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BEHAVIOUR OF JUTE FIBRE REINFORCED CONCRETE WITH JUTE FIBRE REINFORCED POLYMER (JFRP) BARS AS A PARTIAL REPLACEMENT FOR STEEL REINFORCEMENT

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Abstract: Steel is still the reinforcement of choice in most concrete work, mainly because it is strong and behaves predictably, but rising steel prices and ongoing corrosion problems have pushed researchers to look elsewhere. This study looks at jute, a cheap, renewable fibre that is widely available in India, as a way to cut down on steel use without giving up too much performance. Jute Fibre Reinforced Concrete (JFRC) was prepared with fibre contents of 0.25%, 0.50% and 0.75% by weight, and cube specimens were tested for compressive and split tensile strength at 7, 14 and 28 days to find the fibre content that works best. Jute Fibre Reinforced Polymer (JFRP) bars, made from treated jute fibre, binding wire and an epoxy resin coating, were then cast into beam specimens as a partial substitute for conventional steel bars, and their flexural behaviour was compared against beams reinforced entirely with steel. Across every age tested, 0.50% jute fibre gave the best compressive and split tensile results, with the 28-day compressive strength going up by close to 19% over the plain concrete control, while 0.75% fibre content actually performed worse than the control, most likely because the fibres were not dispersing properly at that dosage. Beams cast with 0.50% jute fibre concrete and 50% steel + 50% JFRP bar reinforcement reached a flexural strength of 17.83 MPa, recovering most of the capacity lost when half the steel was swapped out for jute bars. Overall, the results suggest that jute fibre reinforced concrete combined with JFRP bars is a workable, low-cost way to reduce dependence on steel in reinforced concrete members, though the trade-off in stiffness and long-term durability still needs closer study before it can be used in structural applications.

Index Terms - Jute fibre, JFRP bars, natural fibre reinforced concrete, compressive strength, split tensile strength, flexural strength, sustainable construction.

I. INTRODUCTION

Concrete owes its popularity to strength, durability and sheer ease of use, but on its own it is weak in tension, which is why reinforcement is added in the first place. Steel has filled that role for close to a century, and for good reason: it carries tensile loads well and holds up reliably under most conditions. The trouble is that steel prices have been climbing steadily, and that feeds straight into the cost of every project that depends on it. Corrosion is the other persistent headache. Once steel bars are exposed to moisture and aggressive environments, corrosion sets in, cracks and spalling follow, and the structural member loses strength faster than it should. Maintenance costs go up, service life comes down, and the whole cycle repeats.

That combination of rising cost and durability concerns is what has pushed researchers toward alternative reinforcement materials, and natural fibres have drawn a fair amount of attention because they are renewable, biodegradable and generally easy to source. Jute in particular stands out: it is abundant in India, reasonably strong in tension for a natural fibre, and inexpensive compared to steel or synthetic fibres. Jute fibres can be mixed directly into concrete to control crack growth, and, once treated and bound properly, can also be shaped into reinforcement bars.

This work looks at the combined use of Jute Fibre Reinforced Concrete (JFRC) and Jute Fibre Reinforced Polymer (JFRP) bars as a partial replacement for conventional steel reinforcement. JFRP bars were prepared from treated jute fibres, binding wire and an epoxy resin coating, with the epoxy layer meant to protect the fibres from moisture and improve bonding with the surrounding concrete. Cube specimens with 0.25%, 0.50% and 0.75% jute fibre content were cast and tested for compressive and split tensile strength at 7, 14 and 28 days to identify the fibre percentage that performs best. That optimum content was then carried forward into beam specimens cast with JFRP bars, either on their own or combined with steel, and the flexural performance of these beams was compared with beams reinforced conventionally.

The aim throughout is not to do away with steel altogether, but to see how far a supplementary, jute-based reinforcement system can go in reducing the amount of steel needed while still giving reasonable structural performance. If it holds up, this kind of system could offer a cheaper, more corrosion-resistant, and more sustainable option for certain classes of reinforced concrete construction.

1.1 Problem Statement

Steel reinforcement has been the default choice in concrete construction for a long time because it is strong and dependable, but the rising cost of steel is now a real concern for the construction industry, and corrosion continues to shorten the service life of reinforced members once moisture gets in. Jute fibre, being cheap, locally available and reasonably eco-friendly, has been reported to improve crack resistance and certain strength properties when mixed into concrete, and treated jute fibres have also been used to make polymer reinforcement bars. What has not been studied in much depth is the combined use of JFRC together with JFRP bars, and that gap is the starting point for this work.

1.2 Objectives

- To prepare JFRP bars using treated jute fibres, binding wire and epoxy resin.
- To study the effect of 0.25%, 0.50% and 0.75% jute fibre content on the compressive and split tensile strength of concrete.
- To determine the optimum jute fibre percentage from the compressive strength results.
- To cast and test reinforced concrete beam specimens using JFRP bars, with and without partial steel replacement.
- To compare load-carrying capacity and flexural strength of JFRC beams against conventionally reinforced beams.
- To assess whether JFRC with JFRP bars can serve as a partial replacement for steel reinforcement.

II. LITERATURE REVIEW

Wilson et al. [1] looked at how jute fibre affects the shear strength of concrete, testing volume fractions of 0%, 0.25%, 0.5% and 0.75% across four concrete grades (25, 30, 35 and 40 N/mm²), using a total of 32 beams and 96 cubes. They found that 0.5% jute fibre gave the highest compressive strength across all grades, with gains between roughly 9.7% and 12.5% over the control, and shear strength improvements ranging from about 16% to 28%. Workability dropped slightly as fibre content went up, but crack resistance and shear performance both improved.

Amartey et al. [2] studied jute fibre concrete at proportions from 0% up to 1.50% by weight, cured for 3, 7, 14, 21 and 28 days, and tested both fresh and hardened properties. Their 28-day results also pointed to 0.5% as the optimum fibre content for compressive strength, giving about a 10.2% improvement over the plain mix, while split tensile strength kept rising up to 0.75% fibre content before dropping off. Beyond 0.5%, compressive strength started to fall, which the authors linked to poorer fibre dispersion at higher dosages.

A more recent study by Wilson et al. [3], published in the Journal of Infrastructure Preservation and Resilience, examined how jute fibre reinforced concrete performs under long-term environmental exposure. Once again, 0.5% jute fibre came out on top, with compressive strength gains of roughly 8% to 12% depending on grade, and the workability loss was described as minor. The authors concluded that 0.5% offers a reasonable balance between strength gain and workability, and that jute fibre concrete can hold up reasonably well under extended exposure.

Peries and Tharmarajah [4] developed JFRP bars from jute fibre and polyester resin at fibre-to-resin ratios of 75:25, 70:30 and 60:40, and ran tensile tests on the finished bars. Tensile strength went up as fibre content increased, landing between about 18 and 25 MPa, with the 75:25 ratio giving the best results. The modulus of elasticity stayed well below that of steel, as expected, but the authors still considered JFRP bars a workable low-cost, corrosion-resistant option, and suggested that refining the manufacturing process could push performance closer to what structural applications need.

Dayananda et al. [5] cast concrete coupons with jute fibre volumes ranging from 0.2% up to 1.8% and found compressive strength rose from about 8.8 N/mm² to a peak of roughly 44.4 N/mm² at 0.4% fibre content, after which performance dropped off and workability suffered — a trend broadly consistent with the 0.50% optimum identified in the present study, even though the two studies used different baseline mixes. Islam and Ahmed [6] looked more broadly at how jute fibre content influences the fresh and hardened properties of concrete, reporting that moderate fibre dosages improved compressive and flexural performance and toughness, while higher dosages hurt workability and led to fibre balling, reinforcing the idea that there is a fairly narrow dosage window where jute fibre is beneficial.

Kundu et al. [7] examined surface-modified jute fibre in concrete paver blocks and found that treating the fibre surface improved both the physical and mechanical properties of the finished blocks compared to untreated fibre, which lines up with the NaOH treatment used for the jute fibres in this study. Razmi and Mirsayar [8] took a fracture-mechanics approach, testing jute fibre reinforced concrete under mixed mode I/II loading, and found that adding jute fibre measurably improved fracture toughness and crack resistance relative to plain concrete, supporting the crack-bridging explanation given here for the split tensile and flexural gains seen at 0.50% fibre content.

Zhang et al. [9] added jute fibre to high-strength C60 concrete and used an orthogonal test programme to identify the fibre length and content that gave the best balance of compressive and tensile properties, reporting a clear improvement in the tensile-to-compression ratio at the optimum dosage. Their result is a useful counterpoint to the present study, since it shows the same general jute-fibre optimisation behaviour holding even in a much higher-strength concrete than the M20 grade used here.

Sen and Reddy [10] strengthened reinforced concrete beams in flexure with a woven jute fibre textile composite and compared the results against beams strengthened with CFRP and GFRP, finding that JFRP gave meaningfully lower strength gains than the synthetic systems but still improved ultimate load and ductility over an unstrengthened control at a fraction of the cost. In a companion study, Sen and Reddy [11] examined how different pretreatment methods for woven jute fabric affect the performance of the resulting JFRP composite, showing that fibre treatment has a direct bearing on how much strengthening benefit the finished JFRP system delivers — a finding that parallels the NaOH treatment and epoxy coating used to prepare the JFRP bars in the present work.

Archana et al. [12] used a natural jute fibre reinforced polymer composite system to strengthen posttensioned concrete beams in flexure, and reported clear gains in load-carrying capacity and flexural efficiency once the JFRP layers were applied, concluding that jute-based FRP is a viable sustainable alternative to synthetic FRP systems for beam strengthening applications.

Salih et al. [13] tested reinforced concrete beams strengthened with jute fibre strips of varying width and layer count, finding that both toughness and ultimate load-carrying capacity increased with strip width and thickness, though the gains were modest compared to companion beams strengthened with carbon fibre strips — underlining that JFRP is a lower-cost but also lower-performance alternative to synthetic FRP for strengthening applications. More recently, Islam et al. [14] examined the effect of jute fibre content on the compressive and split tensile strength of concrete made with stone chips as coarse aggregate, again finding a clear optimum fibre percentage beyond which both strength and workability declined, consistent with the fibre-dispersion explanation used throughout this study.

Baley et al. [15] compared the compressive and tensile behaviour of unidirectional composites reinforced with flax and jute fibres at different fibre volume fractions, and found that jute-fibre composites reached a useful balance of stiffness and strength at moderate fibre loadings, providing supporting evidence at the composite-material level for the kind of dosage-dependent behaviour seen in JFRC and JFRP bars. Fidelis et al. [16] studied how accelerated ageing affects the fibre-matrix interface in jute textile reinforced concrete, reporting a loss of bond strength with prolonged exposure to moisture and alkaline conditions — a durability concern that is directly relevant to the JFRP bars used in this study, since their epoxy coating is intended to protect the jute core from exactly this kind of degradation.

Taken together, these studies span cube and paver-block testing, fracture mechanics, high-strength concrete, FRP beam strengthening and durability under accelerated ageing, but they point fairly consistently to a fibre content in the 0.4-0.6% range as the practical optimum for jute-reinforced concrete, and confirm that jute-based FRP systems — whether as bars, strips or textile composites — are mechanically viable, even if weaker, more flexible and less durable under long-term moisture exposure than steel or synthetic FRP alternatives. What is missing from the literature, though, is work that combines JFRC and JFRP bars in the same structural member and looks at how they perform together — which is exactly the gap this study tries to fill.

III. MATERIALS AND METHODOLOGY

3.1 Materials

53-grade Ordinary Portland Cement (OPC) was used as the binder, chosen for its early strength gain and durability. Crushed stone was used as coarse aggregate and natural river sand as fine aggregate, both cleaned and graded before mixing. Clean potable water was used throughout, for both mixing and curing. Jute fibres were treated with a NaOH solution to clean the fibre surface and improve bonding with the cement matrix, then cut into short discrete lengths before being added to the mix. Epoxy resin was used as the coating for the JFRP bars, protecting the jute core from moisture and improving the bond with surrounding concrete.

3.2 Methodology

M20 grade concrete cubes (150 × 150 × 150 mm) were cast with jute fibre contents of 0%, 0.25%, 0.50% and 0.75% by weight of concrete, mixed thoroughly enough to keep the fibres reasonably well dispersed. Specimens were demoulded after 24 hours and water-cured, then tested for compressive strength and split tensile strength at 7, 14 and 28 days to identify the fibre percentage giving the best overall performance.

JFRP bars were made by binding treated jute fibres together with wire and coating the bundle in epoxy resin. Beam specimens (100 × 100 × 500 mm) were then cast in four combinations: conventional concrete with 100% steel reinforcement, 0.5% jute fibre concrete with 100% steel, conventional concrete with 50% steel + 50% JFRP bars, and 0.5% jute fibre concrete with 50% steel + 50% JFRP bars, in each case with two replicate specimens. The beams were tested under flexure to determine ultimate load and flexural strength, and the results were compared across the four combinations.

IV. RESULTS AND DISCUSSION

Cube and prism specimens were tested at 7, 14, 28, 56 and 90 days to track how each mechanical property develops over a longer curing window, not just up to the standard 28-day mark. This section presents the compressive, split tensile and flexural (modulus of rupture) trends for the four fibre contents, followed by the beam-level flexural test results for the JFRP bar combinations.

4.1 Compressive Strength Development

Table 1 and Figure 1 show how compressive strength develops from 7 to 90 days for each jute fibre percentage.

table 1. compressive strength (n/mm²) of jute reinforced concrete over 7-90 days of curing.

% Jute Added	7 Days	14 Days	28 Days	56 Days	90 Days
0%	13.80	17.60	24.40	30.80	37.20
0.25%	14.80	18.50	26.20	33.90	41.60
0.50%	15.70	19.57	29.00	38.43	47.86
0.75%	13.20	16.66	22.30	27.94	33.58

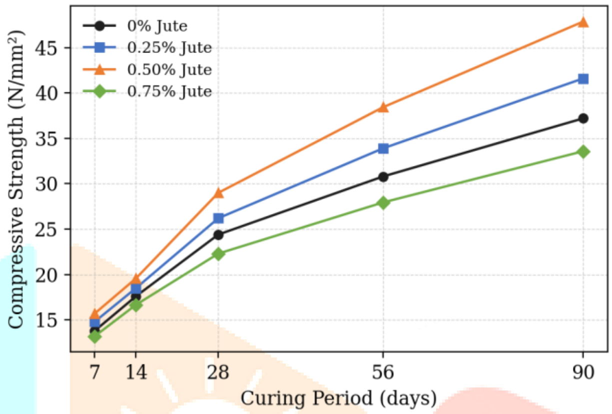

figure 1. compressive strength development of jfrc with curing age for 0%, 0.25%, 0.50% and 0.75% jute fibre content.

Every mix keeps gaining strength well past 28 days, which is expected for OPC concrete, but the gap between the 0.50% mix and the rest actually widens with age rather than closing. By 90 days the 0.50% mix reaches 47.86 N/mm² against 37.20 N/mm² for plain concrete, a jump of close to 29%, compared to the roughly 19% gap already visible at 28 days. The 0.75% mix stays below the control at every age, which points to the same fibre-clumping issue mentioned earlier rather than anything age-related — whatever is limiting strength at 0.75% jute is baked in from the start and does not improve with further curing.

4.2 Split Tensile Strength Development

Table 2 and Figure 2 give the corresponding split tensile results over the same curing period.

table 2. split tensile strength (n/mm²) of jute reinforced concrete over 7-90 days of curing.

% Jute Added	7 Days	14 Days	28 Days	56 Days	90 Days
0%	2.11	2.38	2.77	3.16	3.55
0.25%	2.14	2.41	2.87	3.33	3.79
0.50%	2.22	2.48	3.02	3.56	4.10
0.75%	2.09	2.29	2.64	2.99	3.34

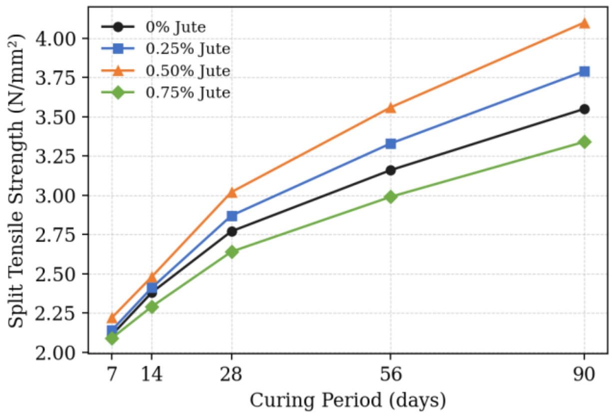

figure 2. split tensile strength development of jfrc with curing age for 0%, 0.25%, 0.50% and 0.75% jute fibre content.

The split tensile trend follows the same shape as compressive strength: 0.50% jute stays on top throughout, reaching 4.10 N/mm² at 90 days versus 3.55 N/mm² for the control, roughly a 15% gain. The 0.75% mix again trails the control at every age. What is worth noting is that the relative gap between mixes stays fairly steady in tension (around 9-15% across ages) rather than widening the way it does in compression, which suggests the fibres are contributing more directly to crack-bridging behaviour than to the bulk compressive response.

4.3 Flexural Strength (Modulus of Rupture) Development

Prism specimens were also tested in flexure at each curing age; Table 3 and Figure 3 present the results.

table 3. flexural strength (n/mm²) of jute reinforced concrete prisms over 7-90 days of curing.

% Jute Added	7 Days	14 Days	28 Days	56 Days	90 Days
0%	2.76	3.52	4.88	6.16	7.44
0.25%	2.96	3.70	5.24	6.78	8.32
0.50%	3.14	3.91	5.80	7.69	9.57
0.75%	2.64	3.33	4.46	5.59	6.72

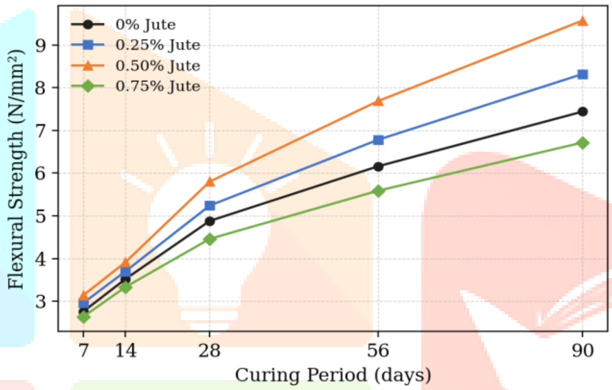

figure 3. flexural strength development of jfrc with curing age for 0%, 0.25%, 0.50% and 0.75% jute fibre content.

Flexural strength shows the largest relative improvement of the three properties: at 90 days the 0.50% mix reaches 9.57 N/mm² against 7.44 N/mm² for the control, close to a 29% increase, and the ranking of the four mixes stays consistent at every single age tested. This lines up with the general behaviour reported for natural fibre concretes — fibres bridging across the tension face of a flexural specimen tend to help more with flexural and tensile capacity than with pure compressive strength, since compression is carried mainly by the aggregate skeleton and cement paste rather than the fibres.

4.4 Flexural Strength of Reinforced Beam Specimens

Table 4 and Figure 4 summarise the beam test results for the four reinforcement combinations, cast using the 0.50% optimum fibre content identified above. Each combination was cast in duplicate and the average ultimate load used to compute flexural strength.

table 4. flexural strength of beam specimens with different concrete types and reinforcement combinations.

Sample	Concrete Type	Reinforcement Type	Avg. Ultimate Load (kN)	Flexural Strength (MPa)
I	Conventional concrete	100% steel	40	18.80
II	0.5% jute fibre concrete	100% steel	42.5	19.98
III	Conventional concrete	50% steel + 50% JFRP bars	32	15.04
IV	0.5% jute fibre concrete	50% steel + 50% JFRP bars	38	17.83

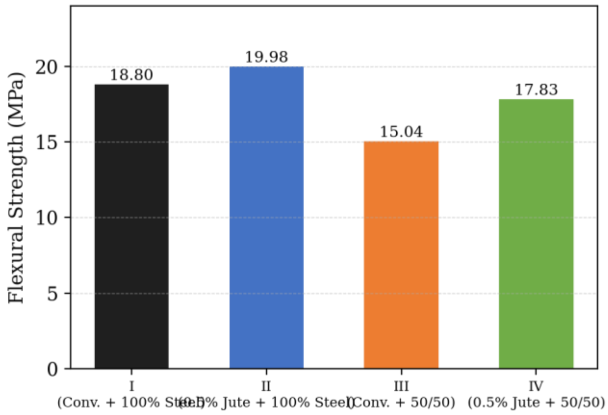

figure 4. flexural strength of beam specimens i-iv under different concrete and reinforcement combinations.

Adding 0.5% jute fibre to a fully steel-reinforced beam (Sample II) pushed flexural strength up by about 6% over the plain steel-reinforced control (Sample I) — 19.98 MPa against 18.80 MPa — so the fibres are doing some useful work even when steel is doing most of the load carrying. The bigger effect shows up once steel is partially replaced by JFRP bars. Swapping half the steel for jute bars in plain concrete (Sample III) dropped flexural strength by about 20% relative to Sample I, which makes sense given how much lower jute's tensile stiffness is compared to steel. But when that same 50% steel + 50% JFRP combination was cast in 0.5% jute fibre concrete instead of plain concrete (Sample IV), flexural strength climbed back up to 17.83 MPa — an 18.5% recovery over Sample III, and within about 5% of the fully steel-reinforced control. In other words, the fibres in the concrete matrix go a fair way toward making up for the strength lost when steel is partially replaced by jute bars, which is really the central finding of this study.

4.5 Overall Discussion

Looking at all four properties together, two patterns stand out. First, 0.50% jute fibre content is consistently the best-performing mix at every curing age and for every property tested — compressive, split tensile and flexural — and the advantage over plain concrete, if anything, grows slightly with age rather than fading out. Second, 0.75% fibre content is consistently the worst performer, usually falling below even the plain concrete control, which points to a dispersion or workability ceiling somewhere between 0.50% and 0.75% rather than a gradual decline. That combination — a clear optimum somewhere around 0.4-0.5%, and a clear penalty just beyond it — matches what Wilson et al. [1], Amartey et al. [2], Wilson et al. [3], Dayananda et al. [5], Zhang et al. [9] and Islam et al. [14] each reported independently, which is reassuring given how different those studies were in terms of concrete grade and testing programme. On the structural side, the beam results show that this same 0.50% fibre content, applied to the surrounding concrete, is what allows a beam with half its steel replaced by JFRP bars to recover most of its lost flexural capacity — tying the material-level optimisation directly to a practical structural benefit.

V. CONCLUSION

Based on the cube, prism and beam tests carried out in this study, a few points come out fairly clearly. 0.50% jute fibre content gave the best compressive, split tensile and flexural strength at every curing age tested from 7 to 90 days, with 90-day gains of roughly 29%, 15% and 29% respectively over plain concrete, while 0.75% fibre content performed worse than the control at every property and every age, most likely due to poor fibre dispersion at higher dosages. JFRP bars, made from treated jute fibre, binding wire and epoxy resin, were successfully used as a partial substitute for steel in beam specimens. Replacing half the steel reinforcement with JFRP bars did reduce flexural strength, but adding 0.5% jute fibre to the surrounding concrete recovered most of that loss, bringing performance close to that of a fully steel-reinforced beam. On the whole, JFRC combined with JFRP bars looks like a workable, low-cost and more sustainable option for reducing steel consumption in select structural applications, though further work on long-term durability, moisture uptake, and bond behaviour between JFRP bars and concrete is still needed before the approach can be recommended for wider structural use.

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