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Research Article

Enhancing the flexural behavior of concrete beams with steel and carbon fiber

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Abstract

Concrete is considered as brittle material with low flexural strength, which makes it susceptible to sudden failure at allow levels of load. As a result, it is necessary to reinforce and strengthen the concrete beams with different strategies to achieve structural stability. This study aims to investigate the behavior of concrete beams when reinforced with steel fibers and strengthen with carbon fibers plates and texture for the same specimen details and under the same testing conditions. The experimental work was conducted by constructing eight (100x100x400mm) concrete beams in order to study the variables; the percentages of steel fiber 0.5%, 1.0%, and 1.5%, the number of sheets in carbon fiber plates and texture (one and two layer). The experimental results showed an increase in the ultimate flexural load by 12.76, 26.10, and 55.85% when beams were reinforced with steel fiber by 0.5, 1.0, and 1.5% respectively, also a noticeable improvement of ductility and reducing deflection was observed. Strengthening by carbon fiber texture further improved the flexural strength of the beam, as the ultimate load was increased by about 61.40% when strengthen with one sheet and 130% when using two sheets. The beams also showed high plastic deformation before failure. The maximum improvement was recorded when the beams strengthen with carbon fiber plates, where the increase in failure load reached 180% and the deflection decreased by 92%, although it led brittle failure and reduced ductility.

1. Introduction

Concrete is considered one of the most important and widespread materials widely used globally in the field of construction. Since its long-term use, concrete has gained great scientific importance for studying its various mechanical properties. Concrete is a well-resistant material if it is subjected to compressive stresses, and vice versa if it is subjected to tensile and bending stresses [1-3].

There are several ways to improve the structural performance of concrete, such as adding fiber or carbon fiber [4,5]. In Fiber reinforced concrete (FRC), the separate and discontinuous steel fiber added to concrete mixture. A reduction in concrete cracks and an increase in tensile strength was investigated [6]. While [7] studied the deformations and ultimate strength of concrete beams reinforced with fiber, a noticeable increase in the load failure of the beams was recorded, in addition to a decrease in the width of the cracks. Despite the improvements provided by steel fiber reinforcement, many construction applications require greater levels of durability and stability. In order to meet these requirements, many concrete strengthening techniques is used such as application of carbon fiber polymeric (CFRP), whether as plates or texture [8]. Karnoub [9] conducted a practical experiment in which a normal concrete beam was compared to another

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strengthen with carbon fiber plates. They concluded through the study that the ultimate strength of the concrete beam increased by about twice that of the unstrengthen one. In addition, through [10] the fatigue performance was greatly improved, as the life of the concrete beam was extended and failure was achieved by breaking the reinforcing steel. When turning to another type of strengthening, which is conducted by using carbon fiber texture, this type of carbon provides the same justifications in terms of enhancing bending and tensile performance and controlling cracks in concrete beams.

In previous studies, the enhancement methods mentioned above were studied individually, each for a specific specimen and under different testing conditions. In this research, a study will be presented on improving the flexural strength of one specimen and one testing conditions using the mentioned techniques (reinforcing with steel fiber, strengthening with carbon fiber plates, and strengthening using carbon fiber texture) to determine the structural effect of each technique in a purer form for the same beam whose dimensions may be imposed for architectural purposes in order to know the engineering feasibility of each technique.

2. Materials and Mix Proportions

In the current study, ordinary Portland cement was used along with both coarse and fine aggregates, in addition to drinking water, to prepare the concrete mix. Steel fibers and carbon fibers of both types (plates and texture) were also used to reinforce and strengthen the concrete beam.

2.1 Cement

The ordinary type of Portland cement was used, and physical and chemical tests were conducted according to the Iraqi standard No.5 [11], and the results were as shown in Table 1.

Table 1. Chemical and physical characteristics of cement used

Chemical compound		Percent of content meets Iraqi No.5
SIO_2 (%)		20.22
AL_2O_3 (%)		4.00
FE_2O_3 (%)		1.78
CAO (%)		60.33
MGO (%)		3.20
SO_3 (%)		1.40
Insoluble Substances (%)		0.95
Burning Loss (%)		2.71
%C_3A		4.23
%CL		/
Physical properties		
Cement fineness (M^2/Kg)		342
Time Of Setting	Initial (Min)	100
	Final (Hr)	3:30
%Cement soundness		0.01
Strength in compressive (MPA)	2 Days	22.6
	28 Days	43.9

2.2 Coarse and Fine Aggregate

All tests required for aggregates were conducted according to Iraqi Standard Specification No. 45 of 1980 [12]. For coarse aggregate, the gradation was (5-20) mm, while for fine aggregate, its gradation indicated Zone 2. The rest of the results are shown in Table 2.

Table 2. Physical compositions of fine and coarse aggregate

Test in laboratory	Coarse aggregate	Fine aggregate
Apparent specific gravity (ASTMC128 & C127)	2.60	2.50
Bulk specific gravity (ASTM C128 & C127)	2.77	2.61
% Absorption (ASTMC128 & C127)	0.51	1.10
% wear Los Angles abrasion (ASTM C131)	24.34	--

2.3 Steel Fiber

As for the steel fiber used, its diameter was 0.2mm and its length 15mm, while its density was equal 7850 kg/m3, and therefore the aspect ratio of length to diameter was equal 75, and maximum tensile strength of 2000 MPa used to reinforce the beams. See Fig. 1.

Fig. 1. Steel fiber used in specimens

2.4 Carbon Fiber

Carbon fiber (plates and texture) was prepared from local markets, specifically from Sika company [13], with a mechanical property stipulated in the product data sheets [14]. Table 3 presents the mechanical properties of carbon fiber. The surface preparation and bonding method were listed in Sika datasheet [13,14].

Table 3. Carbon fiber (plates and texture) properties

Property	Carbon fiber plates	Carbon fiber texture
Thickness (mm)	1.2	0.255
Tensile strength (MPa)	3100	4000
Modulus of elasticity (MPa)	170,000	230,000
Elongation at break (%)	>1.8	1.7

2.5 Mix Proportions

In order to achieve the compressive strength targeted for the study (25MPa), three cylinders (150x300mm) were tested with a mixing proportion (Coarse aggregate:1087kg/m^3, Fine aggregate: 950kg/m^3, cement:325kg/m^3, and w/c:0.48) [15-17].

2.6 Tested Specimen

The experimental program for this study was conducted using eight specimens of concrete beams. The dimensions of the specimens were as specified in the American standard ASTM C78 (100x100x400mm). The tested specimens were simply supported with two external loads and two reactions as indicated in Figure 2. Figure 3 represents the specimens after casting. The specimens were cured with drinking water for 28 days before testing.

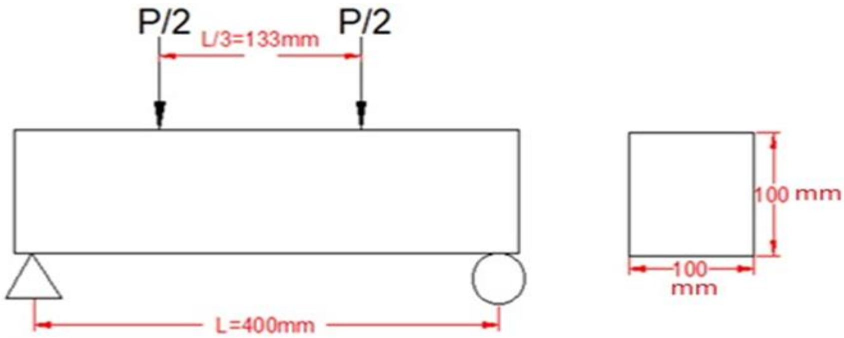

Fig. 2. Test specimen details

Fig. 3. Test specimen after casting

3. Experimental Program

Eight concrete specimens were constructed and then tested in the laboratories of the Civil Engineering Department at the University of Technology in Baghdad. In order to study the flexural behavior of the beams accurately, the test was conducted with four load points instead of three, because the test with four load points provides the area of maximum moment with a constant value with a zero-shear force. The eight specimens were divided into three groups in addition to the reference beam (BR).

The first group includes three specimens (BS0.5, BS1.0, and BS1.5) reinforced with steel fiber percentages of (0.5, 1.0, and 1.5%) which uniformly added through casting. The second group consist of two beams strengthened with one and two layers with carbon fiber texture (BCT1 and BCT2). The third group (BCP1 and BCP2) was related to strengthening with carbon fiber plates, using the same number of layers as in the second groups. See Fig.4.

Fig. 4. Specimens preparation

5.1 Instrumentation and Test Setup

LVDT installed at the top of the specimens was used to measure the deflection at midspan of the beams. The flexural strength test of beams was conducted using a machine with capacity of 50 kN with load rate of 24N/sec. The loading was continued until beams reached to the failure. Fig. 5 shows the test setup of specimen. Table 4 summarizes the experimental program and the results obtained from the flexural test.

Fig. 5. Test setup

6. Results and Discussion

After conducting the test, the flexural strength was calculated using the Eq (1): [18]

$$f_r = \frac{3PL}{2bd^2} \tag{1}$$

Where; P: the ultimate load, L: is specimen length, b: the width of concrete specimen, d: the total depth of concrete specimen.

Table 4. Experimental program results

Group	Specimen	Variable	Steel fiber content (%)	Layer of carbon fiber plates	Layer of carbon fiber texture	Ultimate load P (kN)	Maximum Deflection (mm)
--	BR	--	--	--	--	10.42	2.70
Group 1	BS 0.5	Steel fiber content	0.5	--	--	11.75	2.54
	BS 1		1.0	--	--	13.14	2.20
	BS 1.5		1.5	--	--	16.24	1.80
Group 2	BCT 1	Number of carbon fiber texture sheet	--	1	--	16.82	1.58
	BCT 2		--	2	--	18.76	1.28
Group 3	BCP 1	Number of carbon fiber plates sheet	--	--	1	24.02	0.45
	BCP 2		--	--	2	29.17	0.21

The abbreviations in Table 4, BCT and BCP refer to types of carbon fiber reinforcement, where B stands for “Beam,” C for “Carbon fiber,” and the third letter denotes the form of reinforcement: T for “texture” and P for “Plate”. From the above results, it can be noted that when concrete beams reinforced with steel fiber, the flexural strength improved by 12.76, 26.10, and 55.85% when reinforced by 0.5, 1.0, and 1.5%, respectively, where the steel fibers act as bridges that connect both sides of the cracks, clearly delaying their progress. The results also showed an increasing in the maximum flexural load of the beams by about 61.40% when strengthen with one sheet carbon fiber texture and 130% when using two sheets. The maximum enhancement and best structural performance were recorded when strengthening with carbon fiber plates, where the percentage of increase in failure load reached 180% and the decreasing in deflection 92%, where both types of carbon fiber are defined by modulus of elasticity and high tensile strength, as it acts as an additional layer that greatly resist load and stresses in tension zones.

6.1 Load-Deflection Behavior

The relation between the flexural failure load and vertical displacement at mid span for all studied beam is shown in the fig.6

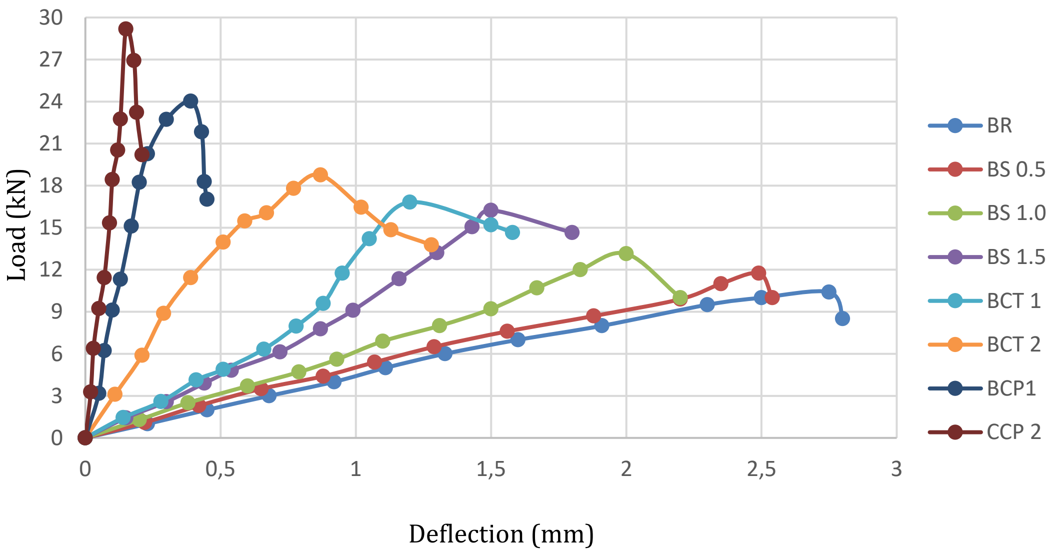

Fig. 6. Load deflection relation

The figure above shows the structural behavior of beams from load application until failure. It can be observed that the reference beam BR shows linear behavior in the initial stages with brittle failure and very little ductility. When the specimen reinforced with steel fibers (BS 0.5, BS1.0, and BS 1.5), the beams show higher plasticity and ductility with increased fiber content and a clear increasing in flexural strength. As for the beams strengthen with carbon fiber texture (BCT1 and BCT2), they show an advanced improvement in reducing deflection and significantly increasing the failure load and ductility, as the beams showed significant plastic deformation compared to previous specimens.

Finally, for the beam strengthen with sheets of carbon fiber plate, it showed the highest levels of capacity and stiffness, as it achieves the maximum load before failure. However, it tends to fail brittle, where it broke suddenly once its strength limit is exceeded due to the high tensile strength of the carbon plates sheets, which clearly reduces ductility.

6.2 Modes of Failure

In general, all specimens showed pure flexural failure with different degrees. The BR specimen failed very suddenly at low load levels due to the absence of any reinforcement in the tension zone, while the beams reinforced with steel fiber showed gradual flexural failure with the appearance of small cracks in the tension zone at middle span (area of pure bending moment), whereas (BCT1 and BCT2) showed a clearer and more controlled flexural failure, contrariwise (BCP2 and BCP2) which broke suddenly by a brittle manner. The failure mode of the tested specimens is shown in Fig. 7.

BR BS 0.5 BS 1.0 BS 1.5

BCT1 BCT2 BCP1 BCP2

Fig. 7. Failure mode of tested specimens

7. Conclusions

The following finding can be concluded from this research:

- The inclusion of steel fiber enhances the flexural capacity and the ductility of concrete beams, also the increasing of steel fiber percentage improves the stiffness and reduce the mid span deflection, resulting in better energy absorption and ductile failure with visible cracking.
- Carbon fiber texture improved structural performance better compared to steel fibers, as they contributed to increased strength and stiffness and showed high ductility compared to steel fiber reinforcement.
- The carbon fiber plate provided the highest efficiency to increase the flexural strength and stiffness of the specimens. Beams strengthen by carbon fiber plate exhibit minimal deflection and superior load capacity, although it showed brittle failure when strengthen with two sheets.
- Optimal enhancement strategy is carbon fiber plates especially if two sheets used, this make it more effective for applications requiring maximum strength and stiffness, while steel fiber and carbon fiber texture are appropriate for scenarios requiring improving ductility and energy absorption.

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