Analysis of the Flexural Strength in Different Reinforced Concrete Beams with the Addition of Carbon Fiber

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***Abstract*—The objective of this research work is to reinforced concrete beams with Carbon Fiber Reinforced Polymers (CFRP) and subject them to a flexural test. For this purpose, two concrete mix designs of 210 and 280Kgf/cm2 were made and CFRP was applied to them. A total of 12 specimens were made for each mix design and reinforced with 1/4", 3/8" and 8mm steels. It was concluded that the addition of CFRP as well as the stressing of different steel diameters improved the reinforced concrete beams in terms of flexural strength, cracking pattern, stiffness and ductility of all beams, compared to the beams without CFRP and steel reinforcement.**

***Index Terms*—CFRP, reinforced concrete, flexural strength**

I. Introduction

The employment of fiber reinforced polymers has become a popular and modern technic in the construction area. These fibers are used to reinforced and balance the structural system in buildings due to some structural deficiencies caused by the environmental exposure, strength degradation of the concrete, corrosion on the steel frame, design and construction errors and adequacy of buildings that increase the load capacity, among others [1,2]. It has been proved that the adherence of Fiber Carbon Reinforced Polymers (CFRP) can reinforce different type of structures such as concrete beams, cantilevers, walls, concrete slabs, etc. Among fibers employed as a reinforcement are carbon fiber, fiberglass, aramid fiber and basalt fiber, which have good mechanical strengths and chemical resistance. However, carbon fiber presents the highest modulus of elasticity, tensile strength, creep and fatigue resistance. The CFRP have a matrix that focus in to protect the fibers from the abrasion, from the environmental effects and from the corrosion; also this matrix acts as an agglutinant of fibers to uniformly distribute the load. Additionally, the CFRP matrix influences in the mechanical properties of composites such as the transverse modulus of elasticity, tensile strength, compressive and shear strength. The resins employed as a matrix are the epoxy, polyester and vinylester [3].

Therefore, the purpose of this study is to analyze the behavior, effectivity and resistance of carbon fiber as a reinforcement in concrete beams subjected to flexural stress where the variables are the concrete resistance, the reinforcement of the steel frame and the magnitude of the carbon fiber external strength (CFRP).

II. Materials and Methods

A. Materials

The materials employed were concrete, thick and fine aggregates, water, steel (1/4”, 3/8” of 8mm and 60cm large), hook anchor of 8cm, CFRP from SIKAWRAP-600C (Thin of 3.5x55cm and width of 7x55cm) and an epoxy resin dorm SIKADUR-301. The test tubes were beams with a transverse section of 15cm x 15cm and a length of 70cm.

B. Methods

The process requires two phases, the first one corresponds to the preparation of the tube tests or samples according to the concrete mixture design (210kgf/cm2 and 280kgf/cm2) and the application of Fiber Carbon Reinforced Polymers (CFRP). The second phase requires the flexural test of the samples in a laboratory to finally analyze the results.

1) Procedure for the preparation of structural samples

The mixture was prepared according to the concrete mixture design. The 10% of water was poured into the mixer followed by the addition of the thick aggregate, fine aggregate, cement and finally 80% of water. Another 10% of water was added to the mixture to let them bend

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for 1 min with an inclination of 20 ° to get an adequate concrete. It is important to mention that for each concrete mixture design the samples were coded as well as the steel reinforcement (of 1/4", 3/8” and 8mm) and the CFRP (thin and wide). Table I and Table II shows the codification.

After the bending, the mixture was poured in three layers of 1/3 each one with 32 vertical impacts in order to ensure the concrete vibration, then the surface of the mold was prepared to be smooth to finally place the codification. Samples were demolded. after 24 hours, to be cured during 28 days submerged in water to achieve its highest resistance, then they were moved away to be dry outdoors. Thus, once the samples were dry, the surface was polished in order to apply the adherent SIKADUR-301 followed by the application of CFRP SIKAWRAP-600C. In order to guarantee a good adherence another layer of SIKADUR-301 was applied carefully with a roller to eliminate bubbles. Finally, the samples were dried for two days as it can be shown in Fig. 1.

Figure 1. A) Concrete beam samples and B) Application of CFRP on the surface of reinforced concrete samples.

TABLE I. CODIFICATION OF SAMPLES ACCORDING TO THE 210KGF/CM2 REINFORCED CONCRETE MIXTURE DESINGN.

Íem	Steel reinforcement	CFRP reinforcement	type of CFRP	code
1	1/4”	WITHOUT CFRP	-	210-1/4-SCFRP
2	1/4”	WITH CFRP	WIDE	210-1/4-CFRP-A
3	1/4”	WITH CFRP	THIN	210-1/4-CFRP-D
4	3/8”	WITHOUT CFRP	-	210-3/8-SCFRP
5	3/8”	WITH CFRP	WIDE	210-3/8-CFRP-A
6	3/8”	WITH CFRP	THIN	210-3/8-CFRP-D
7	8 mm	WITHOUT CFRP	-	210-8-SCFRP
8	8 mm	WITH CFRP	WIDE	210-8-CFRP-A
9	8 mm	WITH CFRP	THIN	210-8-CFRP-D
10	-	WITHOUT CFRP	-	210-SA-SCFRP
11	-	WITH CFRP	WIDE	210-CFRP-A
12	-	WITH CFRP	THIN	210-CFRP-D

TABLE II. TYPE SIZE FOR CODIFICATION OF SAMPLES ACCORDING TO THE 280KGF/CM2 REINFORCED CONCRETE MIXTURE DESIGN

Íem	Steel reinforcement	CFRP reinforcement	Type of CFRP	code
1	1/4”	WITHOUT CFRP	-	280-1/4-SCFRP
2	1/4”	WITH CFRP	WIDE	280-1/4-CFRP-A
3	1/4”	WITH CFRP	THIN	280-1/4-CFRP-D
4	3/8”	WITHOUT CFRP	-	280-3/8-SCFRP
5	3/8”	WITH CFRP	THIN	280-3/8-CFRP-D
6	3/8”	WITH CFRP	WIDE	280-3/8-CFRP-A
7	8 mm	WITHOUT CFRP	-	280-8-SCFRP
8	8 mm	WITH CFRP	THIN	280-8-CFRP-D
9	8 mm	WITH CFRP	WIDE	280-8-CFRP-A
10	-	WITHOUT CFRP	-	280-SA-SCFRP
11	-	WITH CFRP	WIDE	280-CFRP-A
12	-	WITH CFRP	THIN	280-CFRP-D

2) Mechanical tests

Before the testing, both sides of the samples were painted in white color to study the fissures that could appear during the flexural test.

Two support points on the base and one point of application force on the top section were simulated. Samples were tested until they achieve their point of failure. For that reason, the fissure paths were outlined and the data was written for an easy recognition, analysis and study, Fig. 2.

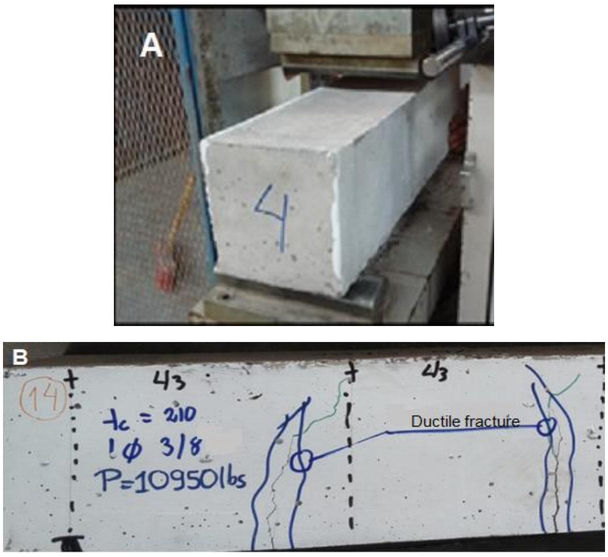

Figure 2. A) Samples of the flexural test and B) Analysis of fissures.

III. RESULTS AND DISCUSSION

A. Flexural Test for Samples of 210kgf/cm2

Table III reveals the lack of ductility of the carbon fiber alongside the 210kg/cm2 non reinforced concrete (no steel frame) leading to an explosive failure. Acoording to this, the use of CFRP in a non reinforced concrete is higly not recommendable.

For the non reinforced concrete samples it is noticed that there is an increase of forces, for example a concrete beam has 1.9Tn strenght, a concrete beam reinforced with a carbon fiber of 3.5cm wide and 60cm length has 2.1Tn strength, and a concrete beam reinforced with a carbon fiber of 7cm wide and 60cm length has 4.6Tn strenght.

On the other hand, the flexural strength of the 1/4" reinforced concrete samples is also variable. The reinforced concrete beam samples have 3Tn strength, however the flexural strength increases for samples reinforced with CFRP with values of 4.2Tn and 5.5Tn according to the wide of the fiber employed. It is also important to mention that while the flexural strength increases the ductility on the samples reinforced with CFRP decreases.

For the 3/8” reinforced concrete samples there is a maximum strength of 4.9Tn for a reinforced concrete alone. However, samples reinforced with carbon fiber had an increase on their flexural strength with values of 6.1Tn and 7.3Tn according to the wide of the fiber employed.

Finally, the 8mm reinforced concrete samples achieve 3.7Tn strength, however samples reinforced with fiber carbon had an increase on their flexural strength with values of 5.6Tn and 6.4Tn according to the wide of the fiber employed. It is also important to mention that while the flexural strength increases the ductility on the samples reinforced with CFRP decreases.

TABLE III. RESULS OF THE FLEXURAL TEST FOR F´C=210 KG/CM2 CONCRETE BEAMS

ÍTEM	CODE	THE LAST LOAD APPLIED IN THE TEST (Tn)
1	210-1/4-SCFRP	3.0
2	210-1/4-CFRP-A	5.5
3	210-1/4-CFRP-D	4.2
4	210-3/8-SCFRP	4.9
5	210-3/8-CFRP-A	7.3
6	210-3/8-CFRP-D	6.1
7	210-8-SCFRP	3.7
8	210-8-CFRP-A	6.4
9	210-8-CFRP-D	5.6
10	210-SA-SCFRP	1.9
11	210-CFRP-A	4.6
12	210-CFRP-D	2.1

B. Flexural Test for Samples of 280kgf/cm2

Table IV reveals the lack of ductility of the CFRP alongside the f'c 280 kg/cm2 non reinforced concrete (no steel frame) leading to an explosive failure with the same characteristics as the previous concrete samples studied.

It is noticed that there is a considerable increase of forces for the non-reinforce concrete samples with a value of 1.7Tn strength. Furthermore, concrete beam reinforced with a carbon fiber of 3.5cm x 60cm length has 2.8Tn strength, and the concrete beam reinforced with carbon fiber of 7cm X 60cm of length has 4.1Tn strength.

On the other hand, the flexural strength of the 1/4" reinforced concrete samples is variable. The reinforced concrete beam samples have 3.6Tn strength, however the flexural strength increases for samples reinforced with CFRP with values of 5.2Tn and 7.8Tn according to the wide of the fiber employed. It is also important to mention that while the flexural strength increases the ductility on the samples reinforced with CFRP decreases.

Additionally, the 3/8" reinforced concrete samples have a maximum strength of 5.2Tn for a reinforced concrete alone. However, samples reinforced with carbon fiber have an increase on their flexural strength with values of 6.1Tn and 6.5Tn according to the wide of the fiber employed.

Finally, the 8mm reinforced concrete samples achieve 3.7Tn strength, however samples reinforced with fiber carbon had an increase on their flexural strength with values of 6Tn and 6.9Tn according to the wide of the fiber employed. It is also important to mention that while the flexural strength increases the ductility on the samples reinforced with CFRP decreases.

TABLE IV. RESULS OF THE FLEXURAL TEST FOR F´C=280 KG/CM2 CONCRETE BEAMS

ÍTEM	CODE	THE LAST LOAD APPLIED IN THE TEST (Tn)
1	280-1/4-SCFRP	3.6
2	280-1/4-CFRP-A	6.5
3	280-1/4-CFRP-D	6.1
4	280-3/8-SCFRP	5.2
5	280-3/8-CFRP-D	6.1
6	280-3/8-CFRP-A	6.5
7	280-8-SFRP	3.7
8	280-8-CFRP-D	6
9	280-8-CFRP-A	6.9
10	280-SA-SCFRP	1.7
11	280-CFRP-A	4.1
12	280-CFRP-D	2.8

The results showed in Table III and Table IV reveal that the addition of the CFRP as well as the steel frame as a reinforcement allow the concrete beams to have a better flexural strength and a better fissure, stiffness and ductility behavior in comparison to the non-reinforced concrete beams with CFRP [3,4,5,6].

IV . CONCLUSIONS

It was demonstrated that the application of CFRP on a reinforced concrete is effective in relation to the flexural strength because of all the reinforced concrete samples had high flexural strengths achieving an increase of 30% to 40% compared to the reinforced concrete samples without CFRP.

When the flexural test applied to the concrete beams with and without CFRP, it could be noticed that the quality of the concrete (f´c= 210 kg/cm2 y f´c=280 kg/cm2) influences, in a 10% approximately, the resistance in the last load. Therefore, it can be inferred that it is possible to reinforced structures with a quality concrete inside the range employed in this study.

On the other side, it is recommended to employ a CFRP with 70cm length that fits the length of the sample because it will improve the resistance to the shearing forces applied to the reinforced concrete.

Finally, the non-reinforced concrete with CFRP presents a fragile and explosive failure, for that reason the CFRP should be applied on reinforced concrete (with steel frame) in order to increase the ductility of the structural system and to avoid the explosive failure.

CONFLICT OF INTEREST

The authors declare no conflict of interest.

AUTHOR CONTRIBUTIONS

Jeniffer Torres-Almirón and Danny Tupayachy-Quispe carried out the laboratory tests. Yosheff Ortiz-Valdivia and Jonathan Almirón analyzed the data. Jeniffer Torres-Almirón and Belinda Chavez wrote the article, all authors had approved the final version

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