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Full Length Research Paper

Strengthening with carbon fiber reinforced polymer and glass fiber reinforced polymer of insufficient bending rigidity simple rectangular beams

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The reinforcement of rectangular sectioned and simple supported beams, with carbon and glass fibers against the bending strength was examined in this study. Reinforcement of the reinforced concrete beams with Carbon Fiber Reinforced Polymer (CFRP) and Glass Fiber Reinforced Polymer (GFRP) were applied with the wrapping method on the entire tensile zone, and a bit enfolded on the side surface. Beams, with the dimensions of 160 × 200 × 2200 mm, made up of C20 (Concrete20) concrete and S420(Steel420) steel were used for this application. Moreover, crack behaviors in bending and shearing zones of the beams were examined. The displacement values of the beams were measured as 43.8, 22.8 and 32 mm for control, CFRP, and GFRP beams, respectively. Cracks occurred at the endpoint of the material that is adhered as two layers; in other words, they were seen 380 mm away from end of the beam. As result of all these findings, it can be stated that the reinforcement was successful; the beams could be reinforced with glass and carbon fibers; and glass fibers could be preferred economically.

Key words: Reinforcement, reinforced concrete beams, carbon fiber reinforced polymer, glass fiber reinforced polymer.

INTRODUCTION

Bending moment and shear force generally affect the reinforced concrete structural elements at the same time. Those structural problems sometimes appear immediately and at other times gradually which cause the structure to be unsafe. In such a case, the structure will collapse if it is not strengthened properly. Therefore, the structure needs to be reinforced. This subject becomes more significant especially in some countries, where the earthquake risk is more, such as Turkey. It should be noted that the structures built according to the old earthquake regulations are not suitable for the new earthquake regulations in Turkey. Thus, the reinforcement of all old buildings is inevitable. Reinforcement implementation is a procedure to raise the safety level of the structure or structural elements (Can, 2002).

Every structure should be reinforced with a intrinsic reinforcement technique. Reinforcement would enhance the present condition of the structures. The Reinforcement of the reinforced concrete columns, beams, and slabs is the first method that comes to mind as regards to reinforcing. The weakest points of the reinforced concrete beams are the regions where tension and shearing stress condensate. The reinforced concrete beams could have significant workmanship errors, as well as engineering mistakes, and the use of low quality materials. The inability to make the stirrup spacing as desired in the project basics, not putting longitudinal main reinforcements in sufficient amounts, inefficient anchorage of the structural reinforcement, low elaboration of the reinforcement spacing, collapse of the non-structural partition walls and chimneys, and not having a desired value of concrete class can be stated as among the main reason

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reasons for implementing reinforcement (Önal, 2002).

A reinforcement method should be developed, so the people who lives in the building does not have to move out from the structure; neighboring structures must not be affected from this method; and reinforcement could be implemented as fast as possible. Furthermore, the safety values of the structure must exceed the requirements of the old earthquake regulations. The reinforcement method should not be contradicting the values of aesthetics but be economic as well. The aim of this study is to experimentally examine the beams that are damaged because of earthquake forces and various reasons under loading conditions. Carbon Fiber Reinforced Polymer (CFRP) and Glass Fiber Reinforced Polymer (GFRP) textiles were used as the reinforcement materials; and these materials were adhered with epoxy. To make a contribution to the comprehension of the reinforcement methods to be applied in this study, these concepts were studied: the contribution of the reinforced concrete element to the bearing strength, comparison of the theoretical data with the results of the experiment, difference between CFRP and GFRP, contribution of the Fiber Reinforced Polymer (FRP) implementation technique to the reinforcement, and comparison and interpretation of the cracks in the cutting, bending, and shearing zones. The authenticity of this technique was evaluated by comparing the experimental observations and results of the theoretical approach.

The use of fiber reinforced polymers (FRP) for the rehabilitation of existing concrete structures has grown very rapidly over the last few years. FRP can be used very efficiently in strengthening the concrete beams weak in shear (Sundarraja and Rajamohan, 2009). Most research in this area has been carried out for the flexural strengthening, whereas, studies on the shear strengthening are more limited. Several studies have demonstrated the effectiveness of the use of FRP in strengthening works of RC beams under static loads of flexure and shear (Constantin and Chalioris, 2008). FRP composites have found increasingly wide applications in civil engineering due to their high strength-toweight ratio and high corrosion resistance. As a result of FRP confinement, both the compressive strength and ultimate strain of concrete can be greatly enhanced(Pan et al., 2007). Numerous theoretical and experimental studies regarding the reinforcements with FRP, were conducted. Literature review, a foundation to this study, was realized. Ways and application methods with FRP were investigated; and the proposed solutions were evaluated. Reinforcement is a change procedure to raise the load bearing capacity, rigidity, ductility, durability and/or stability of a structure above their previous or present levels (Dumanlar, 2005).

Composites are adhered to the concrete elements in forms of fiber structured polymer plates (FRP). These are widely used as glass located in polymer resin (GFRP), aramid fiber reinforced polymer (AFRP), or carbon fiber composites (CFRP). In another experimental study, about this subject, reinforced concrete beams, with dimensions of 460 × 200 × 4570 mm, were used. The beams, manufactured for the experiment were put through loading in the laboratory environment; and then, the loading capacities of the beams, both wrapped in FRP and not wrapped at all, were investigated. FRP was adhered as one of the beam soffits; and prestressing was applied with a lever jack. The lever jack was put aside after FRP had dried. The test beams were supported on both edges; and the load was applied to the beam on the middle section of the beam, by a hydraulic cylinder. The control beam could withstand only 44 kN of loading, whereas, the FRP adhered beam could withstand up to 186 kN of loading. Thus, beams covered with FRP could withstand loading that is four times stronger than a normal beam could withstand (Çelik, 2005).

Yetkin and Çavdar, in their study, reinforced the lower tension zone by an implementation of cement fiber pillow with the purpose of raising the bending strength of the test beams. The applicability of the method was first tested on the smaller dimensions samples by mortar experiments. Following that test, cement pillows with different ratios of fiber containment were located under the steel mould that is dimensioned 150 × 15700 mm and then filled with concrete. Bending experiments for 7 and 8 days were performed on the obtained beams accordingly; and thus these results showed the applicability of the method (Yetkin and Çavdar, 2004).

Carbon Fibred Polymer (CFRP) is one of the FRP materials found and used in Turkey. Considering the specifications of this material, four test samples were prepared by using Carbon Fibred Polymer (CFRP). Load displacement curves were then obtained for every test beam; and the behaviors of the elements under loading conditions were compared. It was observed that, as a result of this study, the reinforcement procedure with FRP materials significantly increase the bearing capacity of the beams (Çetinkaya et al., 2004).

Yurdakul (2003) investigated the use of the prestressed and externally adhered plastic plates, which are reinforced with carbon fibers (CFRP), on the post tensioning of the present structures in their study. Positive results were obtained on the beam by the implementation of the CFRP plates with prestressing; and the benefiting of the high tension strength of the CFRP material was ensured. Two different systems, regarding the prestressing of the CFRP plates, and their anchorage in the field conditions were investigated in this study. Steel plates or carbon fiber plates were adhered and thus, carbon plates prestressed by reinforcement were used; and its differences according to the reinforcement method were mentioned. New opportunities regarding the reinforcement of the present structures were provided with the use of CFRP plates. The use of these plates also provided a decrease

Table 1. Results of the compression tests for concrete.

C20	Cylinder diameter(mm)	Maximum load (mm^2)	Section (mm^2)	Compressive stress (kN/mm^2)
1	150	64	17663	0.0036
2	150	63	17663	0.0036
3	150	65	17663	0.0037

C: Concrete

in the stress on the internal reinforcement as well as a decrease in the values of displacement and crack widths. These effects improved the durability and fatigue behavior of the structure.

Diab (1998) experimentally investigated the reinforcement of the reinforced concrete beams by using shotcrete in his study with the purpose of determining the refitting efficiency value of the reinforced concrete beams with concrete plates. A total of 9 beams were tested in series of three: the three beams in the first series were unsuccessful; the beams in the second series were loaded by creating a steel reinforced shotcrete layer; and the beams of the third series were reinforced with the layer mortar, which was also reinforced with fiber concrete, and tested by the same method used in the second series. The results of the experiment (last loading, deviation, longitudinal stressing, and crack figure values) were evaluated; and consequently, it was determined that this method had credibility and practical use.

In an experimental study by Iki and Kumbasar (2002), conducted at the Building Material laboratory in the Istanbul Technical University, using carbon fiber reinforced polymer (CFRP) composites on the refitting and reinforcement of the structural elements: (a) Experimental examination of the previously damaged elements, under the effects of fixed axial loads and reversed cyclic flexural bending moment, following the element's refitting and reinforcement with CFRP composite material; and (b) Experimental examination of the damaged and undamaged elements under the effects of the axial loads, following the element's refitting and/or reinforcing with CFRP composite material, were performed.

The aim of the both studies is to obtain data regarding the methods for improving the behavior of the present structures under horizontal loading conditions and to develop analytical researches with the purpose of forming a basis for the design of these methods.

Composites in the beams were used in the zones where the tension stresses are mostly in effect in the study by Arduni and Nanni (1997). The occurrence of the breaks in the shearing zone of the beam is an observed condition in many studies when the composite sections are sufficient.

The fracturing modes of different materials were also obtained in the same loading system. The failure occurring in the maximum moment section, due to the crushing of the concrete in the shearing zone, is an ideal failure mechanism for reinforced concrete beams. The most suitable usage area of the composites was also investigated in the same study.

Taljsten and Elfgren (2000) performed a reinforcement procedure on the beams with CFRPs in forms of textile and braids. The capacity of the shearing strength was then examined before and afterwards. Textiles were adhered with three different methods. Methods of adjoining with hands, vacuuming, and pre-puffing were tested. It was displayed that, as a result of the experiments, the adherence of CFRP was the best method for the reinforcement under the shearing stress in the beams.

Myers et al. (2001) conducted a total of 48 beam reinforcement procedures regarding the adherence of FRP on the beams. These reinforced beams were exposed to freezing and thawing under loading, high humidity, high temperature, and the ultraviolet beams of the sun. FRP's crack tensions and figure changes were then examined for the elements on which the loading test was applied on four points. As a result of the study, it was stressed that bending rigidity was increased and the samples were more affected under heavier load; and thus, implementation according to the technical specifications is significant.

EXPERIMENTAL DETAILS

General properties of the beams material reinforcing steel and concrete

The material used for 9 moulds in the experiment is poplar wood. The in to in net dimensions of the moulds were shaped as 160 × 200 × 2200 mm. C20 concrete use for beam manufacturing, was taken from ready-mixed concrete plant. The ready-mixed concrete plant were made according to the TS802 (Turkish Standarts 802). The results of the compression test applied on the 28 days samples can be seen in Table 1. In the test beams, ø8 and S420 were used as longitudinal and horizontal reinforcements. Elasticity module were taken as 2×10^8 kN/m^2 in the calculations. Reinforcement details of the test beams can be seen in Figure 1. The reinforcement, S420 structural steel. One hundred and fifty three (153) stirrups were used in each of the beam samples; 50% condensation was applied to the 1/3 shearing zone in the both ends of the beam; and 3 more stirrups were placed at each end of the beam. Reinforcement plan of the experiment samples can be seen in Table 2 and 3.

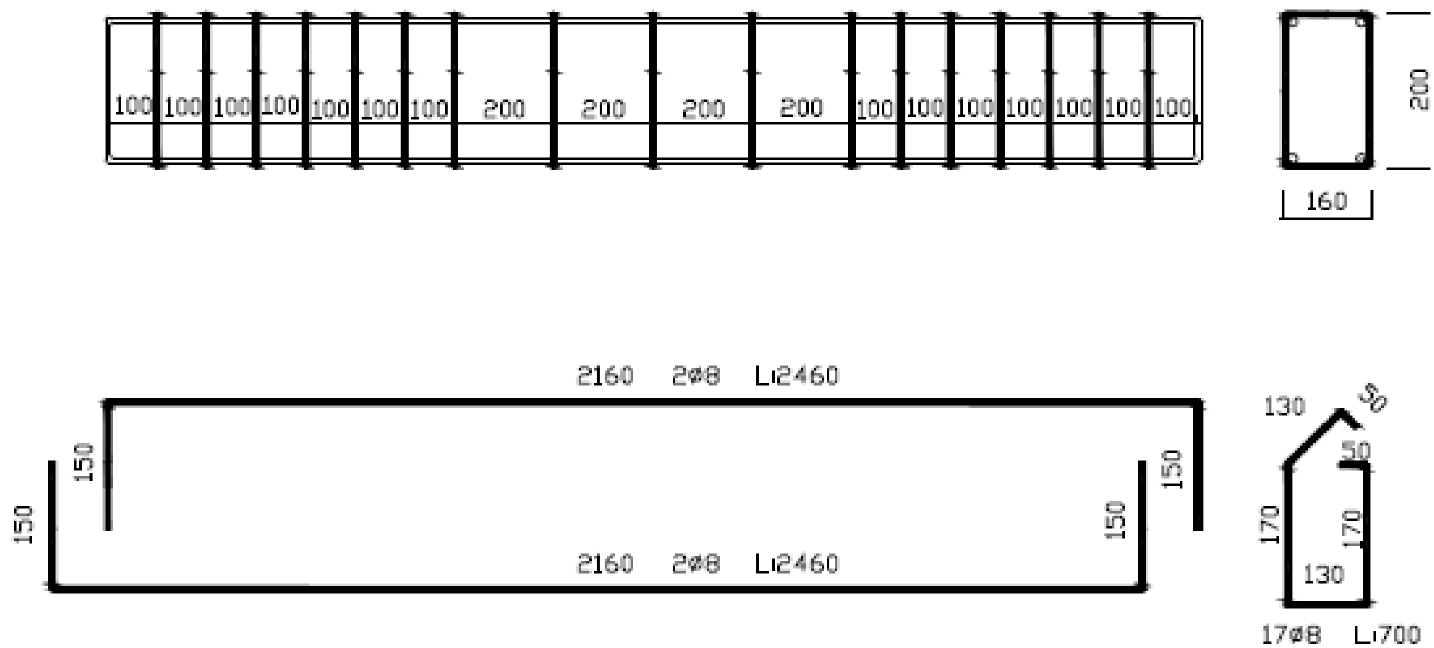

Figure 1. Reinforcement details of the test beams.

Table 2. Reinforcement, strength, and mechanical properties of the beams.

Copy No	Sample	Type	No	Area (mm^2)	Reinf. ratio	f_{ck} (N/mm^2)	f_{yk}(N/mm^2)	F_{su} (N/mm^2)
1	WO1	S420	2ø8	35200	0.0014	0.0036	44.93	68
2	W02	S420	2ø8	35200	0.0014	0.0036	44.93	68
3	W03	S420	2ø8	35200	0.0014	0.0036	44.93	68
4	CO1	S420	2ø8	35200	0.0014	0.0036	44.93	68
5	C02	S420	2ø8	35200	0.0014	0.0036	44.93	68
6	C03	S420	2ø8	35200	0.0014	0.0036	44.93	68
7	G01	S420	2ø8	35200	0.0014	0.0036	44.93	68
8	G02	S420	2ø8	35200	0.0014	0.0036	44.93	68
9	G03	S420	2ø8	35200	0.0014	0.0036	44.93	68

f_{ck}: Concrete cylinder compressive strength, f_{yk}: Yield stress, F_{su}: Tensile reinforcement, W: Witness beam, C: Carbon fiber beam model, G: Glass fiber beam model.

Table 3. Reinforcement plan of the experiment samples

Experiment element	Usage
3 Samples	Control samples.
3 Samples	Two layers CFRP second layer minus 380 mm from both ends. They will be reinforced in bending and tension.
3 Samples	Two layers GFRP second layer minus 380 mm from both ends. They will be reinforced in bending and tension

Table 4. Symbol and names of the beam samples

Beam samples	Reinforcement material and method
WO1	Control
W02	Control
W03	Control
C04	Two layers CFRP second layer, minus 380 mm from both ends. They will be reinforced in bending and tension
C05	Two layers CFRP second layer, minus 380 mm from both ends. They will be reinforced in bending and tension
C06	Two layers CFRP second layer, minus 380 mm from both ends. They will be reinforced in bending and tension
G07	Two layers GFRP second layer, minus 380 mm from both ends. They will be reinforced in bending and tension
G08	Two layers GFRP second layer, minus 380 mm from both ends. They will be reinforced in bending and tension
G09	Two layers GFRP second layer, minus 380 mm from both ends. They will be reinforced in bending and tension

Methods

Various methods are used for the retrofitting of the reinforced concrete beams with insufficient bending strengths. One of them is the reinforcement method performed by using FRP. For determining the efficiency of this method, experiments were conducted by using rectangular sectioned samples in order to examine effects on the behavior of the element. Nine (9) beams, with a clear span length of 2000 mm, were obtained in the Mechanics Laboratory of the Construction Department. Reinforcement was applied on these beams by using CFRP and GFRP textiles. These textiles were adhered to the beams, at the same points of each beam, from the outside of all the beams. Displacement Transducers were then attached on the 4 symmetrical points at both sides of the beams; and 2 more were attached at the tension and pressure zones to determine the cracks. One of the braces was arranged as fixed by loading at four points while the other was fixed by using an epoxy called Sikadur 330. Leaving out 3 beams as the control beams, reinforcement was applied by using 3 layers of CFRP and 3 layers of GFRP, both having the single layer applied minus 380 mm from the both ends, on the bending and tension zones. Six (6) displacement transducers were attached to the brace that was adjusted as mobile. The values of bearing strength, displacement, and crack were obtained as a result of these loadings. The comparison of the values belonging to control samples and reinforced beams were then realized (Yazgı, 2007) as the last step. Symbols and names of the beam samples can be seen in Table 4.

Bearing strength of the sample element

Shear forces found in values higher than the concrete can bear for most beams in practice. The most appropriate method in this condition is the bearing of the inclined tension pressures, which consist of pressure forces, with reinforcement. Although, the ideal shearing force reinforcement does seem to be the reinforcement placed within the orbit of the inclined tension forces, it is not practical. Moreover, these orbits do change for every loading situation. Thus, the most encountered shearing force reinforcements are the lateral reinforcements (stirrups) that are placed perpendicular to the longitudinal reinforcements. The function of these reinforcements is to meet the tension forces and to keep the width value of the cracks, which can occur during this loading, at the minimum (Ersoy, 1998).

According to the TS500 (Turkish Standarts 500), the f_{ck}(Concrete cylinder compressive strength) value is multiplied with the coefficient of 0.85; and the distribution of the stress is transformed into an equivalent rectangle for finding the concrete pressure bearing.

Load-displacement correlation

Load- displacement correlations obtained from the experiment, conducted within the loading program of the beam samples, were compared with the data taken from the Data Logger.

Energy consumption in beams

It is known that energy consumption capacities of the experimental elements are accepted as being equal to the area that is below load- displacement curves. On the other hand, it is one of the known bases of the physics that the total energy does not change but the form of the energy change. Therefore, such a system consumes some of its loaded energy by transforming it to the deformation energy. The energy that might be transferred is generally directly correlated with the length of plastic zone. Thus, energy consumption capacities of the structural system are very significant. Energy is equal to the work performed; work, on the other hand, is equal to the multiplication of the values of force and distance. Derived from these definitions, energy consumption capacities of the experiment elements were found belonging to the area that is loaded with the maximum load within the load-displacement curve.

Ductility ratios in beams

The structural systems of the structures are classified into two groups; as Systems with Normal Level of Ductility and Systems with High Level of Ductility. In the systems that have a high level of ductility, it is required that elastic earthquake forces should be reduced with a higher coefficient because of the energy consumption capacity that could be created by large disfigurations and displacements due to the high level of ductility. The factors below enable a system to have a high level of ductility:

1. Both the strength and ductility of the concrete should be increased by using frequent stirrup arrangements. For example, a condensation in the number of stirrups should be applied near the beam column joints, which are expected to experience difficulty in withstanding earthquake, in the sections of the beams and column.
2. The ductile yield would emerge sooner than the brittle one. For example, shearing force capacity, which emerge the brittle yield, should be kept higher than bending moment capacity that emerge the ductile yield in the elements such as beams and columns (Atımtay, 2000).

The ratio of ductility was found out by using the load-displacement correlation in this study. It could also have been found by using the moment-curvature correlation. Nonetheless, moment-curvature correlation is generally not preferred for the determination of the ductility ratio in experiments because the measurement value is open to discussion as regards to the idiosyncratic behavior of the reinforced concrete. Thus, ductility calculation is performed by using the load-displacement correlation in this study. Then, the deformation at the cross point of the horizontal axis, which is passing through the 85% of the monolithic element strength of the load-displacement graphic, was determined in order to calculate this ratio.

Preparation of the beams

Nine (9) beam moulds were prepared for the pouring of the concrete. Concrete was poured to the mould with a mixer and then compressed with a vibrator. These prepared beams were irrigated for 21 days. Three samples were separated as the control samples after 28 days, whereas, the other samples went through a surface preparation before the reinforcement. Rounding was applied from the both bottom corners of the samples with a radius of 30 mm. The samples were numbered orderly.

Reinforcement of the beams

Epoxy was applied to the region on the prepared experiment beams where the textiles were going to be adhered to. The beams adhered with CFRP and GFRP in such a way so that no air would be left below. The sections, where the crack investigation was going to be performed after one week, were determined. The strain gauges were then adhered to the determined points as the last step of the reinforcement.

Installation of the strain gauges and the experiment mechanism

Ninety (90) items from the brass material were prepared as the joint elements. Twenty (20) items, with jaw opening of 5 × 12 × 180 mm mould aluminum, and 40 items, with jaw opening of 5 × 12 × 280 mm mould aluminum, were prepared. 3 mm holes, with axial interval of 150 mm, were punched on the mould with jaw opening of 5 × 12 × 180 mm. For the others, however, the holes were punched so that axial interval was kept at 250 mm. Apparatus in two different sections were adhered at 45° to capture the cracks at the highest level; and the same procedure was applied on the middle sections at both the top and bottom of the beam. Displacement transducer, with a sensitivity of 0.001 mm, was utilized to determine the changes in the figure due the movements of tension and pressure at the bottom and top, respectively. This device was composed of three sections; displacement transducer, fixing jig, and a dummy plate. Two different types of displacement transducers, with jaw openings of L50 (Bar length) and 250 mm, were used for the experiment. Adhesion of the displacement transducers to the beams can be seen in Figure 2.

Loading device, which is located at the Structural Mechanics Laboratory of the Construction Department, was utilized for the preparation of beams used in this research. The device has two brace apparatus that are on the top of a vehicle moving in rails. Those braces were adjusted so that the distance between them was kept at 2000 mm and one of the braces was fixed. Loading was implemented on the beams at four points. The interval distance between those loading points were kept fixed as 660 m. Metal plates, with a thickness of 10 mm, were prepared to prevent the crushing at the loading points. A magnetic apparatus that was to be attached to the top section of the device, on which LVDT (Linear Variable Differential Transformer) was to be attached, was then prepared. Demountable strain gauges were attached at 6 points in the same sections (previously marked points) on each beam sample for the determination of the cracks. The values were recorded within one second intervals by means of a value recorder that was placed on the table near the loading device. Six (6) values of crack and one value each for displacement and loading were recorded by the value recorder. The records were taken for every second from a total of 8 channels. The braces were adjusted as fixed and mobile; and crack changes from the bottom section on the beams, which was previously determined, were monitored. Displacement transducer (LVDT), with a sensitivity of 0.01 mm, recorded values just at the midpoint of the beam. All of the data was recorded for every five seconds; and the values were observed from the Data Logger digital screen during the recording. The experiment was repeated again by setting the initial values to zero in all the channels before every new recording session. Loading mechanism used in the experiment can be seen in Figure 3.

RESEARCH FINDINGS AND EVALUATION

Experimental findings

The changes monitored in the behavior and strength during the experiments were observed very carefully and then presented with all its details.

Beam displacement values

LVDT model, with 0.01 mm sensitivity, was used for the measurement taken from the same points during the

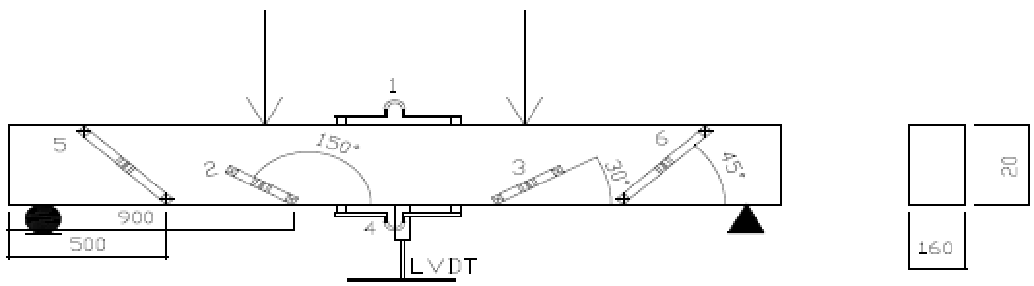

Figure 2. Adhesion of the displacement transducers to the beams.

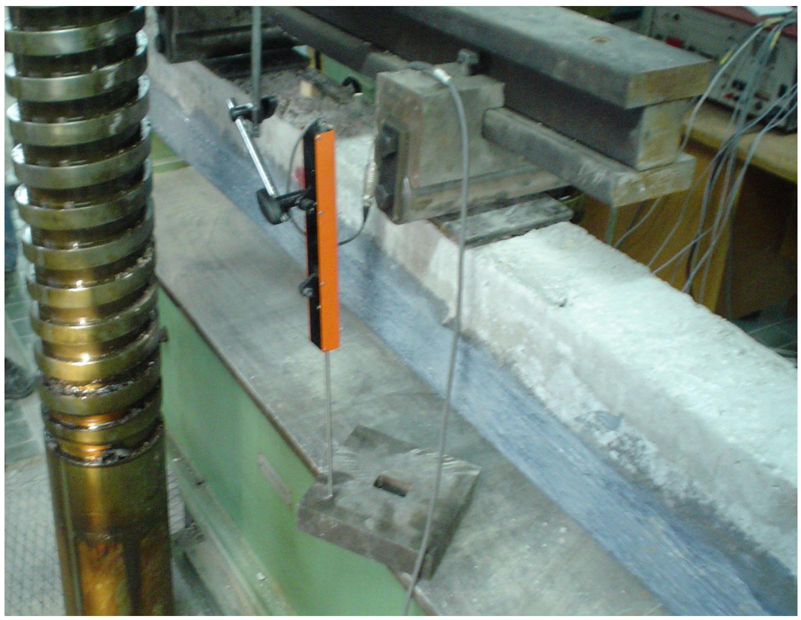

Figure 3. Loading mechanism in the experiment.

loading of all beams. Channels connected to the Data Logger were set to zero before the initiation of each loading. Displacement values were recorded with intervals of five seconds until the end of the experiment.

Load displacement values

Load-displacement correlations were drawn, by using the data obtained from the computerized loading program. Load values measured from the beams are displayed graphically in Figure 4, 5, and 6.

The displacement values obtained by the application of the maximum loading are presented in Table 5 for further interpretation.

As comprehended from the Figures and Table 5, the displacement values obtained in the control beams were 43.8 mm, whereas, the displacement values of 22.8 and 32 mm were obtained for the beams reinforced with

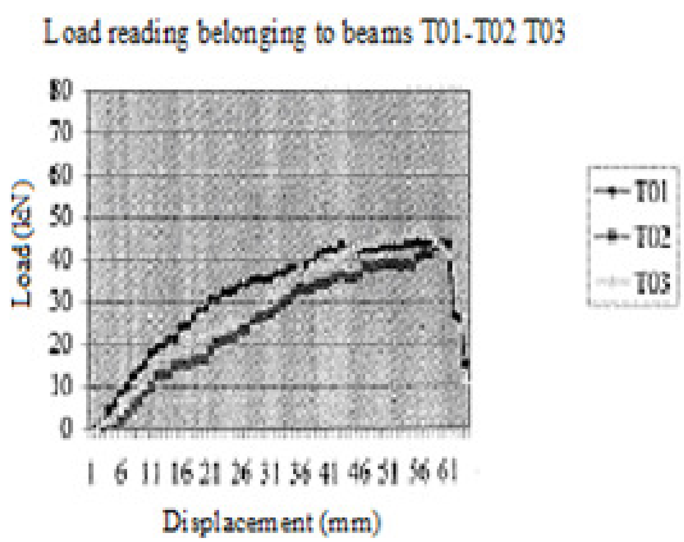

Figure 4. Load displacement graphic belonging to the control beam.

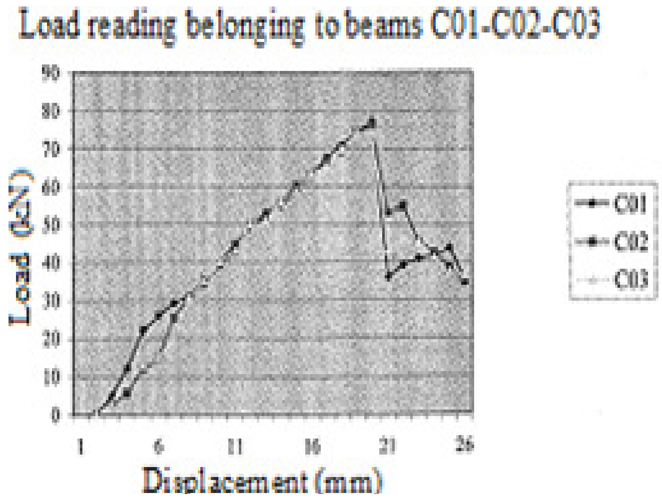

Figure 5. Load displacement graphic belonging to the CFRP beam.

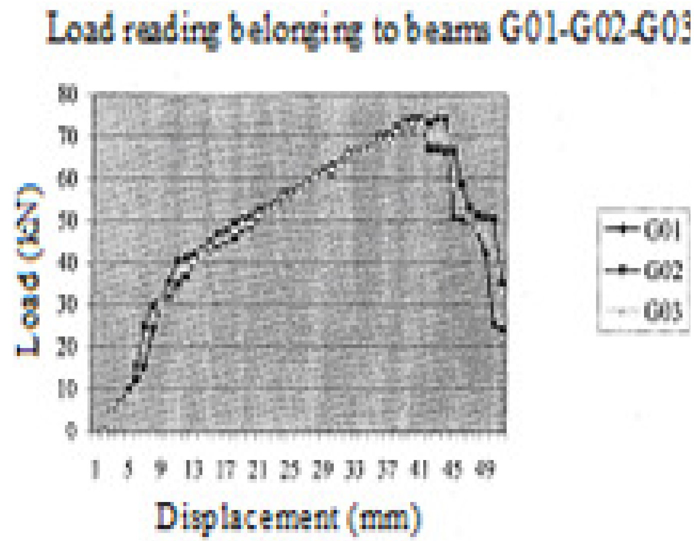

Figure 6. Load displacement graphic belonging to the GFRP beam.

CFRP and GFRP, respectively. When the loading values were considered, the maximum loading value of 46.933 kN was reached for the control beams while the beams reinforced with CFRP and GFRP had the maximum loading values of 75.80 and 74.10 kN, respectively. It was seen that the fracturing load values for CFRP and GFRP beams were not so much different when the values were evaluated.

Energy consumption values

The energy consumption capacities of the test elements were accepted as equal to the area below the load displacement curves; which is the area belonging to the values equivalent to 15% more than yielding point. Nonetheless, it is one of the known bases of the physics that the amount of total energy does not change but the form of the energy changes. Therefore, such a system consumes some of its loaded energy by transforming it to the deformation energy. The energy that might be transferred is generally directly correlated with the length of plastic zone. Thus, energy consumption capacities of the structural system are very significant. Energy consumption values of the beams can be seen in Table 6.

It can be seen in Table 2 that the maximum energy consumption was monitored in the beams reinforced with GFRP. Control beams did consume 15% less energy than the beans reinforced with GFRP. The lowest energy consumption, on the other hand, was seen in beams reinforced with CFRP.

Load crack values

Four (4) strain gauges were placed in the both ends of the beam to determine the values of the crack that occurred on the shearing zones of beams. The cracks on this zone, obtained from the strain gauges, in the maximum loading conditions were recorded to the table for further interpretation. The same procedure was implemented for the cracks in the bending zone. Shearing cracks of the beam samples in maximum loading conditions was recorded in Table 7, whereas, descriptive statistics regarding the maximum breaking loads of the beams can be seen in Table 8, and, finally, descriptive statistics regarding the displacement values during the application maximum breaking load was recorded Table 9.

According to the results of the variance analysis performed, there is a difference with significance level of $p < 0.05$ between both breaking load values and deformation values regarding the reinforcement techniques. In other words, the values for breaking load and displacement do change in relation with the reinforcement technique applied on the beam samples. The results of the variance analysis can be seen in Table 10 and 11.

According to the results of the multiple comparison test conducted on the fracturing tension values, the fracturing load values belonging to GFRP and CFRP beams were not found to be statistically significant. On the other hand, fracturing load values belonging to the GFRP and CFRP beams were found to be significantly different than the control samples. The results of the multiple comparison test can be seen in Table 12.

According to the results of the multiple comparison test performed on displacement values V, however, the displacement values of all the beam samples were statistically different from each other. The results of the multiple comparison test can be seen in Table 13.

Table 5. Displacement of the beam samples against maximum loading.

Beam samples	Maximum load (kN)	Displacement (mm)
WO1	43.0	44
W02	46.0	39
W03	50.5	43
CO1	77.0	22
C02	75.6	23
C03	74.0	27
G01	75.0	37
G02	74.0	28
G03	73.5	35

Table 6. Energy consumption values of the beams.

Beam serial no	Maximum load (kN)	Displacement (mm)	Energy absorption capacity (kNmm)
W01	43.0	44	99750.50
W02	46.0	39	99219.50
W03	50.5	43	106637.65
CO1	77.0	22	74298.30
C02	75.6	23	69981.20
C03	74.0	27	79179.40
GOI	75.0	37	118008.53
G02	74.0	28	105660.15
G03	73.5	35	137245.35

Table 7. Shearing cracks of the beam samples in maximum loading conditions.

Beam samples	Maximum load (kN)	Strain gauge no 2 (mm)	Strain gauge no 5 (mm)
WO1	43.0	27	0.15
W02	46.0	26	0.005
W03	50.5	21	0.28
CO1	77.0	0.54	0.18
C02	70.6	0.48	0.52
C03	74.0	0.58	0.76
G01	75.0	0.50	0.22
G02	74.0	0.32	0.22
G03	73.5	0.15	0.28

Table 8. Descriptive statistics regarding the maximum breaking loads of the beams.

Reinforcement technique	Number of samples	Mean	Standard deviation	Standard error	95% confidence intervals for means		Min.	Max.
					Lowest Limit	Highest Limit		
Control	3	4.6933	0.3690	0.2130	3.7768	5.6099	4.38	5.10
GFRP	3	7.4100	3.464E -02	2.000E -02	7.3239	7.4961	7.37	7.43
CFRP	3	7.5800	0.1411	8.145E -02	7.2296	7.9304	7.43	7.71
Total	9	6.5611	1.4167	0.4722	5.4721	7.6501	4.38	7.71

Table 9. Descriptive statistics regarding the displacement values during the application maximum breaking load.

Reinforcement Technique	Number of samples	Mean	Standard deviation	Standard error	95% confidence intervals for means		Min.	Max.
					Lowest limit	Highest limit		
Control	3	43.8167	2.3079	1.3324	38.0836	49.5497	41.18	45.47
GFRP	3	32.0067	3.9749	2.2949	22.1325	41.8808	28.55	36.35
CFRP	3	22.8167	3.5713	2.0619	13.9450	31.6884	20.70	26.94
Total	9	32.8800	9.5701	3.1900	25.5238	40.2362	20.70	45.47

Table 10. Variance analysis of the maximum breaking loads of the beams.

Variance source	Sum of squares	Degrees of freedom	Mean of squares	F-test	Significance level (p).
Between groups	15.742	2	7.871	150.178	0.000
Within groups	0.314	6	5.241E-02		
Total	16.056	8			

Table 11. Variance analysis of the displacement values of the beams during the application of maximum breaking load.

Variance source	Sum of squares	Degrees of freedom	Mean of squares	F-test	Significance level (p).
Between groups	664.932	2	332.466	29.439	0.001
Within groups	67.761	6	11.293		
Total	732.693	8			

Table 12. Duncan multiple comparison analysis results for maximum fracturing load (tf) values.

Reinforcement technique	Number of samples	Groups with difference (p < 0.05)	
		1	2
Control	3	4.6933	
GFRP	3		7.4100
CFRP	3		7.5800

Table 13. Duncan multiple comparison analysis results for displacement (mm) values.

Reinforcement technique	Number of samples	Groups with difference (p < 0.05)		
		1	2	3
CFRP	3	22.8167		
GFRP	3		32.0067	
Control	3			43.8167

According to the regression analysis conducted in the study, the correlation between the fracturing load and displacement values could be represented by a second degree model equation; $Y = a + bX + cX^2$. Fracturing load = 2.6258 + (0.4068 × Displacement) - (0.0081 × Displacement^2) (R^2 = 0.941). Regression Analysis graph of the correlation between maximum fracturing load (ft) and displacement values (mm), on the other hand, can be seen in Figure 7.

The beam samples reinforced with CFRP and CFRP

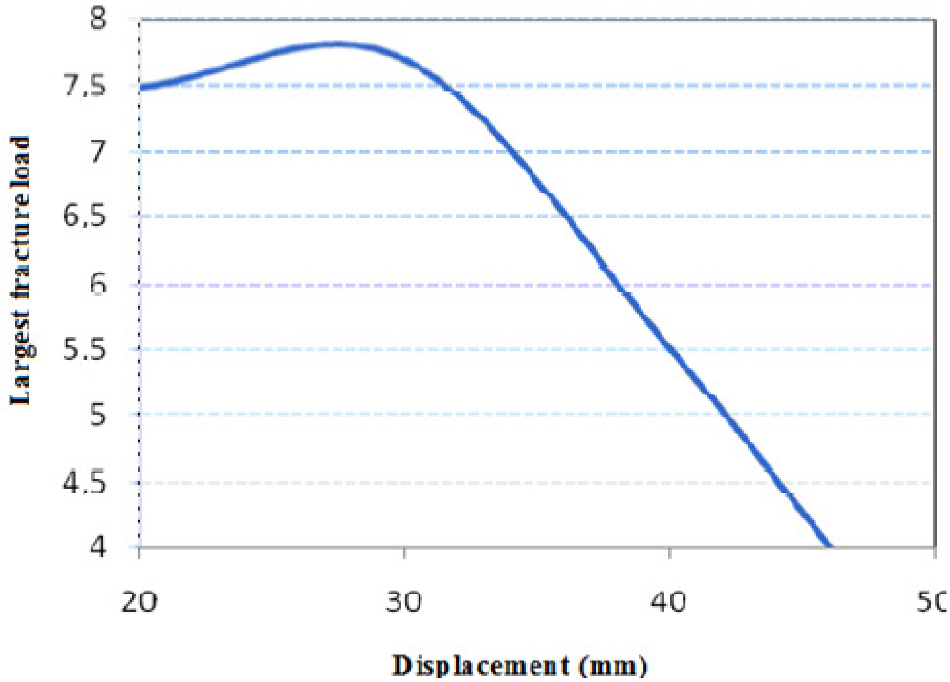

Figure 7. Regression Analysis graph of the correlation between maximum fracturing load (ft) and displacement values (mm).

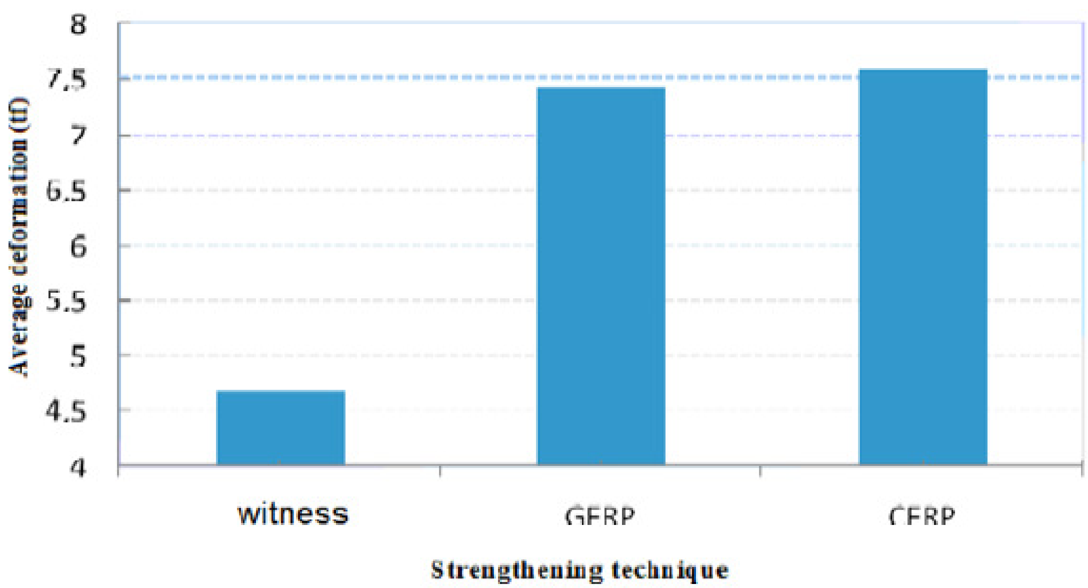

Figure 8. Bar graphics belonging to the mean maximum fracturing load values of the control, GFRP, and CFRP beams.

could endure almost twice as much as mean maximum fracturing load than the control samples as can be seen in maximum fracturing load values bar graphics (Figure 8). Likewise, line graphics belonging to the mean maximum fracturing load values of the beam samples in relation with the reinforcement technique used can be seen in Figure 9; bar graphics belonging to the mean maximum displacement values of the beam samples in

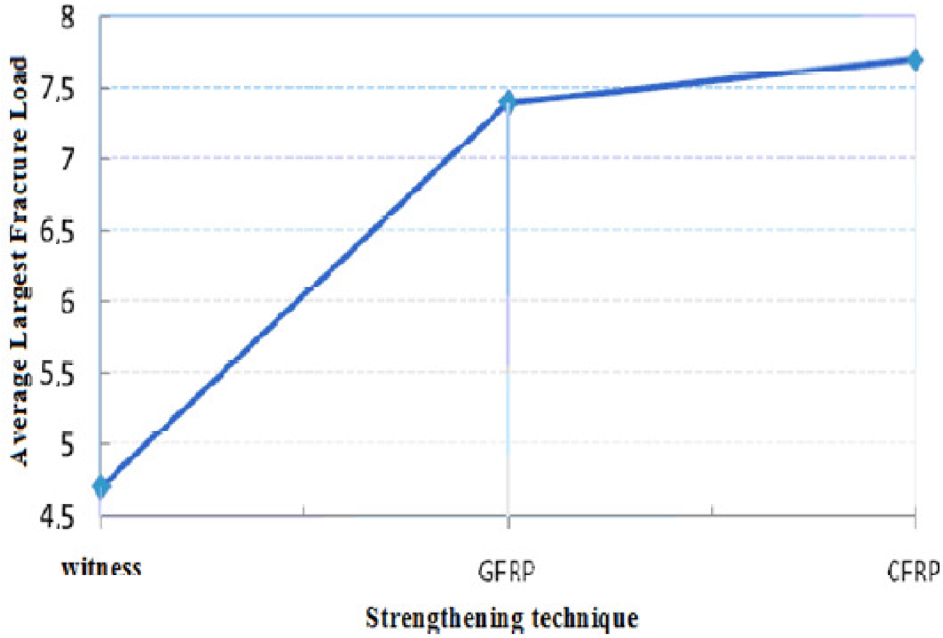

Figure 9. Line graphics belonging to the mean maximum fracturing load values of the beam samples in relation with the reinforcement technique used

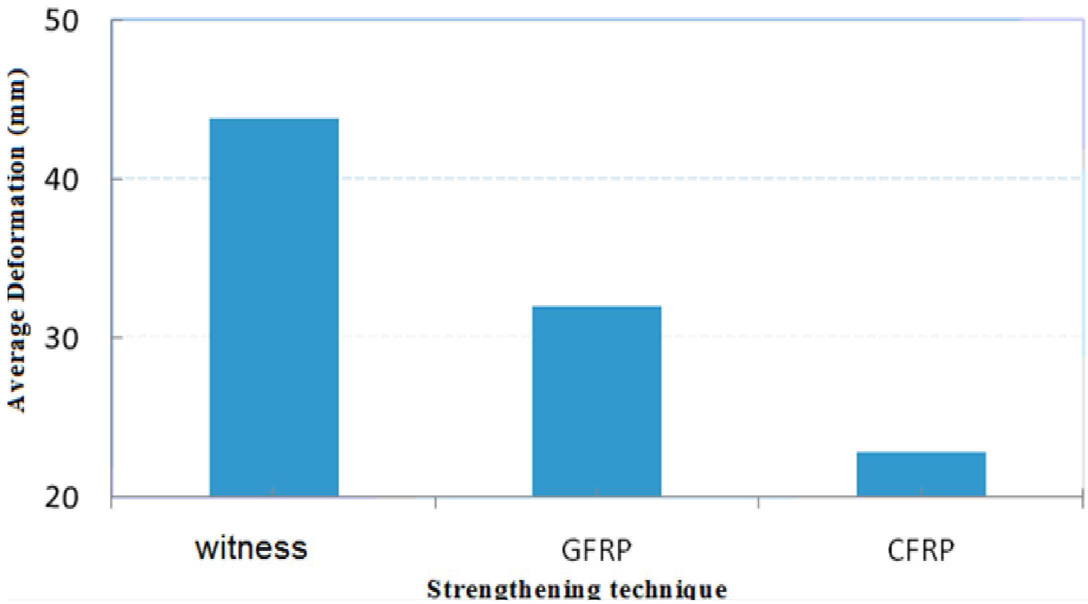

Figure 10. Bar graphics belonging to the mean maximum displacement values of the beam samples in relation with the reinforcement technique used.

relation with the reinforcement technique used is presented in Figure 10; and line graphics belonging to the mean maximum displacement values of the beam samples in relation with the reinforcement technique used can be seen in Figure 11.

RESULTS AND RECOMMENDATIONS

The sample beams started creating a squawk when the loading intensity was increased and it was then ended with the sound of a brittle fracture following the maximum

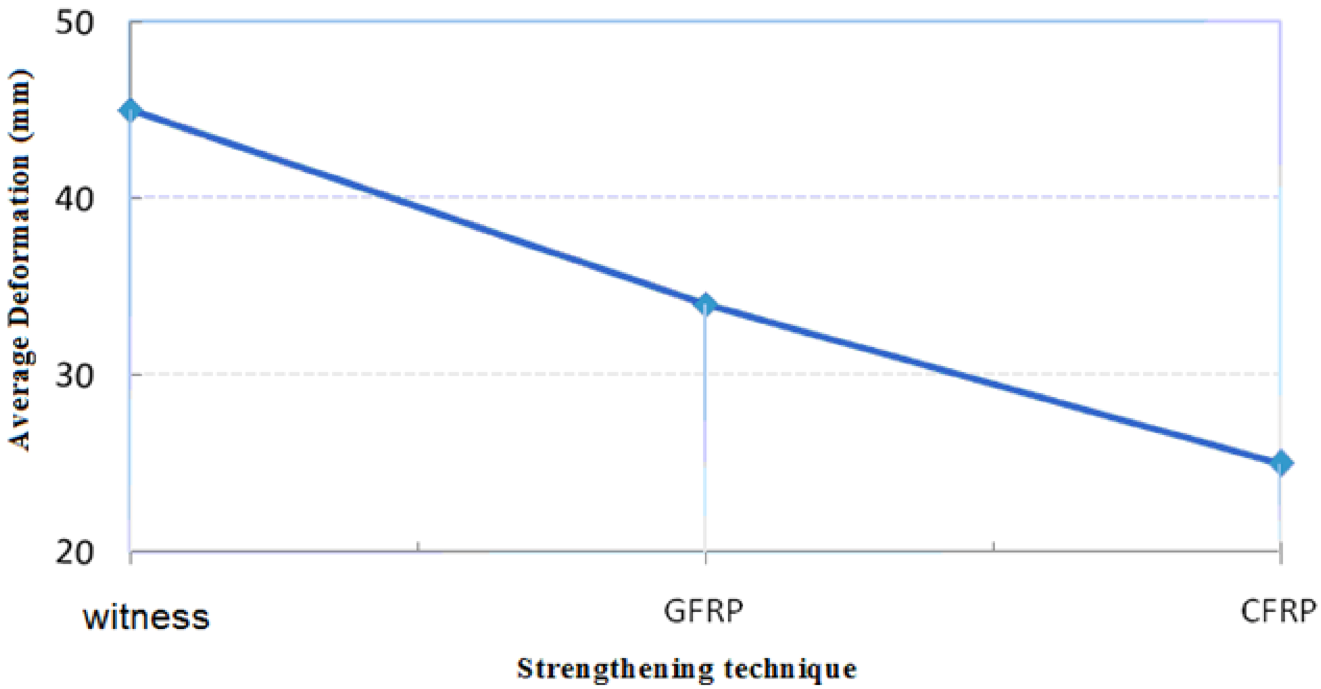

Figure 11. Line graphics belonging to the mean maximum displacement values of the beam samples in relation with the reinforcement technique used.

loading. The maximum load monitoring of the textiles was performed at the same time as the occurrence of the brittle fracture.

Cracks occurred at the endpoint of the material that is adhered as two layers; in other words, they were seen 380 mm away from the end of the beam.

The results were obtained from Data Logger by means of printout and diskettes. It was observed that CFRP, as a layer, had almost the same endurance values as GFRP. Since the use of GFRP strips in the shear deficient beams, the initial cracks are formed at higher loads than their respective control beams. This shows that use of GFRP strips are more effective in the case of strengthening of structures in shear. The ultimate strength of beams can be increased by the use of GFRP inclined strips.

The presence of GFRP inclined strips on the beam inhibited the development of the diagonal cracks. A significant difference was seen in the load causing the initial cracks. The load deflection behaviour was betterfor beams retrofitted with GFRP inclined strips.

The displacement values of the beams were measured as 43.8, 22.8, and 32 mm for control, CFRP, and GFRP beams, respectively.

As result of all these findings, it can be stated that the reinforcement was successful; the beams could be reinforced with glass and carbon fibers; and glass fibers could be preferred economically.

RECOMMENDATIONS

1. Investigation of the precautions to reduce the negative effects of the epoxy, for decreasing the ductility of the mortar fibers, maybe the use of more elastic adhesives, in similar studies and actual implementations,
2. Conducting a study using an aramid material with the abovementioned aim,
3. The implementation of a study by using different wrapping styles could also be recommended.

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