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Effect of adding glass fiber on the properties of asphalt mix

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Abstract

The continuing rapid growth in traffic, along with the rise in allowable axle loads, requires improvement of highway paving materials. In the recent decades, different types of fiber materials are utilized for improving the performance of asphalt mixture. A laboratory investigation was carried out into the effect of adding Glass Fiber (GF) on some properties of Hot Mix Asphalt (HMA) mixtures. Subsequently, five HMA specimens were prepared using the Marshall mix design method for wearing surface mix (mix 4C). Marshall Stability (MS) and flow tests were applied to the specimens. Also, MS and flow values were recorded. For the Optimum Asphalt Content (O.A.C) and different GF percentages, the Marshall parameters were calculated. Then, some special tests were conducted to measure the different mix properties, including loss of stability, wheel tracking and indirect tensile strength tests. Results of the study led to important conclusions regarding using of Glass Fiber (GF) to improve most of the properties of HMA mixtures. Finally, this study recommended a proposed mix with 0.25% GF by weight of the total mix.

Keywords: Hot mix asphalt; Glass fiber; Loss of stability; Wheel tracking; Indirect tensile strength

1. Introduction

Flexible pavement which is considered a major type has been widely constructed in highway engineering all over the world [1,2]. However, flexible pavement deteriorates over time because of the influence of traffic loading and the environment [3]. Many researches aim to better materials and modifications have been conducted to improve the properties of HMA and reduce the distresses of flexible pavement. Therefore, various types of fibers have been utilized in asphalt mixtures to enhance the performance [4].

The use of fibers in HMA improves engineering properties, fatigue resistance, rutting resistance and stiffness and has therefore become an effective alternative for the road pavements construction [5,6]. For this objective, many studies have been carried out to examine the properties and performance of HMA mixtures containing various types of fiber such as steel, carbon, aramid, polyethylene, polypropylene, basalt, polyester and glass fibers [4,6–10].

The influence of various types of fibers was examined on the mechanical properties of asphalt mixtures [11]. Glass fibers can increase stiffness and tensile strength of HMA but these fibers must be handled carefully during asphalt manufacturing [6]. However, stability and stiffness reduction and increasing the voids in the mix have been noted [12]. The incorporation of glass fibers led to higher resistance to fatigue cracking and rutting. It was distributed in random directions in a mixture resist shear displacement that effectively prevent the internal dislocation of aggregates [12].

Glass fibers enhance the fracture energy and crack intensity factor substantially [13]. Asphalt mixtures modified with glass fibers are also more resistant against rutting, crack initiation and crack propagation [14]. In another study, fracture and rutting performance of asphalt mixtures containing glass fibers was examined [15]. The results were in agreement with previous studies, and the rutting and fracture resistance of HMA mixtures were significantly enhanced while being modified with glass fibers.

In the work presented herein, the Marshall design method was used for HMA preparation. Glass Fibers (GF) were added at different ratios for the preparation of HMA specimens. The experimental results were compared with a control mix and with specification limits. Therefore, this study showed that adding of GF with a suitable ratio is an effective solution to improve the characteristics and performance of HMA mixtures.

2. Objectives

The main objectives of this research are to investigate the effect of adding different percentages of GF on the properties of asphalt

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mix and determine the Optimum Glass Fiber Content (O.GF.C) to achieve the best values of stability and flow, then providing recommendations.

3. Experimental work

In the first stage, 10 tests were conducted on the selected materials to ensure their validity: five tests were conducted on aggregate (Los Angeles abrasion, water absorption, specific gravity, stripping value and selection of design gradation to attain the condition of stone-on-stone contact) and five tests were conducted on asphalt (penetration, softening point, flash point, viscosity and ductility). In the second and third stage, the Optimum Asphalt Content (O.A.C) was determined by Marshall mix design and kept constant for all mixes. GF was added to control mix at ratios 0.25%, 0.5%, 0.75% and 1.0% by weight of the total mix. Marshall Stability (MS) and flow tests were applied to the specimens, and MS and flow values were recorded. According to these values, the optimum percentage of GF was calculated. Also, all the properties of the investigated specimens were compared with those of the control mix without GF additives. In the final stage, special tests were conducted on the mixes with Optimum Glass Fiber Content (O.GF.C), including loss of stability, wheel tracking and indirect tensile strength tests.

4. Materials

The asphalt concrete mixes tested in this study were composed of aggregate, asphalt, mineral filler and Glass Fiber (GF). The engineering properties of the applied materials were calculated by conducting laboratory tests according to the American Association of State Highway and Transportation Officials (AASHTO), as presented below.

4.1. Aggregate

Crushed dolomite stone obtained from "ATAKA" quarry, Suez governorate was used as coarse aggregate portion in the asphalt concrete mixtures. The fine aggregate of the investigated asphalt mixes was siliceous sand obtained from "FAYED" quarry Ismailia governorate. Table 1 presents the aggregate design gradation and specification limits according to the Egyptian code [16]. Los angles abrasion of the aggregate was determined as per AASHTO T-96 [17]. Water absorption and bulk specific gravity of the aggregate were determined as per AASHTO T-85 [18]. Table 2 presents the properties of the used aggregate according to the Egyptian specification of asphalt concrete mixes [16].

4.2. Asphalt

One type of asphalt, Suez asphalt cement (60/70 penetration grade, 1.02 g/cm^3 specific gravity), was used in this study to prepare all investigated asphalt mixtures. Penetration, softening point, flash point, kinematic viscosity and ductility of the asphalt specimen were determined as per AASHTO T-49 [19], AASHTO T-53 [20], AASHTO T-48 [21], AASHTO T-201 [22] and AASHTO T-51 [23] respectively. Table 3 presents the different properties of the used asphalt.

4.3. Mineral filler

The mineral filler used in the investigated mixes was limestone dust with bulk specific gravity of 2.75 g/cm^3. Table 4 presents the gradation of the mineral filler and the specification limits. The design gradation of aggregate and mineral filler were merged.

Table 1
Gradation of aggregate used.

Sieve size inch	mm	Design gradation	Specification limits
1	25	100	100
3/4	19	92.4	80-100
1/2	12.5	79.6	--
3/8	9.5	74.7	60-80
No.4	4.75	52.9	48-65
No.8	2.36	43.5	35-50
No.16	1.18	39.1	--
No.30	0.6	28.7	19-30
No.50	0.3	19.2	13-23
No.100	0.15	12.0	7-15
No.200	0.075	7.6	3-8

Table 2
Aggregate properties.

Test no.	Test		AASHTO designation no.	Results	Specification limits
1	Los angles abrasion (%)	After 100 revolution	T-96	7%	≤ 10%
		After washing after 500 revolution		30%	≤ 40%
2	Water absorption (%)		T-85	2.6%	≤ 5%
3	Bulk Specific gravity (g/cm^3)		T-85	2.67 g/cm^3	--

Table 3
Asphalt binder properties.

Test no.	Test	AASHTO designation no.	Results	Specification limits
1	Penetration (0.1 mm)	T-49	66	60-70
2	Softening point (ºC)	T-53	47	45-55
3	Flash point (ºC)	T-48	+270	+250
4	Kinematic viscosity (cst)	T-201	434	+320
5	Ductility (cm)	T-51	+100	≥ 95

4.4. Glass fiber (GF)

Table 5 shows the physical properties of GF. The mixes were prepared with GF of different percentages "i.e. 0.25%, 0.50%, 0.75% and 1.0%" by the total weight of asphalt mix.

4.5. Improved asphalt mixtures

Five HMA mixtures were prepared to evaluate the effect of using Glass Fiber (GF) on the properties of the asphalt mix. The first HMA mixture consisted of the selected materials with the Optimum Asphalt Content (O.A.C), being called the (Control Mix.). Then, four HMA mixtures with the selected materials, the O.A.C, and different contents of GF (0.25, 0.50, 0.75, 1.0 % by weight of the total mix) were prepared, and the Marshall mix design method was conducted to determine the Optimum Glass Fiber Content (O.GF.C), leading to the first comparison mixture (Comp. Mix. 1). Then, these two main mixtures (Control Mix and Comp. Mix. 1) were subjected to special tests to compare the performance of HMA mixtures with GF as additive. Table 6 presents these 5 HMA mixtures.

5. Experimental work and results

5.1. Optimum asphalt content (O.A.C)

Four HMA mixtures with the selected materials in the previous stage, different asphalt contents (4.5, 5.0, 5.5, 6.0%), were prepared. Then, Marshall mix design method was conducted for the wearing surface mix (mix 4C) to calculate the properties of the mixtures according to AASHTO T-166 [24]. Also, these four HMA mixtures were tested using Marshall apparatus to obtain stability and flow values. Then, the Optimum Asphalt Content (O.A.C) was determined, yielding a value of 5.3% to provide maximum stability and suitable flow, actual specific gravity, and acceptable percentage of air voids. Table 7 presents the properties of the O.A.C mixture (Control Mix).

Table 4
Mineral filler gradation.

Sieve size		Design gradation	Specification limits
inch	mm		
No.30	0.6	100	100%
No.50	0.3	100	--
No.100	0.15	93	85% (min)
No.200	0.075	82	65% (min)

Table 5
Properties of glass fiber.

Property	Detail
Fiber type	Glass fiber
Color	White
Shape	Rectangular
Length (mm)	10
Width (mm)	1
Density (g/cm^3)	2.53
Melting point (ºC)	> 300
Moisture (%)	< 0.2
Loss on ignition (%)	< 0.25
Non-Fibrous materials (%)	< 1.0

Table 6
The Five HMA mixtures.

Code	Description	Function	Objective
Mix 0	O.A.C% AC 60/70	Determine Stability & Flow	Control Mix
Mix 1	O.A.C% AC 60/70 + 0.25% GF	Determine O.GF.C of Comparison Mixes	Comp. Mix.1
Mix 2	O.A.C% AC 60/70 + 0.50% GF		
Mix 3	O.A.C% AC 60/70 + 0.75% GF		
Mix 4	O.A.C% AC 60/70 + 1.0% GF		

Table 7
Marshall properties at Optimum Asphalt Content (O.A.C).

Properties	Results	Specification limits
Stability (kg)	1445	900 kg (min)
Flow (mm)	3.8	2-4 mm
Stiffness (kg/mm)	380	300-500 kg/mm
Bulk specific gravity (G_{mb}) (g/cm^3)	2.327	--
% Air voids in total mix (V_a)	3.77	3-5 %
% Voids in Mineral Aggregate (VMA)	14.28	--
% Voids Filled with Asphalt (VFA)	73.6	--

5.2. Mixing method of glass fiber in asphalt concrete mixtures

Generally, there are two methods for mixing used to disperse the fiber in HMA mixtures, namely dry process and wet process [6,25-27]. Dry process mixes the fibers with aggregates and bitumen is the binder material in the mixture. The wet process depends on the type of additive and its nature, the additive is mixed with aggregates before adding binder [6,26,28] or added after mixing the binder and aggregates as a part of solid materials [28]. Normally, the dry process is more desirable than the wet process. Furthermore, the field work done on fiber reinforced asphalt mixture has commonly used the dry process, probably because of the problems of production that introduce fibers directly into the asphalt [6]. In this study, the dry mixing process was used.

5.3. Optimum glass fiber content (O.GF.C)

Four HMA mixtures with the selected materials, the optimum asphalt content (5.3%), and different contents of GF (0.25, 0.50, 0.75, 1.0 % by weight of the total mix) were prepared, and the Marshall mix design method was conducted to determine the Optimum Glass Fiber Content (O.GF.C), yielding a value of 0.25%. Table 8 presents the Marshall test results for different contents of GF, whereas Table 9 presents the properties of the O.GF.C mixture.

6. Effect of glass fiber content on Marshall properties

6.1. Effect of glass fiber content on Marshall stability

The results in table 8 show that the Marshall mix stability for the GF mixes decreased as the GF ratio was increased. Since a glass fiber has a smooth surface with low interfacial skin friction, it may

Table 8
Properties of glass fiber mixtures.

Mix. No. / properties	M1	M2	M3	M4
Stability (kg)	1615	1561	1547	1426
Flow (mm)	3.3	3.4	3.6	4.1
Stiffness (kg/mm)	489	459	430	349
Bulk specific gravity (g/cm^3)	2.394	2.358	2.367	2.305
% Air voids in total mix (V_a)	3.4	3.54	3.62	4.2
% Voids in Mineral Aggregate (VMA)	11.82	13.14	12.8	15.1
% Voids Filled with Asphalt (VFA)	71.27	73.05	71.72	72.19

Table 9
Marshall properties at optimum glass fiber content (O.GF.C).

Properties	Results	Specification limits
Stability (kg)	1615	900 kg (min)
Flow (mm)	3.3	2-4 mm
Stiffness (Kg/mm)	489	300-500 kg/mm
Bulk specific gravity (g/cm^3)	2.394	--
% Air voids in total mix (V_a)	3.4	3-5 %
% Voids in Mineral Aggregate (VMA)	11.82	--
% Voids Filled with Asphalt (VFA)	71.27	--

reduce the contact points of the aggregate which can decrease the stability value [29]. The Marshall mix stability achieved its highest value of 1615 kg at 0.25% GF (M1), representing a 11% increase compared to the control mix (M0). For the two subsequent mixes (M2 and M3), as the GF ratio was increased, the mix stability decreased, reaching 1547 kg at 0.75% GF, but remained higher than that of the control mix (1445 kg). For the subsequent mixes (M4), also as the GF ratio was increased, the mix stability decreased, reaching its lowest value of 1426 kg at 1.0% GF. According to these results, it could be concluded that adding of GF to the mix had a pronounced effect on the mix stability at the specific added percentage of 0.25% by weight of the total mix.

6.2. *Effect of glass fiber content on Marshall flow*

The flow value of the investigated mixes is presented in table 8. The most suitable value of flow was 3.3 mm, corresponding to the highest value of stability at 0.25% GF (M1). This value decreased the flow by 13% compared with the control mix (M0). The highest flow value was 3.6 mm at 0.75% GF ratio (M3). Mix M4 lay beyond the specification value for flow (> 4 mm) according to the Egyptian code [16]. Glass fiber causes an increase in the flow because it develops the empty space between the aggregates and decreases the connectivity and friction between them. As a result, internal friction decreases, and the flow increases [30].

7. Loss of stability test

The loss of stability percentage is used as an index for mix durability under various use cases. In this test Marshall samples are placed in bath filled with water and tested at several times (0, 1 day, 2 days, 3 days) to measure the loss of stability for mixtures as shown in Figs. 1 and 2. Fig. 3 presents the loss of stability percentages versus immersion time for the chosen mixtures: Control Mix and Comp. Mix. 1 with the Optimum Glass Fiber Content (O.GF.C) at specific adding percentage of 0.25%.

The Control Mix and Comp. Mix. 1 showed loss of stability values in an acceptable range (< 25%) [31]. The control mix showed the highest loss ratio. For Comp. Mix. 1, the loss of stability decreased, reaching the lowest ratio of 19%, representing a 14% decrease compared with the control mix. It is due to the addition of the glass fiber increases the stiffness of the asphalt binder resulting in stiffer mixtures with decreased binder drain-down [32]. According to these results, it could be concluded that adding of GF to the mix had a pronounced effect on the mix stability at its optimum ratio of 0.25%.

8. Wheel tracking test

Rutting is one of the major distresses observed in bituminous pavements [33]. The wheel tracking test was conducted on some specimens according to the Egyptian code [16]. This test was performed on the following chosen mixtures: Control Mix, Comp. Mix. 1 with Optimum Glass Fiber Content (O.GF.C) at specific adding percent of 0.25% by weight of the total mix to study the effect of GF on the capability of pavement to withstand rutting phenomena. Fig. 4 shows wheel tracking test machine. One slab with dimensions of 440 mm × 330 mm × 50 mm according to LTG 2015 [31,34] was prepared for each mixture and subjected to the test at 60 °C under wheel load of 53 kg to indent a straight track in the specimen as shown in Fig. 5. The track depth was recorded at regular intervals up to 45 minutes using a spring less dial gauge. The rutting depth results are presented in Fig. 6 to compare the results of the different tested mixtures.

Fig. 1. Water bath. Fig. 2. Marshall specimens in water bath.

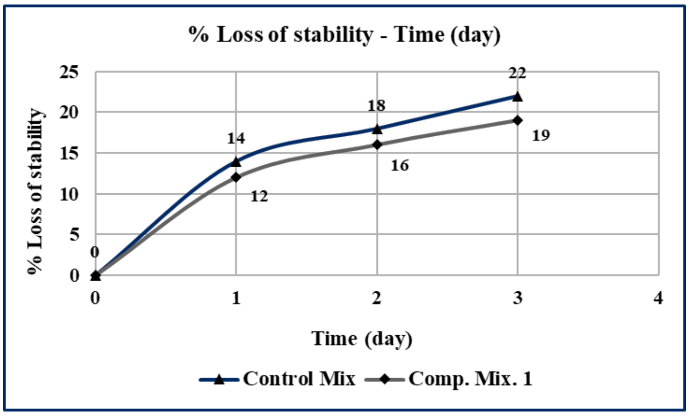

Fig. 3. loss of stability percent with time.

Fig. 4. Wheel track device.

Fig. 5. Slab under wheel load.

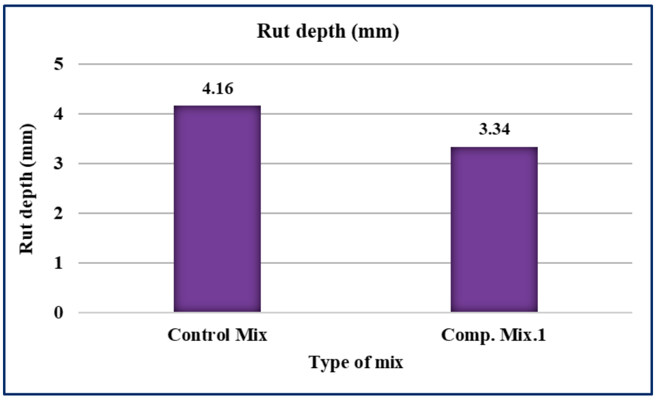

Fig. 6. Rut depth of each mixture.

The control mix showed the highest value of rutting depth (4.16 mm). For Comp. Mix. 1, the rutting depth decreased, achieving the lowest value of 3.34 mm, which represents a decrease of 20% compared with the control mix. According to these results, it can be concluded that adding of glass fiber to the mix had a pronounced effect on the mix stability at its optimum ratio of 0.25% by weight of the total mix.

8.1. *Indirect tensile strength test*

Tensile characteristics of asphalt mixtures are determined according to (AASHTO T-283) [35] test method, by loading Marshall specimen along its diametric plan with a constant rate, producing uniform stress. The indirect tensile mode of testing can be used to establish the tensile properties of asphalt mixtures to evaluate the performance of the pavement. Fig. 7 shows the indirect tensile strength test. Two sets of the two main mixtures (Control mix. and Comp. Mix. 1) were prepared. One set is conditioned by soaking it in water 60 ºC for 24 hours. The other set is used as unconditioned mixtures, which are tested without conditioning. The ratio of the average indirect tensile strength of the conditioned samples over the average indirect tensile strength of the unconditioned samples is recorded as the tensile strength ratio (TSR) which specified as 80% at least. Fig. 8 shows the comparison between the TSR results of Control Mix. and Comp. Mix. 1.

According to these results, The Control Mix had the lowest value of TSR (84.1%). For Comp. Mix.1, the TSR increased and achieved the highest value (88.6%). This value increased the TSR by about 5% compared to the Control Mix. These results showed that the HMA mixtures which were modified by GF at its optimum content (0.25% by weight of the total mix) had a high resistance to moisture damage phenomena. Based on this discussion, it could be concluded that the performance of GF additives in HMA mixtures presented a good performance compared with the Control Mix.

Fig. 7. Indirect tensile strength test.

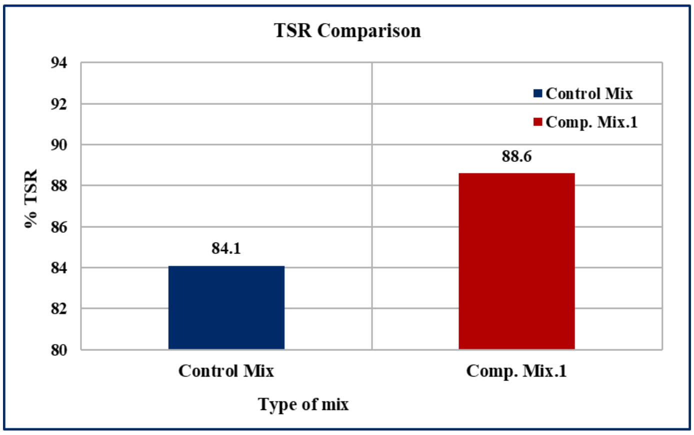

Fig. 8. Tensile Strength Ratio (TSR) for the two main mixtures.

9. Conclusions

Based on the results of this study, the following conclusions are shown:

1. The optimum content of GF is 0.25% by weight of the total mix, producing improved mixtures of hot asphalt, which provide higher stability value by 10%, adjusted flow value by reducing it with 13%, and more rutting resistance by reducing rutting value by 19.7% comparing with control asphalt mixture.
2. The asphalt mixture containing GF at percentage of 0.25% shows a good resistance to moisture damage (indirect tensile strength) comparing with control asphalt mixtures.
3. The loss of stability value increased when using GF at its optimum content, compared with the control mix. However, it remained in the acceptable range (< 25%).
4. The asphalt mixture containing GF at percentage of 0.25% does not meet the minimum VMA requirements. This is because according to the gradation of aggregates, the nominal maximum size of aggregates is 19 mm and therefore a minimum VMA of 13.0 percent is specified. However, a VMA of 11.82% was obtained for Mix M1. This specification not provided for in the Egyptian code.
5. Based on the results of this study, a mix was proposed and prepared with 0.25% GF by weight of the total mix. This mix exhibited suitable values for almost all mix properties and is therefore recommended.

10. Recommendations

Based on the conclusions above, the following recommendations can be made:

1. Adding of Glass Fiber (GF) at 0.25% by weight of the total mix in HMA mixtures achieve satisfactory properties, in turn providing optimum field performance and limiting pavement rutting to a considerable extent.
2. Other fiber materials should also be investigated to be used in the production of asphalt mixes, to overcome dangerous pavement distresses. Elimination of pavement cracking is considered to be a vital goal of such investigations.
3. Complete economic evaluation should be carried out to confirm the feasibility of using HMAs containing Glass Fiber (GF).
4. Future research should be conducted as well as updating the Egyptian code especially in specifying the requirements of VMA.

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