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*Full Length Research Paper*

# Reinforcement of beams by using carbon fiber reinforced polimer in concrete buildings

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**Concrete beams, which have insufficient bending and shear strengths, were strengthened wrapping them with Carbon Fiber Reinforced Polimer (CFRP) in this study. The work was implemented on the rectangular section beams that were observed to requiring reinforcement after the examination and statistical analysis conducted. The aim was to strengthen beams that have insufficient shear strength values. Three among the nine used for the examination, was reinforced by using CFRP and epoxy in the tension surface whereas another three of them was reinforced by wrapping CRFP with 45° angle in the shear. The remaining three beams, on the other hand, were used as the reference beams. The reinforced beams were tested under the loading on the four points. The values were then compared with the reference beams' values. As a result of the test; the strength was observed to increase with a 40% whereas a small increase was determined when rigidity and energy consumption values were determined.**

**Key words:** Concrete structures, beam, reinforcement, strength, shear strength.

## INTRODUCTION

The works in order to build dwellings, social facilities, school buildings etc., which are among the structures that have become main requirement with the increasing desire to live in the urban, and then to put them in the usage of the community, to develop a systematic method in the more rational structures, and to enable effective use of the resources have been ongoing. Therefore, built concrete buildings are designed regarding the features of strength, economy, and aesthetics. The dimensions that are considered in the designing phase should be enabled in the implementation phase as well. Insufficiencies in the concrete building elements can occur because of the possible changes in the usage after the construction, seismic, wearing, corrosion, aging etc. effects, or poor workmanship during the construction phase.

The structures should therefore be reinforced because of such implementation and design errors. Moreover, the reinforcement becomes a necessity because of the wearing due to age and changes in the initial aim of usage. The implementations of reinforcing the structures are as old as the building of the structures. Even though various implementations regarding reinforcement have been implemented, new methods that are easier to apply are being developed with every passing day (Önal, 2002).

Reinforcing is the work and change implemented to increase the values of load bearing capacity, rigidity, ductility, and stability, or just some of these values, to the level of original values and or above.

Reinforcing of structural elements of a building is the shortest way. The implementations regarding the reinforcement of especially concrete columns, beams, and slabs are the first ones that come to mind. The weakest points of the concrete beams are the sections where tensile and shear stresses are intensified.

The studies that were done on reinforcement will enlight and suport the subject matter of this study.

Ferrocement was adhesed to two surfaces of the damaged concrete beams to reinforce them with ferrocement laminates; performance results obtained by applying load on these beams. Ferrocement was observed to be the most suitable alternative for the restoration of the concrete structures and reinstating the structural elements according to the results obtained (Yazar, 1997).

Diab (1998) examined the reinforcement of the beams empirically by using sprayed concrete and examined nine beams, with three different series, to evaluate the restoration efficiency value of concrete beams with concrete layers. He was unsuccessful in the three beams belonging to the first series: the reinforced steel was loaded by sprayed concrete layer in the second series while the beams in the third series were reinforced by reinforced mortar layer that was manufactured by fiber concrete. The beams in these series were tested by the same method used in the second series. The results were discussed; and the results obtained from the mathematical modeling, empirical observation, and theoretical approaches were compared. The credibility of the method and its practical use was accepted as a result.

Collins et al. (1990) tried the restoration techniques by using gum injection for the reinforcement of the concrete beams. The special beams were shattered after the restoration and left to gain its endurance strength. The gum injected concrete beams were observed to be supporting the fracture after the first damage more efficiently.

It was observed that Fiber Reinforced Polimer (FRP) has showed better performance when applied to the beam's bending section with angles of 45 - 135°C. It was obtained during the researches that when a damaged beam is reinforced by using FRP, it was observed to reach a better value than the design capacity (Arduni and Nanni, 1997).

The concrete beams were reinforced with FRP. Analytical and emprical studies were conducted about this concept matter. CRRPs adhesed perpendicular to the fractures were concluded to be increasing the durability and rigidity. Brittle fractures were observed because of the stress accumulation (Norris et al., 1997).

Two different types of reinforcement were implemented on the sliding sections of the beams. Textiles were adhesed both on all of the shear section and scattered on the section. This study again gave the idea that a different type of reinforcement could enable an economic advantage. Many new results were obtained in the study in which plates were adhesed to the bending section of the U and L shaped beams in order to prevent the tilt of the composite edges. The benefits of the composites adhesed perpendicular to the fractures and difference between the scattered and whole wrapping methods were researched (Triantafillou, 1998).

Reinforcement was implemented with both textile and stripe shaped CFRPs on the beams. The capacity of the shear strength was researched for before and after. Textiles were adhesed in three different shapes. The methods of adjoining with two hands, vacuuming, and pre-blowing were tried. It was conluded as a result of the experiments that the best reinforcement method was the adhesion of CFRP (Täljsten and Elfgren, 2000).

The shear capacities of the beams were investigated by using CFRP. The experiments were conducted on the six t-beams. CFRP was adhesed on the outer surfaces of the t-beams; the results showed that the material could be applied without any additions (Khalifa and Nanni, 2000).

Full scale beams were strengthened to increase bending and shearing capacities, by replacement, with FRP plates. Four bridge beams were reinforced against shearing and bending with CFRP. Load deflection and stresses were measured in the four point bending tests. It was detected that 150% increase in strengths was ensured in all of the samples (Yang and Nanni, 2001).

The effect of angle rounding in FRP reinforcements was examined. FRP capacity reached 67% for the circular columns. It was pointed out that the angle rounding had a significant effect (Yang, et al., 2001).

Experiments were conducted on the 17 beam samples, with three different dimensions, and CFRP, with two different thicknesses, in this study. The effect of FRP on the shear section was investigated. Shear stress was observed to be increasing when FRP on the shear section was decreased; the reinforcement inside the beam could countervail the tension of the concrete without displaying any lengthening effect on the dimension of the beam (Khalifa and Nanni, 2002).

Altın and Anıl (2001) empirically researched the behavior of the beam reinforced to increase shear capacity with steel plates. Three different types of steel plates were used that includes many variances in their study. Total of five t-shaped beam samples, one being the control, was produced in the labotary and tested. The efficiency of the reinforcement technique and its effects on the element's strength and behavior was evaluated.

After 48 beams were reinforced with FRP, high temperature and moisture were exposed and experimentally tested. It was found that the regidity was decreased relatively (Neef, 2002).

Can (1994) examined the method of creating a new concrete layer of vertical reinforcement and concrete additions on the upper and lower surface of the beam, which is widely used for the restoration of the reinforcement of the concrete beams, in his empirical study. The beams reinforced with the aforementioned restoration method were tested with the reversible stresses similar to the earthquake. The behavior and strength of the test beams were compared with the behaviors and endurances of one-cast beams after the restoration. It was observed that the endurance strength was increased.

Ashour et al. (2004) performed a three point bending experiment on reinforces elements and found that those beams carried 80% more load.

Wu et al. (2005) highlighted that reinforcement with FRP had many advantages and easy to apply because of not having any corrosion and rust effect.

The beams, strengthened in this study, were reinforced in their bending and shear sections with the abovementioned aim. CFRP textiles were used as the material in the reinforcement implementation. The studies conducted nationally and internationally regarding the concept matter was examined. It was planned to conduct experiments on nine concrete beams. Nine concrete beam samples, with 150* 250* 2200 mm dimensions were produced, by using C 20 concrete and S 420 structural steel in the Structural Mechanics Laboratory.

CFRP was wrapped, in three of the samples, on their tension surface. Three of them were wrapped with 45° angle on their shear section and tested. The measured values were compared with the values obtained from the

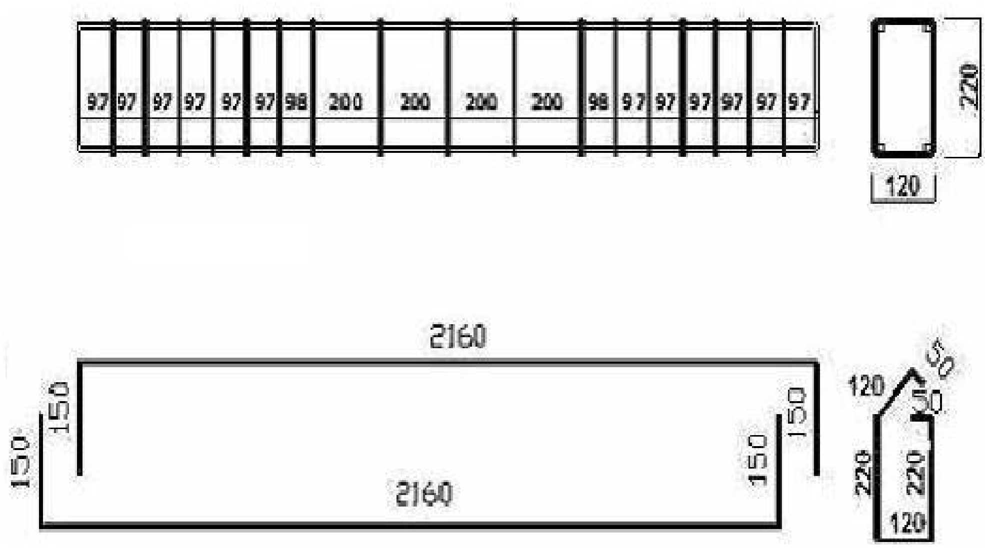


**Figure 1.** Reinforcement details of the tested beams.

three reference samples. Numerous studies about restoration and reinforcement, and experimental studies regarding the subject matter were analyzed.

## EXPERIMENTAL DETAILS

### General properties of the beams reinforcing steel and concrete

Nine beams having 150* 250* 2200 mm dimensions were prepared by using C 20 concrete. Ribbed iron, having ф8 and ф12 diameters, were used as the reinforcement material. Total of 11 stirrups were placed in all of the samples. Total stirrup number in the 1/3 shear section on the both sides became 17 by condensing the stirrups with a ratio of 50% (Önal, 2006). Schema belonging to the reinforcement used in the tested beams and its details were given in Figure 1.

Structural steel to be used in the elements of the experiments was purchased at one time; and mechanical characteristics determined in the tensile tests were done at Middle East Technical University Materials laboratory and conducted on the gained samples (Table 1).

The concrete of the samples, were poured, by compressing with a vibrator at the same time. The concrete used was purchased from a ready-mix concrete plant. The values obtained with the compression tests of the 28 days cylinder samples, taken during production and given in Table 2.

### Proporties of the epoxy mortar and CFRP

Special care was paid to the temperature of the exopy environment, called Sikadur with specifications and two concurrent materials of A and B, and amount of the epoxy used. It was elaborated that the amount of the adhesive material was 2 kg/m$^2$; and CFRP was covered so that it was protected from the external effects (Teknomed, 2000). The specifications of the epoxy were given in Table 3.

CFRP is a uniaxial fiber reinforcement material, with a weight of 230 gr/cm$^2$, made from carbon fiber. The material used in the experiment was 0.60 x 50 m rolled Sika Wrap 230℃ (Teknomed, 2000). Its specifications were given in Table 4.

### Applications of CFRP on the beams

Epoxy was applied to the marked area on the tension faces of the loaded the beams, for the first three samples. CFRP was adhesed in such a way that its axis was the same as lower axis. Textile, which has been intensed by using gloves, was pressed with a roller so that no air is left under the material. The adhesion of the intensified CFRP was ensured so that no air was left under it. After the reinforcement textiles have been covered by epoxy, it was made sure that the material was dried completely. The beams were made ready for the experiment by keeping them at +20℃ temperature for ten days.

Epoxy was applied to the marked area in the shear sections of the samples. Following the CRFP wrapping 1/3 shear section with 45°; intensifying the textile with glove; adhesing of the textile by applying pressure with a roller; and completion of the reinforcement by the suitable application of the materials according to the instruction manual, the beams were then made ready for the experiment by keeping them for ten days. Method of adhesing CFRP on the beams is given in Figure 2.

### Measuring the fracture on the beams

Displacement transducer was used to measure the fractures on the beam. The measurement device used is composed of three sections: displacement transducer, fixing jig, and dummy plate. Two different types of displacement transducer, with measuring capacities of 150 and 250 mm, were used for the experiment. The molds in for elements used in connections and between claws were produced separately with wood. Wood cubes, with dimensions of 12 x 12 x 12 mm, were fixed on the beam surface with epoxy as the connection elements. These cubes were used along with montage apparatus called Dummy plate; these montage apparatus were obtained from the material wood. These plates were prepared with dimensions of 5* 12* 180 mm and 5* 12* 280 mm. The montage apparatus were previously prepared so that 3mm holes existed on 1500 mm axes on the 5* 12* 180 mm plate while the axial distances were 250 mm each. Montage apparatus that are suitable for their area of use were previously fixed, by using 17 mm wood screws, on the cubes. Apparatus were adhesed on two separate regions with 45° in order to catch the fractures on the adhesion sections with a higher level.

**Table 1.** Specifications of the reinforcement steel.

| Notation | Specifications | Unit | Ø8 mean | Ø12 mean |
|---|---|---|---|---|
| D | Diameter | mm | 8.25 | 12.37 |
| A | Sectional Area | $mm^2$ | 53.42 | 120.05 |
| Py | Yield Load | kN | 24 | 54 |
| Fyk | Yield Stress | $kN/mm^2$ | 0.4493 | 0.45 |
| Pu | Breaking Load | kN | 36.33 | 82 |
| Fsu | Breaking Stress | $kN/mm^2$ | 0.68 | 0.68 |
| L | Clutch Length | mm | 100 | 200 |
| S | Total stretch | mm | 121.6 | 239.67 |
| | Elongation | % | 21.3 | 19.83 |

**Table 2.** Experiment results of the concrete cylinder samples.

| C20 samples | Cylinder diameter (mm) | Axial load (kN) | Section ($mm^2$) | Axial pressure tension ($kN/mm^2$) |
|---|---|---|---|---|
| 1 | 150 | 64 | 17663 | 0.0038 |
| 2 | 150 | 66 | 17663 | 0.0039 |
| 3 | 150 | 63 | 17663 | 0.0036 |

**Table 3.** Specifications of the epoxy.

| Apperance | Mixture A- white, mixture B- gray |
|---|---|
| Density | 1.31 kg/L |
| Mixture Ratio | A/B = 4/1 (According to mass) |
| Mixture Working Life | +35℃ 30 min. +10℃ 90 min |
| Viscosity | Not fluent like flour |
| Application Temp. | +10℃- +35℃ |
| Adherence | Concrete breaks but the gum does not break in the tensile test implemented one day after |
| Tensile Strength | 30 MPa 7 days +23°) |
| Elasticity Module | 3800 MPa 7 days +23°) |
| Shelf Life | 24 months 15 - 25° |

**Table 4.** Specifications of CFRP.

| Weight | 230 $gr/m^2$ |
|---|---|
| Thickness | 0.13 mm |
| Roller Width | 60 cm |
| Roller Length | 50m |
| Tensile Breaking Limit | 3500 MPa |
| Tensile design Strength | 920 Mpa |
| Breaking Strech | 0.013 |
| Design Strech | 0.004 |

The same procedure was applied on the centers of top and bottom of the beam. Montage apparatus was dismantled after epoxy cubes were adhesed to the beam. A unit deformation meter was adhesed on these during the experiment. All of the unit deformation meters. which are shown in the figure below. had a precision value of 0.01 mm deformation. The pressure device in the Structural Mechanics Laboratory was used as the experiment mechanism. Pressure was applied on a total of four points. two upper and two lower. to the experiment elements. The distance between the locations where the pressure was applied was fixed as 660 mm. Metal plates with a thickness of 10 mm was prepared for using them in pressure application regions. A magnetic apparatus. over which Linear Variable Differential Transformer (LVDT) was to be attached and placed on the upper section of the device.

Deformation meters demontable on the previously drawn locations, were attached to six points on the sample beam for the determination of the fractures. The values were recorded for every five seconds via data collection system placed on the table beside the loading device. Data collection system recorded six values for fractures, one value for displacement and one value for loading. The values were recorded for every five seconds from a total of eight channels. Photograph of the experiment mechanism is given in Figure 3. And loading mechanism of the experiment was given in Figure 4.

A displacement transducer LVDT. with a precision of 0.01 mm. was placed on the dead center of the beam. The recording was observed through Data Logger digital screen. The values were set to

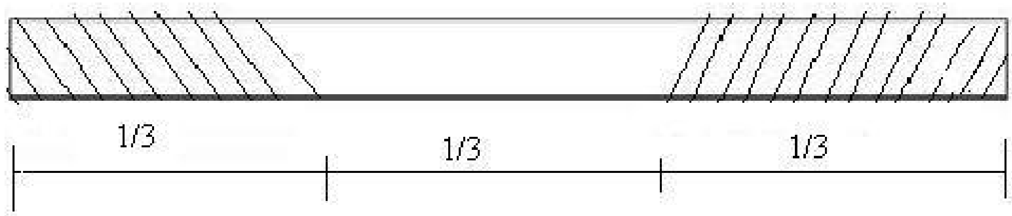


**Figure 2.** Method of adhesing CFRP on the beams.

**Figure 3.** Photograph of the experiment mechanism.

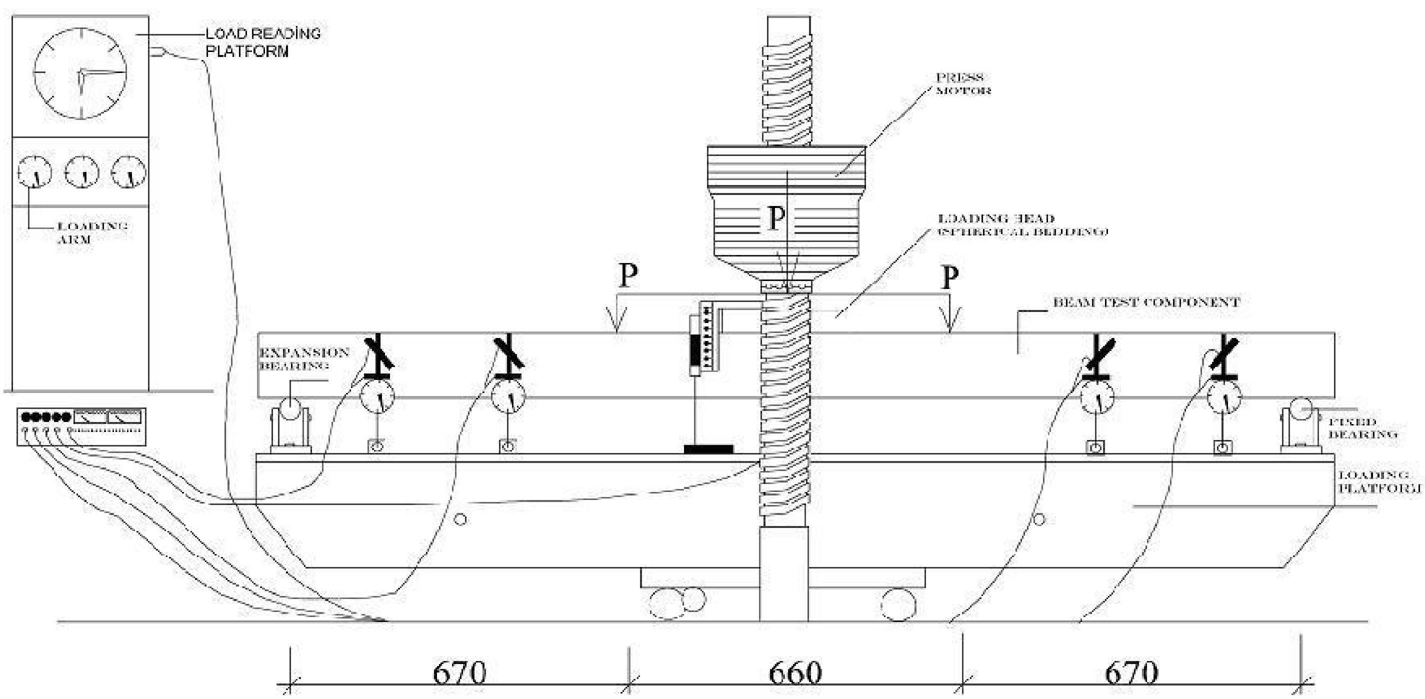


**Figure 4.** Loading mechanism of the experiment.

**Table 5.** Reinforcement plans of experiment samples.

| Number of experiment elements and dimensions (mm) | Explanation |
|---|---|
| 3<br>150 x 250 x 2200 | 3 CFRP was reinforced in tensile in bending.<br>1/3 Shear Section was wrapped with $45^0$. |
| 3<br>150 x 250 x 2200 | 3 CFRP was reinforced in Tensile in Bending.<br>Only Lower Region tensile section was wrapped. |
| 3<br>150 x 250 x 2200 | 3 beams were used as control elements. |

**Table 6.** Displacement of the beam samples at the maximum load level.

| Beam samples | Maximum load (N) | Displacement (mm) |
|---|---|---|
| B101 | 99000 | 32 |
| B102 | 92600 | 49 |
| B103 | 95900 | 55 |
| BC101 | 133100 | 31 |
| BC102 | 136500 | 37 |
| BC103 | 128100 | 44 |
| BC201 | 125900 | 39 |
| BC202 | 122600 | 40 |
| BC203 | 119300 | 19 |

B: Beam; BC: Beam Carbon Fiber

zero before every new recording; and the experiment was initiated following this reset.

## METHODS

Nine beams having dimensions of 150 x 250 x 2200 mm. were produced. by using C 20 concrete and S 420 structural steel. Reinforcement was implemented on these beams by using CFRP textile Sikadur 330 epoxy. Three beams were used as the control elements: another set of three was reinforced in their tensile sections while the remaining set of three was reinforced by wrapping with 45° CFRP in their shear sections. Six Displacement Transducers was attached to the beams. It was aimed to determine the fractures. 4 on the both sides of the beams and 2 on the tensile and shear sections. which occurred in the total of six regions. The distance between the braces was set as 2000 mm in the tested elements; which has been exposed to tension on four points. The values of force. displacement. and fractures were measured during the experiment. The reinforcement material and its method were shown in Table 5.

## RESEARCH OBSERVATIONS AND EVALUATION

### Load displacement values

Load-displacement relationship was plotted on the computer by using the observations that were obtained as a result of the loading procedure. The displacement measured on the center of the beams and load values obtained during the first breaking moment were graphically shown in Figure 5. 6 and 7.

Displacement values of the samples at the maximum loading level were presented below for interpretation in Table 6. Displacements were observed to be increasing after the reinforcement material loses its efficiency. The maximum strengths of all the experiment elements are given below as well as the displacement values against these strengths. A decrease in the displacement values was observed following the reinforcement application. The increase in the strengths of the CFRP beams was measured as 44% while the decrease in the displacement ratio was calculated to be 39.5%.

### Fracture load values

The fractures obtained from the four unit deformation meter. placed on shear section of the beams to interpret at which load values the fractures occurred. The same procedure was applied for the bending section of the beam.

Shear fractures occurred as 28 mm in sample 2 while it was 0.17 mm in sample 5. The decrease in fractures occurred as 109% in sample 2, belonging to the samples with CFRP. whereas fractures increased by 230% in the control sample 5. The fracture values for the reinforced samples however were observed to be varying and the values were given in Table 7 and 8.

Shear section number 2 was considerably strengthened with the help of the reinforcement condensation (Ersoy and Özcebe. 2001).

The changes in the tensile section of the beams were observed as below. The changes of the samples against the maximum loading occurred as 75 mm in average. The fractures decreased by a ratio of 80% in the reinforcements with CFRP. It can be interpreted that the rehabilitation in these sections increased the rigidity of the beams.

### Energy consumption values

The energy consumed in the beams was calculated by finding the energy yield and failure points. CFRP failure decreased by 30% while the energy consumption increased by 14.5% in the concrete beams; according the values obtained from the control samples (Table 9).

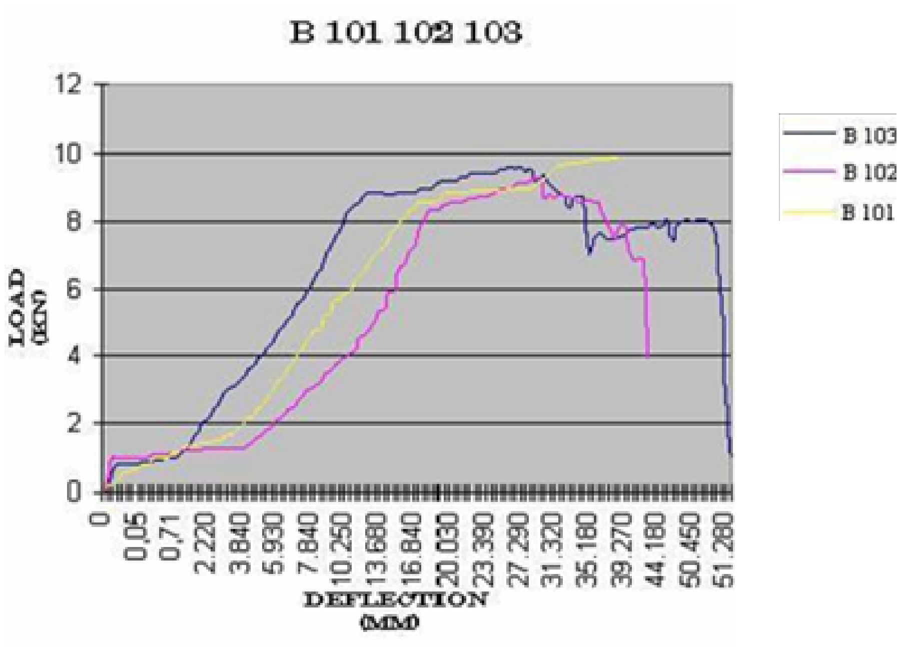


**Figure 5.** Load displacement graphic for B 101. B 102 and B 103.

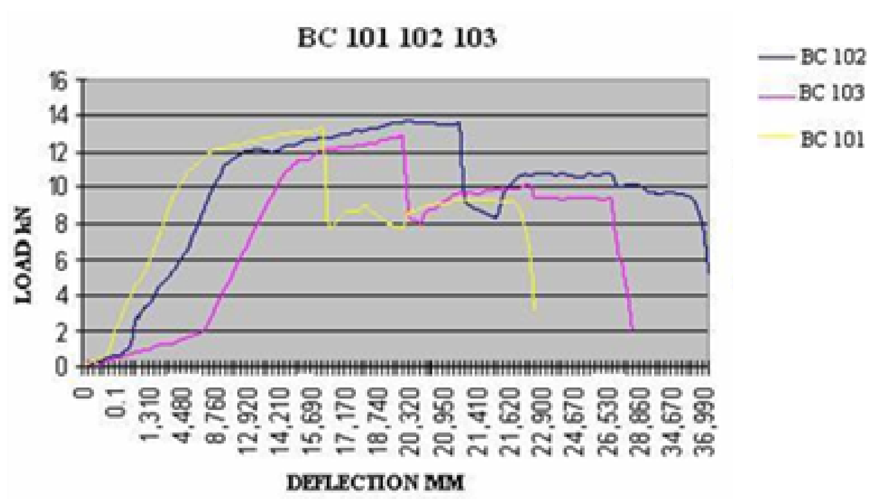


**Figure 6.** BC 101 102 103 load displacement graphic.

## RESULTS AND SUGGESTIONS

The reinforced beams have reached failure in the form of Brittle fractures as a result of the increasing forces. Although the strengths of the reinforced sample elements increased a considerable amount with no significant increase compared to the reference beams as was observed according to ductility and energy consumption. The textiles used for reinforcement was torn apart in fibres. CFRPs which had been curled upwards with a 45° angle. were observed to encounter a difficulty in the region 50 mm away from the curling area.

The failure in all of the beams occurred in the middle points; where maximum tensile stress due to flexure is expected to occur.

The specimens reinforced with CFRP carried an average of 40 - 45% more load than the control elements.

The maximum fracture in the beams could be measured by using a 250 mm unit deformation meter that is located 450 mm inside from both sides of the beam with a 45° angle. Although 0.25 mm fractures occurred in the first shear region of the control samples fractures occurred as 0.55 and 0.42 mm on the bending and shear

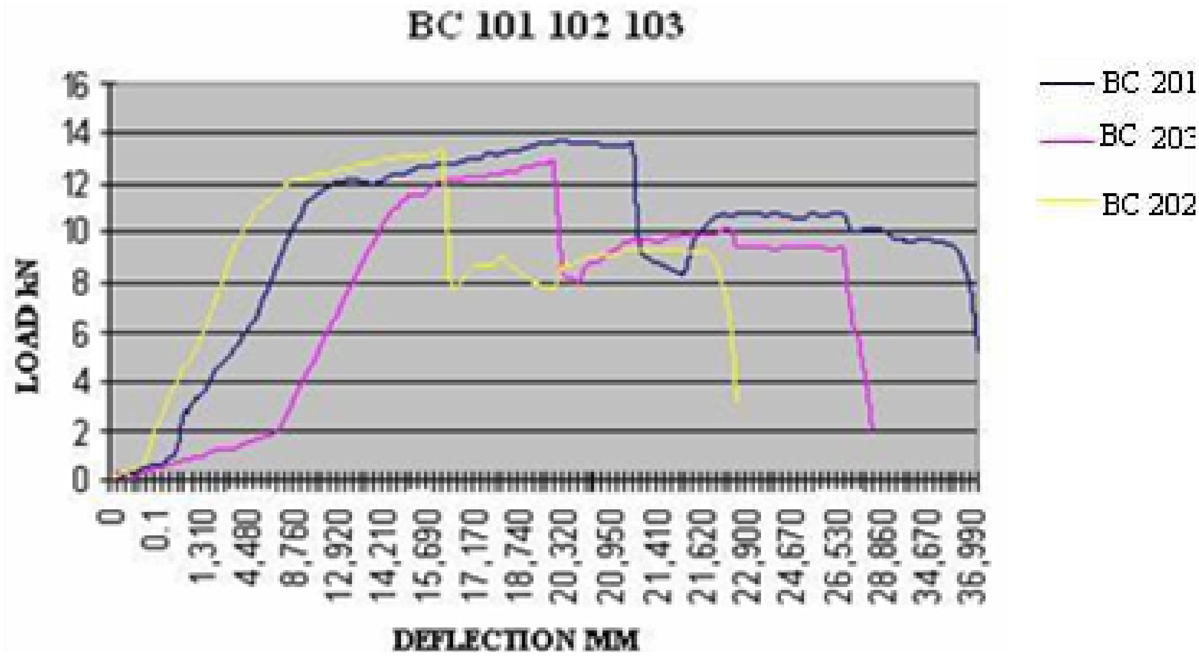


**Figure 7.** BC 201 202 203 load displacement graphic.

**Table 7.** Bending fractures of the sample beams against maximum loading.

| Beam samples | Maximum load (N) | Number 2 unit strain meter (mm) | Number 5 unit strain meter (mm) |
|---|---|---|---|
| B101 | 99000 | 28 | 0.14 |
| B102 | 92600 | 29 | 0.17 |
| B103 | 95900 | 28 | 0.21 |
| BC101 | 133100 | 0.57 | 0.15 |
| BC102 | 136500 | 0.54 | 0.45 |
| BC103 | 128100 | 0.56 | 0.81 |
| BC201 | 125900 | 0.52 | 0.16 |
| BC202 | 122600 | 0.47 | 0.46 |
| BC203 | 119300 | 0.58 | 0.80 |

**Table 8.** Shear fractures of the sample beams against maximum loading.

| Beam samples | Maximum load (N) | Number 4 unit strain meter (mm) |
|---|---|---|
| B101 | 99000 | 58 |
| B102 | 92600 | 85 |
| B103 | 95900 | 75 |
| BC101 | 133100 | 0.68 |
| BC102 | 136500 | 0.69 |
| BC103 | 128100 | 0.64 |
| BC201 | 125900 | 0.67 |
| BC202 | 122600 | 0.69 |
| BC203 | 119300 | 0.65 |

**Table 9.** Energy Consumption Capacities of the beams.

| Beam samples | Maximum load (kN) | Central slump (mm) | Energy consuming capacity (kNmm) |
|---|---|---|---|
| B101 | 99000 | 43.51 | 996.371 |
| B102 | 92600 | 38.08 | 1004.640 |
| B103 | 95900 | 48.14 | 1445.449 |
| BC101 | 133100 | 33.96 | 1381.616 |
| BC102 | 136500 | 26.74 | 1233.620 |
| BC103 | 128100 | 31.84 | 1411.518 |
| BC201 | 125900 | 33.24 | 1428.631 |
| BC202 | 122600 | 28.17 | 1317.824 |
| BC203 | 119300 | 31.44 | 1436.858 |

sections of CFRP respectively. The fracture width measured with the 150 mm unit deformation meter placed 900 mm inside the edges with a 45° angle and adhesed perpen-dicular to the fractures. was 0.12 mm on the second shear region of the beam whereas the fractures were determined as 0.47 and 0.33 mm on the bending and shear sections of CFRP respectively.

The fracture values measured on the bottom point of the beam which is exposed to the maximum tensile tension occurred as 0.74 mm in the reference beams whereas the fractures were measured as 0.68 and 0.17 mm on the bending and shear sections of the beams reinforced with CFRP respectively.

The displacement values on the other hand, occurred as 49.37 and 30 mm on the elements reinforced in CFRP bending section and elements reinforced in the shear section respectively.

It was stated that the thicker application of epoxy on the top and bottom sections of CFRP could generally prevent the separations in adhesion; adhesion of CFRP as an additional reinforcement on the lower parts of the breaking areas of beams (1/3 middle section) could increase the strength; adequately covering the edges of the reinforcement materials with epoxy from both sides throughout the beam could be beneficiary. and reinforcement by forming a ratio between reinforcing and strengthening material would be useful since the reinforcing material is suddenly exposed to excessive load following the brittle fracturing.

The shear safety should be checked while restoration or reinforcement by using CFRP is decided upon. The surface should be cleaned significantly well just before the application of the CFRP material. Epoxy adhesive should be prepared in sufficient amounts since it is observed to be solidificate fast. CFRP increases the load bearing capacity and ductility when the material is used with care paid on the restoration and reinforcement of the concrete elements. Moreover, the elements will absorb more energy by more displacement.

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