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Original Research

# FLEXURAL BEHAVIOR OF RC BEAMS CONTAINS RUBBERIZED PIECES AND STRENGTHENED WITH CFRP SHEETS

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**Abstract:** When rubberized, concrete beams lose some of their flexural strength. Conversely, flexural strengthening accounts for a sizeable portion of the structural applications for external carbon fiber reinforced polymers (CFRP) sheets that strengthen reinforced concrete beams. In this study, externally bonded sheets of (CFRP) were used to compensate for the flexural strength loss brought on by using rubberized concrete in constructing the beams. The study's reinforced concrete beams were split into two groups, each with three beams. In the first group, waste tire rubber (WTR) replaced (5 and 10) % of the fine and coarse aggregate, respectively. The reference group is the second group of typical concrete-mixture beams without used tire rubber. Each beam measured (2.1 m× 0.3m × 0.2m) has the same tensile, compression, and shear reinforcement. Every group of concrete beams contained a beam without any external reinforcement, a beam with a single layer, and a beam with double layers of (CFRP) sheet, where the beam soffit was externally strengthened. ABAQUS' finite element analysis software was used to represent the third external strengthening layer numerically. The mechanical properties of the two groups have been tested; additionally, the flexural response of the beams was examined using a monotonic two-point loading. The outcomes denote that strengthening with one and two layers of (CFRP) sheet increases the first crack load (FCL) and failure load (FL) by (8.57 and 17.64) with (17.14 and 34.27) %, respectively. The first crack deflection (FCD) also increased by (58.64) and (78.19) %, while the failure deflection (FD) decreased by (13.25) and (5.42) %, respectively.

***Keywords:*** *Beam strengthening; external reinforcement; rubberized concrete; waste tire rubber*

## 1. Introduction

It's interesting to use non-biodegradable rubber in concrete because it consumes fewer natural resources and disposes of used tires. [1]. Since 2003, more research has been done on recycling used tire rubber in concrete. Numerous studies have investigated the effectiveness of modifying the rubber ratios in concrete by replacing or adding fine and coarse aggregate [2]. Waste tire rubber can be

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used to improve the structural qualities of concrete, such as its capacity for deformation, capacity for damping (resistance to impact), resistance to repeated thawing and freezing, and dissipation of energy. Rubberized concrete reported lower unit weight and proper workability when compared to normal concrete. However, as the rubber content increases, the concrete's compressive, flexural, and tensile strengths and its elasticity modulus may also be reduced [3, 4]. When rubber was employed as aggregates, its engineering features reduced as the rubber content increased, whereas when rubber was employed as filler materials, these characteristics increased . All beams' flexural stiffness and (FL) decreased as the amount of (WTR) increased. The outcomes explained that the toughness, ductility, and deformability indicators rose as rubber content raised. By incorporating rubber particles and micro steel fibers, the failure mode of the examined beams alters from brittle to ductile [5]. Concrete's compressive strength was influenced by rubber grain size and replacement volume. Concrete's elastic modulus and flexural, tensile, and compressive strengths decreased when rubber was used instead of cement or aggregate. [6]. Compared to the control mix, the flexural strength results of the concrete gradually decreased as the proportion of crumb rubber increased [7]. Compression strain and deflection capacities have increased along with the increase in rubber content of the corresponding member [8]. Because of its hydrophobic qualities, aggregate rubber in concrete offers better resistance to mass loss because acidic solutions can't instantly penetrate the concrete matrix. The concrete was more resistant to the diffusion of chloride ions thanks to the rubber aggregate [9]. Lack of hydrophobicity, cement matrix adhesion, and elastic modulus in rubber lead to poor adhesion and stress concentration. The mechanical and durability characteristics of rubberized concrete can be enhanced through chemical or physical surface treatment, strengthening the rubber-cement interface's bond. [10]. It can be seen that the seismic forces that the crumbling rubber concrete frame will experience during the earthquake will be less than those that a regular concrete frame will experience because the maximum acceleration of the seismic response for the crumbling rubber concrete frame was 20.40% less than for the conventional concrete frame [11].

The most effective method for enhancing the flexural performance of a reinforced concrete beam depends on several considerations. These considerations include the price of strengthening, an increase in size, the rate of load capacity improvement, and the availability of used materials. The flexural and shear strengths of externally bonded composites (FRP) can be improved, and compression members can be contained and given ductility due to the use of these materials. Concrete structural members can be strengthened using (CFRP), which have advantages like corrosion resistance, ease of execution, and excellent specific strength [12]. With each additional layer added to the (CFRP) sheet, the (RC) beams' ability to support load increased. Beams that have been strengthened have a considerably lower degree of ductility than un-strengthened beams. When combined with unidirectional fiber and inorganic epoxy types, the ultimate tensile strain of the (CFRP) composite can be as low as (0.65) % [13]. Combining longitudinal (CFRP) sheets and U-side strips increase shear and flexure strength. When the longitudinal (CFRP) bond strength and shear strength of the beam must be increased, mechanical anchors with U-side (CFRP) strips are used. A different option is to use (CFRP) U-side strips to prevent debonding failure between the (CFRP) sheets and the beam soffit [14]. Strengthening that externally adheres (EBR) systems, such as (CFRP), is used to reinforce beams with a lower percentage of steel reinforcement (1%). The range of load growth rates is (26%) to (50%), with the highest rate of (1.5%) occurring between (17%) and (33%). The ductility has decreased due to the end debonding of the (CFRP) strengthening's brittle failure [15]. When strengthened with (CFRP) sheets, all repaired beams typically restore near to (80%) of their initial bearing capacity. The strengthened beam has an increased flexural strength of (30 to 40) %. The deflections are considerably decreased because the strengthened beams become stiffer. Some shear cracks cannot spread because of the exterior strengthening made of (CFRP), while others take longer to form [16]. Rupture only occurs with a single layer, whereas de-bonding occurs with dual layers. As the number of layers increases, debonding is more likely than rupture [17].

## 2. Aim of Research

This study will investigate whether externally adhered sheets of (CFRP) on the beam soffits can increase concrete beams' flexural strength, which has decreased due to the creation of rubberized concrete.

## 3. Program and Experimental Tools

### 3.1 Configuration of Specimens

There were two groups of reinforced concrete beams, each with three beams with the same mixing parameters. In the first group, well-graded (WTR) was utilized in place of volumetric amounts of coarse aggregates (10%) and fine aggregates (5%). The second group, which served as the reference group, a concrete mix initially designed to be free of rubber from the used tire, was used. The dimensions of each beam are (2.1 meters long, 0.2 meters wide, and 0.3 meters high). It was developed using the ACI Code (318-19) [18]. Each of the two groups of beams was reinforced with the same proportion ($\rho_{min}$) of steel bars. The compression zone was reinforced using two rods, each (12) mm in diameter, similar to the tensile zone. To withstand shear stress, stirrups with a diameter of (12) mm were used every (200) mm c/c, as shown in Fig. 1. The following (CFRP) sheets were used to reinforce the beam soffit, which has dimensions of (2.1×0.2) m, as shown in Fig. 2 and Fig.3, the first beam had no external reinforcement, the second had one layer of reinforcement, and the third had two layers. The numerical representation of the third layer of external reinforcing was performed using the ABAQUS finite element analysis program.

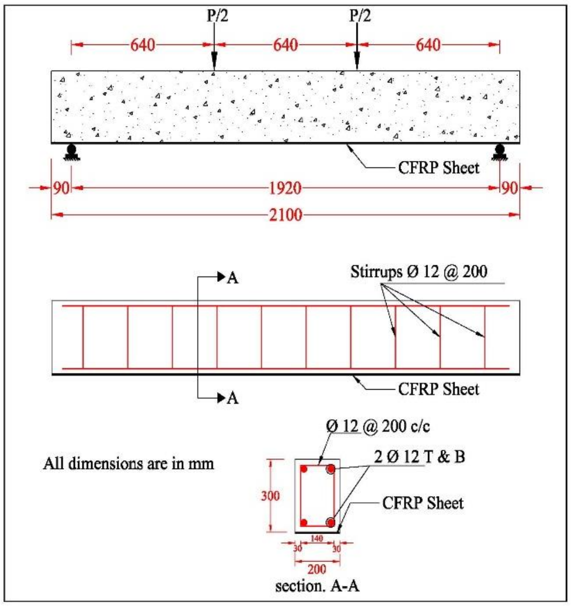


**Figure 1.** Details of the Tested Beam Specimens

**Figure 2.** Preparing the beam soffit before installing the CFRP sheets

**Figure 3.** Adhering (CFRP) sheets

Besides that, each beam contained the same amount of admixture of silica fume admixture as well as the water/cement ratio. At the same time, a change was made to the superplasticizer to keep the slump at (110 ± 5) mm. The strain gauges used were TML Japanese-made. A strain gauge was positioned in the center of the tensile reinforcement for each of the two steel reinforcement bars. Moreover, as explained in Fig. 4 and Fig.5, a double strain gauge connected in the middle of each (CFRP) layer would be used.

**Figure 4.** Strain gauges are being installed on the main reinforcement.

**Figure 5.** Strain gauges are being installed on sheets of (CFRP).

### 3.2 Control Mix Design

The following ingredients were combined to create a reference concrete mixture with a compression strength of at least 45 MPa after 28 days: cement, water, silica fume, coarse and fine aggregate, and superplasticizer. The precise composition of the mix is shown in Table 1. In the casting process for each group, the proportion of superplasticizer admixtures as a percentage of cement weight ranged from (0.3 to 5%), as specified in the technical paper for this product.

**Table 1.** Details of the adopted concrete mix proportions

| | | | |
|---|---|---|---|
| Cement (kg/m$^3$) | 500 | Coarse aggregate (kg/m$^3$) | 1020 |
| Silica fume (kg/m$^3$) | 25 | W/C ratio | 0.37 |
| Super plasticizer (Liter/m$^3$) | 5 | Resulting compressive strength (MPa) | 64 |
| Fine aggregate (kg/m$^3$) | 680 | Required compressive strength (MPa) | 45 |

### 3.3 Sizes of Used Rubber

Tables 2 and 3 display the sizes employed of (WTR) as a percentage of coarse and fine aggregates.

**Table 2.** Sieve analysis of (WTR) utilized as coarse aggregate

| **Sieve size (mm)** | **Passing (%)** | **Limits of ASTM C 33/2003 [19] (9.5 to 1.18 mm)** |
|---|---|---|
| 12.5 | 100 | 100 |
| 9.5 | 95 | 90 – 100 |
| 4.75 | 38 | 20 – 55 |
| 2.36 | 18 | 5 – 30 |
| 1.18 | 5 | 0 – 10 |

**Table 3.** Rubber used as a fine aggregate: sieve analysis

| **Sieve size (mm)** | **Passing (%)** | **Limits of IQS No. 45/1985 [20] (zone 2)** |
|---|---|---|
| 4.75 | 95 | 90 – 100 |
| 2.36 | 88 | 75 – 100 |
| 1.18 | 73 | 55 – 90 |
| 0.6 | 48 | 35 – 59 |
| 0.3 | 19 | 8 – 30 |
| 0.15 | 5 | 0 – 10 |

### 3.4 Exterior Reinforcement (CFRP) Sheets

Using unidirectional (CFRP) sheets improved concrete beams' flexural qualities. The results are provided in Table 4 below, with the approved specifications and a complete list of the (CFRP) sheets.

### 3.5 Materials Quantities Used in Research

Table 5 below shows the components used in the mixtures used to create the concrete beams, including the raw materials, (WTR), and additives.

**Table 4.** Properties of the utilized CFRP*

| Item | Test result | Limitation | Specification | Item | Test result | Limitation | Specification |
|---|---|---|---|---|---|---|---|
| Dry fiber density (g/cm3) | 1.82 | – | – | Tensile strength of laminates (N/mm2) | 3500 | 3200 | ASTM D 3039 [21] |
| Area density (g/m2) | 304 ± 10 | – | – | Laminates' modulus of elasticity (kN/mm2) | 220 | 210 | |
| Laminate nominal thickness (mm) | 0.167 | – | – | Laminates' elongation at tension breaks (%) | 1.59 | – | |
| Laminate nominal cross-section (mm2/m.l) | 167 | – | – | Tensile resistance (N/mm) | 585 | 534 | |

*Provided by the manufacturer catalog

**Table 5.** Amounts of the materials used to construct a concrete beam

| Group No. | Group sym. | Beam sym. | Water (Liter) | Cement (Kg) | Coarse aggregate (Kg) | Fine aggregate (Kg) | Coarse rubber (Kg) | Fine rubber (Kg) | Silica fume (Kg) | Superplasticizer (Liter) | CFRP layers (No.) | Strain gauges (No.) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Group 1 | B1 | B1-0 | 27.13 | 73.33 | 134.65 | 94.75 | 5.84 | 1.99 | 3.67 | 0.35 | 0 | 2 |
| | | B1-1 | 27.13 | 73.33 | 134.65 | 94.75 | 5.84 | 1.99 | 3.67 | 0.35 | 1 | 4 |
| | | B1-2 | 27.13 | 73.33 | 134.65 | 94.75 | 5.84 | 1.99 | 3.67 | 0.35 | 2 | 6 |
| Group 2 | BR | BR-0 | 27.13 | 73.33 | 149.6 | 99.75 | – | – | 3.67 | 0.4 | 0 | 2 |
| | | BR-1 | 27.13 | 73.33 | 149.6 | 99.75 | – | – | 3.67 | 0.4 | 1 | 4 |
| | | BR-2 | 27.13 | 73.33 | 149.6 | 99.75 | – | – | 3.67 | 0.4 | 2 | 6 |

## 4. Testing Program

### 4.1 Testing Fresh Concrete

The workability of the group mixtures was assessed using the slump test following ASTM C143-01a guidelines [22]. The superplasticizer was altered for the (B1) group mix to keep the slump at (110 ± 5) mm.

### 4.2 Testing Hardened Concrete

At the beam test age and before that, at the age of (28) days, concrete has undergone compression strength testing ($f_{cu}$) in the manner prescribed by BS (1881 - part 116:2000) [23]. To verify the rupture modulus ($f_r$), flexural testing was performed according to ASTM C78-02 [24]. The splitting tensile strength ($f_t$) of beam test specimens at the testing age was calculated using the ASTM C496-04 [25] requirements. The static elastic modulus ($E_c$) of the concrete was established following ASTM C469-02 [26]. A beam with a (1.92) m effective span was tested for its flexural response using two-point monotonic loading, as shown in Fig 6.

**Figure 6**. Beam Specimens Set-up

## 5. Layout of the Experimental Study

### 5.1 Concrete Properties

Waste tire rubber behaves in a way that needs to be viewed in light of its mechanical characteristics when used in concrete beams in place of a particular proportion of fine and coarse aggregate. Table 6 displays the characteristics of hardened rubberized concrete.

**Table 6.** Results of the properties of rubberized concrete

| Group No. | Group symbol | Ave. Density (kg/m$^3$) | Ave. ($f_{cu}$) at (28) day (MPa) | Ave. ($f_{cu}$) at the age of beam (MPa) | Ave. ($f_r$) at (28) days (MPa) | Ave. ($f_t$) at (28) days (MPa) | Ave. ($E_c$) (28) days (MPa) |
|---|---|---|---|---|---|---|---|
| Group 1 | B1 | 2248 | 35.008 | 36.333 | 3.405 | 2.708 | 25339 |
| Group 2 | BR | 2337 | 45.759 | 48.167 | 4.120 | 3.832 | 28808 |

**Table 7.** Beam flexural test results

| Group No. | Beams | | (FCL) kN | (FCD) mm | (FL) kN | (FD) mm |
|---|---|---|---|---|---|---|
| | Group symbol | Beam symbol | | | | |
| Group 1 | B1 | B1-0 | 32 | 1.515 | 131.8 | 25.452 |
| | | B1-1 | 40 | 1.927 | 169 | 16.949 |
| | | B1-2 | 44 | 2.047 | 212.5 | 22.743 |
| Group 2 | BR | BR-0 | 35 | 1.018 | 149.7 | 23.397 |
| | | BR-1 | 47 | 1.647 | 172.3 | 16.565 |
| | | BR-2 | 49 | 1.902 | 218.7 | 16.834 |

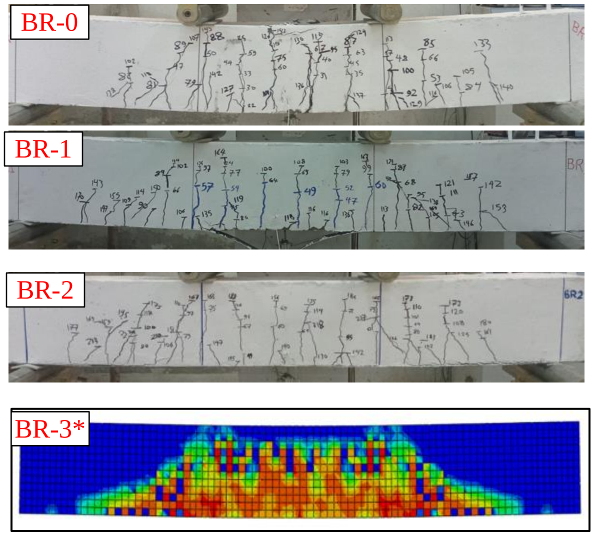


**Figure 7.** Flexural test of the group (BR) beams, BR-0, BR-1, BR-2, and BR-3*

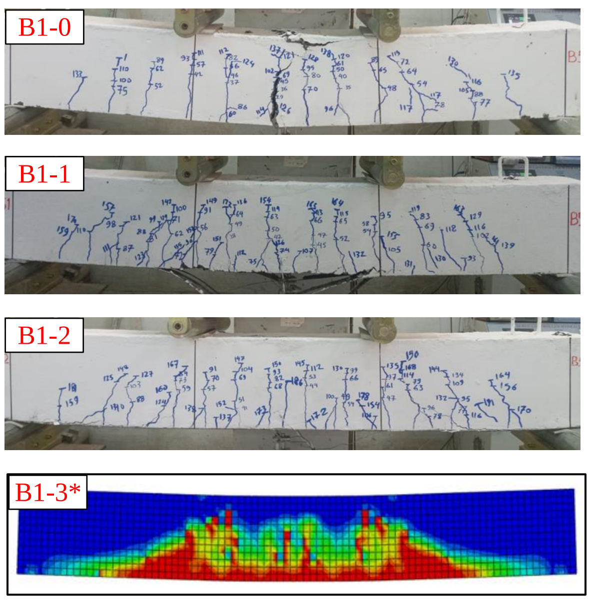


**Figure 8.** Flexural test of the group (B1) beams, B1-0, B1-1, B1-2, and B1-3* (*= Numerically representation by finite element analysis)

*5.2.1 First crack load (FCL)*

(FCL) of the beams in the group (B1) that was externally reinforced with single and double layers of (CFRP) sheets, respectively, (B1-1) and (B1-2), increased ascendingly by (46.15 and 57.69) % in comparison to the un-strengthened beam (B1-0). The addition of (WTR) reduced the load at the first crack by (25.71) percent for beam (B1-0) but increased the load by (8.57) and (17.14) percent for beams (B1-1) and (B1-2) strengthened with single and double layers of (CFRP) sheets. Additionally, despite the beams (B1-1) and (B1-2) being reinforced with (CFRP) sheets, the (FCL) decreased in descending ratios (25.71, 19.15, and 16.33%) when the beams in the (B1) group were contrasted to the corresponding beams in the reference group (BR). The addition of waste tire rubber brought this on.

*5.2.2 Failure load (FL)*

The (FLs) of the beams (B1-1) and (B1-2) with one and two layers of externally adhered (CFRP) sheets, respectively, increased ascendingly by (26.78 and 44.71) % in comparison to the un-strengthened beam (B1-0). This improvement resulted from using (CFRP) sheets for external reinforcement. However, when the beams' failure load of the (B1) group was compared to the reference beam (BR-0) that had not been strengthened, the replacement of (WTR) caused a decrease in the load at failure of (7.21) % in the beam (B1-0). In comparison, the strengthening of the beams (B1-1) and (B1-2) with (CFRP) sheet caused an ascent in the load at failure of (17.64 and 34.27) %. Additionally, compared to the equivalent beams in the control group (BR), the (FLs) for beams (B1-0) and (B1-2) decreased by 7.21 and 8.09 percent, respectively, and increased by 2.21 percent.

*5.2.3 First crack deflection (FCD)*

With single and double layers of externally reinforced (CFRP) sheets, (FCDs) in the group (B1) beams, respectively, ascended by (15.77 and 30.04) % in comparison to the unenhanced beam (B1-0). The first crack load increased due to external strengthening, which led to this development. Additionally, compared to the reference beam that had not been strengthened (BR-0), the (FCD) of the (B1) group beams increased by an ascending (37.03, 58.64, and 78.19) %. Due to the reinforcement provided by the (CFRP) sheets, the (FCD) for the beam (B1-0) increased by (37.03%) compared to the corresponding beams in the reference group (BR), while it decreased by (1.94 and 4.63) % for the beams (B1-1) and (B1-2).

*5.2.4 Failure deflection (FD)*

The (FD) of beams with one and two layers of (CFRP) sheets, respectively, decreased in descending ratios by (44.84 and 39.86) % as compared to the un-strengthened beam (B1-0). The (FD) of the (B1) group beams increased by (57.28) % due to the rubber inclusion but decreased in descending rates by (13.25 and 5.42) % due to the external reinforcement using single and double layers of (CFRP) sheets, respectively, when compared to the reference beam without external reinforcement (BR-0). (WTR) was added, and even with external reinforcement, the failure deflection of the group (B1) was (57.28, 22.53, and 31.46) % greater than that of the corresponding beams in the reference group (BR).

*5.2.5 Load-deflection relationship*

Fig. 9 demonstrates how strengthening beams (B1-1) and (B1-2) with single and dual layers of (CFRP), respectively, can increase their exterior strength in comparison to the beams (B1-0). This decreases deflection at similar load levels, raising (FLs) and lowering the (FDs) of the beams. The load-deflection drawing for the group (BR) beams is shown in Fig. 10.

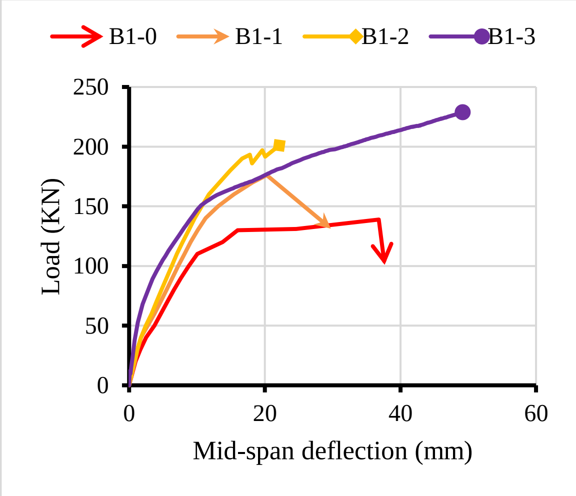


**Figure 9.** Load-deflection diagram of group (B1) beams

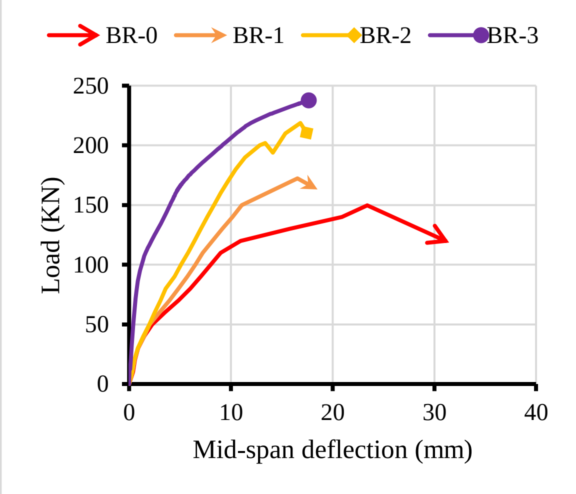


**Figure 10.** Load-deflection diagram of group (BR) beams

As a result of the use of (WTR), Fig. 11 shows how the beam (B1-0) fails with a lower load and greater deflection than the beam (BR-0).

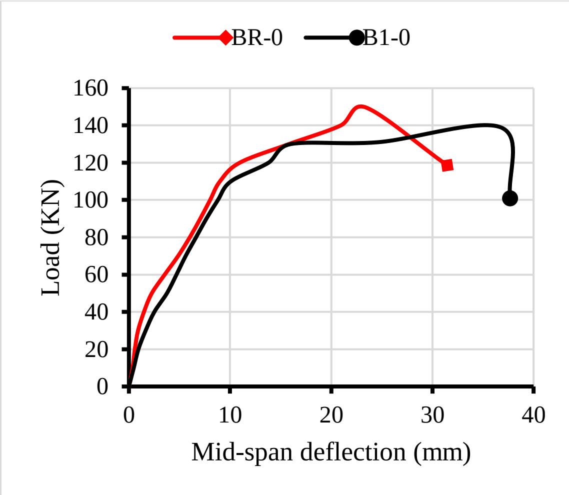


**Figure 11.** Load-deflection diagram for beams (BR-0) and (B1-0)

The beam (B1-1) has greater (FL) and (DL) values than (BR-1). Additionally, they deform convergently in response to symmetrical loads, as shown in Fig. 12.

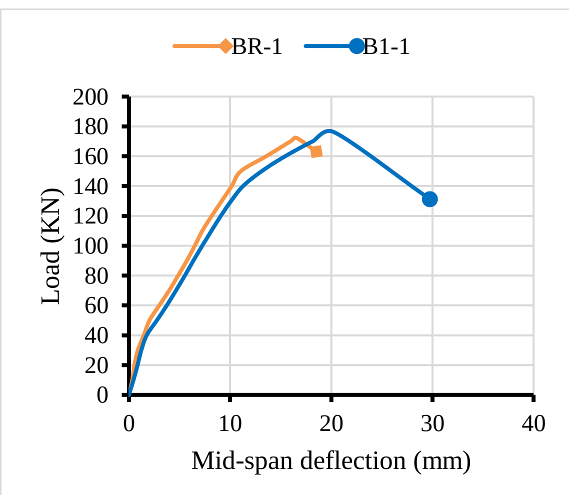


**Figure 12.** Load-deflection diagram of the beams (BR-1) and (B1-1)

According to Fig. 13, the beam (BR-2) fails with less deflection and a greater (FL) than the beam (B1-2) at equivalent load levels.

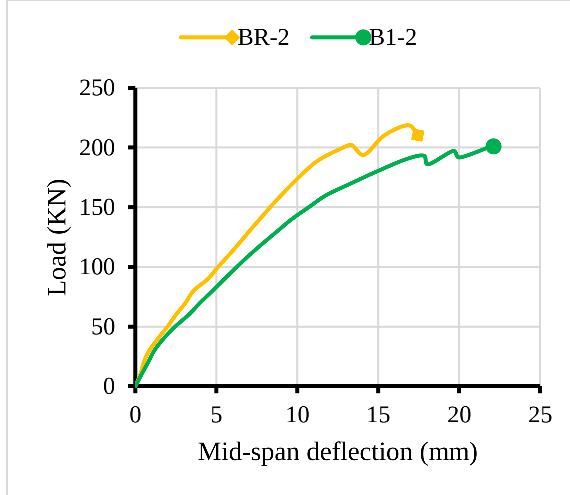


**Figure 13.** Load-deflection diagram of the beams (BR-2) and (B1-2)

At symmetrical load levels, the deflection of the beams (B1-1) and (B1-2) is significantly less than that of the control beam (BR-0). According to Fig. 14, the (FLs) for the beams are greater, and there is less deflection during failure.

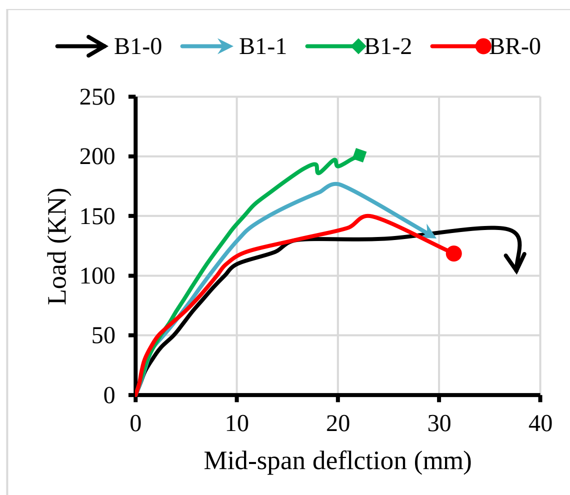


**Figure 14.** Load-deflection diagram of group (B1) beams and (BR-0)

*5.2.6 Main steel reinforcement and (CFRP) sheet strains*

The main steel reinforcement of the beam (B1-0) is shown in Figure 15 to be subjected to greater strain than the beam (BR-0) under symmetrical loads.

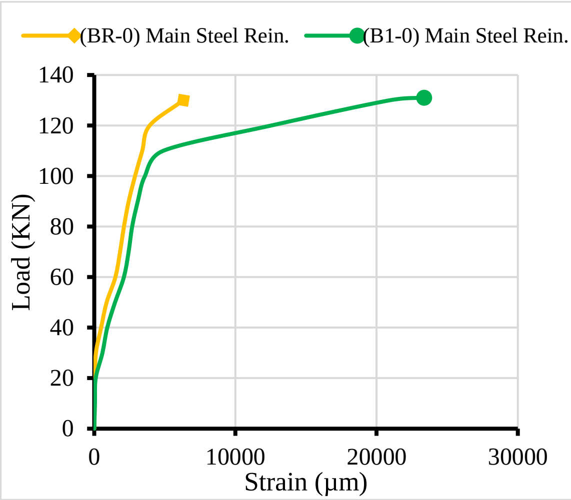


**Figure 15.** Beams (BR-0) and (B1-0) main steel reinforcement load-strain diagram

In the most symmetrical loads, the tensile reinforcement of beam (B1-1) experiences less strain than (BR-1); the same is true for the (CFRP) sheet used as a single layer for strengthening, as shown in Fig. 16.

Besides, under the most symmetrical loads, the (CFRP) sheets' second layer, as depicted in Fig. 17, will experience convergent strain. The (CFRP) used as the first layer to strengthen the beam (B1-2) and the tensile steel reinforcement both experience less strain under symmetrical loads than does the second layer (BR-2).

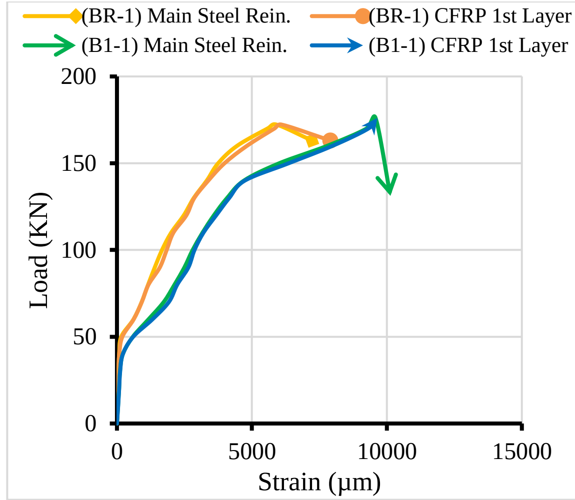


**Figure 16.** load-strain diagram for beams (BR-1) and (B1-1)'s main steel reinforcement and CFRP sheet

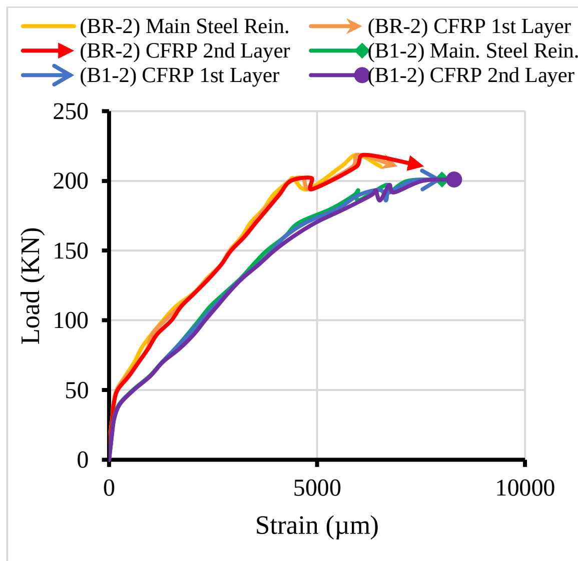


**Figure 17.** The load-strain diagram for the beams (BR-2) and (B1-2)'s main steel reinforcement and CFRP sheet

## 6. Finite Element Representation

Using numerical simulations in the finite element software ABAQUS (version 2021), as shown in Fig. 18 and Fig.19, to evaluate the structural performance of the beam in each of the two groups and assess the flexural strength following the addition of the third layer of the (CFRP) sheet.

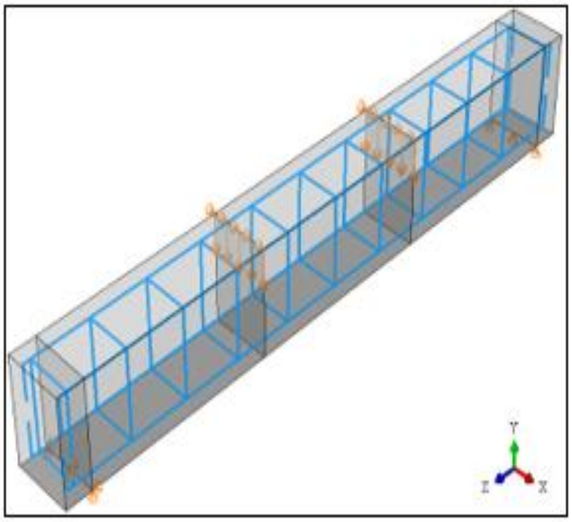


**Figure 18.** Boundary conditions

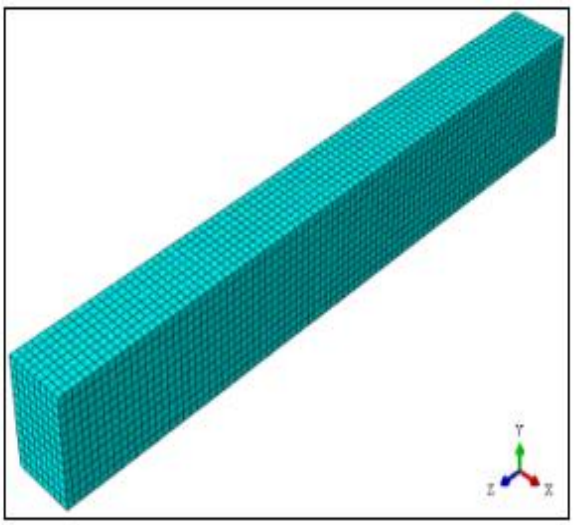


**Figure 19.** Simulating beam specimens with finite element meshes

This program will use two beams to represent the features of the two different study groups for the volume replacement waste tire rubber. The concrete beams are represented by an 8-node linear brick (C3D8R), whereas a linear three-degree-of-freedom two-node truss element (T3D2) with the representation of the reinforcing steel has two nodes. Due to their perfect bond (no slip between concrete and reinforcing bar) and steel reinforcement is restricted because it is embedded in the concrete. The reinforced concrete beams' boundary conditions were modeled on the right as a roller by a constraint in the Y-direction (U2) and on the left as a hinge constraint in the Z-Y direction (U2, U3). Displacement control was considered to calculate the (FL) and simulate the applied load on the reinforced concrete beams. Three layers of (CFRP) sheets will be applied externally to reinforce each beam. The load-deflection diagrams for the three numerically reinforced layer (CFRP) beams are shown in Fig. 9 and Fig.10. Inside the curves for each beam are those for the other beams, including the group that the beam is a part of. This demonstrates how increasing the reinforcement of a beam with three (CFRP) sheets reduces deflection at corresponding load levels, increases the load at failure, and reduces deflection if that beams fail. Additionally, Tables 8 and 9 display the behavior of beams that have undergone numerical reinforcement utilizing three sheets of (CFRP) and were assessed for ((FCL), (FCD), (FL), and (FD). The results were compared to the actions performed by the various beams in the control group.

**Table 8.** The comparison of numerically strengthened beams by three layers of (CFRP) sheets using (FCL) and (FCD) results with reference beams

| (FCL) Group | | | (FCL) comparison Comparative ratio to: | | |
|---|---|---|---|---|---|
| Name | Beam | Load kN | unstrengthen beam in the same group (%) | (BR-0) beam in the reference group (BR) (%) | (BR-3) beam in the reference group (BR) (%) |
| B1 | B1-3 | 37.81 | + 45.42 | + 8.03 | – 25.39 |
| **(FCD) Group** | | | **(FCD) comparison Comparative ratio to:** | | |
| Name | Beam | Def. mm | unstrengthen beam in the same group (%) | (BR-0) beam in the reference group (BR) (%) | (BR-3) beam in the reference group (BR) (%) |
| B1 | B1-3 | 0.82 | – 41.22 | – 19.44 | + 100.0 |

**Table 9.** The comparison of numerically strengthened beams by three layers of (CFRP) sheets using (FL) and (FD) results with reference beams

| (FL) Group | | | (FL) comparison Comparative ratio to: | | |
|---|---|---|---|---|---|
| Name | Beam | Load (kN) | unstrengthened beam in the same group (%) | (BR-0) beam in the reference group (BR) (%) | (BR-3) beam in the reference group (BR) (%) |
| B1 | B1-3 | 228.86 | + 64.77 | + 52.88 | – 3.71 |
| **(FD) Group** | | | **(FD) comparison Comparative ratio to:** | | |
| Name | Beam | Def. (mm) | unstrengthened beam in the same group (%) | (BR-0) beam in the reference group (BR) (%) | (BR-3) beam in the reference group (BR) (%) |
| B1 | B1-3 | 49.18 | + 33.64 | + 110.2 | + 178.64 |

## 7. Results and Discussion

### 7.1 Experimental Test Results

All mechanical properties decreased when fine and coarse aggregates were replaced with (WTR) in 5% and 10% volumetric ratios, respectively. These properties included compression strength, rupture modulus, elasticity modulus, splitting tensile strength, and density.

A significant decline in the load-deflection curve of the rubberized reinforced concrete un-externally strengthened beam (B1-0) compared to the reference beam (BR-1) was observed because (WTR) was used to replace fine and coarse aggregates in a volumetric manner.

Rubberized beams with volume replacements of fine and coarse aggregates of (5%) and (10%) and external (CFRP) sheet reinforcement in single and dual layers, respectively:

- Comparing the beam (B1-0) from the same group that was not externally strengthened: the (FCL) enhanced by (46.15 and 57.69) %. The (FL) improved by (26.78 and 44.71) %, the (FCD) rose by (15.77 and 30.04) %, and the (FD) reduced by (44.84 and 39.86) %.
- Compared to the reference group beam (BR-0) that was not externally strengthened: the (FCL) improved by (8.57 and 17.14) %. The (FL) was enhanced by (17.64 and 34.27) %, the (FCD) exceeded by (58.64 and 78.19) %, and the (FD) was reduced by (13.25 and 5.42) %, respectively.
- Compared to the symmetric reference beam of the reference group (BR-1) and (BR-2): the (FCL) was reduced by (19.15 and 16.33) %. The (FL) rose by (2.21%) decreased by (8.09) %, the (FCD) declined by (1.94 and 4.63) %, and the (FD) multiplied by (22.53 and 31.46) %, respectively.

### 7.2 Numerical Analysis Results

The addition of three (CFRP) sheets reduces deflection at symmetrical load levels, raising the beams' (FL) and lowering their (FD). For rubberized concrete beams (B1-3), the (FCL) increased by (45.42) % compared to un-strengthened beams in the same group, but the (FCD) decreased by (41.22) %. Additionally, in contrast to the (BR-0) reference beam, which has not been strengthened, the (FCL) increased by (8.03) %, and the (FCD) decreased by (19.45) %, in that order due to the external reinforcing utilizing triple layers of (CFRP) sheets. Compared to un-strengthened beams in the same group, the (FL) rose by (64.77) %, and the (FD) increased by (33.64) %. In comparison to the un-strengthened reference beam (BR-0). The (FL) exceeded (52.88) %, and the (FD) raised by (110.2) % as a result of the triple layers of (CFRP) sheets that are used for external reinforcement.

## 8. Conclusion

This study aims to demonstrate that the flexural strength lost while rubberized reinforced concrete beams were being built can be restored. A comparison between reinforced non-rubberized concrete beams and reinforced rubberized concrete beams that have been externally reinforced with single, dual, or triple layers of (CFRP) sheets makes the most sense regarding the study's objectives.

Therefore, by using single or double layers of (CFRC) sheets to externally strengthen the beams made of (WTR), the (FCL) and (FL) rates can be increased.

The (FCL) and (FL) will increase by almost twice as much if two layers of (CFRP) sheet are used for external reinforcement instead of one layer. The (FCD) increases but decreases when reinforced with two layers.

The deflection of externally strengthened rubberized concrete beams is significantly reduced at symmetrical load levels compared to the reference un-strengthened unrubberized beam. The (FLs) for the beams are higher, and there is less (FD).

As a result, given the volumetric replacement rates found in this study by (5%) of fine aggregate and (10%) of coarse aggregate, when the rubberized concrete beam was externally reinforced with single, dual, and triple layers of (CFRP) sheets, its flexural strength would have increased. At the same time, its ductility would have decreased when strengthened by dual and triple layers of CFRP sheets.

### Conflict of Interest

The authors confirm that the publication of this article causes no conflict of interest.

### Author Contribution Statement

Both authors proposed the research problem, developed the theory, performed the computations, verified the analytical methods and developed the model, supervised the findings of this work, discussed the results, and contributed to the final manuscript.

## 9. References

[1] Mendis, A.S.M., Al-Deen, S. and Ashraf, M., (2018). *Flexural shear behavior of reinforced Crumbed Rubber Concrete beam*. Journal of Construction and Building Materials, Vol. 166, pp. 779–791.

https://doi.org/10.1016/j.conbuildmat.2018.01.150

[2] Al-Azzawi, A.A., Shakir, D., and Saad, N., (2018). *Flexural Behavior of Rubberized Reinforced Concrete Beams*. International Journal of Engineering & Technology, Vol. 7, pp. 316-320.

https://doi.org/10.14419/ijet.v7i4.20.25946

[3] Gurung, S., (2020). *Flexural Analysis of Rubberized Concrete Beams using Finite Element Method*. Thesis, Arcada University of Applied Sciences, Helsinki, Finland. http://www.theseus.fi/handle/10024/338913

[4] Assaggaf, R.A., Ali, M.R., Al-Dulaijan, S.U., and Maslehuddin, M., (2021). *Properties of concrete with untreated and treated crumb rubber - A review*. Journal of Materials Research and Technology. Vol. 11, pp. 1753–1798.

https://doi.org/10.1016/j.jmrt.2021.02.019

[5] Hasan, T.M., and Ali A.S., (2020). *Flexural Behavior of Fiber Reinforced Self-Compacting Rubberized Concrete Beams*, Journal of Engineering. Vol. 26, Issue 2, pp. 111–128.

https://doi.org/10.31026/j.eng.2020.02.09

[6] Ganjian, E., and Khorami, M., (2009). *Scrap-tyre-rubber replacement for aggregate and filler in concrete*, Journal of Construction and Building Materials. Vol. 23, Issue 5. pp. 1828–1836.

https://doi.org/10.1016/j.conbuildmat.2008.09.020

[7] Thomas, B.S., and Gupta, R.Ch., (2016). *Properties of high strength concrete containing scrap tire rubber*. Journal of

Cleaner Production. Vol. 113, Issue 1, pp. 86–92.

https://doi.org/10.1016/j.jclepro.2015.11.019

[8] Hassanli, R., Youssf, O., and Mills, J.E., (2017). *Experimental investigations of reinforced rubberized concrete structural members*. Journal of Building Engineering. Vol. 10, pp. 149–165.

https://doi.org/10.1016/j.jobe.2017.03.006

[9] Gupta, T., Siddique, S., Sharma, R.K., and Chaudhary, S., (2019). *Behaviour of waste rubber powder and hybrid rubber concrete in an aggressive environment*. Construction and Building Materials. Vol. 217, pp. 283–291.

https://doi.org/10.1016/j.conbuildmat.2019.05.080

[10] Li, Y., Zhang, X., Wang, R., and Lei, Y., (2019). *Performance enhancement of rubberized concrete via surface modification of rubber: A review*. Construction and Building Materials, Vol. 227, Art. 116691.

https://doi.org/10.1016/j.conbuildmat.2019.116691

[11] Khan, I., Shahzada, K., Bibi T., Ahmed, A., and Ullah, H., (2021). *Seismic performance evaluation of crumb rubber concrete frame structure using shake table test*. Structures, Vol. 30 pp. 41–49.

https://doi.org/10.1016/j.istruc.2021.01.003

[12] Al-Khafaji, A., Salim, H., El-Sisi, A., (2021), *Behavior of RC beams strengthened with CFRP sheets under sustained loads*. Structures, Vol. 33 pp. 4690–4700.

https://doi.org/10.1016/j.istruc.2021.07.049

[13] Toutanji, H., Zhao, L., and Zhang, Y., (2006). *Flexural behavior of reinforced concrete beams externally strengthened with CFRP sheets bonded with an inorganic matrix*, Engineering Structures. Vol. 28, Issue 4, pp. 557–566.

https://doi.org/10.1016/j.engstruct.2005.09.011

[14] Wang, Y.C., and Hsu, K., (2009). *Design recommendations for the strengthening of reinforced concrete beams with externally bonded composite plates*. Composite Structures, Vol. 88, Issue 2, pp. 323–332.

https://doi.org/10.1016/j.compstruct.2007.12.001

[15] Ceroni, F., (2010), *Experimental performances of RC beams strengthened with FRP materials*. Construction and Building Materials, Vol. 24, Issue 9, pp. 1547–1559.

https://doi.org/10.1016/j.conbuildmat.2010.03.008

[16] Cazaucu, Ch., Galatanu, T., Mizgan, P., Muntean, R., and Tamas, F., (2017). *Experimental Research in Flexural Behavior of Carbon Fiber Polymer Strengthened Beams*. Procedia Engineering, Vol. 181, pp. 257 –264,

https://doi.org/10.1016/j.proeng.2017.02.387

[17] Ism, M.M., and Rabie, M., (2019). *Flexural behavior of continuous RC beams strengthened with externally bonded CFRP sheets*. Alexandria Engineering Journal. Vol. 58, Issue 2, pp. 789–800.

https://doi.org/10.1016/j.aej.2019.07.001

[18] ACI 318. (2019). *Building Code Requirements for Structural Concrete*, American Concrete Institute-ACI Committee 318, Farmington Hills, Michigan, USA

[19] ASTM C 33 (2003). *Requirements For Grading and Quality of Fine and Coarse Aggregate for Use in Concrete*. ASTM Committee on Standards, West Conshohocken, PA, United States, 11 p.

[20] Iraqi Specification No.45, (1985), *Aggregate from Natural Source for Concrete, Central Agency for Standardization and Quality Control, Planning Council, Baghdad, Iraq.*

[21] ASTM D3039/D3039M-08. (2008), *Standard Test Method for Tensile Properties of Polymer Matrix Composite Materials*, ASTM Committee on Standards, West Conshohocken, PA, United States, pp. 105–116

[22] ASTM C 143/C143M. (2003). *Standard Test Method for Slump of Hydraulic-Cement Concrete*. ASTM Committee on Standards, West Conshohocken, PA, United States.

[23] BS 1881-Part 116 (2000). *Method for determination of compressive strength of concrete cubes*. British Standards Institute BSI, London.

[24] ASTM C 78 (2002). *Standard Test Method for Flexural Strength of Concrete*. ASTM Committee on Standards, West Conshohocken, PA, United States.

[25] ASTM C 496/C 496M (2004). *Standard Test Method for Splitting Tensile Strength of Cylindrical Concrete Specimens*. ASTM Committee on Standards, West Conshohocken, PA, United States.

[26] ASTM C 469 (2002). *Standard Test Method for Static Modulus of Elasticity and Poisson's Ratio of Concrete in Compression*. ASTM Committee on Standards, West Conshohocken, PA, United States.