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A COMPARISON STUDY ON THE USE OF JUTE FIBER REINFORCED POLYMER TO STRENGTHEN RCC BEAMS IN FLEXURE

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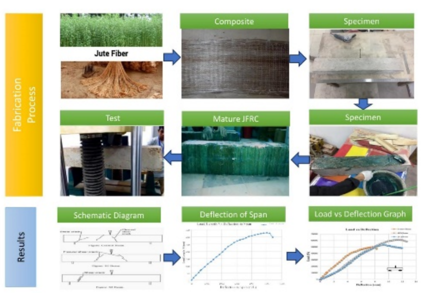
Graphical abstract



Abstract

This study aims to evaluate the efficacy of woven jute fibers in strengthening RC beams and provides a thorough description of RC beam rehabilitation using a natural fiber composite. Three beams were cast and tested with Center Point Loading configuration: one beam acted as a control specimen, while the other two beams were wrapped with heat-treated woven jute fiber using a U-wrapping technique. The experimental specimens, with dimensions of 36" x 6" x 6" (914.4 mm x 152.4mm x 152.4mm x 152.4mm), underwent static load tests. Load, mid-span deflection, and cracking patterns were meticulously measured and analyzed for the control and retrofitted beams. The retrofitting of concrete beams with U-wrapped Jute Fiber Reinforced Polymer (JFRP) layers yielded significant improvements. When compared to the control beam, a single layer of JFRP (1.13 mm) raised the load-to-length ratio by 7.57%, while a two-layer JFRP (2.26 mm) increased it by 22.72%. The retrofitted specimens also exhibited increased deflection and strain compared to the control beam, indicating improved strength and stiffness. Moreover, the shift in crack pattern from flexural to shear cracks after U-wrapping highlights the enhanced ability of the beam to withstand shear forces, extending its performance period.

Keywords: Universal Testing Machine, Steel Fiber-Reinforced Polymer, Carbon Fiber-Reinforced Polymer, Glass Fiber-Reinforced Concrete, Epoxy.

1.0 INTRODUCTION

Buildings are primarily low-rise in poor nations like Bangladesh. Most of the time, buildings are not constructed in accordance with national or international norms due to a lack of awareness, regulation, and law enforcement. Buildings like Rana Plaza and Spectra Sweater Factory in Savar, Dhaka, Bangladesh, collapsed because of inadequate awareness and oversight, where retrofitting could have saved the beams and columns where cracks first appeared [1]. On April 12, 2005, an incident at the Spectra Sweater Factory claimed more than 60 lives and injured over 100 more [2]. On April 24, 2013, Rana Plaza collapsed, leaving more than 1,000 people dead [1]. To prevent catastrophic events, many more buildings in Bangladesh need to be retrofitted. Particularly in reinforced concrete buildings with insufficient design, and lack of detailing for seismic and other extreme natural disasters may cause significant structural damage and fatalities. Retrofitting damaged structures is crucial for safety and cost-effectiveness compared to rebuilding.If the failure of a structure can be changed from brittle to ductile after a sudden earthquake, the inhabitants will have much more time to flee and save many more lives before ultimate collapse. For the retrofitting of RC elements, various strategies and methodologies have been devised. For retrofitting purposes, a variety of materials are used. There are some other polymers available that are being used for retrofitting, like CFRP, GFRP, SFRP, etc. Carbon fiber reinforced polymer, carbon fiber reinforced plastic, or carbon fiber reinforced thermoplastic (CFRP, CRP, CFRTP, or often simply carbon fiber, carbon composite, or even carbon) is an extremely strong and light fiber-reinforced plastic that contains carbon fibers. Carbon fiber-reinforced concrete exhibits exceptional performance characteristics, surpassing those of traditional concrete, making it a dependable and robust structural material. The Breeding Division of Bangladesh Jute Research Institute has developed 54 varieties of jute, with farmers predominantly cultivating Tossa jute due to its higher market demand and fiber quality [3]. Bangladesh exports 282 tons of jute and jute-based goods to approximately 135 countries globally [3].

Ed-Dariy Y et al. [4] examined in their study the impact of jute fiber reinforced polymer (JFRP) treatment on concrete members, showing increased ultimate load capacity for 24-hour treatment in a 10:1 liquor ratio, while 48-hour treatment in the same ratio resulted in a slight increase, and 15:1 ratio treatment exhibited slight degradation in performance. Patel et al. [5] explored the use of chemically modified jute fibers in an epoxy-resin composite with red mud filler to enhance adhesion and moisture resistance, resulting in significantly improved flexural strength and reduced water uptake compared to untreated fibers. Sridhar et al. [6] evaluated the mechanical properties of treated bamboo and jute fiber-reinforced concrete, finding that 1.5% bamboo and 2% jute fibers yielded optimal strength, with SEM analysis confirming good fiber-concrete bonding. Abayomi [7] investigated the enhancement of concrete properties by incorporating sisal fibers, revealing improvements in splitting tensile strength, crack resistance, and overall beam-column joint performance, with potential for Finite Element Analysis modeling. The addition of carbon fiber to concrete has been found to improve several properties, primarily cracking resistance, ductility, and fatigue life [8]. Bangladesh, the second-largest producer of jute globally, presents potential for utilizing natural fiber composites in concrete structures like Glass Fiber Reinforced Concrete (GFRC), which enhances tensile strength and overcomes traditional concrete's brittleness [9]. Sarıbıyık A et al. [10] assessed the strengthening of RC beams with low flexural and shear strength using CFRP and GFRP composites, finding that while GFRP-composite-reinforced beams exhibit lower flexural and shear strengths than CFRP-reinforced ones, they demonstrate higher ductility and energy absorption capacity, with GFRP-reinforced beams being less brittle upon fracture. El-Ghandour[11] evaluated the effectiveness of CFRP flexural and shear strengthening in concrete beams, finding reduced efficiency at high damage levels, with U-wraps showing partial activation and challenges in predicting combined failures. Many experiments were conducted on carbon fiber reinforced polymer (CFRP), Glass fiber reinforced polymer, and other artificial polymer wrapping strengthening, and researchers found them very impressive [12].

Natural fiber composites offer cost-effective, eco-friendly alternatives with promising mechanical properties; jute fiber reinforced polypropylene composites were studied for tensile strength variations under different processing parameters using hot compression molding, analyzed via optical and scanning electron microscopy[13]. Milanese et al. [14] investigated the mechanical behavior of natural fiber composites, finding higher tensile strength, and demonstrating that double wrapping enhances load-bearing capacity by limiting beam deflection due to increased fabric stiffness. Navaratnam et al. provided a comprehensive review of the application of both synthetic and natural fiber-reinforced polymer (FRP) composites in civil infrastructure, emphasizing their mechanical, fire, durability, and sustainability performance, as well as recent developments, with a focus on the promising potential of hybrid FRP for enhancing infrastructure performance and sustainability[15]. Mohana Sundari et al. [16] demonstrated significant enhancement (up to 42% increase) in flexural strength of reinforced concrete beams through external bonding with Kevlar, kenaf, and basalt fibers, offering promising applications in repair and rehabilitation efforts, particularly in environmentally affected areas. Gassan et al. [17] investigated improving the mechanical properties of jute/epoxy composites by alkali treatment. In a study by Jeyabharathy S et al. [18], three reinforced concrete beam specimens were cast, with one adhering to IS 456:2000 (control), another adhering to IS 13920:1993 (control), and the third retrofitted with JUTE fiber sheets using epoxy resin according to IS 456:2000 (retrofitted). In the experimental study, the beams were subjected to static loading at the top until reaching a controlled load deflection[18].

Reshma et al. [19] investigated the effectiveness of enhancing shear capacity in RC beams using a hybrid composite of glass and jute fiber FRPs through various wrapping configurations, aiming to understand the mechanical properties and failure behavior experimentally. Sen T et al. [20] compared Jute Textile Reinforced Polymer (JFRP), Carbon Textile Reinforced Polymer (CFRP), and Glass Textile Reinforced Polymer (GFRP) composites' mechanical behavior in strengthening reinforced concrete (RC) beams, finding JFRP to have the highest deformability index and significant flexural strength improvements, making it a promising structural strengthening material. Makhlouf et al [21] explored the efficacy of jute fiber-reinforced polymer (JFRP) sheets as a cost-effective and environmentally friendly alternative for strengthening reinforced concrete (R.C.) structures, demonstrating significant increases in shear strength (28% to 175%) and validating findings through finite element analysis and parametric studies. Akid et al. [22] investigated the flexural characteristics of jute fiber reinforced polymer (JFRP) bonded reinforced concrete beams, demonstrating increased ultimate load and flexural strength, despite diminishing load with higher corrosion levels, with analytical calculations supporting experimental findings. Benaddache et al. [23] explored the effectiveness of jute fabric reinforced epoxy composites in strengthening concrete beams, revealing significant enhancements in flexural strength and sustainability compared to traditional materials like glass FRP.

The objective of this study is to assess the effectiveness of using woven jute fibers in strengthening reinforced concrete (RC) beams through a U-wrapping technique, with a focus on enhancing load-bearing capacity, structural performance, and analyzing the shift in crack patterns after U-wrapping. By addressing these objectives, the study aims to fulfill gaps identified in existing research works related to the evaluation of natural fiber composites, reinforcement techniques, quantitative analysis of reinforcement effects, and investigation of crack pattern shifts in RC beam rehabilitation.

2.0 METHODOLOGY

2.1 Materials and Procedure

The aggregate's size was maintained at 25 mm passing, 19 mm retained, and 12.5 mm retained, respectively. River sand having a Fineness Modulus of 2.55 according to AASHTO T27 [24] and OPC 53 grade (Ultra-tech Cement grade 53) in accordance with IS 12269-1987 [25] are among the materials used. The steel bar of different dia, which is of Grade 60 and conforms to ASTM A615/A615M standards, has a yield strength of 413.7 megapascals (MPa). Concrete had a design strength of 35 MPa was made using the determined water ratios, cement, coarse aggregate, and fine aggregate blended in a ratio of 0.45:1:2.2:1.35. According to AASHTO T119 [26], the workability was established as 120 mm, measured from the slump cone, and the maximum water to cement ratio permitted was 0.55. In the intended mix percentage, 9 cylinders were cast. The average compression strength for a week, 14 days, and 28 days was found to be 22.7 MPa, 33.95 MPa, and 38.45 MPa respectively. Bangladesh's Azimpur neighborhood in Dhaka is where the jute fabric for this project was sourced. The Woven Jute Fiber Composite used in this experiment is shown in Figure 1. The density of fiber is 1.43 g/cm3, and elongation is 1.79%. Woven fiber mats were cut to specific dimensions for flexural strength testing, following ISO 14125:1998, and then subjected to mechanical treatment in accordance with ISO 527-4:1997(E) for evaluating tensile properties of fiber-reinforced plastic composites. Tensile strength was 25 MPa for 1.13 mm thickness and 33 MPa for 2.26 mm thickness of treated woven jute fiber.

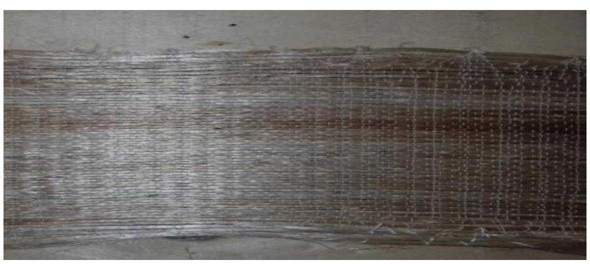


Figure 1: Woven jute fiber used in this experiment.

2.2 Test Specimens

Three specimens have the following measurements: length = 36 inches (914.4 mm), width = 6 inches (152.4 mm), and height = 6 inches (152.4 mm). One was used as a control, while the other two were wrapped with JFRP in U shaped and with different thickness. A schematic diagram of specimens is shown in Figure 4. Steel molds with inside dimensions of 920 mm (length), 155 mm (width), and 155 mm (breadth) were used for framing. Lubricant oil was applied to the interior walls of the steel molds to make removal easier. Two sizes of steel bars were used in this experiment; details are provided in Table 1. The steel reinforcements were put inside the mold with a 25-mm clear cover, as shown in Figure 4. After being poured into the mold, the concrete was given a full day to set before being given a 28-day curing period. While pouring concrete into the molds, a 20-mm needle vibrator was used to ensure proper compaction. The whole process followed during the casting of beams is shown in Figure 3 (a-d). Table 1 provides detailed information on the wrapping detail. The woven fibers are saturated with resin before being applied to the mold or structure. To reduce air entrapment, a calculated amount of epoxy resin base and hardener, at a ratio of 2:1 by weight, were fully combined with careful stirring to minimize air entrapment. Figure 3 (e-h) illustrates the epoxy samples laid on beams in different patterns. Epoxy resin has been meticulously applied to the underside of the control, while for the S1 beam, and S2 beam, it has been expertly laid not only on its bottom surface but also along both of its sides (Figure 4).

Curing time was provided as 72 hours for the resin to harden perfectly. In this experiment, a digital Universal Testing Machine (UTM) with a 1000 KN capacity was used Figure 3 (i)). Load cell of the UTM was used to measure load and displacement data. This experiment used a displacement boundary condition and a 3 mm/min displacement rate.

2.3 Experimental Works

The strengthening effect under flexure was assessed using three experimental findings, explained in Table 2. A loading frame was used to conduct an experimental study on the behavior of the beam under flexure. Center Point Loading configuration was applied for all of three beams according to ASTM C-293 [27]. Utilizing a hydraulic jack, a load is applied. A loading cell is connected to the jack, and a digital indicator is used to measure the loading increments. All beams with a simply supported span of 920 mm were put to the test using a three-point bending system. In Figure 2, a schematic diagram shows loading details. Three digital deflection gauges were put under the beam: one in the center, one beneath each load, and two beneath the loads.

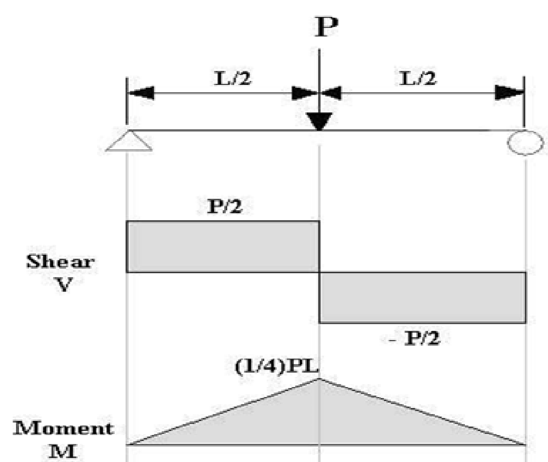


Figure 2 Shear and Moment Diagram under Center Point Loading configuration.

2.4. Final Strength, Load-Deflection Relationship, and Failure Mode Analysis

The beams were designed to fail flexibly. The flexural performance of the control beam and retrofitted beams (S1 and S2) was compared.

2.5. Crack Width Study Under Working Loads

The crack widths of the strengthened and control beams were measured under working loads during the experiment Figure 3). The use of JFRP wraps dramatically changed the cracking behavior of the beams, according to experimental observations. Schematic Diagram of a Center Point Loading Pattern and Failure Pattern are shown in Figure 5.

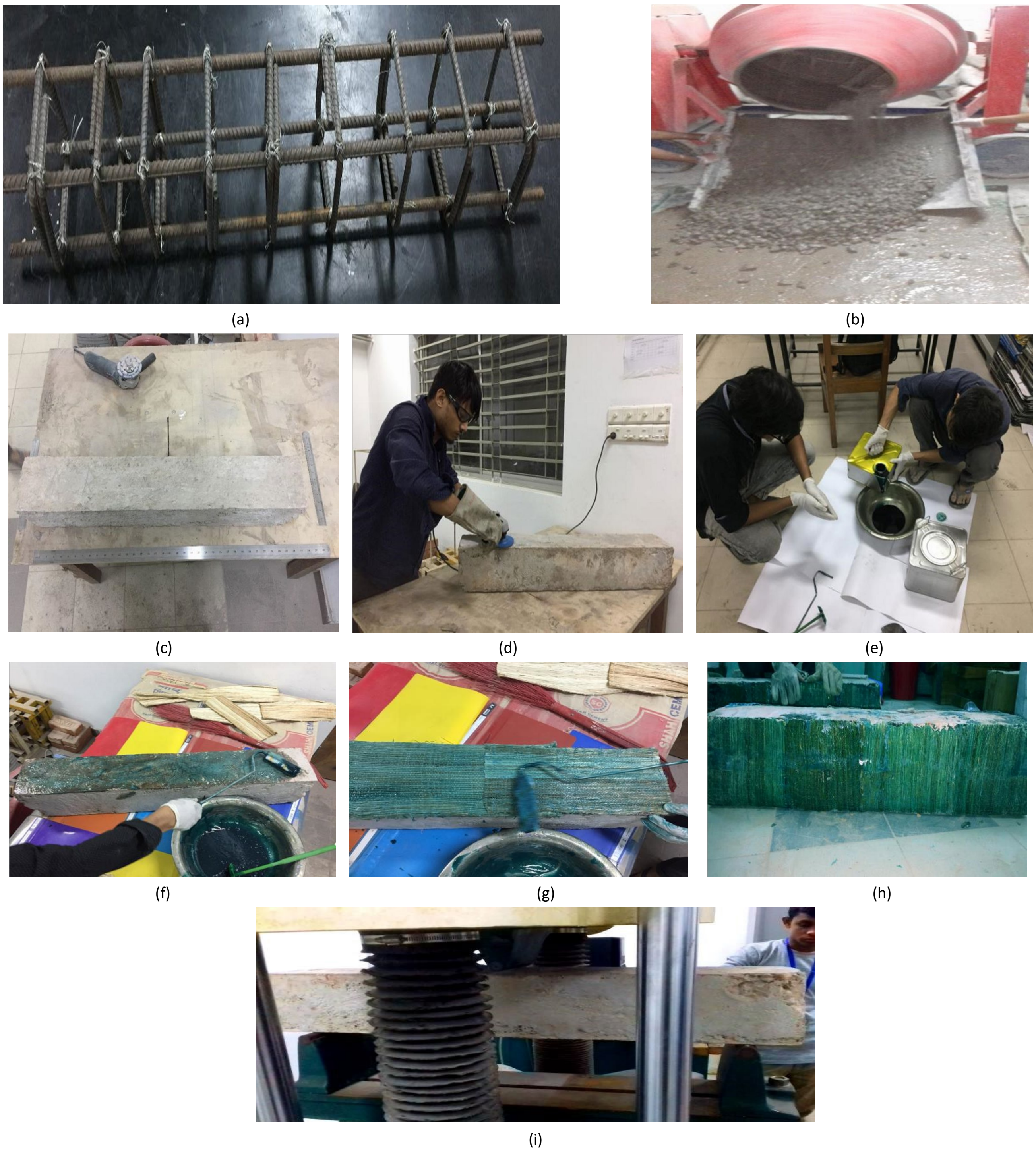


Figure 3 (a) Reinforcement; (b) Concrete Mixing by Mixing Machine (c) Experimental specimen; (d) Surface preparation of beams by grinding; (e) Epoxy mixing; f) Primer application on the beam surface g) Application of epoxy hardener mix on the beam; h) wrapped beam after hardening i) Test setup for Center Point Loading configuration.

Table 1 Configuration of the beam specimens.

Test Specimen	Reinforcement Details			Woven Fiber Configuration			Woven Jute Fiber Wrapping Configuration
	Top Bar Dia (mm)	Bottom Bar Dia (mm)	Stirrup Bar Dia (mm)	Layer No	Fiber Orientation	Fiber Thickness (mm)	
Control Beam				--			(No wrapping)
S1 Beam	8	10	8	Single Layer	Longitudinal to beam length	1.13	U wrapped
S2 Beam				Double Layer	Longitudinal to beam length	2.26	U wrapped

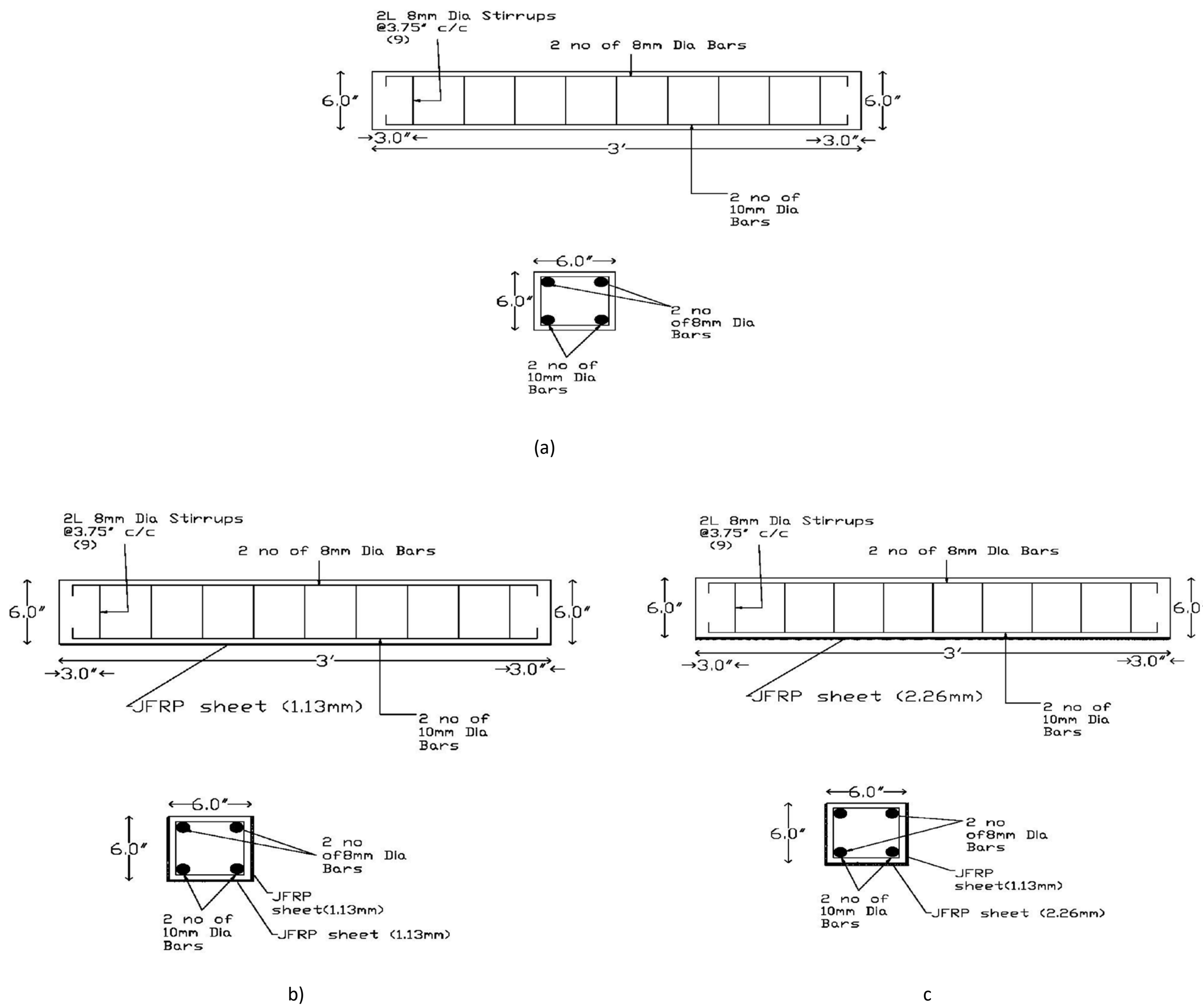


Figure 4 a) Schematic diagram of the Control beam; b) and c) Schematic diagram of the S1 and S2 beams.

3.0 RESULTS AND DISCUSSION

Experimental analysis was used to estimate the ultimate load-carrying capacity of the C, S1, and S2 beams. The maximum load/length ratio of three beams was determined, and the deflection behavior of the beams was also monitored. The ultimate strength value was found to be highest for the 'S2' beam in terms of load/length ratio and deflection. Table 2 compiles all the experimental findings.

3.1. Failure Mode Study and Ultimate Failure Load

Different types of failure modes were seen during the experimentation Table 3. The failure of the control beam in midspan and support showed that the beam lacked in significantly flexural strength and also shear strength (Figure 5). The pure flexure zone, which is situated in the center of the span length, has cracks. These cracks started on the beam's bottom face and moved up to the top face, we can see clearly in the Figure 5. The S1 beam failed in flexural shear (Table 3), and demonstrated a significantly higher ultimate load-carrying capability than the Control beam. The vertical cracks were noticed in the support of the span, which is the pure shear zone, when load was applied to S2. The S2 beam failed in the shear crack (Figure 5), and demonstrated a significantly higher ultimate load-carrying capability than the Control, and S1 beams. The JFRP neither ruptured nor developed even a single flexural crack. The S2 beam showed an ultimate failure load of 61.371KN. The first fracture loads of several beam systems are compared in Table 2. Due to the high deflections of the beams prior to failure and the following adequate warnings before collapse, brittle failure of the beams was greatly mitigated in this case by continuous JFRP. Superior load deflection was achieved because continuous U-wrapped JFRP was attached to the beams, which prevented the onset of the first cracks.

3.2 Study of the Load-Deflection Relationship

The load-deflection behavior of Scheme C, S1, and S2 beams was meticulously examined and compared to elucidate their structural response under applied loads. Figure 6 provides a graphical representation of the mid-span deflection behavior for each beam configuration. Notably, the S2 beam demonstrated notably superior deflection characteristics compared to both the control beam and S1. The incorporation of continuous U-wrap JFRP reinforcement effectively delayed the initiation and propagation of cracks within the structural members. Consequently, the S2 beam exhibited prolonged structural integrity and resilience under increasing loads. The observed delay in crack formation is reflected in the load-deflection curve by a more gradual increase in deflection compared to the control beam and S1. This delayed onset of cracks not only enhanced the load-bearing capacity of the S2 beam but also contributed to its superior deflection behavior. The comprehensive analysis of the load-deflection behavior provides compelling evidence of the efficacy of JFRP reinforcement in enhancing structural performance, mitigating brittle failure, and improving load-bearing capacity. The observed crack patterns, particularly in the S2 beam, provide valuable insights into the structural response of the beams under loading conditions. The correspondence between crack initiation points and nonlinear behavior in the load-deflection curve highlights the significance of crack propagation in influencing structural behavior.

3.3 Effect on Ductility

The application of JFRP composites notably augmented the load-carrying capacity, peak stress deflection, rigidity, and strength of the beams. Both S1 and S2 beams exhibited increased deflection compared to the control beam, with S2 showing the highest increase (44%). Moreover, S1 and S2 beams demonstrated significant increases in load/length values (7.57% and 22.72% respectively) and ultimate failure loads, highlighting their improved ability to withstand deformation before failure Table 2. Overall, these findings suggest that the application of JFRP composites led to a notable enhancement in ductility compared to the control beam.

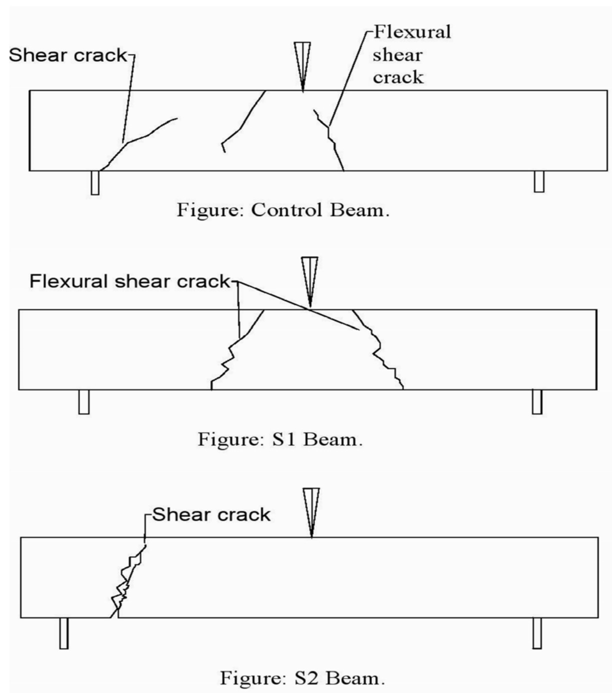


Figure 5 Schematic Diagram of a Center Point Loading Pattern and Failure Pattern and Locations of Cracks

Table 2 Experimental findings.

Specimen Designation	Maximum Load/Length (N/Mm)	Deflection to Span at Peak Load/Length Value	Ultimate Failure Load (KN)	Percentage Increase in Load/Length Value	Percentage Increase in Deflection to Span compared to the C beam
Control Beam (C)	330	0.050	49.91	-	-
(S1)	355	0.061	53.96	7.57 (Increased)	22 (Increased)
(S2)	405	0.072	61.371	22.72 (Increased)	44 (Increased)

Table 3 Crack Pattern Details of Tested Beams.

Specimens	Crack position of the beam	Crack type	Crack Pattern
Control beam	Support and mid span	Shear & Flexural shear crack	
S1 beam	Mid span	Flexural shear crack	
S2 beam	Support	Shear crack	

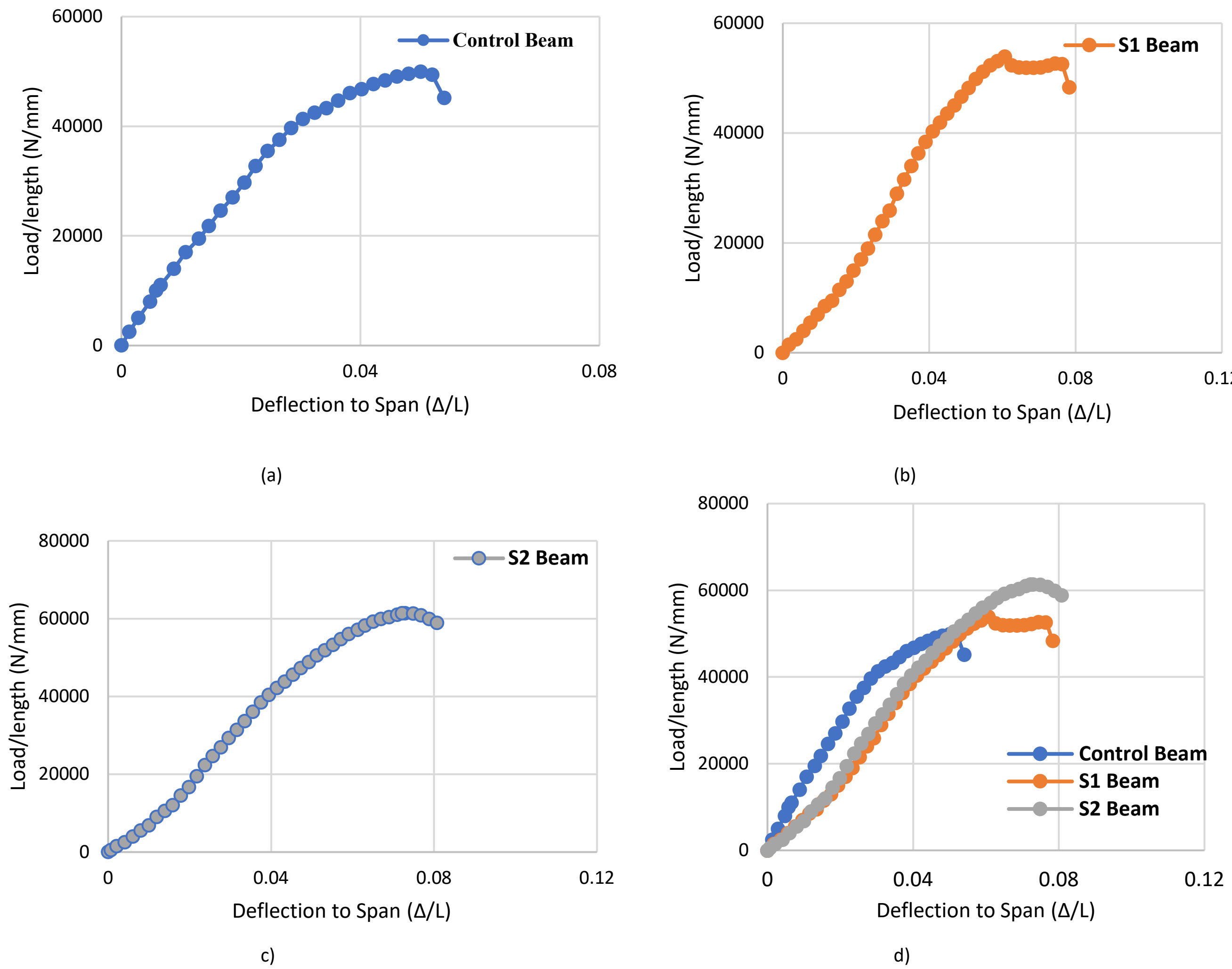


Figure 6 a) Load/length vs. deflection/length for control beam; b) Load/length vs. deflection/length for S1; c) Load/length vs. deflection/length Graph for S2; d) Load/length vs. deflection/length Graph for Three Beams.

3.4. JFRP Layering Effects

Examining the impact of JFRP layers and their thickness, one layer of JFRP (1.13 mm) increased load/length by 7.57% and deflection by 22%, while two layers of JFRP (2.26 mm) increased load/length by 22.72% and deflection by 44%, highlighting the effectiveness of JFRP composites in enhancing structural resilience and strength

4.0 CONCLUSION

Based on the analytical and experimental investigations listed below, the following conclusion can be drawn:

- A specimen retrofitted with one layer of JFRP (1.13 mm) shows a maximum of 7.57% more load/length than the control beam. At peak stress, the S1 specimen undergoes 22% more deflection along its length than the control beam.
- A concrete specimen retrofitted with two-layer JFRP (2.26 mm) shows a maximum of 22.72% more load per meter of length than a control beam. At peak load/length ratio, the S2 specimen undergoes 44% more Deflection than the control beam.
- The beams' maximum load-carrying capacity rose up to 22.72% compared to their un-strengthened counterpart. So, the beams strength was greatly improved.
- Continuous JFRP reinforcement significantly mitigated brittle failure in beams by enhancing flexural and shear strength, as evidenced by the absence of ruptured or developed flexural cracks, and the superior load-carrying capability observed, particularly in the S2 beam with an ultimate failure load of 61.371KN.
- The notable enhancements in load-carrying capacity, deflection, and ultimate failure loads, particularly in S1 and S2 beams, indicate a significant improvement in ductility achieved through the application of JFRP composites.

So, with the exterior wrapping of JFRP composites, the final load-carrying capacity of the beams has increased, steadily increasing values by a sizeable margin ranging from 7.57% to 22.72%. It has been found that JFRP composites significantly increased the unwrapped beam's ability to support loads.

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Conflicts of Interest

The author(s) declare(s) that there is no conflict of interest regarding the publication of this paper

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