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ORIGINAL ARTICLE

Performance of Steel Fiber Reinforced Concrete Slabs under Bending Loads

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ABSTRACT
*In this paper, the effect of type and quantity of steel fiber and concrete strength on ductility of small concrete slabs has been studied. Steel Fiber reinforced concrete slabs in 8*82*82 cm were examined in an experimental program regarding bending and their load-displacement curve were obtained. The experimental variables were two different fibers with four different percents (0, 0.5, 1, and 1.5 percent) and two strengths were 30 and 45 MPa. The results of experiments showed that in different concrete strengths, increasing the fiber quantity and increasing the ratio of fiber length to diameter increased the ductility. The type of failure was changed from fragile in non-fiber samples to ductile in fibered samples. Fiber 0.5% did not have a significant effect on slabs' behavior and the least required quantity of fiber shall be more than 0.5%.*
Keywords: Fiber Concrete, Steel Fiber, Ductility, Slab, Bending, Crack

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INTRODUCTION

The fibers in concrete lead to decreasing the concrete frangibility significantly and fiber concrete shows ductile behavior under different loads such as strain, tension and impact [1]. The fibers improve the mechanical properties of concrete and provide a uniform material and prevent from expansion of cracks in concrete. Fiber concrete can be used in structural slabs. Such slab can be used in structural ceilings and stairs sidewalk due to its ultra impact strength and energy absorption and can also be used in walls of ammunition depots and in places which are subject to extreme dynamic loads. Meanwhile, it can be used as a structural slab on the floors of industrial places.

In 1980, Ghalib proposed a method according to final strength criteria for bending design of small steel fiber reinforced concrete slabs [2] which was merely based on the statistical studies resulted from studying on a few number of bilateral slabs. Meanwhile, the effect of fibers' quantity, length and diameter (ratio of length to diameter) was not considered. No new method had been proposed for designing such slabs and ACI 544 committee recommended the same method for designing small-span slabs. It was highly recommended that such designing method shall not be used in slabs with high dimensions as it was used in Ghalib's studies, therefore, its application is limited [3].

This research aims at defining the bending strength and ductility and studying the P – δ curve for steel fiber reinforced concrete slabs with different percents in two-size fibers and meanwhile the effect of concrete strength on them.

Statement of Purpose

Although several researches have been done on mechanical properties of fiber concrete and different concrete members under different loadings, studies related to the performance of fiber reinforced concrete slabs were limited regarding different parameters. In this research, the effect of concrete strength, percent and the ratio of length to diameters of steel fibers on concrete slabs have been studied regarding strength and ductility.

EXPERIMENTAL PROGRAM

In an experimental program, 14 types of concrete mix with four different fiber percents and two strengths and two sizes of steel fiber were considered. Cylindrical compressive strength of non-fiber concrete were 30 and 45 MPa during 28 days. The experimental program was summarized in table 1.

The used mix ratios for reaching the basic strength of 30 and 45 MPa were shown in table 2. The mix ratios for fiber concretes were the same as provided in table 2 which add 25, 50, 75 Kg fibers for 0.5, 1, 1.5 percent respectively. In experiments in which Portland cement I and river aggregates were used, the sand was softening modulus of 2.7 and gravel had broken edges and the highest size of coarse grains were 0.75 inches (19 mm). Two used types of fibers had rectangular section and were as indented along the length.
Other dimensional properties of the fibers were shown in Fig (1) and Table (3). The used ultra lubricate was normal and conforming ASTM C494 Type F standard. The slabs were square in 8*82*82 cm. These slabs were put on four corners of a square on roller point bearings such that the distance between two centers was 68 cm from each other. The load was exerted on a steel plate in 1*8*8 cm by a hydraulic jack that was put in the middle of the upper of the sample. Force (F) and displacement of steel plate to support (w) were read at any moment [4].

Table 1: experimental program

Concrete strength	Type of fiber	Percent of fiber	Slab samples No.	Number of cylindrical samples	Number of slab
$f_c' = 30MPa$	Nil	0	1	5	1
	Jc25	0.5	2	2	1
		1	3	2	1
		1.5	4	2	1
	Jc35	0.5	5	2	1
		1	6	2	1
		1.5	7	2	1
$f_c' = 45MPa$	Nil	0	8	5	1
	Jc25	0.5	9	2	1
		1	10	2	1
		1.5	11	2	1
	Jc35	0.5	12	2	1
		1	13	2	1
		1.5	14	2	1
Sum of Samples				34	14

Table 2: ratio of mix for concrete in the strengths of 30 and 45 MPa as kg/m3

Concrete strength (MPa)	Cement	Sand	Gravel	water	Ultra lubricate	Ratio of water to cement
30	400	800	1000	192	%0.5=2kg	0.48
45	450	750	1000	166.5	%1.5=6.75kg	0.37

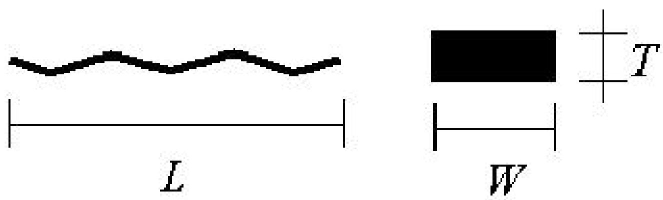


Fig (1) geometrical properties of fibers

Table 3: properties of used fibers

Type of fiber	Length (L) mm	Width (W) mm	Thickness (T)mm	Diameter (d_f) mm	L/d_f= Aspect ratio
Jc25	25	0.8	0.35	0.597	41.9
Jc35	35	1	0.35	0.668	52.4

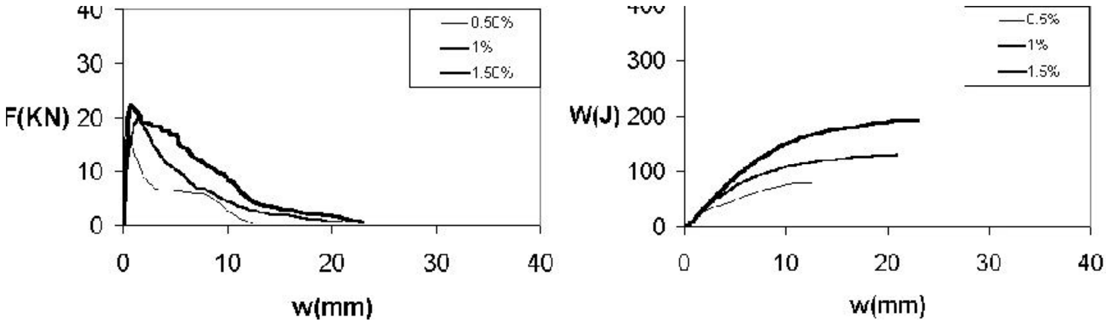
ANALYSIS OF RESULTS AND DISCUSSION

The results of experiments were summarized in table 4. The results of cylindrical compressive strength in table 4 showed that usually adding the fibers to concrete increase its compressive strength.

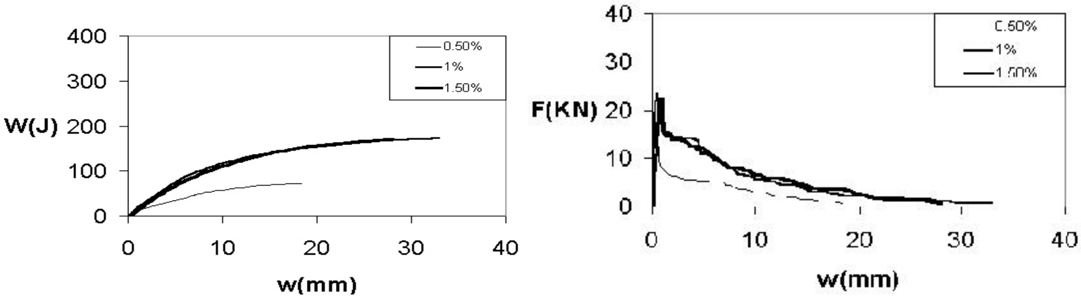
The results of slab bending experiments were provided in figures 2, A to E with load-displacement and absorbed energy-displacement curves.

Table 4: the results of experiments

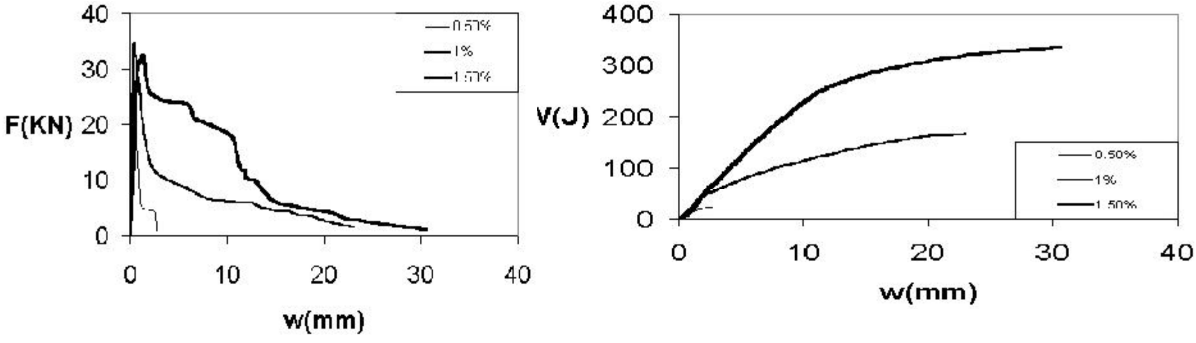
Sample No.	Cylindrical compressive strength (f_c') MPa	Max load (F_{max}) KN	Displacement for max load mm	Absorbed energy until max load J	Final displacement mm	Total absorbed energy J
1	30.0	22.1	0.52	6.1	0.52	6.1
2	32.2	21.3	0.40	6.0	12.50	78.5
3	31.6	20.2	1.50	21.0	21.00	129.0
4	30.4	22.4	0.70	8.8	23.00	192.4
5	32.4	18.4	0.22	2.2	18.50	73.0
6	33.1	23.2	0.52	8.1	33.00	172.0
7	33.0	22.4	0.95	12.2	28.00	170.5
8	44.9	26.9	0.35	6.2	0.37	6.2
9	47.6	28.0	0.42	7.0	2.75	24.1
10	45.7	34.6	0.40	7.4	23.00	166.2
11	43.7	32.4	1.25	28.1	30.50	335.2
12	45.5	25.0	0.46	7.1	17.50	94.5
13	48.3	27.2	0.78	11.7	20.50	169.8
14	45.9	33.8	0.85	17.8	39.05	372.0



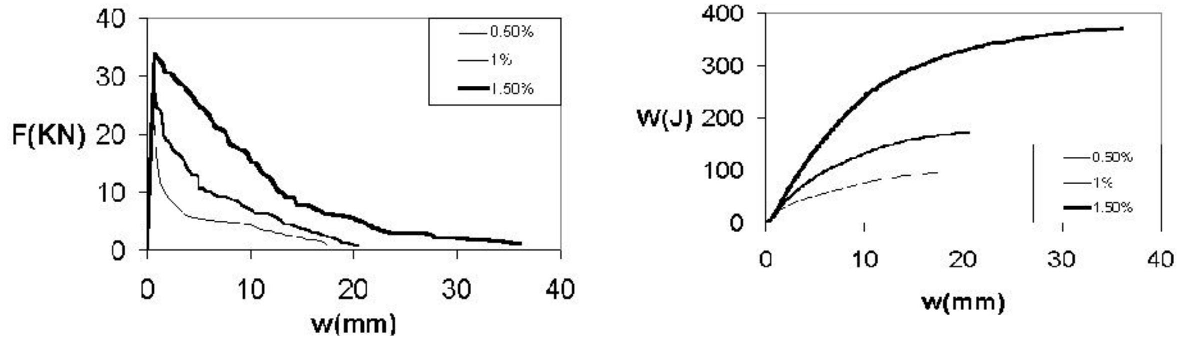
A: base strength 30 MPa and Jc25 fiber



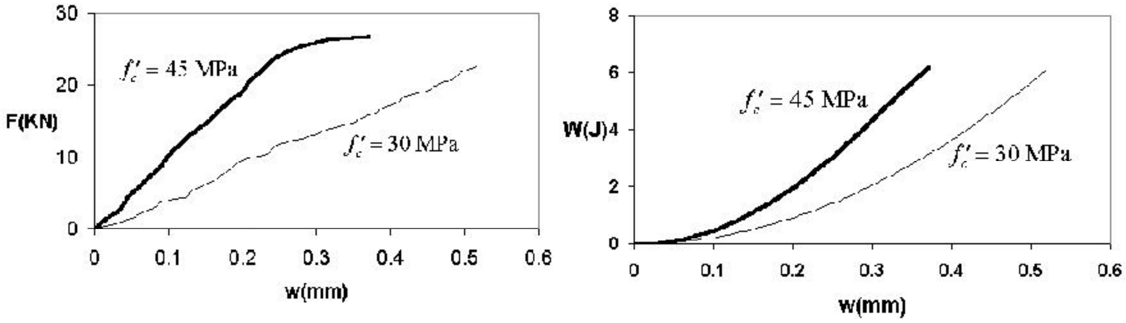
B: base strength 30 MPa and Jc 35 fiber



C: base strength 45 MPa and Jc 25 fiber



D: Base strength of 45 MPa and Jc 35 fiber



E: non-fiber slabs:

Fig (2) load-displacement and ratio of absorbed energy to displacement for slabs

A: Effect of fiber on slab's final strength

The availability and quantity of fibers did not have a significant effect on the final load of slabs. The minor difference could be resulted from the difference in concrete's compressive strength due to adding fibers. Mainly, the final load was related to the time of cracking threshold in concrete and the fibers did not have a significant effect on slab's bending properties until cracking onset. Although adding fibers decrease the elasticity module of concrete somehow, the main aim of adding fiber to the concrete was its ductility and energy absorption. Therefore, this paper considered the effect of fiber on ductility of steel fiber reinforced concrete slabs.

B: Effect of used fiber's quantity on slab's ductility and energy absorption

Generally, increasing the quantity of fiber would increase the area under the load - displacement curve or the concrete's energy absorbability. Meanwhile, increasing the fiber's quantity woulddecrease the ratio of increasing energy absorbability and therefore would increase the ductility. As it could be seen in Fig (2) B, in slabs with a base strength of 30 MPa and Jc35 fiber, increasing the quantity of fiber from 1.0% to 1.5% would not lead to increasing the ductility.

In samples with 0.5% fiber, sudden decreasing in strength after max force was seen. This was especially obvious in sample (9) with a base strength of 45 MPa and Jc25 fiber (Fig 2, C). Generally, the low quantities of fibers could not show its positive properties well. Approximately, increasing the energy absorbability and therefore ductility in fibers of 0 to 0.5% was about 12 times, in fibers from 0.5% to 1% was about 2 times and from 1% to 1.5% was about 1.5 times and increasing the fibers decreased the ratio of increasing ductility.

C: Effect of the type of fiber

According to obtained curves, increasing length and ratio of length to diameter increased the ductility. Nevertheless, increasing the quantity of fiber hada significant effect on increasing the ductility. The curves of absorbed energy to displacement showed that in four items out of six ones, Jc35 fiber absorbed more energy. Non-increasing the ductility in slab with a base strength of 30MPa and 1.5% giver compared to the similar sample with 1% fiber could be due to lack of uniformity of mix with high quantity of fibers. In the sample with a base strength of 30 MPa and 0.5% fiber, minor decrease in Jc35 fiber ductility was seen comparing Jc25 fiber.

Generally, Jc35 fiber with high ratio of length to diameter increased the ductility for 1.2 times comparing Jc25 fiber.

D: Effect of base strength

According to studies, it can be seen that increasing the concrete's compressive strength increases the concrete ductility while fiber is available. Meanwhile, type and quantity of fiber have similar effects of different base strengths.

E: Type of failure

Before final load, no considerable crack was seen in slabs. Non-fiber slabs broke suddenly during cracking load. In fact, the displacement before final failure in non-fiber slabs was between 0.35 to 0.55 mm and the absorbed energy based on the area of the load - displacement curve was very low and about J6. Fiber reinforced slabs endured considerable displacement after final load and these displacements ranged from 12.5 to 36 mm except in slab No. 9. In other words, the ratio of displacement in middle of span length was located in 1.8% to 5.3%. Fiber reinforced slabs especially slabs including 1% and 1.5% fiber fractured gradually. Though, slab's breaking accompanied bypulling out the fibers from concrete. Manner of breaking all slabs is such that they are divided from the middle.

CONCLUSION

Regarding the studies, the following ones can be concluded:

1- Adding fiver would increase the final bending strength of the slab a little but it is not significant. Meanwhile, the fibers have little effect on the slope of the ascending part of the load - displacement curve.
2- Increasing the quantity of fibers has significant effects of ductility and absorbed energy of concrete slabs. Approximately, increasing the ductility in fibers from 0 to 0.5% is about 12 times, in fibers from 0.5% to 1% is about 2 times, and in fibers from 1% to 1.5% is about 1.5 times. Increasing the fiber would decrease the ratio of increasing ductility. Adding a high quantity of fiber can limit the ductility due to lack of uniformity.
3- Generally, it is not recommended to use very-low quantities due to sudden decreasing of max force and meanwhile to use very-high quantities of fiber due to lack of uniformity. It is suggested that the fibers' percent shall be ranged from 0.8 to 1.7.
4- Increasing the length and the ratio of length to diameter of fiber would increase the ductility. Nevertheless, increasing the quantity of fiber has a significant effect on increasing the ductility. The energy absorbability of concrete including Jc35 fiber with the ratio of length to diameter is about 1.2 times comparing Jc25.
5- Increasing the concrete strength in fiber would increase the ductility and energy absorbability and meanwhile, the type and quantity of fibers have similar effects for different base strengths.

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