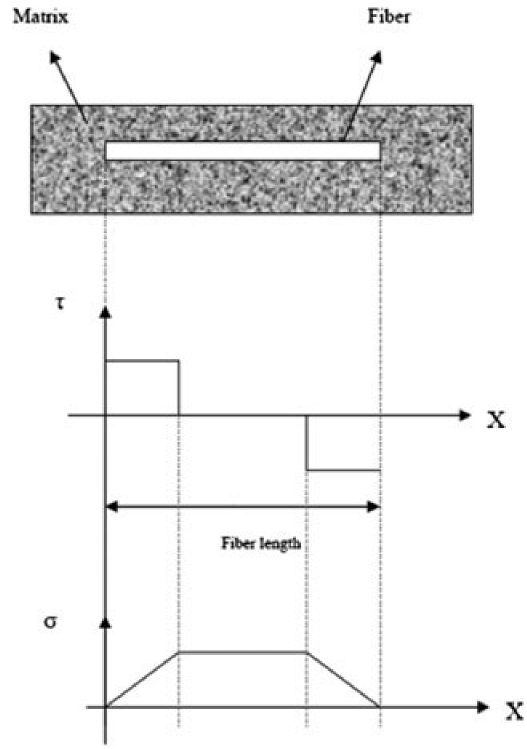

Figure 2 The shear and tensile stress charts for a fiber in a matrix, as AC, considering slippage theory.

Based on the extensive research carried out by the Ohio Department of Transportation, the polypropylene (PP) fibers were suggested to be added to asphalt mix.[14] Serkan Tapkin's studies showed that PP fibers can improve the mechanical properties of AC, and this is similar to the procedure where specimens were fabricated for Marshall's Test and repeated load indirect tensile tests.[15]

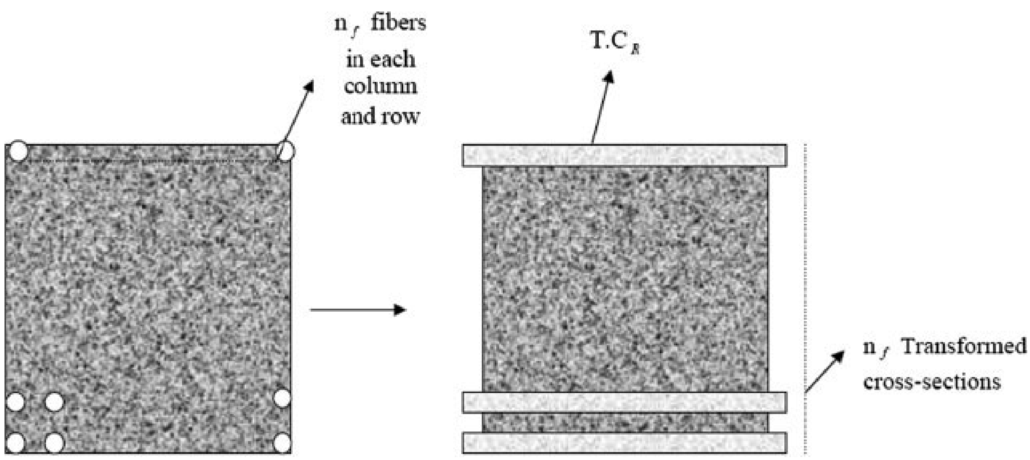

Figure 3 A "$n_f \times n_f$" matrix of ordered fibers in AC and equal cross sections to show the effect of fiber attendance.

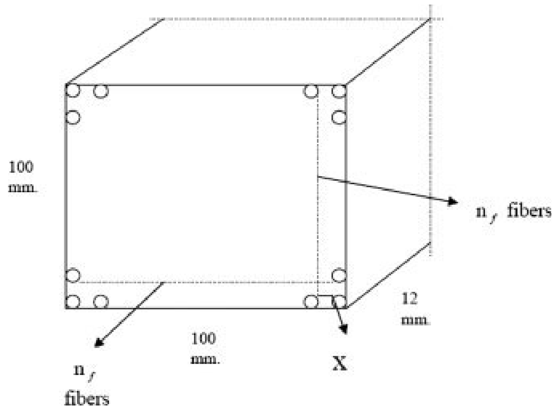

Figure 4 A assumable cubic of FRAC in equal-cross section model.

Till now, besides using the aforementioned fibers, the cellulosed fibers,[16–18] polyesters,[8] and glass[19] were also reported to be applied for asphalt.

As it is observed, most researches were based on adding different fibers to asphalt and reporting some special test results. However, there are few comments and analysis about the mechanism of reinforcement and fiber performance in the inner structure of AC and/or exposing some models to predict fiber recital as a modifier. That is why Mahrez et al.[19] announced that the fiber performance mechanism in asphalt mixes is complicated.

So this study is going to introduce two simple models for predicting FRAC behavior during longitudinal loads; the former is called ''Slippage Theory'' and the latter is ''Equal Cross-Section.''

INTRODUCING THE TWO MODELS

Slippage theory

According to Figure 1, it is assumed that a fiber is in a matrix under a compressive load P, as in Marshall's Test. This load can make an interfacial shear stress, τ, between fiber and matrix, and consequently causes a tensile stress σ in the fiber. Now it is supposed that during extension, there is slippage near both ends of fiber and a central region along the fiber length gripped by the matrix, which is called the nonslippage region. If λ is defined as the fiber slippage ratio, which is the ratio of fiber length of the slipping portion to the whole fiber length L_f, the slippage from each end of the fiber will occur over a length of

$$\lambda L_f/2 \quad (1)$$

λ is the value of fiber cooperation and assistance in the bearing of tensile stresses entered into the matrix. Figure 2 shows the τ-x and σ-x diagrams related to the fiber, considering the slippage phenomena.

According to the short-fiber composites theory,[20] the fiber tensile stress σ_{1f} at the slippage region and σ_{2f} in the nonslippage region at the central portion are determined by

$$\sigma_{1f} = 4\tau x/d_f \quad (2)$$

$$\sigma_{2f} = E_f \times \varepsilon_f \quad (3)$$

where x is a position of point located on the fiber and d_f, E_f, and ε_f are diameter, Young's modulus, and strain of fiber, respectively. It is clear that at $x = \lambda L_f/2$, the tensile stresses σ_{1f} and σ_{2f} are equal, so the combination of eqs. (1)–(3) gives

$$\lambda = (d_f \cdot E_f \cdot \varepsilon_f)/(2 \cdot \tau \cdot L_f) \quad (4)$$

It is supposed that the shear stress τ is too big to make the fiber breakage during the insertion of load P. So the fiber strain can be assumed as in breakage point, and thus the parameter λ can be obtained as the FRAC fails.

Equal cross-section theory

''Transformed Area'' or ''Equal Cross-Section'' is a famous theory that is related to the analysis of steel-reinforced concrete structures; thus in this way, the

TABLE I
The Results of Tests Performed on Bitumen

Penetration, 25°C, 100 g, 5 s (1/10 mm)	ASTM D5	66
Specific gravity (g/cm^3)	ASTM D70	1.01
Flash point (°C)	ASTM D 92	283
Softening point (°C)	ASTM D 36	48.2

TABLE II
Some Physical Properties of Aggregates

Los Angeles abrasion test	23<35%
Flatness	Cubic
Organic material	None
The percentage of absorption of water	0.96%
Frost	0<12%
Mean specific gravities of aggregates (g/cm^3)	2.58

TABLE III
Gradation Used in this Study and Gradation Limits

Sieve size (in.)	Gradation limits	Used gradation
1	100	100
3/4	90–100	93.8
3/8	56–80	76
No. 4	35–65	57.1
No. 8	23–49	39.9
No. 50	5–19	8.3
No. 200	2–8	4.0

TABLE IV
The Properties of the Fibers Used in this Study

Fiber type	Modulus (MPa)	Finesse (denier)	Density (g/cm^3)	Diameter (mm)	Strain (%)	Fiber length (mm)
Nylon 6.6	5,214	1.6	1.14	0.014	38	12
Glass	60,014	2	2.59	0.010	2.875	12
Polypropylene	6,840	3	0.92	0.021	118	12
Polyester	15,703	2	1.39	0.014	31.25	12

occupied area (cross section) by fibers will be replaced with asphalt, like the steel bars which are replaced by concrete (Fig. 3). Consequently, to obtain this transformed/equal area S_{new}, the basic suitable equilibration for the ''Strength of Materials'' and/or ''Mechanics of Materials'' is needed:[21,22]

$$S_{new} = (E_f/E_{AC}) \times A_f \quad (5)$$

where E_f and E_{AC} are fiber and AC Young's modulus, and A_f is the whole fibers occupied cross section. Meanwhile, the new moment of inertia of cross section I_{new}, about neutral axis comes from the fundamental-related equilibration of ''Engineering Mechanics'' and is according to the following formula:[23]

$$I_{new} = \Sigma(I_{old} + A_{loc.} \cdot y)^2 - [(\Sigma A_{loc.} y)^2 / \Sigma A_{tot.}] \quad (6)$$

where I_{old} is the old moment of inertia of AC cross section, $A_{loc.}$ depends on the desired cross section and includes two areas: A_{AC}, TC_R (i.e., whole fibers transformed cross section to AC surfaces in each row), y is the distance between neutral axis and AC structure edge, which varies with each fibers row and depends on certain target row, and A_{tot} means the accumulation of A_f (total fiber occupied surface) and A_{AC}.

Alternatively, a FRAC cubic cutting slice is assumed (shown in Fig. 4), which indicates that all fibers will be paralleled to the main AC longitudinal axis. Therefore the following denominations and eqs. (7)–(11) are needed:

P: the percentage of fibers used (%);

D: fiber denier (defines as the number of grams in 9000 m of a fiber or a yarn);

d_f: single fiber diameter;

s_f: single fiber cross section (cm^2);

S_f: total fibers cross section oriented in the supposed cubic (cm^2);

ρ_f: fiber density (g/cm^3);

m_f: single fiber mass (g);

N_f: number of total fibers used in a FRAC sample (as in a Marshall Test Mold);

n_f: number of fibers in each row or column in the supposed cubic;

Q_f: number of total fibers employed in the supposed cubic;

E_f and E_{AC}: fiber and AC Young's modulus, respectively, (MPa);

TC_R: whole fibers transformed cross section to AC surfaces in each row; and

x: the distance between two neighboring fibers in a row or a column (cm).

Moreover, the following assumptions are necessary: all fibers have been paralleled to the main FRAC longitudinal axis and they have been arranged as a square matrix $n_f \times n_f$ in accordance with Figure 4 (at first; it seems unreal, but at the end, the utility and ability of theory to predict different fiber performances will be illustrated), the cross section of all fibers are circular and they have the same length and linear weight, the sizes of supposed cubic are: 100 mm × 100 mm in cross section just like the Marshall molds and 12 mm in height due to the fiber length used in the experimental section of this study. Total weight of AC purred in Marshall mold is 1200 g. The following steps will result in the theory outcomes:

A. The calculation of total numbers of fibers (12 mm in length) used in a Marshall sample:

$$N_f = \frac{1200P/100}{0.012D/9000} = 9000000P/D \quad (7)$$

TABLE V
The Initial Random Matrix V_0 Created by Software

	V_0														
Length	0.0063	0.0062	0.00995	0.002	0.005	0.0016	0.001	0.0063	0.008	0.001	0.008	0.0088	0.0029	0.003	0.0007
Finesse	0.0059	0.0019	8.82E-05	0.004	0.001	0.0057	0.008	0.0079	0.003	0.009	0.003	0.0005	0.0081	0.0004	0.0086
Density	0.0009	0.0014	0.00098	0.001	0.007	0.0028	0.003	0.0036	0.004	0.01	0.001	0.0098	0.0058	0.0034	0.0089
%P	0.0075	0.0062	0.00527	0.002	2E-04	0.0018	0.007	0.0063	0.006	0.001	0.005	0.006	0.0088	0.0092	0.0045
Melting Point	0.0005	0.0015	0.00085	0.002	0.003	0.0048	0.004	0.0046	0.006	0.005	0.008	0.001	0.0021	0.0034	0.0091

TABLE VI
The Initial Random Matrix W_0 Created by Software

W_0		
Specific gravity	Stability	Flow
0.002571	0.008743	0.002393
0.002658	0.009449	0.00505
0.002453	0.003087	0.004714
0.003232	0.003644	0.001119
0.009042	0.007744	0.002793
0.009154	0.002706	0.007159
0.004344	0.009965	0.001608
0.002707	0.007936	0.009488
0.002058	0.003084	0.003838
0.002754	0.003702	0.008809
0.009558	0.004074	0.00732
0.0096	0.005378	0.003506
0.009122	0.006767	0.00671
0.00402	0.007891	0.000658
0.008807	0.001146	0.003397

TABLE VIII
The Final Matrix W Corrected by ANN

W		
Specific gravity	Stability	Flow
−0.1082	−1.7389	−0.3111
−0.0348	−0.5809	−0.1008
−0.0025	−0.0743	−0.0092
−0.0672	−1.1081	−0.1983
−0.0177	−0.4147	−0.073
−0.1013	−1.7404	−0.3055
−0.1471	−2.379	−0.4269
−0.1505	−2.4099	−0.4242
−0.0547	−0.8932	−0.1569
−0.1634	−2.6183	−0.4615
−0.0668	−1.2001	−0.2087
−0.0033	−0.1979	−0.033
−0.1438	−2.406	−0.4261
−0.0091	−0.1998	−0.0366
−0.1611	−2.679	−0.4774

B. The computation of m_f: single fiber mass (g):

$$m_f = 0.012D/9000 = 0.0000013D \tag{8}$$

C. And thus the single fiber diameter d_f can be obtained by eq. (9):

$$d_f = \sqrt{4m_f/1.2 \times \pi \times \rho_f} \tag{9}$$

So the combination of eqs. (8) and (9) gives:

$$d_f = 0.0012\sqrt{D/\rho_f} \tag{10}$$

D. Consequently, single fiber cross section s_f comes from eq. (11):

$$s_f = \pi \times {d_f}^2/4 \tag{11}$$

From eqs. (10) and (11) it is concluded that

$$s_f = 0.00000113D/\rho_f \tag{12}$$

E. Fibers putting equations in a matrix $n_f \times n_f$:

E.1. The calculation of Q_f:

$$Q_f = 12N/63.5 = 0.19N \tag{13}$$

Since the ideal sizes of the samples in Marshall Test are 63.5 mm in length and 100 × 100 mm^2 for cross section, the value of height of the specimen here was selected as the same amount, i.e., 63.5 mm.

E.2. Equations used for determining n_f and x are as follows:

$$d_f \times n_f + x \times (n_f - 1) = 10 \tag{14}$$

$${n_f}^2 \times s_f = S_f \tag{15}$$

$$S_f = Q_f \times s_f \tag{16}$$

From eqs. (7), (15), and (16) the n_f is obtained as follows:

$$n_f = 1307.67 \times \sqrt{P/D} \tag{17}$$

And from eq. (14) and (17), the amount of x is obtained as follows:

$$x = \frac{10 - 1.57 \times \sqrt{P/\rho_f}}{n_f - 1} \tag{18}$$

TABLE VII
The Final Matrix V Corrected by ANN

	V														
Length	0	0	0	0	0	0	0	0	0	0	0	0.19	0	0	0
Finesse	0	0	0	0	0	0	0	0	0	0	0	15.6	0	0	0
Density	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
%P	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Melting Point	0	0	0	0	0	0	0	0	0	0	0	1.09	0	0	0

TABLE IX
The Performance of Different Fibers in Slippage Theory

Fiber type	Λ
Glass	71.89T[a]
Nylon 6.6	115.577T
Polyester	286.25T
Polypropylene	709.22T

[a] $T = 1/\tau$.

TABLE X
The Outcomes of Equal Cross-Section Theory

Fiber type	d_f (mm)	s_f (mm^2)	n_f	x (mm)	TC_R (mm^2)	TTC_R (mm^2)	I_{new} (mm^4)	ΔI (%)
Glass	0.010	0.0000785	327	0.296	0.5502	179.91	8470671.966	2.05%
Polyester	0.014	0.00015	327	0.292	0.2751	89.96	8390617.921	1.09%
Nylon 6,6	0.014	0.00015	366	0.260	0.1022	37.40	8337394.980	0.45%
Polypropylene	0.021	0.00035	267	0.354	0.2283	60.96	8278708.810	−0.26%

On the other hand, the fundamental parameter TC_R can be calculated by the following eq. (19):

$$TC_R = \frac{E_f}{E_{AC}} \times n_f \times s_f \tag{19}$$

The eq. (6) will, therefore, give the new moment of inertia of FRAC cross section I_{new} and this is because of the availability of TC_R. As it is clear from Figure 4, y is a variable parameter that depends on each fiber row position. So it consists of an arithmetic progression with the distance of x. This makes it possible to calculate the amount of I_{new} easily. At the final stage an important new parameter TTC_R will be defined as the ''Total Transformed Cross-Section'' of different rows, which can be obtained through

$$TTC_R = n_f \times TC_R = \frac{E_f}{E_{AC}} \times {n_f}^2 \times s_f = \frac{E_f}{E_{AC}} \times S_f \tag{20}$$

It is clear that if a fiber causes a larger TC_R and/or TTC_R, the compressive load P will be inserted to a wider equipollent area (specially in the case of FRAC when compared with AC), thus, with the same load insertion of P for both comparative structures, a less compressive load will be inserted to the surface unit of the structure which has a bigger TC_R and/or TTC_R. On the other hand, an increase in the moment of inertia of cross section makes a stiffer structure against the loads, which will be led to bending. It is due to the Euler's equation that states the minimum compressive load P motivating the structure to buckle depends on Young's modulus, moment of inertia, and the square length of the structure.[24] Therefore, when the moment of inertia rises, a greater compressive load of P will be needed to decompose the structure.

MATERIALS AND METHODS

Two tests were conducted to determine the effect of fiber type on AC samples that also made it possible to evaluate the models. The former was specific gravity (ASTM D-1188) and the latter included Marshall's Test, as stability and flow outcomes carried out according to the ASTM D-1559-76.

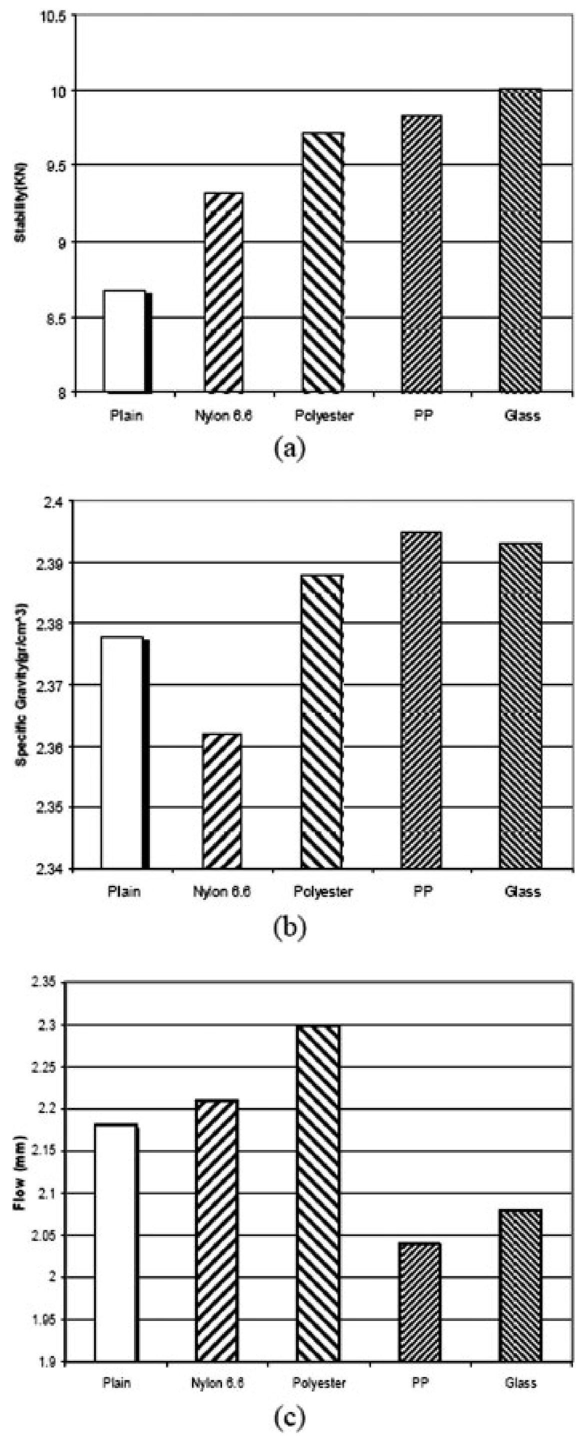

Figure 5 The effect of fiber type (0.0625% and 12 mm) on the FRAC specifications: (a) stability, (b) specific gravity, and (c) flow.

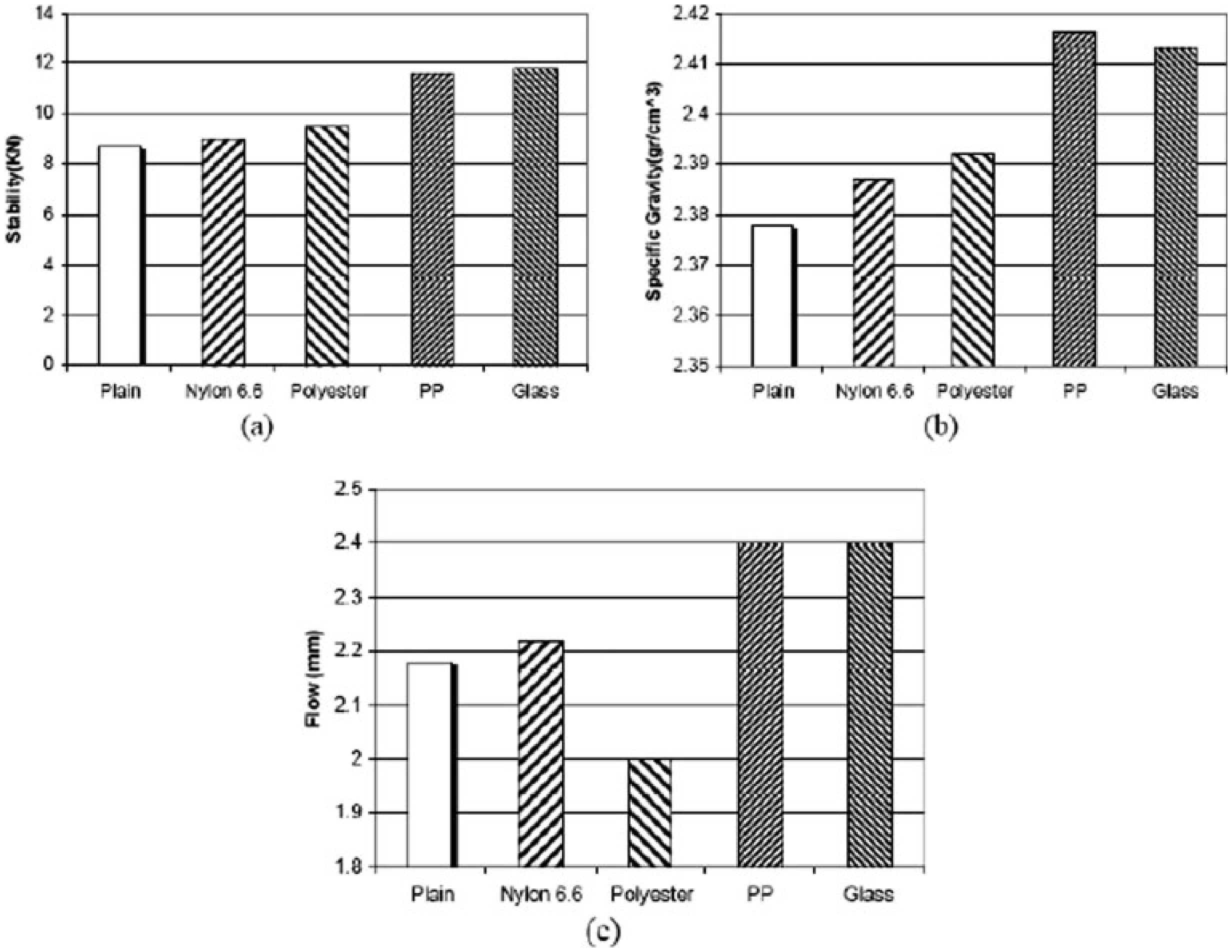

Figure 6 The effect of fiber type (0.125% and 12 mm) on the FRAC specifications: (a) stability, (b) specific gravity, and (c) flow.

The bitumen used in this study was subjected to typical standard laboratory tests. The results of these tests are incorporated in Table I. Crushed limestone was used as the aggregate material. A typical heavy traffic gradation for AC, designated as Type II in the Iranian State Highway Specifications, was selected. The selected gradation and the specification limits are shown in Table II. Some properties of the crushed limestone are given in Table III. Nylon 6.6, polypropylene, glass, and polyester fibers, and waste recycled tire cords (WRTC) were also employed as additives to AC. The specifications of these textile materials are shown in Table IV. According to previous literature reviews,[12,14,15] all fibers and WRTC had been cut at a length of 12 mm and three percentages of fibers were selected: 0.0625, 0.125, and 0.25% for the total weight of mixture.

The Marshall specimens were fabricated in accordance with ASTM D-1559. The next step was the addition of fibers to AC. The dry procedure was selected in all samples. However, for making a comparison, both wet and dry procedures were used in a special experimental case (Nylon 6.6 : 0.125%). In the wet procedure, at first fibers and bitumen were blended, whereas in the dry one it was suggested to add fibers to aggregates.

For each specimen, at first the aggregates were kept in a heater for 16 h at 170°C and then they were blended with fibers. At the end, the bitumen (132°C heated) was poured on the mixture. A mixer mixed them until whole aggregates seemed to be impregnated with bitumen and a homogeny mixture appeared. During this process, the temperature was controlled and it was selected at 150°C (ASTM D-1559 : 140–163°C). Then the mixture was placed in a Marshall mold and compacted by applying 75 blows on each side of the specimen at 145°C.

The standard dimensions of the samples were 63.5 mm in height and 101.5 mm in diameter. After cooling them at the room temperature for 1 day, specific gravity test was carried out in accordance with the ASTM D-1188. Thus for each sample the weights in the air and in water were obtained, and then according to the Archimedes formula the specific gravity was calculated as follows:

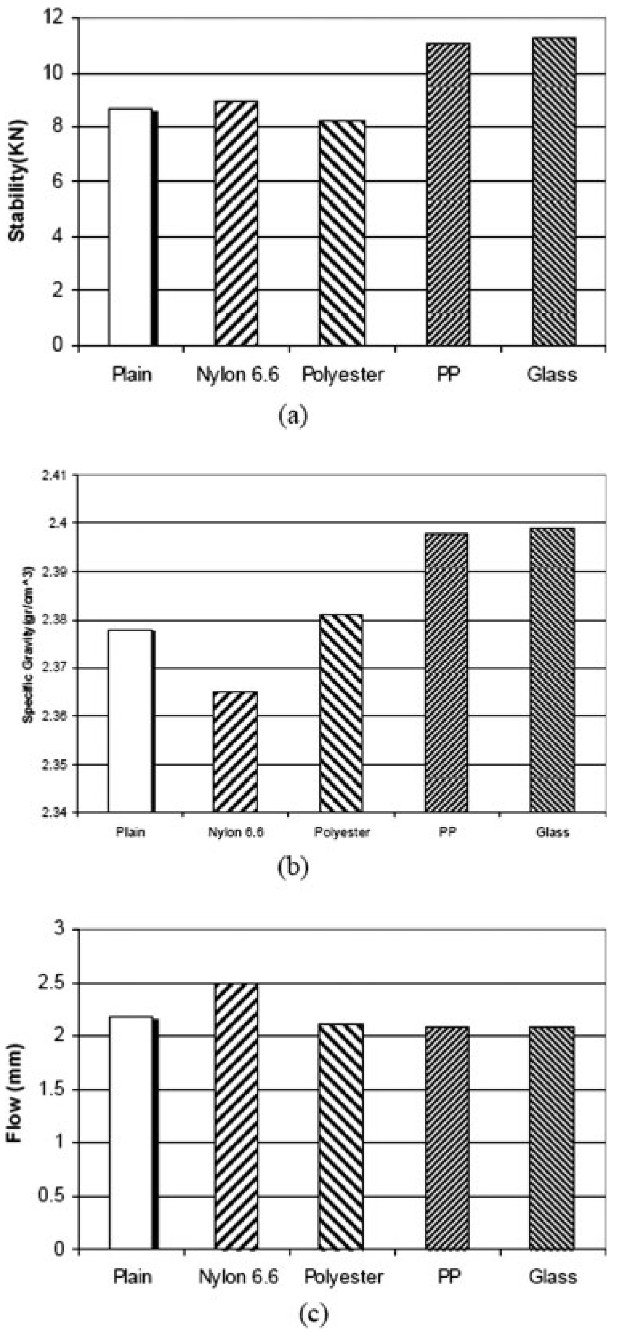

Figure 7 The effect of fiber type (0.25% and 12 mm) on the FRAC specifications: (a) stability, (b) specific gravity, and (c) flow.

$$\mathrm{SG_{AC}} = \frac{W_D}{W_D - W_W} \tag{21}$$

where W_D and W_W are weights of AC in the air and in water, respectively. In the final stage, they were left in water at 60°C for 30 min. and they were tested with the Marshall Test apparatus. All the results were obtained from compacted specimens at the optimum bitumen content of each mix type. Each of the tests was carried out for three times. Therefore, each result shows the average of three test specimens.

At the end, it was decided to establish an artificial neural network (ANN) on the experimental results. The main motive was the exceptional behavior of PP fibers against models predictions. Both models predicted and introduced PP as the worst fiber in FRAC. ANN could help to investigate important fiber parameters which affected FRAC properties. Mainly; ANN is an information processing system with certain performances. The idea of the creation and development of ANN has been derived from the model, which exists in the human bodies.[25]

In this project, an ANN was selected to identify the effect of fiber parameters (as input neurons) on the FRAC properties (specific gravity, stability, and flow as output neurons). The processor algorithm was a combination of Back-Propagation and Perceptron. Five input neurons (fiber length, density, finesse, percentage, and melting point) with a hidden layer of 15 neurons and three output neurons or units (specific gravity, stability, and flow) formed the technical architecture of the system. Matlab 6.1 software was used to implement the algorithm. After seven epochs, two important matrices were obtained as V and W (the weights which link the layer neurons to each other). Figure 8 indicates the schematic diagram of the applied ANN. At first the V_0 and W_0 matrices were selected randomly by the software and finally after seven epochs, these matrices were corrected by the algorithm as V and W. V is the weight matrix multiplied by input values. After combining the result with activation function, hidden layer values will be obtained. W is multiplied by the hidden layer matrix and again after the activation function processing, predicted outputs will be appeared. The stop condition had defined for the time when the sum squares of errors (SSE) of error matrix (i.e., the difference between predicted values and real FRAC properties) became less than 0.5. Tables V–VIII illustrate the initial random matrices V_0 and W_0, and final corrected matrices V and W, respectively.

RESULTS AND DISCUSSIONS

Table IX focuses on the ''Slippage Theory'' results. It introduces the indicator index λ of each fiber. It is clear that the glass fibers should have the best performance in AC due to the smallest value of λ, which is because of its low strain. It is also clear that nylon has a smaller λ than polyester, and since polypropylene has the highest λ, it is the worst to be used here.

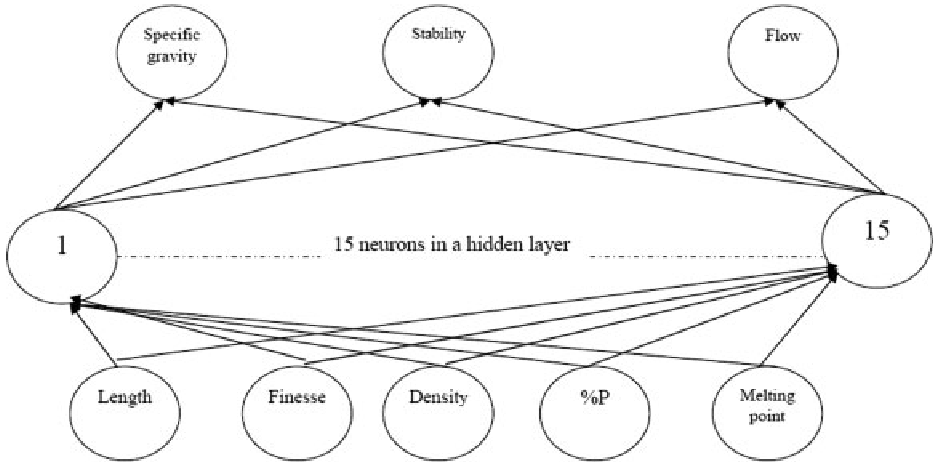

Figure 8 The schematic form of applied neural network.

Table X indicates the results of ''Equal Cross-Section Theory''; it is obvious that again the glass can make the most value of TTC_R because of its high modulus. This model argues that polyester fibers perform better than nylon 6.6 in equal/transformed cross section, and here again polypropylene performance is the worst like before. It is accentuated that the higher amount of TTC_R causes a higher resistance against longitudinal loads, and this is due to the bigger and increased cross section created as well as equipollent AC materials. Another proof in this theory was an increase appeared in the moment of inertia of cross section I_{new} (Table X) that indicates the more bending rigidity of FRAC structures. The amount of this parameter was decreased in the case of PP fibers compared with the plain state, which is due to the high value of x and the low value of n_f.

Fortunately, the results (Figs. 5–7) match significantly with the aforementioned theories. The glass inclusion in AC caused the greatest stability and specific gravity as the models predicted. Although nylon can perform better than polyester in slippage theory, polyester is preferred in Equal Cross-Section theory since it acts better. So it can be found that they (nylon and polyester) behave similarly. It is important to know that the polypropylene performance in AC is well (Figs. 5–7) and it is concluded that, unlike what the theories announced, PP is a serious competitor for glass. The only significant difference between PP and other fibers is in their melting points: PP has the lowest melting point (162°C) compared with all fibers used in this study. The environmental working temperature during the blend process was 150°C, as expressed, and this is very close to the melting point of PP. Perhaps, PP fibers have a special feature called ''tacky'' and that is why the cohesion between fiber and matrix will be enhanced. As a result a more coherer composite can be created. For more assurance, it was necessary to use an ANN to determine and recognize the most effective fiber parameters on outputs: specific gravity, stability, and flow.

It is clear from the V matrix that only finesse and melting point are important (Table VII). Therefore it underscores the important role of the finesse in slippage theory. It also reveals the importance of melting point in PP performance in FRAC (The considerable value of 1.09 in V matrix, which is related to the melting point neuron, shows the importance of this parameter). W matrix states that only stability can be affected by inputs, and it was obvious that flow and specific gravity variations were smaller. The flow variations are small and this is due to the optimized asphalt content utilization (4.5%) in all cases. The specific gravity was affected slightly with fibers attendance: the low percentage of fibers attendance in one hand and the adherence of FRAC structures to the blends density law on the other were the two factors involved in this regard.

CONCLUSIONS

The main conclusions from this study are summarized as follows:

Two simple models; ''Slippage Theory'' and ''Equal Cross-Section'' theory were introduced to analyze and predict the performance of different fibers in FRAC structures. The first theory outcome was a parameter called slippage ratio λ. The more the value of λ leads to the more fiber disobedience during the insertion of tensile stresses. The other model introduced TTC_R: total transformed fiber cross sections, as an indicator. If a fiber causes a larger TTC_R, the compressive load P will be inserted to a wider equipollent area (specially in the case of FRAC when compared with AC) and thus with the same load insertion of P for both comparative structures, a less compressive load will be inserted to the surface unit of the structure which has a bigger TTC_R. These parameters were calculated for four fibers including: glass, nylon 6.6, polyester, and polypropylene. In the experimental section, these fibers were employed in AC as FRAC. Two tests were carried out: Marshall's test (as stability and flow outcomes) and specific gravity test. The results indicated that glass and polypropylene fibers could improve the stability better than other fibers. The flow and specific gravity, however, showed less sensibility toward adding the fibers. The models introduced PP fibers as the worst fibers, therefore, an ANN was established on the system and thus the low melting point of PP was recognized as the important factor causing the ''tacky'' property of fiber in matrix. Therefore, a more coherer structure could be obtained. At the final part of the study, the models concluded a good position for glass, polyester, and nylon, and they were suggested for predicting any textile fibers that may be used in AC.

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