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An Experimental Study of Concrete Reinforced with Glass Fibers under Tensile and Compressive Loading

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Abstract: *By reviewing the history and benefits of the use of glass fibers in concrete and by using a fixed mix design in this study, glass fiber lengths of 12 mm were used for the production of fiber concrete samples of 3 types of fiber-cement ratio* (F/C) *equal to 1.5%, 3%, and 4.5% and the effects of these parameters on the compressive and tensile strengths of concrete were assessed. The Portland cement utilized in this research was of type (I). The water used to produce the sample was local drinking water. To select the reinforced concrete mix design, a compressive strength range of 36-54 MPa and density of about 2350* $\left(\frac{Kg}{m^3}\right)$ *were considered and the experimental projects were evaluated on this basis and 4 weighted mix designs were finally presented in this study. To compare the results, the fibers were distributed in the concrete as smoothly and uniformly as possible. The tested fibers were of glass type.*

Key words: Glass Fibers, Tensile and Compressive Loading, Reinforced Concrete, Concrete Mix design.

1. Introduction

Concrete is essentially a brittle material and its tensile strength is far less than its compressive strength. Concrete reinforcement with short fibers randomly dispersed in its volume is an effective method to reduce cracking, increase ductility, improve energy absorption, and enhance the tensile strength of concrete. Many chemical and physical changes in the concrete start with surface cracks creating a significant impact on the ultimate durability of the concrete. Thus, application of cement reinforced with fibers in concrete is an economic idea. The fiber length plays an important role in its performance. An excessive fiber length causes it to turn into a ball-like shape when mixing and since the balls open against tensile stresses, they lose their powers to deal with stress. On the other hand, if the fibers are shorter than the required length, a good adhesion does not occur between the concrete and the fibers and therefore the fibers are dragged out from the concrete under tensile stress. The fibers should have a certain length-to-diameter ratio. The optimum length/diameter ratio of the fibers is called the aspect ratio, ranging from 50 to 210 for some fibers. To increase the adhesion of fiber to cement, methods such as twisting and curling their ends are considered. Of the other research on fiber concrete, the effects of various fibers, including glass fibers in controlling concrete cracks could be mentioned. The results of this study indicate that the use of this type of fiber leads to a 0.1% drop in concrete failure and cracking. By changing the structure of the fibers, P. Kravaev (2010) improved concrete penetration into the fiber clusters and thus fiber efficiency was proven to be

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raised by using the proposed method [1]. M. Kamali D. (2008) introduced a geometric model to improve the structural influence of knitted fabrics on concrete penetration into fiber clusters. Also, he was able to dramatically increase concrete flexural strength by changing the interface of fibrous composites reinforcing concrete [2]. Li (1995) reported that Matrix reduces, while ductility increases by the mentioned procedure. Balaguru and Rjmakirishna (1996) examined a lightweight concrete with air content and the use of short fibers and sand instead of aggregates. A common fiber-reinforced concrete has a less bending strength compared to the light one. They found that fibers essentially improve ductility against pressure, split-tension, bending, and shear load models. Fibers raise split-tensile strength, flexural strength, and elasticity modulus up to 160%, by 90%, and 80%, respectively. The mentioned design was prepared in comparison with a conventional concrete with normal weight in this study [3]. The main objective of this research was to evaluate the impacts of the 2 parameters of a mix design type and the percentage ratio of fiber to cement on the failures and ultimate tensile and compressive strengths of the samples.

2. Materials:

2.1. Glass fibers:

The fibers used in this research were made of E-glass type. The glass fibers had been cut in the manufacturing factory by the use of fiber cutting machine

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Table 1: Characteristics of the glass fibers used in this research

Type of fiber (℃)	Type (℃)	Length $[mm]$	Nominal diameter $[\mu m]$	Percentage of length increase	Moisture absorption	Unit weight $\left[gr/cm^3\right]$	Modulus of elasticity $[GPa]$	Tensile strength $[MPa]$	Melting point (℃)	Ignition temperature (℃)
Glass	E-glass	12	14	9	0	0/6	72	360	170	360

Fibers can enhance strain capacity, resistance to stroke, energy absorption, abrasion resistance, and tensile strength of concrete. Fibers resist to cracks and prevent their developments and increase concrete resistance to strain, stroke, shrinkage, and thermal stresses, affecting the mechanical properties of concrete in all modes of failure.

2.2. Superplasticizer

This lubricant reduces the surface tension of water and significantly raises lubricity of the set. In this study, GLENIUM 110P superplasticizer made in O-BASF Company was used. This superplasticizer is the aqueous solution of polycarboxylic ether. As recommended by the manufacturing company, the right amount of the above-mentioned lubricant to be used in concrete mixtures is between 0.5% and 1.5% of cement material weight. To achieve maximum performance, it is recommended to add the mentioned superplasticizer to the mixture as a solution in the remaining mixing water after adding 50% to 70% of mixing water and continue the mixing operation at least 60 seconds after adding it.

2.3. Properties of the materials used in the concrete

Aggregates usually constitute 60% to 75% of concrete volume and strongly affect on the fresh and hardened concrete properties. In the current research, the concrete construction materials included coarse aggregates (gravels) of broken types as well as normal fine aggregates (sands). To comply the aggregate grading with the standard terms [4] (ASTM C33), the grading correction was necessary. In the present scheme, graded aggregates with a maximum size of 19 mm were used to construct the samples. The abrasion resistance of the aggregates utilized was controlled based on ASTM C131 standard by using the D method [5] and eventually confined to 35%. On the other hand, the sand used owned the required capability of not reacting to alkaline chemicals based on ASTM C289 standard [6]. The Portland cement used in the study was of type (I). The consumed cement met ASTM C150 criteria [7]. The water used to produce the samples was local drinking water in this research. To achieve the desired goals, 4 mixing projects were selected as shown in Table 2.

Table 2: Materials consumed for the mix designs in a cubic meter of concrete

No Mix Design	Sample	Send $[kg]$	Grave $[kg]$	Water $[kg]$	Cement $[kg]$	$\left[\frac{w}{c}\right]$
1	C1	732	1118	178	318	0.55
2	C2	686	1137	178	350	0.50
3	C3	604	1170	164	400	0.40
4	C4	590	1142	163	450	0.36

2.4 Method of constructing a fiber concrete in the laboratory

According to ASTM C192 guidelines for manufacturing concrete samples, the gravel was poured into a concrete mixer and less than one-fifth of the mixing water was added to it. With the rotation of the concrete mixer drum, sand grains were evenly moistened. At this time, the consuming gravel was added to the sand and mixing was continued. Then, cement was added to the mixing of sand and gravel driven by the concrete mixer rotation simultaneously and the remaining mixing water, in which the fibers had been immersed, was poured into the concrete mixer. To separate the glass fibers from each other, they were poured into the remaining mixing water and the concrete.

2.5 Ambient conditions

During the experiment, to obtain more accurate results of the samples made, it was tried to maintain the ambient conditions constant. Thus, the consuming materials and laboratory work was conducted in a room with controlled ambient conditions. The temperature of the depot of the materials and construction and maintenance of the samples was set at 24°C and the treatment pond water was considered 22°C.

3. Fibrous concrete samples in the laboratory

3.1 Grouping of the fibrous concrete samples

A total of 16 designs of the concrete samples with and without fibers were prepared based on 4 mixing schemes and by applying 3 types of fiber/cement (F/C) ratio of 1.5%, 3%, and 4.5% of the cement weight, a total of 48 designs were presented. Accordingly, 288 cylindrical or cubic types were made for indirect tensile (fission) and compressive tests in accordance with A23.2-13C and A23.2-9C standards, respectively, after 7, 14, and 28 days. Additionally, to evaluate the results of the tests carried out, the mean values the 3 samples measured at each stage were used to reduce errors. Naming of the designs was presented as follows:

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$\left[C\,\boxed{X} - \boxed{Y} - \boxed{Z} \right]$ is the cylindrical sample of the fiber concrete constructed from mix design No. $\boxed{X = 1,2,3,4}$ according to Table 2 with the fiber/cement weight ratio of $\boxed{Y = 1.5,3,4.5\%}$ of the samples in kilograms and $\boxed{Z}$ is the number of the samples. The samples were tested with different fiber-armed and -unarmed mixing designs. The average weight of the cylindrical samples was 13150 g. It should be noted that the mix designs applied in this study were presented based on weight.

3.2 The test results of tensile and compressive loading on the samples

According to ACI318-11 regulations, the samples were placed under the test machine in a way that the load direction was perpendicular to the concreting direction in the casts. The load was applied in a stress form at a constant rate. The results of tensile and compressive strengths obtained in this study are presented in the tables and graphs below. After examination and compressive loading at the age of 7, 14, and 28 days, the results of the samples were extracted as shown in the following tables:

Table 3: Results of the concrete samples with mix design No. 1 and different fiber percentages

pushing resistance $\left(N/mm^2\right)$	Tensile strength $\left(N/mm^2\right)$	Age day	Sample with fiber%	Row
36/60	3/62	7	$C1-0.0$	1
39/25	4/05	14		2
44/12	4/45	28		3
42/46	4/20	7	$C1-1.5$	4
45/92	4/74	14		5
51/74	5/25	28		6
41/82	4/14	7	$C1-3$	7
43/91	4/54	14		8
51/13	5/19	28		9
39/62	3/94	7	$C1-4.5$	10
42/99	4/45	14		11
46/24	4/71	28		12
41/50	4/23	7	$C2-0.0$	13
46/05	4/68	14		14

49/72	5/12	28		15
48/56	4/91	7	$C2-1.5$	16
53/42	5/38	14		17
58/17	6/12	28		18
46/13	4/66	7	$C2-3$	19
51/21	5/22	14		20
56/28	5/83	28		21
45/28	4/62	7	$C2-4.5$	22
49/28	5/10	14		23
54/82	5/52	28		24
47/92	4/78	7	$C3-0.0$	25
52/24	5/35	14		26
58/05	5/94	28		27
57/50	5/59	7	$C3-1.5$	28
60/60	6/15	14		29
69/66	6/98	28		30
55/62	5/24	7	$C3-3$	31
58/47	5/89	14		32
67/43	6/76	28		33
53/26	5/20	7	$C3-4.5$	34
56/43	5/70	14		35
65/37	6/40	28		36
54/18	5/56	7	$C4-0.0$	37
59/96	5/89	14		38
66/09	6/65	28		39
62/31	6/34	7	$C4-1.5$	40
69/55	6/66	14		41
78/65	7/56	28		42

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59/21	6/10	7	$C4-3$	43
63/28	6/06	14		44
73/52	7/16	28		45
57/94	5/88	7	$C4-4.5$	46
61/61	5/79	14		47
72/23	7/10	28		48

Fig. 1: Tests of indirect compressive and tensile strengths

4. Conclusion:

The aim of this investigation was to assess the effects of the 2 parameters of mix design types and fiber/cement ratio on the failure method and ultimate tensile and compressive strengths of the samples. According to the results obtained, the tensile and compressive strengths of the concrete samples of $C1,2,3,4-1.5$ were greater than any other samples in all the age ranges. It was observed that in all the samples with fiber application, the properties of fibrous concrete were better than non-fibrous concrete. The results showed increased plasticity of the fibrous samples. It was also observed that fibers prevent the development of cracks and concrete fracture in the strength balance of non-reinforced concrete and this phenomenon becomes more evident by increasing the percentage of fibers. Fibers are of high specific surface area, enhance the mechanical reinforcement of cement pulp, and hold concrete. After a force exertion, the samples without fibers ($C1,2,3,4-0.0$) were completely destroyed, while the fibrous samples retained their shapes and were not damaged under the same force. Instead of the collapse of the structure, the fibrous concrete samples underwent almost uniformly dispersed cracks in the direction of the applied force. At the time of loading and creation of the cracks in the unarmed concrete samples of $C1,2,3,4-0.0$, the cracks continuously developed and eventually attached together to form a fracture with an angle of about 20º-30º proportionate to the direction of the load applied to the samples. Failure in a fiber concrete was associated with a less fragility compared to a non-reinforced concrete since the energy required for the formation and development of cracks in these samples was lower due to the presence of glass fiber. Basically, in the fissure test of the concrete reinforced with glass fibers, no new cracks occur to the concrete by forces under fracture stresses. At stresses higher than the mentioned amount, new cracks appear in the concrete, while their numbers and sizes grow quickly by increasing stresses. In the samples, it was observed that an increase of 3% and 4.5% of fibers had no significant impact on the increasing tensile and compressive strengths. Nevertheless, addition of 1.5% of fiber contents created an evident enhancement in all the concrete parameters. The samples of 3% and 4.5% fibers showed finer cracks and fewer detachments at the time of failure. Failure of samples with some fibers mostly occurs suddenly, but the growth of cracks appears gradually in those with 1.5% of fibers. Although the purpose of this study was to evaluate the improvement of the tensile strengths of the desired fibrous concrete samples through fiber application, tests of compressive strength were further conducted to better understand the behaviors of the concrete samples. In general, it can be said that application of an optimum percentage of fibers can be effective on the compressive strengths, ductilities, and flexibilities of concrete samples, thus restricting and delaying a complete rupture and failure. Therefore, this alternative seems to be more favorable compared to the other options if it is not possible to increase the size or percentage of the consuming armature.

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