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Improve the structural performance of GFRP longitudinally reinforced concrete beams have a cold joint using CFRP sheets

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Abstract. This research aims to assess the structural efficiency of reinforced concrete beams with casting joints made of GFRP bars that are longitudinally reinforced and CFRP sheets added to the system. The focus is mainly on the effects of casting discontinuities at strategic locations, such as the shear and flexural regions, that may significantly affect the structural strength. To determine the initial hardening time, the effect of retarding plasticizers on hardening on the initial setting time and mechanical properties of concrete was studied. Then, seven beams made of high-strength concrete were cast and subjected to failure testing in the initial phase of the study, two beams reinforced with GFRP bars and three with conventional steel reinforcements have a cold joint. The third stage involved casting two more beams with GFRP and having cold joints at the flexural zone, representing the most critical scenario similar to previous beams reinforced with CFRP sheets placed in different configurations. The results show risks in concrete beam have joint at flexure or shear zone due to delayed casting that the lowest failure value for beam reinforced longitudinally with GFRP bars have cast-joint was 23.6 kN a decreasing till 46% due to weak efficacy GFRP bars at joint. So, for these beams must be strengthened by the CFRP layers. The effect of the CFRP layers was improved a behavior of these beams. The strengthened of these beams reinforced longitudinally with GFRP bars have joint at mid by using CFRP sheets was increased a load capacity about 111% to 118%. This paper provides new information about CFRP sheets debonding at the casting joint was after concrete crushing in the compression zone. According to the results, CFRP strengthening is a good way to increase load capacity and reduce the flaws that casting joints introduce. Generally, this study endeavors to yield novel insights into the behavior of such composite systems to enhance concrete beams have cold joints.

Keywords: CFRP sheets; cold- joint; GFRP bars; RC beams; strengthening

1. Introduction

Due to their superior tensile strength, remarkable corrosion resistance, and lightweight nature when compared to traditional steel reinforcement, Glass Fiber Reinforced Polymer (GFRP) and Carbon Fiber Reinforced Polymer (CFRP) have garnered significant scholarly attention in the construction industry in recent years (Prajwal *et al.* 2024, Elkafrawy *et al.* 2024).

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These composite materials have been extensively utilized in the fortification and rehabilitation of concrete structures, particularly in settings where corrosion poses significant risks, such as coastal regions or industrial environments (Sen and Mullins 2007, Karbhari and Zhao 2000).

However, despite the many benefits of GFRP and CFRP, the presence of casting joints, which are often unavoidable in practical construction settings because of logistical constraints and the size of structural components, may negatively impact the structural integrity of concrete components (Su *et al.* 2024, Zhou *et al.* 2024, Shokrzadeh *et al.* 2024).

The casting joints may engender points of weakness or stress concentrations, potentially diminishing the constructed edifice's overall durability and load-bearing capacity. Researchers have investigated various remedial strategies to mitigate these concerns, including enhanced joint design and sophisticated adhesive technologies (Teng *et al.* 2002, Zhao and Zhang. 2007).

Researchers Thomas and Ramadass tested the shear span to depth ratio of 8 concrete beams with longitudinal reinforcement GFRP rebars ratio from 1.16 to 1.75 without stirrups (Thomas and Ramadass 2015). However, the ductile behavior of the GFRP reinforcement of concrete beams is less ductile than the conventional steel-reinforced concrete beams. Increasing the amount of GFRP reinforcement can enhance ductility (El Zareef *et al.* 2018). Hence, understanding the behavior of concrete beams requires many applications of GFRP reinforcement in flexural members (Kinjawadekar *et al.* 2023).

In Australia, alternative technology using non-corrosive GFRP-reinforced polymer bars has been applied as an alternative to steel bars in concrete structures under harsh conditions (Manalo *et al.* 2021). In other studies, the effect of the diameter of GFRP bars used in concrete structures was taken as a factor affecting the strength of the bar. The results showed that the physical properties were not affected by the diameter of the bar except for the increased water absorption of smaller diameters (Benmokrane *et al.* 2017). Regarding the efficiency of FRB-reinforced beams, the failure modes were concrete rupture compared to ductile failure when reinforced with steel at the same ratio under bending load (Attia *et al.* 2022). The important factor in achieving the maximum flexural strength of concrete beams and the amount of carbon fiber bars is the bonding strength between the carbon fiber bars and the concrete (Bakar *et al.* 2022). From the above, there are many advantages to using carbon fiber reinforcement in reinforcing concrete beams. However, the factors mentioned above must also be considered to improve the behavior of these beams under the influence of bending, including strengthening these beams with carbon fiber laminates.

Mehmet Mustafa Önal found that the reinforcement of beams using carbon fiber reinforced polymer with many features such as lightweight, flexible, and non-corrosive with an epoxy coating layer is very effective in increasing the resistance and preventing fracture (Önal 2014). Mukhtar and Jawdhari found that a hybrid retrofitting by using carbon fiber sheets with FRC layer has a good effect on reinforced concrete members subjected to bending loads (Mukhtar and Jawdhari 2024). Lafta *et al*. (2024) investigated the effect of strengthening the flexural strength of beams using carbon fibers in the tension zone, which leads to stopping the cracks from continuing and enhancing the performance of beams and serviceability of structures (Lafta *et al.* 2024).

The efficiency of reinforced concrete beams with GFRP bars has been studied by many researchers and strengthened by using carbon fiber reinforced polymer (CFRP) laminates with high elasticity to lead the sustainability of concrete beams (Hassan *et al.* 2020). The ultimate load capacity increased from 29.8% to 188.46% compared to the control beams (Uz *et al.* 2023, Gurram and Pannirselvam 2024). The FRP sheet improves reinforced concrete beams' behavior and maximum load (Azuwa and Yahaya 2024). Combining CFRP with FRC layers enhanced the ultimate load by about 29-59% and ductility (Faisal *et al.* 2024). Therefore, in this paper, the effectiveness of GFRP reinforcement as bars in concrete beams having cast joints instead of conventional steel due to its corrosion resistance and other properties, but the problem of joint due to casting lag has been investigated. Then, strengthening these reinforced concrete beams with longitudinal GFRP bars cast-joint by CFRP sheets will give good results. The phenomenon of casting joints, which emerge from disruptions occurring during concrete placement, is commonly observed in large-scale construction projects, such as bridges, skyscrapers, and diverse infrastructure systems (Su *et al.* 2024). These joints can introduce vulnerabilities within the structural framework, particularly in regions subjected to shear or bending stresses, which may ultimately result in structural failures if not adequately addressed. Although previous studies have thoroughly examined the benefits of Glass Fiber fiber-reinforced polymer (GFRP) and carbon-reinforced polymer (CFRP) for strengthening concrete structures (Bank 2006, Hollaway 2010, Abdel-Kareem 2014, Ganesh and Murthy 2019, Safiaa *et al.* 2023), there is a significant gap in the literature regarding the behavior of these materials in casting joints (Sen and Mullins 2007, Wu *et al.* 2010). In particular, the dynamics among GFRP reinforcement, CFRP enhancement, and casting joints remain insufficiently explored, creating a crucial gap in the academic domain. This investigation aspires to fill this void by scrutinizing the structural efficacy of GFRP-reinforced concrete beams that incorporate casting joints and are augmented with CFRP sheets. The originality of this research resides in its emphasis on the synergistic impact of GFRP longitudinal reinforcement and CFRP external enhancement in alleviating the deficiencies engendered by casting joints. Through the execution of experimental methodologies, this study seeks to provide new insights into the behavior of such composite systems and to offer practical recommendations for improving the design of concrete structures exhibiting casting joints.

2. Signification research

In this paper, it is necessary to study the effectiveness of GFRP as reinforcement bars in concrete beams instead of conventional steel in case of joint problems due to casting delay. Also, improving the structural performance of GFRP longitudinally reinforced concrete beams with joint-casting lag using CFRP sheets has been investigated. Thus, CFRP sheets is a very important technique for concrete structures that suffer from poor structural performance due to aging, seismic damage, or excessive loads. Concrete beams are a critical component of these structures, and strengthening them extends their operational life and achieves economic efficiency compared to complete replacement. So, this study endeavors to yield novel insights into the behavior of such composite systems and provide pragmatic recommendations to enhance the design and construction practices of concrete components that exhibit casting joints.

3. Materials and prepare samples research

It is necessary to clarify the working method with the materials used to give the desired results.

Cement: The ordinary Portland cement product of Kabisa Cement Factory was consistent with Iraqi specifications.

Sand: A quarry in Anbar Governorate produced fine aggregate graded for concrete mixes that were consistent with Iraqi specifications.

Table 1 Different concrete mixtures

Grade of concrete	Cement (kg)	Fine aggregate (kg)	Coarse aggregate (kg)	W/C ratio	Admixture
M0	544	633	924	0.4	-
M0.5	544	633	924	0.4	0.5%
M1.0	544	633	924	0.4	1%
M2.0	544	633	924	0.4	2%

Table 2 Properties of typical Unidirectional MasterBrace FIB sheets from the company

Material type	Elasticity modules (N/mm2)	Tensile strength (N/mm2)	Thickness (mm)	Wight (g/m2)	Elongation %
Carbon	230	4900	0.11	230	2.1

Gravel: The coarse aggregate used in the concrete mix was from Anbar Governorate, with a maximum size of 12.5 mm. A grading of coarse aggregate was conducted, and the results were following Iraqi specifications.

Water: the concrete samples were mixed and cured by using potable water.

Admixture: In this experimental study, a HARD STONE chemical company superplasticizer (Hard—Con-824) improves concrete's early and ultimate compressive and tensile strengths by reducing the water-cement ratio. The superplasticizer dosage is 0.5, 1, and 2 liters for 100 kg of cementitious materials.

Additionally, Master Press Sat 4500 adhesive was used to reinforce concrete beams with CFRP sheet.

The materials used were Ordinary Portland Cement, river sand, crushed gravel of larger size 12.5 mm, potable water, and a superplasticizer at 0.5%, 1%, and 2% to produce different concrete mixtures for obtaining a consistency suitable for the attached Table 1.

3.1 Master brace fiber sheets

Unidirectional Master Brace FIB sheets with high strength and flexibility, as shown in Table 2, were used to strengthen the flexural and shear loads of concrete beams.

3.2 GFRP bars and steel bars

Two concrete beams reinforced longitudinally with GFRP bars were cast to make a joint in the shear and flexure zone. Also, CFRP sheets with different configurations strengthened two reinforced concrete beams by GFRP bars with cast-joint in the flexure zone. Three reinforced longitudinally with conventional steel bars were also cast to make joints in the shear and flexure zone. Properties of these GFRP bars and steel bars are present in Table 3.

3.3 Prepare and cast of samples

Prepare and weigh the materials of ordinary Portland cement, sand, crushed gravel of larger

Table 3 GFRP bars and steel bars specifications

Type of bar	Bar size	Area mm2	Elastic tensile GPa	Tensile strength MPa	Tensile strain
Steel bar	10 mm	78	200	414	0.2 %
GFRP bar	10 mm	78	53	877	1.89%

size 12.5, potable water, and plasticizer at a rate of 1.5% to produce a consistency suitable for the concrete mix.

Prepare cubic, cylindrical, beam molds, pans, bowls, tumblers, and an electronic balance.

Mix the concrete mixture inside the pan. After the materials are combined, add water, then add the superplasticizer to the concrete mixture

After checking the concrete slump test, fill the molds.

After (24) hours, remove the molds and put the samples. in the water tank laboratory until testing (7) days, (14) days, and (28) days.

Conduct the necessary tests for hardened concrete.

3.4 Strengthened GFRP longitudinally reinforced concrete beams have joint due to casting lag by using CFRP sheets

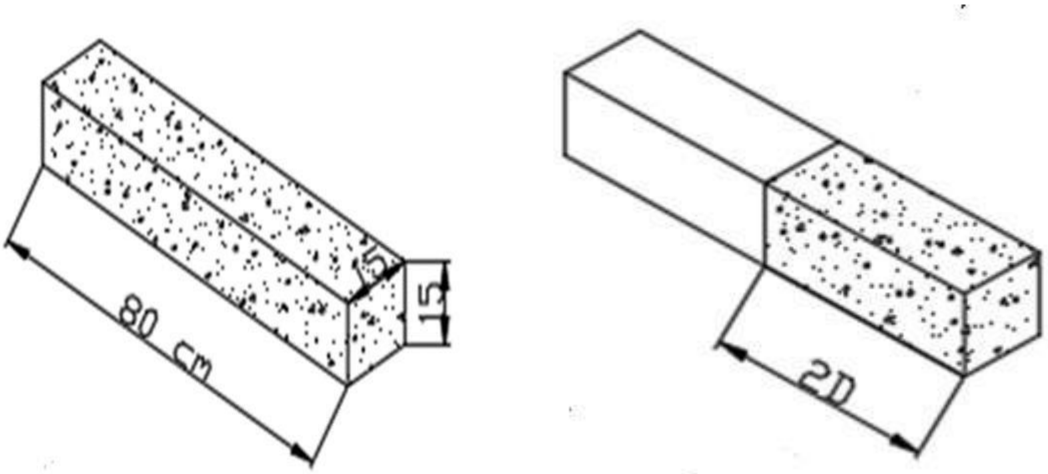
The experimental design to evaluate the structural reliability of concrete beams strengthened with Glass fiber-reinforced polymer (GFRP) included additional reinforcement of the joints with Carbon fiber- reinforced polymer (CFRP) sheets through casting. Pragmatic considerations and previous studies determined the beam dimensions, reinforcement ratios, and CFRP configurations to confirm the validity of the conclusions.

Beam Dimensions: The experimental beams had dimensions of 80 × 15 × 15 cm, representing the standard size for research on small structural components. The chosen dimensions permit precise testing within controlled environments (Ameli *et al.* 2024).

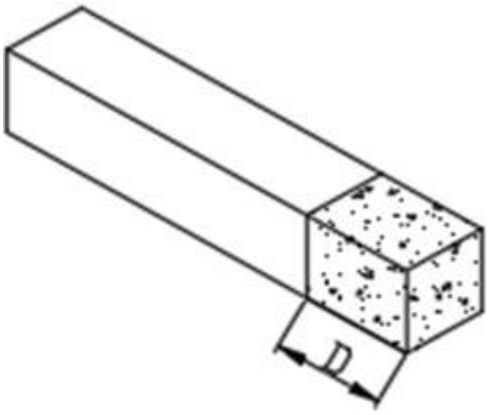
Reinforcement Ratios: The set reinforcement ratio of 1.5% meets standard values for beams strengthened with glass fiber reinforced polymer (GFRP). Previous studies demonstrated that this reinforcement ratio effectively provides necessary flexural strength and reduces the risk of brittle failure (Yang *et al.* 2024).

CFRP Configurations: Carbon fiber reinforced polymer (CFRP) sheets with a thickness of 1.2 mm were installed using the U-wrap method, which is a common choice for strengthening purposes. The selected configuration achieved complete coverage of the casting joint area along with sufficient shear and flexural reinforcement (Shokrzadeh *et al.* 2024).

So, in this study, at the first stage, seven high-strength reinforced concrete beams were cast and tested till failure to study the effect of stopping the casting in the shear zone or the bending zone. Two concrete beams were reinforced longitudinally with GFRP bars, and three were reinforced longitudinally with conventional steel bars. In comparison, the first whole beam was cast without stopping. In comparison, the second beam was cast till the bending zone. After hardening the concrete, the second layer was cast to complete the beam. Meanwhile, the third beam was also cast till the shear zone. After hardening the concrete, the casting of this beam was completed, as shown in Figure 1. In the next stage, two reinforced concrete beams by GFRP bars were cast to make a joint in the bending zone, which represents the most dangerous case in which these beams were strengthened using CFRP sheets with different configurations. The following are the details of the main stages of the experimental program.



(a) Casting high-strength reinforced concrete beams (b) Casting high-strength reinforced concrete beams with joint at flexure zone

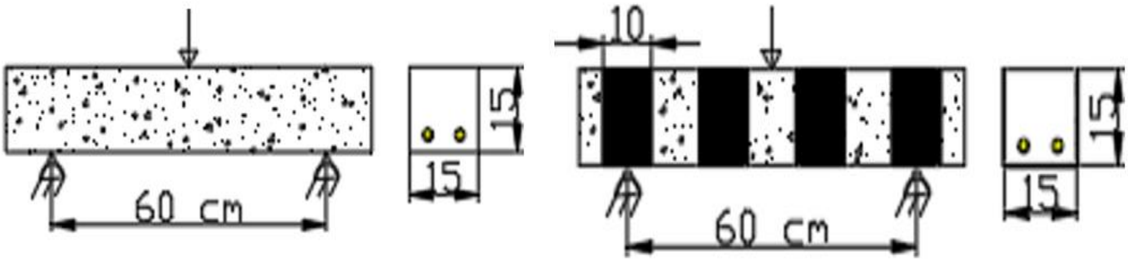


(c) Casting high-strength reinforced concrete beams with joint at shear zone

Fig. 1 Casting high-strength reinforced concrete beams have joint in the shear zone or in the flexure zone

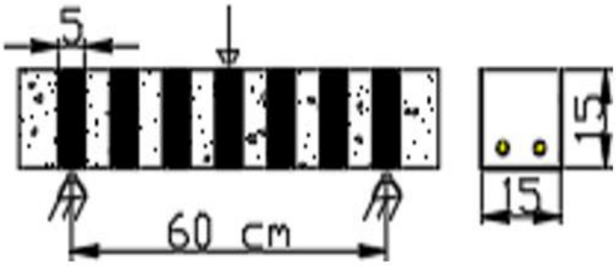
Each longitudinally reinforced beam of 80 × 15 × 15 cm dimensions was cast to determine its strength, and three concrete cubes of 10 cm3 were cast to test the compressive strength. Twenty-four hours after casting, the specimens were removed from the mold and placed in water at laboratory temperature for 28 days until the test day. As for the concrete beams reinforced with GFRP bars, which were cast in two stages, the first stage stopped casting the sample in the flexure zone (stop cast beam at half distance from two supports), and after hardening, the sample was cast entirely. After 28 days, these reinforced concrete beams were removed from the water tank, leaving the surface dry. The concrete beams were reinforced using carbon sheets and adhesive (Master Brace SAT 4500).

Then, it started cutting the carbon sheets and forming the first beam in the shape of the letter U with a distance of 10 cm between each slice, while the second beam had a distance of 5 cm between each slice, as shown in Fig. 2.



(a) GFRP longitudinally reinforced concrete beam

(b) Strengtheneing GFRP longitudinally reinforced concret-e beam by CFRP sheets at distance 10 cm



(c) Strengthening GFRP longitudinally reinforced concrete beam by CFRP sheets at distance 5 cm

Fig. 2 Strengthening reinforced concrete beams with longitudinally GFRP bars having cast- joint by CFRP sheets

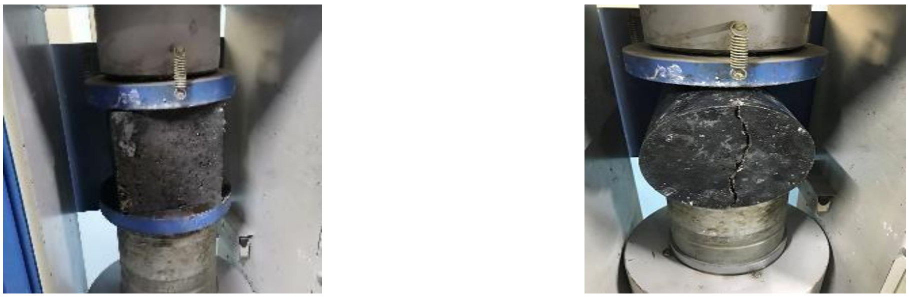
4. Test results

4.1 Effect retarding admixture on the initial setting time of concrete

The incorporation of retarding admixtures in concrete significantly influences the initial consistency of the material, necessitating a thorough examination to comprehend both its beneficial and detrimental implications. The initial consistency of concrete is defined as the capacity of the material to preserve its uniformity and structural integrity during the formative stages after casting, a pivotal phase that substantially impacts on the overall quality of the resultant concrete. The impact on the initial cohesion is exemplified in Table 4. In the early stages following casting, the utilization of a plasticizer may extend the softening period of the concrete by retarding the hardening mechanism. The primary function of a plasticizer is to impede the dynamics of hydration reactions, thereby alleviating the thermal energy generated within the concrete matrix. However, suppose the pouring process is interrupted excessively between subsequent batches. In that case, the initial layer may begin hardening before the next layer's application, leading to the development of cold joints. These joints can serve as potential weaknesses within the concrete assembly. Climatic variables, encompassing heightened thermal conditions and reduced humidity levels, can significantly affect the kinetics of concrete curing. If the concrete dries too quickly, it may crack or form unwanted joints. So, this research delayed casting after the initial set period to obtain cold joints.

Table 4 Effect retarding admixture on the initial setting time of concrete

Grade of concrete	Initial concrete hardening time (Hours)
M0	1:02
M0.5	1:45
M1.0	3:15
M2.0	3:54



(a) Compressive test (b) Tensile test

(c) Flexural test

Fig. 3 Mechanical properties of concrete

4.2 Mechanical properties of concrete mix

The experimental program of concrete properties was carried out in two parts: fresh and hardened. According to ASTM C143-10a, the slump test was performed using a slump cone after preparing the concrete mix. A conventional cube, a cylinder, and beam molds were used to cast concrete after the slump test to ascertain the properties of the hardened concrete. After 24 hours of casting, the concrete was removed from the molds and submerged in water to cure until the testing date. Concrete samples of sizes 15x15x15 cm and 30x15 cm were produced to be subsequently tested at ages 7, 14, and 28 days to test compressive strength and tensile strength, respectively. Concrete samples of sizes of height of 10 cm, width of 10 cm, and length of 40 cm for test flexure strength were studied at 28 days, as shown in Fig. 3. The compressive strength test based on (BS. 1881: Part 116: 1989), this test was conducted using a universal testing machine with a capacity of 2000 kN. Specimens were loaded at a uniform rate of 0.25 ± 0.05 MPa/s to ensure accurate load distribution and provide reliable, comparable results. Meanwhile, the splitting test based on ASTM

Table 5 Test compressive strength (N/mm2) results of concrete mixes

Grade of concrete	7 days	14 days	28 days
M0	30.3	37.2	42.9
M0.5	31.6	38.9	43.1
M1.0	32.7	39.1	45.6
M2.0	31.8	38.4	44.3

Table 6 Test tensile strength (N/mm2) results of concrete mixes

Grade of concrete	7 days	14 days	28 days
M0	2.71	3.16	3.86
M0.5	2.76	3.22	3.91
M1.0	2.94	3.45	4.02
M2.0	2.83	3.28	3.93

Table 7 Test flexure strength (N/mm2) results of concrete mixes

Grade of concrete	7 days	28 days
M0	4.26	5.98
M0.5	4.86	6.87
M1.0	5.24	6.94
M2.0	4.77	6.33

C496-2004, loading rates ranged from 0.7 to 1.4 MPa/min, allowing for simulation of the transverse stress conditions experienced by concrete elements in practical applications. The flexural strength test was performed in the second stage of the investigations using a middle-third loading system ASTM C78, the specimens were mounted on two supports 30 cm apart, with the load applied at a constant rate of 0.10 mm/min to determine the flexural resistance of the beams, as shown in Tables 4, 6, and 7.

4.3 Effect GFRP bars of strength concrete beams having a cold-joint

To study the effect of casting stop zones on five concrete beams subjected to flexural test. Table 8 shows the effect of the type of longitudinal reinforcement on the failure resistance of concrete beams containing a pour joint in the shear or bending zone. It has been noticed that the reinforcement of carbon fiber bars reduces the failure resistance value under bending tests compared to steel reinforcement. It was also noted that the casting stop location dramatically affects the failure value. The lowest failure value for the concrete beam reinforced longitudinally with GFRP bars was 23.6 kN, which decreased by 46%. In general, the presence of a casting joint in the shear or bending area dramatically affects the resistance and durability of the concrete beam, as shown in Fig. 4. Therefore, the casting stop area must be handled using standard connection methods between the old and the new concrete structure.

Table 8 Effect of the type of longitudinal reinforcement on strength of concrete beams having a pour-joint in the shear or bending zone

Code of beam	Load (kN)	Modulus of fracture (MPa)	Decrease %
SRCB	43.9	11.71	-
SRCB- md	34.3	9.15	-22%
SRCB- d15	38.7	10.32	-12%
GRCB- md	23.6	6.29	-46%
GRCB- d15	31.1	8.29	-29%

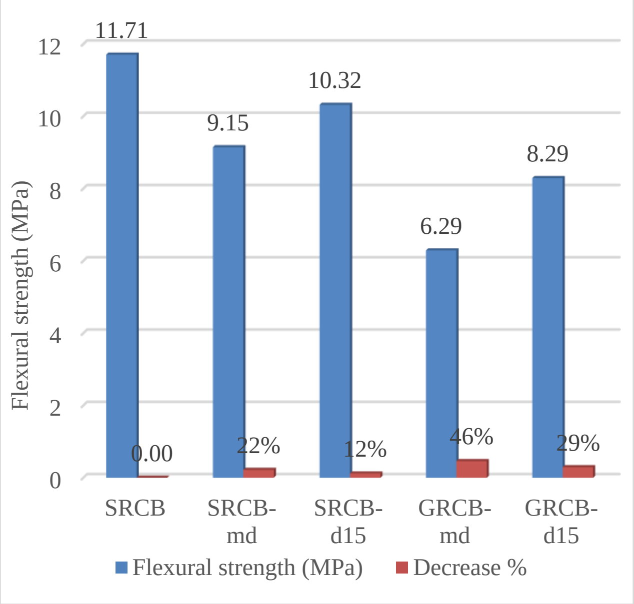


Fig. 4 Effect of joint at the shear or bending zone on GFRP longitudinally reinforced concrete beams

4.4 Effective the CFRP strengthening of beams have flexure -joint

Flexure joints were subjected to flexural tests to study the effect of CFRP strengthening on three concrete beams. The results of strengthening the concrete beams reinforced longitudinally with GFRP bars showed that the flexure joint was more resistant to failure than the unstrengthened concrete beams reinforced longitudinally with GFRP bars (see Fig. 5). The effect of strengthening by different widths and distances between the CFRP layers on the failure load was almost equal at the maximum load of 49.8 to 51.4. The effect of the CFRP layers was determined for the beams at a load capacity of more than 111% to 118% compared to the unstrengthened beam due to the weak ability of GFRP bars reinforcement at the joint, as presented in Table 9.

The experimental results show that CFRP strengthening significantly increased the load-bearing capability of GFRP-reinforced concrete beams with casting joints, increasing from 111% to 118%. Because of the effective stress transfer between the CFRP sheets and the concrete substrate, the overall stiffness and load distribution across the beam were improved. As exterior

Table 9 Effect of CFRP strengthening of GFRP reinforced beams have flexure -joint

Code of beam	Load (kN)	Modulus of fracture (MPa)	Increase %
GRCB- md	23.6	6.29	-
GRCB- md S@ 10 cm	49.8	13.28	111%
GRCB- md S@5 cm	51.4	13.71	118%

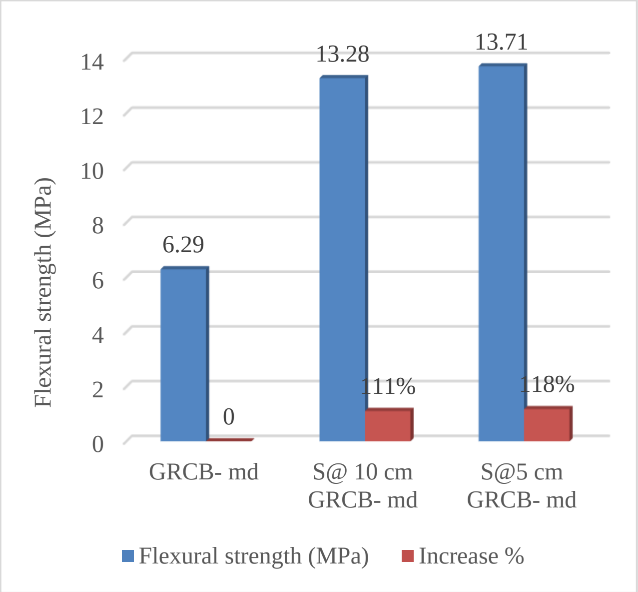
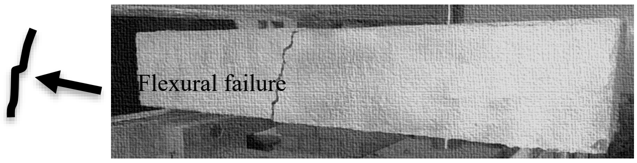


Fig. 5 Effect strengthening by using CFRP sheet on GFRP reinforced beams have flexure -joint

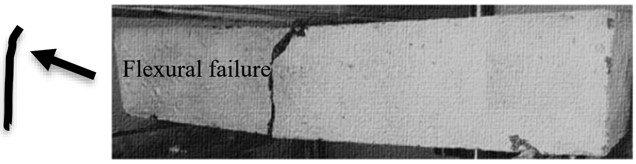
reinforcements, the CFRP sheets could reduce stress concentrations at the casting joint and delay the start of cracking. However, the level of improvement was changeable depending on the casting joint location. A more significant increase in load capacity was observed in beams with joints close to the supports than in beams with joints mid-span or inside shear zones. The differences in stress distribution can be used to explain this phenomenon since joints close to the supports undergo lower bending moments and shear forces than joints in critical zones.

These observations align with antecedent research, including the works of Alsuhaibani (2024), which documented analogous improvements in load capacity upon implementing CFRP sheets to fortify concrete beams. Nevertheless, the present investigation extends these conclusions by illustrating the efficacy of CFRP strengthening in contexts involving casting joints, a scenario that has not been comprehensively examined in existing literature.

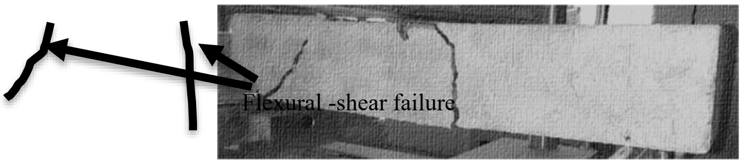
The outcomes of this investigation were juxtaposed with those of prior studies to authenticate the findings and reinforce their validity. For example, El-Sayed *et al.* (2006) documented an analogous rise in load capacity when employing CFRP sheets to strengthen concrete beams absent of casting joints. However, the current inquiry broadens these conclusions by demonstrating that



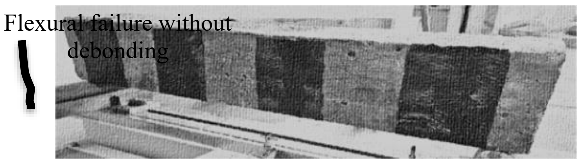
(a) GFRP reinforced beam without joint



(b) GFRP reinforced beam with joint at flexure zone



(c) GFRP reinforced beam with joint at shear zone



(d) CFRP sheet strengthened GFRP reinforced beam with joint at flexure zone

Fig. 6 Modes of failure GFRP reinforced beam with flexure-joint or shear-joint

CFRP strengthening retains its effectiveness in the presence of casting joints, provided that appropriate surface preparation and installation methodologies are adhered to. Meanwhile, the possibility the load capacity when CFRP sheets were utilized to reinforce beams recorded a lesser increase with casting joints. This inconsistency may be ascribed to variations in the experimental configuration, such as the type of adhesive employed and the surface preparation techniques utilized. Therefore, the present study underscores the significance of these factors in attaining optimal performance, as highlighted by Ahmed *et al*. (2025), Sheng and Gong (2024), Abdelkrim *et al.* (2024), Shokrzadeh *et al*. (2024) and Kopiika *et al*. (2024).

4.5 Mode of failure

Fig. 6 shows the failure modes of the tested beams. Flexural failure was the most common mode for beams, whether fully cast or partially cast, forming a bending joint. Meanwhile, the failure mode was shear and bending for partially cast beams with a joint in the shear region. As for the CFRP sheet, strengthened GFRP reinforced beams affected delaying failure and did not show cracks clearly due to the good bond between the material and these beams. From the failure mode of these beams, the reason for the longitudinal reinforcement with GFRP bars only in the critical section (casting joint) led to the flexural failure. Meanwhile, these beams were strengthened, and it can be observed that the failure mode changes much better. Stress distribution according to the analysis of stress distribution, the CFRP sheets successfully spread stress away from the casting joint to reduce stress concentrations in this crucial area. This reallocation of stress played a key role in the observed load capacity improvement.

Debonding was determined to be the primary failure mode in CFRP-strengthened beams in earlier research, including Teng *et al.* (2002). These failure modes are in line with those found in these studies. Nonetheless, this paper covers the behavior of beams with casting joints a subject that has not received much attention in previous research in fresh detail. Bond behavior, the quality of the adhesive used, and the carefulness of surface preparation significantly impacted the bond behavior seen at the casting joint. Insufficient surface preparation caused premature debonding in multiple cases, highlighting the importance of appropriate installation methods in real-world applications.

Thus, this paper provides new information about the characteristics of concrete beams with casting joints reinforced with glass fiber-reinforced polymer (GFRP). As for the selection of 10 cm and 5 cm widths, the decision was based on the results of previous studies and preliminary experiments aimed at examining the effect of strip width on reinforcement effectiveness. The larger width provided greater coverage of tensile zones, while the smaller width provided better control over specific areas prone to localized cracking. The delamination of the carbon fiber reinforced polymer (CFRP) laminates at the casting joint was not obvious, as the concrete failed gradually, causing loads to drop, and cracks were difficult to see due to their thinness. By successfully sealing these emerging cracks, the CFRP laminates slowed their propagation and increased the load-bearing capacity of the beams. This result confirms how the bond strength between the CFRP laminates and the concrete substrate using an epoxy material improves the overall performance of the beams.

5. Conclusions

To sum up, this study offers important new information about the structural performance of CFRP-sheet-strengthened GFRP-reinforced concrete beams with casting joints.

The carbon fiber bars as longitudinal reinforcement have less failure resistance value under the bending test than steel reinforcement. Also, it was also noted that the cast joint at the flexure zone significantly affects the failure value. So, the lowest failure value for a beam reinforced longitudinally with GFRP bars was 23.6 kN by decreased 46%.

The effect of the CFRP layers was clearly determined at a load capacity of more than 49 kN to 51 kN for the beam with cast-joint that of the unstrengthened beam due to the weak effective GFRP bars at the joint. As result, the effect of the CFRP layers improved the modulus of fracture of these beams by about 111% to 118%.

The failure mode for beams with a fully cast or partially cast flexure joint was a flexural failure. Meanwhile, shear and bending were the failure modes for partially cast beams with a joint in the shear zone. This paper provides new information about carbon fiber-reinforced polymer (CFRP) sheets was not obvious debonding at the casting joint by successfully sealing these emerging cracks and cracks were difficult to see due to their thinness, the CFRP laminates slowed their propagation and increased the load-bearing capacity of the beams.

According to the results, CFRP strengthening is a good way to increase load capacity and reduce the flaws that casting joints introduce. To overcome its shortcomings and investigate other factors, the study also emphasizes the necessity for more investigation. Further studies can build on these results to create more solid and trustworthy design guidelines for applying CFRP in structural repair and rehabilitation by enlarging the experimental dataset, integrating FE modeling, and examining environmental and loading impacts.

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TY

Abbreviations

SRCB	Steel reinforced concrete beam
SRCB- md	Steel reinforced concrete beam -stop cast at half distance from two support
SRCB- d15	Steel reinforced concrete beam -stop cast at 15 cm distance from support
GRCB- md	GFRP reinforced concrete beam -stop cast at half distance from two support
GRCB- d15	GFRP reinforced concrete beam -stop cast at 15 cm distance from support
GRCB- md with S@ 10 cm	Strength beams each 10 cm by carbon sheet of GFRP reinforced concrete beam -stop cast at half distance from two support
GRCB- md with S@5 cm	Strength beams each 5 cm by carbon sheet of GFRP reinforced concrete beam -stop cast at half distance from two support