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Rehabilitation of Pre-Damaged RC Beam Containing Recycled Plastic Waste Using CFRP

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ABSTRACT

Over the past few decades, the utilization of fiber-reinforced polymer (FRP) composites for the purpose of strengthening and rehabilitating reinforced concrete (RC) structures has become widely recognized as a very effective approach to improving structural integrity and increasing lifespan. Ageing structures frequently require maintenance and repair as a result of severe environmental conditions, natural disasters, alterations in applied loads, corrosion of reinforcement, and insufficient maintenance. In this study, two aspects were considered. The first is to study the behavior of preloaded RC beams after rehabilitation using CFRP composite. The second aspect is to find the effects of waste plastic Polypropylene (PP) on the behavior of preloaded RC beams. Thus, three mixes were prepared with two different PP fiber plastic lengths 30 and 50 mm with a constant ratio equal to 1% as recommended by the literature. A total of ten RC beams with dimensions of (100 x 160 x 1600) mm were cast two of them played as control and the other were preloaded to 70% of the ultimate load calculated based on the control sample. Results showed adding waste plastic waste as PP fiber leads to an enhancement in overall concrete properties. Furthermore, retrofitting the pre-damaged RC beams with CFRP composite application resulted in a 70% enhancement in load-carrying capacity when U CFRP anchorage is used at both ends.

Keywords:

PP fiber; Pre-damaged; RC beam; CFRP; Waste plastic; Flexural

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1. INTRODUCTION

Concrete is a vital and widely utilized substance in the fabrication of construction materials. It ranks as the second most utilized material globally, following water [1]. Typically, fibers are employed to enhance the mechanical characteristics of concrete, provided that an optimal ratio is utilized [2-9]. The exponential rush in plastic waste has prompted substantial environmental apprehensions surrounding its disposal. Recycling plastic garbage provides a valuable option for managing it instead of disposing of it in scarce landfill areas. An effective approach involves integrating plastic waste into concrete construction, resulting in the production of a sustainable material known as green concrete. Based on multiple research, it has been indicated that the ideal amount of plastic waste fiber to be used as an extra material is approximately 1% [10].

In addition to the environmental consequences, the expansion of global infrastructure has led to an increased number of reinforced concrete (RC) structures that need to be strengthened in order to mitigate the danger of collapse. A significant number of reinforced concrete (RC) constructions fail to meet the necessary criteria and are classified as defective structures [11-14]. Structures should be changed or reinforced to address insufficient capacity and retrofitted in cases where some structural elements are damaged. Typically, strengthening is the optimal approach in terms of both environmental impact and cost-effectiveness, when compared to demolition and rebuilding [15].

An effective method to enhance the performance of a broken RC beam is to externally reinforce it using a Carbon Fibre Reinforced Polymer (CFRP) composite [16]. FRP laminates and sheets are increasingly being used in reinforced concrete constructions due to the development of strong structural adhesives with high tensile strength. FRP has emerged as the most efficient material for strengthening RC structures worldwide, surpassing steel plates. FRP is a composite material consisting of a polymer matrix reinforced with fibers, offering exceptional mechanical properties such as resistance to corrosion, reduced maintenance costs, high stiffness, high strength-to-weight ratio, compact size, easy handling, and straightforward installation [16]. This project aims to utilize plastic waste PP of varying lengths to mitigate cracks in a preloaded RC beam. In addition, several reinforced concrete beams will undergo reinforcement using carbon fiber reinforced polymer (CFRP) after being subjected to significant damage. This study employs several strategies to enhance and reinforce the research.

2. STRENGTHENING OF DAMAGED RC BEAM

A reinforced concrete beam is a crucial part of the RC structural system, transferring loads from adjacent slabs and walls as well as live loads to nearby columns safely. Therefore, beams must be designed to ensure significant safety and serviceability against the flexural and shear stresses that develop under service conditions. In practice, RC beams are often exposed to various distressing factors such as design errors, construction mistakes, material deficiencies, operational issues, and harsh environmental conditions. These factors can lead to an ultimate limit state, resulting in complex shear and flexural stresses in the beams. Such stresses can exceed the beams' resistance capacity, potentially causing tensile cracks. These cracks primarily occur because concrete's tensile strength is much lower than its compressive strength. The adverse conditions mentioned above can cause RC beams to fail due to tensile cracks. Therefore, it is essential to strengthen these critically damaged or vulnerable beams to enhance their load-carrying capacity and performance during service [17].

Strengthening encompasses repair, retrofitting, and rehabilitation, each serving distinct purposes. Repair involves minimally enhancing a structure's performance from its original state or meeting aesthetic requirements without significantly boosting performance [17]. Retrofitting aims to improve various performance aspects, including flexure, shear, ductility, and service life. Rehabilitation focuses on restoring the strength or performance lost due to various distressing factors, as implied by the term "rehab." Effective methods for retrofitting and rehabilitation include using externally bonded steel plates, concrete jacketing, fiber-reinforced plastic (FRP) laminates or sheets, external prestressing or bar reinforcement, and ultra-high performance concrete (UHPC) overlays. It is crucial to strengthen structural components through repair, retrofitting, and rehabilitation to ensure they meet their intended service life [17-20].

3. EXPERIMENTAL WORK

The experimental phase of the research consists of the preparation of the required material for the concrete mix including trial mixes. Secondly, is sample preparation and required flexural tests.

3.1. Materials

In this research, OPC I-42.5 R cement was used, which was manufactured by the Mardin Cement Factory. The physical and chemical composition of cement studied were according to ASTM C150 [21], BS EN 2013 [22], BS EN 2016 [23], IQS 1984 [24]. Coarse-grained, naturally occurring clean river sand was collected from the Alkhazer quarry and employed as fine aggregate. Figure 1 displays the actual grading obtained from sieve analysis of fine and coarse aggregate in accordance with ASTM C136 [25], ASTM C33 [26], ASTM C127 [27], ASTM C33-99a [26], C136 [25], and IS-383 [28]. Crushed stone, with a maximum size of 10 mm from the Alkhazer quarry, was used as coarse aggregate. Tap water at laboratory temperature was employed to wash the coarse aggregate, mix the concrete, and cure the samples, following ASTM C 1602 standard [29].

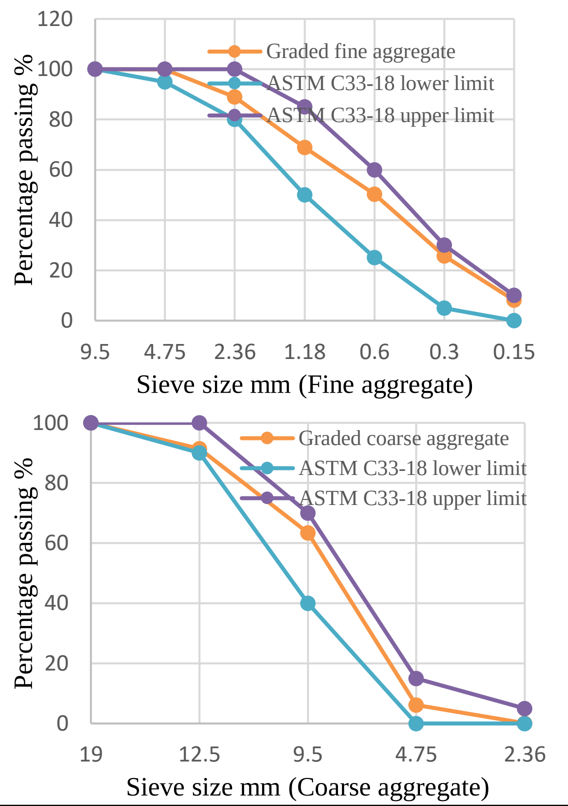

Figure 1: Aggregate sieve analysis.

3.1.1. Polypropylene plastic fibers (PP)

Polypropylene plastic fibers in lengths of 30 mm and 50 mm were used at a ratio of 1%. The fibers are in a cylinder fiber-form with an equivalent diameter range between 0.6-1 µm. A sample of these fibers is shown in Figure *2*, and their properties are listed in the table below. Polypropylene (PP) is a widely used thermoplastic found in various applications, including toys, containers, pipes, automotive parts, and electrical components. In Australia, 0.23 million tonnes of PP products were consumed in 2013, with a recycling rate of only 24% (0.056 million tonnes) (A'Vard and Allan, 2014) [30]. To control plastic pollution, global legislation has been introduced to limit plastic waste disposal and promote more environmentally friendly options (Achilias et al., 2008) [31]. Consequently, efficient recycling and recovery methods are being researched and developed. According to the Australian National Plastics Recycling Survey (A'Vard and Allan, 2014) [30], mechanical recycling is the most widely practiced method in Australia due to its relative ease and cost-effectiveness, with the necessary technology and infrastructure for collection and mechanical reprocessing of plastic waste readily available.

Table *1* displays the properties of plastic waste, including tensile strength (ft), thermal conductivity (k), and Young's modulus of elasticity (E) for commonly used polymers. The table shows that all types of plastic have lower elastic moduli and thermal conductivity compared to concrete components. Fine and coarse aggregates have elastic moduli roughly 22 times greater than polypropylene (PP), which explains why adding PP to the mix lowers the overall modulus of elasticity. For example, polyethylene (PE) has a thermal conductivity that is 9.1% lower than sand, so increasing the PE content in the mix reduces the concrete's overall thermal conductivity. On the other hand, plastic has a higher tensile strength than concrete components, suggesting that incorporating plastic waste into concrete could improve its tensile strength [32].

Figure 2: Polypropylene plastic fiber.

Table 1: Polypropylene plastic properties

Fiber properties	Description
Fiber's name	Polypropylene fiber
Color	White
Density (g/cm³)	0.91
Melting point (°C)	160-170
Equivalent diameter (um)	0.6-1.0
Tensile strength (Mpa)	>400
Elastic modulus (Gpa)	>5.0
Fracture elongation (%)	15-30
Length (mm)	30

3.1.2. CFRP Composite

CFRP is mainly utilized in two structural applications. The first involves the use of externally bonded (EB) plates or sheets to strengthen and rehabilitate deficient structures, such as columns, slabs, beams, and walls [33-36]. These EB FRP sheets can be applied as full wraps, U-wraps, along the entire span, or at specific intervals as required by design codes [37-39]. The second application is the embedment of FRP bars or strips within RC (reinforced concrete) structures, either during initial construction or post-construction using the near-surface mounted (NSM) technique [40, 41]. In this study CFRP sheet was used for the flexural strengthening and as anchorage end span application Figure 3. The CFRP was manufactured by Sika manufacturer, properties illustrated in Table *2*. Sikadure 330 was used as structural epoxy provided by Sika.

Table 2: Material properties of CFRP fabric and CFRP laminate provided by the manufacturer.

Characteristics	Manufacturer data
Ultimate tensile strength (MPa)	3100
Fiber modulus (GPa)	170
Ultimate tensile elongation (%)	1.8
Thickness (mm)	1.4
Fiber density (g/cm^3)	1.6

Figure 3: CFRP composite.

3.1.3. Trial Mix Design

In this research, several mix trials were conducted to achieve a concrete with the strength target with acceptable flow and workability, as detailed in Table 3.

Table 3: Trial Mix Design.

Mix. design Trial	Cement (kg)	Sand (kg)	Coarse Agg. (kg)	Water (kg)	Water/ Cement	SP 1%	P.P Fiber % (V)	f'c (MPa) 28 days	Flow test (mm)
Trial 1	360	720	960	180	0.5	0.9	---	26.4	150
Trial 2*	400	974	120	200	0.5	1	---	48.4	170
Trial 3	400	1100	700	216	0.54	0.95	---	28.7	185
Trial 4**	400	974	720	200	0.5	1	1	50.6	150
Trial 5	400	974	720	200	0.5	1	1.5	29.7	140

Note: * The adopted mix design without Polypropylene fiber;
** The adopted mix design with Polypropylene fiber

3.2. Sample Construction

A total of ten RC beams with dimensions of (100×160×1600) mm were cast with 49 MPa concrete, four of them played as control, and the other were preloaded to 70% of the ultimate load and then strengthened with CFRP composite with and without end-span anchorage Table 4. Group C represents samples casted with concrete without fiber addition (COF0), group R represents samples casted with concrete with 1% 30 mm fiber addition (CWF3), group P represents samples casted with concrete with 1% 50 mm fiber addition (CWF5). All three groups contain RC beam damaged to 70% of Pu and then strengthened with 100 mm CFRP composite at the bottom soffit and the other sample strengthened with the same configuration with end-span anchorage using 500 mm U CFRP composite. All the reinforcement was designed in accordance with ACI-318-19 standard, to ensure that RC beam samples fail in a flexural manner. The expected ultimate flexural and shear load capacities were 50 kN and 70 kN respectively, the section was reinforced with 2Ø10 mm bars at the bottom and top as longitudinal reinforcement. Shear reinforcement bars were Ø8 @150 mm c/c. The RC beam was 1600 mm in length with a total depth of 160 mm and width of 100 mm. Concrete cover was maintained along the entire beam with a thickness of 25 mm, Figure 4. A set of strain gauges was bonded into the steel rebars, concrete surface, and CFRP composite surface to monitor the strain level during loading.

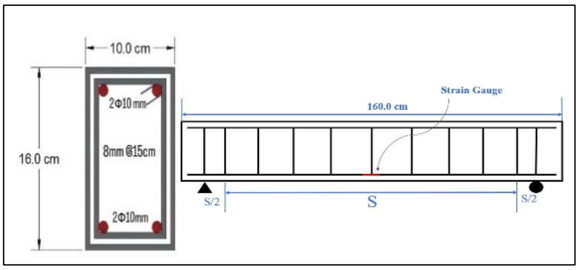

Figure 4: Section reinforcement detailing.

3.3. Strengthening program

Before starting the strengthening application using CFRP composite, the RC beams' surface was prepared in accordance with the ACI 440.2R-17. The surface was roughened using an electrical grinding machine, to achieve a strong bond between the RC beams specimen and the CFRP composite. The bottom and top edges along the length of the RC beams were rounded using a grinding machine. The diameter of the trimmed corner was approximately 20 mm. This step was significant to prevent stress concentrations of CFRP composite at the corners, as illustrated in Figure *6* The surface was then cleaned using an air blower. Then the samples were washed with a jet water machine, followed by wiping the surface with a clean towel to remove any residual dust and impurities. Finally, before starting the strengthening application, the surface of the samples was left to fully dry. This precaution was necessary as any moisture on the surface may potentially impact the epoxy application Figure 6.

Because of the numerous benefits of employing FRP materials, the externally bonded FRP composite system has been investigated for reinforcing RC elements in flexural Figure 7. However, the efficiency of FRP strengthening is subjected to early debonding failure at stresses less than the FRP's strain capacity. Bonacci and Maalej [42], claimed that the CFRP sheet deboned at only 50% of its tensile capacity. Thus, in this research, the end anchorage technique was investigated to increase the efficiency of the strengthening program.

This study presents the experimental work conducted to investigate the most efficient flexural strengthening technique. In which ten RC beams were designed to fail in flexural. The specimens were: two beams serving as a control for group C samples and one control sample for groups R and P. Samples C3, R2, and P2, were preloaded to 70% of Pu and then strengthened with two layers of 100 mm CFRP composite at the bottom fiber.

Table 4: Sample matrix.

Sample label	Addition %	Fiber length	Preloading %	Strengthening type
C1	0	-	-	-
C2	0	-	70	-
C3	0	-	70	Tension zone
C4	0	-	70	tension zone + End U anchorage
R1	1	30	-	-
R2	1	30	70	Tension zone
R3	1	30	70	Tension zone + End U anchorage
P1	1	50	-	-
P2	1	50	70	Tension zone
P3	1	50	70	Tension zone + End U anchorage

Samples C4, R3, and P3, were preloaded to 70% of Pu and then strengthened with two layers of 100 mm CFRP composite at the bottom fiber and anchored at end-spans with 500 mm U CFRP composite Figure *5*.

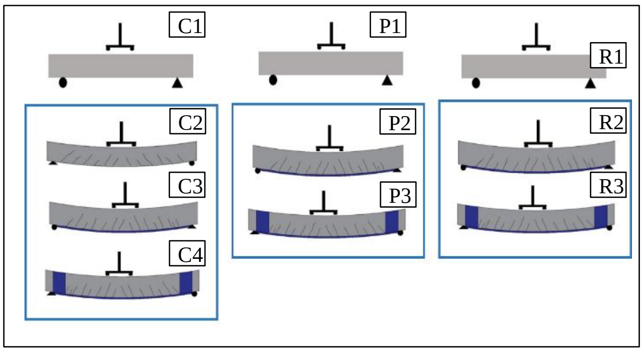

Figure 5: Strengthening program.

Figure 6: Surface preparation prior to CFRP application.

Figure 7: CFRP application.

Figure 8: Test set-up

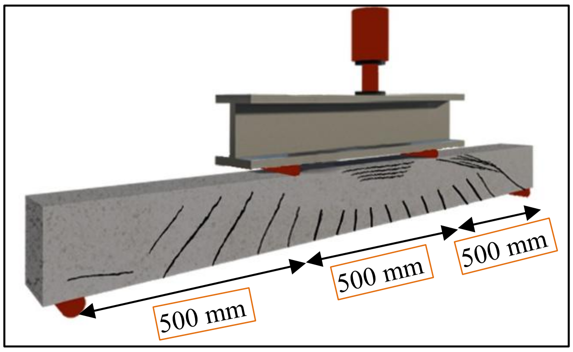

Figure 9: 3D drawing for the four-point flexural test.

3.4. Test set up

The tests were conducted at the College of Engineering lab - University of Duhok. Four-point test loading was conducted to load up the specimens up to failure. A flexural machine with 400 kN capacity was used. The RC beams were tested under the load control test method at a rate of 0.2 kN/second using a 400 kN flexural testing machine in which the control RC beam took about 5 minutes from starting the loading up to failure. A series of 100 mm LVDTs were used to record the deflection at mid-span and under the loads. Moreover, strain gauges were used to measure strains at the tension zone at mid-span, and compression zone at mid-span. DIC technique was also used using a Cannon D90 camera to capture the distortion of the RC beam during loading. All RC specimens were painted with a white color on one side to capture the initiation of cracks conveniently while loading. The other side was painted with white and black dots for the digital image correlation (DIC) test procedure. Cracks were marked on the RC specimens with a pen while loading and cracking loads were recorded. A controlling computer with a data logger was used to collect all data from the bonded strain gauges, dial gauges, and load cell. DIC was also used to record the RC specimens while loading and all recorded data were analyzed using GOM correlate software and results were then compared with the results obtained from experimental work and numerical models. Figure 8 and Figure 9, illustrate the test set-up including the flexural machine, data logger, DIC camera, and tested sample.

4. RESULTS

4.1. Mechanical properties

In this study, the effects of different PP fiber lengths on the mechanical properties of concrete were investigated. The workability of COF0 was lower than the mix without PP by 12% based on flow test results which agreed with Rahmani, Dehestani [43]. A concrete flow test was 171 mm for COF0, 151 mm for CWF3, and 149 for CWF5. A set of six cylinders (Ø 150 × 300) mm were casted for each group to identify the compressive strength. The specimens were tested with a stress rate of 0.23 MPa/second Figure 10: Small beams result.. All samples were sulfur-capped following (ASTM C617-15) [44] prior to loading. The loading was according to (ASTM C39-21) [45], The Compressive strength of concrete without the addition of COF0 was 49.2 MPa, CWF3 was 50.2 MPa, and CWF5 was 49.6 MPa Figure 10: Small beams result..

The concrete splitting test was then carried out on eighteen cylinders. Six cylinders for each concrete type. The cylinders' dimensions were (Ø 100 × 200) mm. The testing was under uniaxial compression according to (ASTM C496-17) [46], using a Besmak 2000 kN testing machine with a loading rate of 0.1 MPa / min. The average splitting strength was found to be 4.07 MPa for COF0, CWF3 was 4.17 MPa and CWF5 was 4.21 MPa. The splitting tensile strength of concrete was increased by adding PP fibers to the mixture by 2.5 % when 1% 30 mm fiber was used and by 3.4% when 1% 50 mm fiber was used as listed in Table *5*. Concrete flexural strength was tested using the Walter Baiag 2000 kN flexural test machine. A 5 mm dial gauge was used to record the load versus deflection. The average flexural strength of six specimens of (100 × 100 × 400) mm was 6.28 MPa for COF0, CWF3 was 6.67 MPa and CWF5 was 6.35 MPa. The flexural tensile strength of concrete was increased by adding PP fibers to the mixture by 6% when 1% 30 mm fiber was used and by 1% when 1% 50 mm fiber was used. Deflection also was increased with the presence of PP fiber and this related to the reduction in modulus of elasticity when PP is used Figure 10. The modulus of elasticity was determined in accordance with (ASTM C469-22) [47]. Cylinder specimens (Ø 150 × 300) mm were used and sulfur capped in accordance with (ASTM C617-15) [44]. The average modulus of elasticity (E) was 28.36 GPa for COF0, 28.03 GPa for CWF3, and 27.91 GPa for CWF5. Concrete density is rarely reduced when PP fiber is added to the mix.

Table 5: Mechanical properties of LSCO and LSCW.

Type of Concrete	f_c' MPa	f_t MPa	f_r MPa	(E) GPa	Poisson ratio	Flow test (mm)	elocity (UPV) mm/μs	Density (kg/m^3)
OF0	49.27	4.07	6.28	28.36	0.192	171	.55	350
WF3	50.22	4.17	6.67	28.03	0.187	151	.75	335
CWF5	49.56	4.21	6.35	27.91	0.185	149	.53	337

Figure 10: Cylindrical sample under compression machine test.

4.2. Structural behavior

The effects of adding PP fiber with different lengths on the behavior of pre-damaged RC beams were investigated by testing different fiber lengths (30 mm and 50 mm) using the optimum ratio identified by the literature. Moreover, the effects of CFRP composite on the flexural behavior of pre-damaged RC beams were investigated.

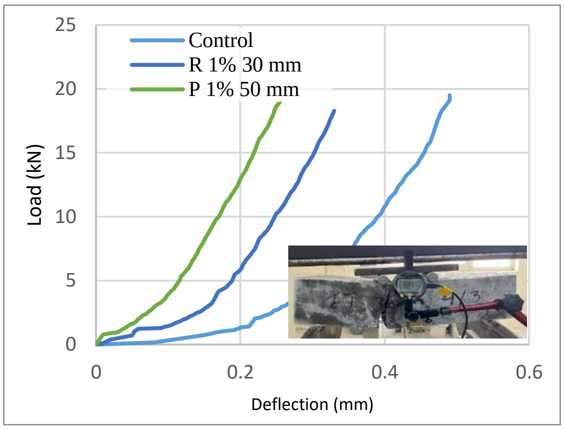

Figure 10: Small beams result.

Table 6: Beams result.

Code	Fiber addition %	Fiber length mm	Pre-loading %	P_{cr} KN	Δ_{cr} mm	$P_{y\text{-}Pre}$ KN	$\Delta_{y\text{-}Pre}$ mm	P_y KN	Δ_y mm	P_u KN	Δ_u mm	$P_u/P_{u control}$ %	Strengthening type	Failure type
C1	0	-	-	15	1.14	-	-	35.8	3.99	51.2	23.43	-	-	Flexural Failure
C2	0	-	√	8	0.49	36	4.86	35.4	4.66	51.4	25.81	0.39	-	Flexural Failure
C3	0	-	√	9	0.54	38.4	4.63	47.4	5.02	69.8	15.19	36.3	tension zone	CFRP debonding + shear failure
C4	0	-	√	12	0.88	36.4	4.8	45.6	5.17	87.2	21.7	70.3	tension zone + U	crushing of compressive concrete
P1	1	30	-	13	0.71	-	-	37	3.97	54.2	21.72	5.8	-	Flexural Failure
P2	1	30	√	10	0.29	34.2	4.19	43.8	4.36	74.8	16.47	38.1	tension zone	CFRP debonding
P3	1	30	√	9	0.55	36.8	4.59	46	5.11	88.8	25.44	63.8	tension zone + U	crushing of compressive concrete
R1	1	50	-	12	0.89	-	-	36.4	4.45	53.4	22.96	4.3	-	Flexural Failure
R2	1	50	√	11	0.51	42	5.61	51.4	6	66.4	14.48	24.3	tension zone	CFRP debonding
R3	1	50	√	9	0.55	34	4.46	49	4.97	87.6	25.44	64.1	tension zone + U	CFRP rupture

4.3. Effects of PP fiber on flexural behavior

Results illustrate that adding PP fibers to the concrete mix leads to improving total carrying load in the flexural test for the tested RC beams by 6% when adding 1% 30 mm fiber and by 4% when adding 1% 50 mm fiber. In terms of ductility, adding PP fiber increases ductility behavior as presented in Figure 11. Stain levels in RC samples without CFRP strengthening exposed to higher strain levels due to the influence of fibers in improving post-cracking behavior, increasing energy absorption, and reducing the formation and propagation of cracks.

The load-deflection relationship is affected by the material properties, geometry, and reinforcement of the beam. When waste fibers are added, they can enhance the structural performance of RC beams by improving post-cracking behavior, increasing energy absorption, and reducing crack formation and propagation. Consequently, adding waste fibers generally reduces deflection under load, leading to an increase in ductility and overall structural integrity.

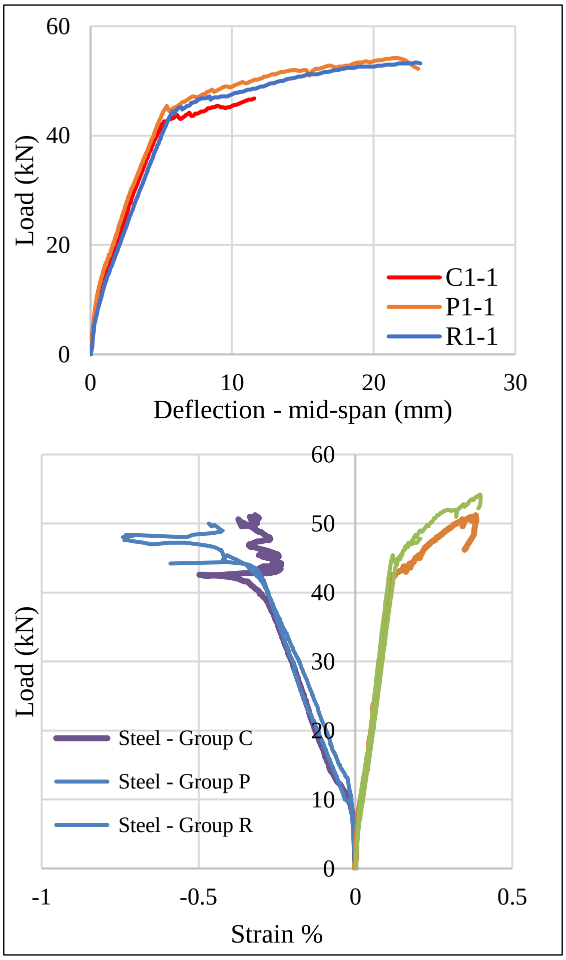

Figure 11: Load-deflection for RC samples without CFRP strengthening.

4.4. Effects of CFRP composite on flexural behavior

Strengthened RC beams showed excellent performance after CFRP strengthening. The total increase in ultimate load increased by 36% for samples casted with concrete without fiber addition, by 38.1% for samples in group P casted with concrete containing 1% PP fiber with 30 mm length, and by 24.3% % for samples in group R casted with concrete containing 1% PP fiber with 50 mm length. Samples with 1% PP fiber with 30 mm length showed better performance compared with those with 50 mm fiber length Figure 12. Total deflection was also increased in samples with CFRP composite from 21.7 mm to 16.4 mm for group P samples, from 22.9 to 14.4 for group R samples, and from 23.4 to 15.1 for group C samples. This conclusion is agreed with several studies conducted in the literature. This is because the CFRP composite adds to the stiffness of the RC member resulting in a reduction in total deflection. RC beams became more stiffer after CFRP strengthening. The first crack initiation was also recorded and presented in Figure *15*. The cracking load was also reduced by about 10% in samples with PP fibers (groups P and R) and about 40% in samples without fiber addition (group C). Steel and CFRP strain levels are illustrated in Figure 13, steel strain levels reduced after applying CFRP composite.

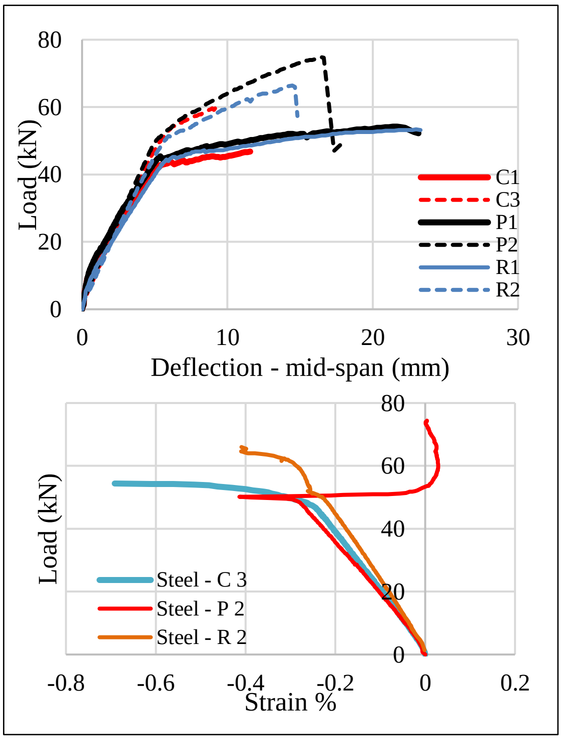

Figure 12: Load-deflection for RC samples with fiber addition.

On the other hand, RC beams strengthened with CFRP composite showed high strain levels at mid-span. This behavior illustrates excellent CFRP strengthening application as CFRP fabric played a good role as main reinforcement resulting in a reduction in the steel strain level.

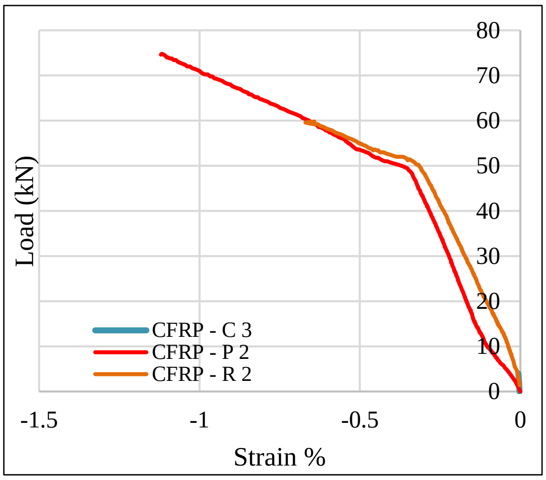

Figure 13: Strain level in steel and CFRP for C3, P2, and R2.

4.5. Effects of End-span anchorage on flexural behavior

As mentioned in the literature, CFRP debonding and separation of concrete cover are the most common flexural failures when a pre-damaged RC beam is strengthened with CFRP composite. Thus, in this research, end-span anchorage was investigated to study the effects of anchorage on load-carrying capacity of strengthened RC beams. Figure 14 (a) presents results of pre-damaged RC beams with end-span anchorage and pre-damaged RC beams without end anchorage. The results clearly show that end-span anchorage resulted in excellent enhancement in total carrying load capacity compared to the strengthened RC beam without end anchorage. The samples improved by 25% for group C, by 19% for group P, and by 32% for group R as presented in Figure *14*. Total deflection increased compared to samples without anchorage, this due to the excessive deflection related to the new ultimate carrying capacity resulted in increase the flexural curvature. Figure 14 (b) show that RC beams with end-span anchorage got similar flexural behavior to those without anchorage except when the load-deflection curve reached the one without anchorage, it held a larger amount of load and transfers the failure mode from CFRP debonding into steel yielding or concrete crushing after pushing up the neutral axis.

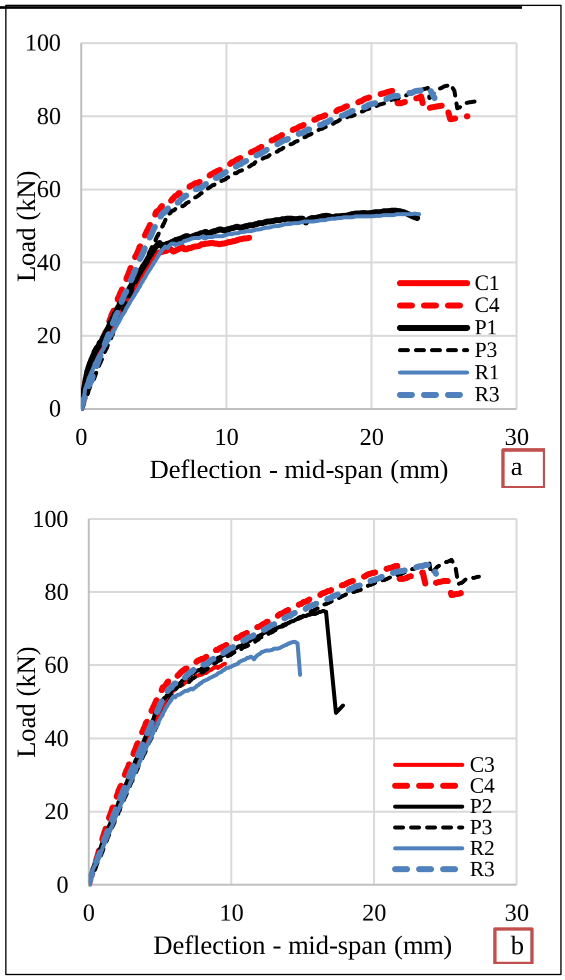

Figure 14: Load-deflection for RC beams with end-anchorage vs non anchorage

4.6. Failure modes

The failure modes of all pre-damaged RC beams are illustrated in Figure 15. Control RC beams C1, C2, P1, and R1 failure was due to steel yielding which is a typical flexural-tension failure for similar beam detailing. Flexural failure, in all the controls, happened gradually as the flexural stresses resisted by steel reinforcement, and this led to steel yielding, and ductile failure was observed. This failure mode occurs when the steel reinforcement reaches its yielding point, leading to an excessive deflection and potentially compromising the beam's load-carrying capacity. Strengthened RC beams without anchorage C3, P2, and R2 failed due to CFRP debonding, as the CFRP separated at the end span, which agrees with the common failure mode in CFRP-strengthened RC beams described in the literature. Using U CFRP anchorage at both ends led to a change in the failure mode compared to the samples strengthened with CFRP without anchorage. Sample C4 and R3 failure mode become concrete compression failure. Sample P3 failure mode became CFRP rupture compared to CFRP debonding after adding a U CFRP layer at both ends. These results illustrate the quality and performance of the strengthening application in increasing ultimate carrying load and changing the failure mode from CFRP debonding which is not preferred compared to CFRP rupture or concrete crush which is more cost effective in such strengthening application.

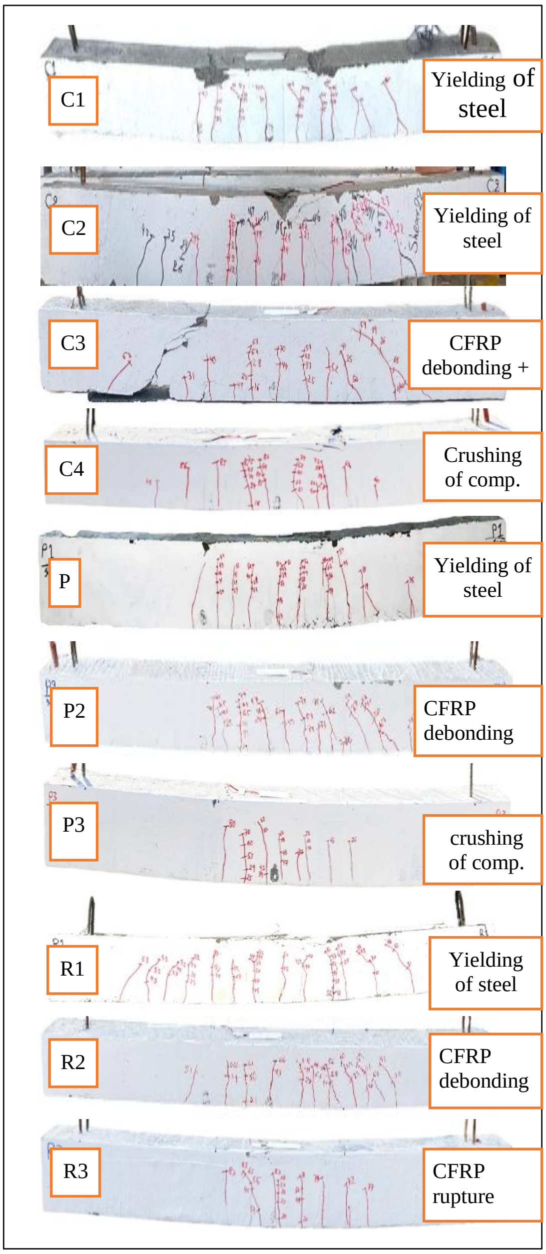

Figure 15: Failure mode

5. CONCLUSION

This research studies the effects of plastic waste PP fiber addition on the mechanical properties of normal-strength concrete and also investigates its effects on the flexural behavior of pre-loaded RC beams. The second stage of the research is retrofitting the pre-damaged RC beams using CFRP composite and finding the effects of using anchorage at both ends on strengthening application. The results main findings are illustrated below:

- Compressive strength is increased by about 2% when adding 1% 30mm PP fibers and 1% when 1% 50 mm is added.
- Tensile strength is increased by about 4% when adding 1% 50mm PP fibers and 3% when 1% 30mm is added Flexural strength of concrete is increased by about 4% when adding PP fibers.
- Adding polypropylene (PP) increased the flexural behavior of the RC beams by about 4% when 1% 30 mm is added, and about 6% when 1% 50 mm is added.
- The addition of the fiber does not affect the homogeneity of the concrete
- Strengthening RC beams in the tension zone by CFRP sheet, casted without fiber addition, increases the flexural capacity by about 36%, and using the anchorage scheme increases flexural capacity by about 70%.
- Using CFRP strengthening increases the yield strength by about 24%.
- Adding PP fibers leads to a reduction in the number of cracks at failures.
- The incorporation of CFRP fabric in the tension zone results in a notable reduction of flexural deformation and an increase in strain resistance, as the high tensile strength and stiffness of CFRP enhance the resistance to flexural stresses.
- The failure modes observed in strengthened RC beams were either CFRP debonding or CFRP rupture, which agreed with typical failures defined in the literature.
- In group R, using CFRP anchorage leads to a change in the failure mode from CFRP debonding to CFRP rupture.
- In flexural strengthening applications, the CFRP plates played a significant role in enhancing the flexural behavior and strain characteristics of the tested RC beam. CFRP laminate effectively distributed and transferred flexural forces, leading to an increase in load-carrying capacity and improved overall structural performance.
- The high level of CFRP strain reveals that the strengthening technique was effective, with the CFRP composite serving as the primary reinforcement.
- In flexural strengthening application, crack width is reduced when the RC beam that is weak in flexural is strengthened with CFRP composite.
- In flexural strengthening applications, the addition of PP fiber to the concrete results in a reduction in crack width.

6. FUTURE DIRECTION

In future directions, the effects of fiber addition on shear behavior and on the properties of concrete with elevated temperature is suggested by using theoretical analysis.

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إعادة تأهيل العوارض الخرسانية التالفة مسبقاً والتي تحتوي على نفايات بلاستيكية معاد تدويرها باستخدام ألياف الكربون المقوى بألياف الكربون

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الملخص

على مدى العقود القليلة الماضية، أصبح استخدام مركبات البوليمر المقوى بالألياف (FRP) لغرض تقوية وإعادة تأهيل هياكل الخرسانة المسلحة (RC) معترفًا به على نطاق واسع باعتباره نهجًا فعالًا للغاية لتحسين السلامة الهيكلية وزيادة العمر الافتراضي. تتطلب الهياكل القديمة في كثير من الأحيان الصيانة والإصلاح نتيجة للظروف البيئية القاسية، والكوارث الطبيعية، والتغيرات في الأحمال المطبقة، وتآكل التسليح، وعدم كفاية الصيانة. في هذه الدراسة، تم النظر في جانبين. الأول هو دراسة سلوك كمرات RC المحملة مسبقاً بعد إعادة تأهيلها باستخدام مركب CFRP. الجانب الثاني هو إيجاد تأثير مخلفات مادة البولي بروبيلين البلاستيكية على سلوك كمرات RC المحملة مسبقاً. وبالتالي، تم تحضير ثلاث خلطات باستخدام طولين مختلفين من ألياف البلاستيك PP 30 و50 مم بنسبة ثابتة تساوي 1% كما أوصت به الأدبيات. تم صب عشرة عتبات RC بأبعاد (100×160×1600) ملم، تم صب اثنتين منها كعنصر تحكم والأخرى تم تحميلها مسبقاً بنسبة 70% من الحمل النهائي المحسوب على أساس عينة التحكم. أظهرت النتائج أن إضافة مخلفات البلاستيك كألياف PP يؤدي إلى تحسين الخواص الخرسانية الشاملة. علاوة على ذلك، أدى التعديل التحديثي لعوارض RC التالفة مسبقًا باستخدام مركب CFRP إلى تحسين قدرة حمل الحمولة بنسبة 70% عند استخدام مرساة U CFRP في كلا الطرفين.

الكلمات الداله :

ألياف البولي بروبيلين؛ متضررة مسبقًا؛ شعاع RC. ألياف الكربون؛ نفايات البلاستيك؛ العاطفة