Innovative Fiber Integration For Enhanced Reinforcement of Concrete Structures

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Abstract – This research investigates the enhancement of concrete strength through fibre reinforcement, synthesizing insights from five prominent research papers. The focus centers on the impact of various fibres, such as steel, polypropylene, and glass, on concrete properties like strength, durability, and crack resistance. In conjunction with the literature review, a practical experiment was conducted involving the controlled breaking of 150x150x150mm concrete cubes And 700x150x150mm Beam. The broken cubes were then meticulously repaired using Fibre Reinforced Concrete (FRC) to assess the effectiveness of FRC in improving strength. Preliminary results indicate a substantial increase in compressive strength and enhanced resistance to cracking in the repaired cubes compared to the control group. These findings align with trends observed in the literature, highlighting the positive influence of fibre reinforcement on concrete performance. The research contributes valuable insights, with the practical experiment emphasizing the applicability of FRC for repairing and strengthening concrete structures.

Key Words: **Fibre Reinforced Concrete (FRC), Concrete strength enhancement, Fibre types (steel, polypropylene, glass), Durability, Crack resistance, Compressive strength, Concrete repair**

1.INTRODUCTION

In recent years, the enhancement of concrete properties through fibre reinforcement has garnered significant attention in civil engineering research. This study delves into the realm of fibre-reinforced concrete (FRC), focusing on its profound impact on the strength, durability, and crack resistance of concrete structures. By synthesizing findings from prominent research papers, this investigation explores the effects of various fibres, including steel, polypropylene, and glass, on concrete performance.

Central to this research is a practical experiment designed to assess the efficacy of FRC in enhancing concrete strength. The experiment involved controlled breakage and subsequent repair of 150x150x150mm concrete cubes and 700x150x150mm beams using Fibre Reinforced Concrete (FRC). Initial results from the experiment reveal promising outcomes, indicating a notable increase in compressive strength and improved resistance to cracking in the repaired structures compared to the control samples.

These findings not only corroborate trends observed in the literature but also underscore the transformative potential of FRC in reinforcing and repairing concrete structures. By bridging theoretical insights with practical application, this research contributes valuable knowledge to the field, emphasizing the practical viability and effectiveness of FRC as a sustainable solution for enhancing concrete performance.

1.1 Aim And Objective

1. Comprehensive Analysis of Strengthening Techniques:
   - Evaluate and analyze a wide range of strengthening techniques applied to reinforced concrete structures, encompassing both traditional and innovative methodologies.
   - Investigate external and internal reinforcement approaches to provide a holistic understanding of the available options.
2. Mechanical Behavior Assessment:
   - Critically assess the mechanical behavior of reinforced concrete structures, focusing on flexural, shear, and axial capacities under various loading conditions.
   - Explore and document deformation characteristics resulting from the application of different strengthening techniques.
3. Long-term Durability Considerations:
   - Investigate the long-term durability aspects of strengthened structures, specifically examining resistance to environmental factors such as corrosion and chemical exposure.
   - Identify optimal strengthening strategies that contribute to the longevity of reinforced concrete elements.
4. Application to Real-world Scenarios:
   - Incorporate practical case studies to exemplify the successful implementation of strengthening techniques in diverse structural settings.
   - Assess the implications of strengthened structures on sustainability, considering both environmental and economic aspects.

5. Synthesis of Current Knowledge:
   - Provide a comprehensive synthesis of the current state of knowledge in the field of reinforced concrete strengthening.
   - Consolidate information from previous research, identify gaps in existing literature, and propose avenues for future research and innovation in structural engineering.
6. Contribution to Practical Decision-making:
   - Bridge the gap between theoretical advancements and practical applications by showcasing the adaptability and effectiveness of various strengthening techniques through real-world case studies.
   - Empower engineering practitioners with actionable knowledge to facilitate informed decision-making in the planning and execution of strengthening interventions.
7. Addressing Challenges of Aging Infrastructure:
   - Deepen the understanding of challenges associated with aging infrastructure by examining the mechanical behavior and durability aspects of reinforced concrete structures undergoing strengthening.
   - Provide a holistic perspective considering the broader implications on the resilience and sustainability of the built environment.

2. METHODOLOGY

Flexural and Tensile Strength

- Casting the beam
- Materials and Equipment
- Cement: Ordinary Portland Cement (OPC) 43 grade.
- Fine Aggregates: River sand conforming to IS 383.
- Coarse Aggregates: Crushed stone with a maximum size of 20 mm.
- Water: Clean, potable water.

- Fibers: (as per: is 14871 2001)
  i. Natural fibers: Jute (0.5% by volume).
  ii. Synthetic fibers: Polypropylene (0.1% by volume).
  iii. Composite fibers: Composite mix (0.75% by volume).
- Molds: Steel molds with internal dimensions of 700 mm x 150 mm x 150 mm.
- Release Agent: Oil for coating the molds.
- Mixing Equipment: Concrete mixer.
- Curing Tank: For water curing of the specimens.
- Vibrating Table: For compaction of concrete

➢ Concrete Mix Design: (24 Beam sample for each grade)

- **M30**

  Water = 192 x 0.378 = 72.58 kg (Water-Cement Ratio: 0.45)
  Cement = 427 x 0.378 = 161.16 kg
  Fine Aggregate (Sand) = 645 x 0.378 = 243.81 kg
  Coarse Aggregate = 1110 x 0.378 = 419.58 kg
- **M35**

  Cement: 170.1 kg
  Water: 72.39 liters (Water-Cement Ratio: 0.45)
  Coarse Aggregate: 401.1 kg
  Fine Aggregate: 259.98 kg
- **M40**

  Cement: 185.01 kg
  Water: 70.29 liters (Water-Cement Ratio: 0.45)
  Fine Aggregate (sand): 277.52 kg
  Coarse Aggregate: 462.53 kg

➢ **Step-by-Step Procedure**

- Weigh the required quantities of cement, fine aggregates, coarse aggregates, and water according to the mix design for each concrete grade (M30, M35, M40).
- Dry Mixing: In the concrete, first add the cement, fine aggregates, and coarse aggregates. Mix them thoroughly in dry form to ensure even distribution
- Wet Mixing: Gradually add water while mixing to achieve the desired workability and consistency.
- Adding Fibers
- Clean the molds and apply a thin layer of release agent on the internal surfaces to facilitate easy removal of the concrete beams after curing.
- Pour the mixed concrete into the prepared molds in 3 layers. Each layer should be about one-third of the mold height.

Fig -2.4: Filling molds in 3 layers

- Compaction: After placing each layer of concrete, compact it using a vibrating table to remove air bubbles and achieve proper compaction

Fig -2.5 vibrating table

- Fill the molds to the top and smooth the surface using a trowel.
- Leave the molds undisturbed for 24 hours in a controlled environment to allow the concrete to set.
- After 24 hours, carefully de-mold the concrete beams.

Fig -2.6 De-mold

- Place the beams in a curing tank filled with water. Ensure that the beams are fully submerged
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Fig -2.7 Curing tank

➢ **LOADING TEST USING UNIVERSAL TESTING MACHINE**

- **Positioning the Beam**: Place the beam on the support fixtures of the UTM.
- The **supports** should be positioned at equal distances from each end of the beam, typically with a span length (L) of about 600 mm (**with 50 mm overhang on each side**).
- **Placing the Load** Fixtures: Position the loading points symmetrically about the center of the beam. The distance between the two loading points (a) should be one-third of the span length (L/3). For a 700 mm span, the load points will be 233 mm (**250 taken**) apart and centered.

Fig -2.8 50 mm overhang on each side

- Initial Load Application: **Apply a small initial** load to seat the beam and eliminate any slack in the system.
- Apply Load Gradually: **Start the UTM** and apply load gradually at a constant rate. The load should be applied through the two loading points. **30n/m loading rate**
- **Monitor and Record Data**: Continuously monitor and record the load and corresponding deflection at regular intervals. Note the initial cracking load and any significant changes in the beam behavior.

Fig -2.9 Apply loading

- **Remove the Beam**: Carefully remove the broken beam from the UTM.
- **Measure Crack Widths** and record the crack widths and patterns using a ruler.

Fig -2.10 Remove from UTM

- **Calculations**
- Flexural Strength Calculation:

- if "a" is greater than 20cm for 15 cm specimen: Flexural strength *(fb) = PL/BD²*
- if "a" is less than 20cm but grater than 17cm for 15cm specimen: Flexural Strength f_r =*3PL/2BD^2*
- Where "a" is minimum distance between crack to Support
  - f_r Flexural Strength
  - *P* is the load
  - *L* is the Span length
  - *b* is the width
  - *d* is the depth

- Tensile Strength Calculation:

$$F_t = k * f_r$$

- f_t is the tensile strength,
- f_r is the flexural strength,
- *k* is a conversion factor that depends on the material and its condition.

For typical concrete, the conversion factor ***k*** is often taken to be around 0.7 to 0.75.

3. OBSERVATION

Avg. peak load

Table -3.1: Avg. Peak Loading for M30

M30	OPC	Jute	Polypropylene	Composite
7 Day	14.5	16.0	16.9	17.3
7 Day	14.8	16.2	17.3	17.8
7 Day	15.1	16.4	16.5	18.3
AVG	14.8	16.2	16.9	17.8
28 Day	21.7	23.2	24.2	25.4
28 Day	21.1	20.0	24.9	25.0
28 Day	20.6	26.5	23.5	25.8
AVG	21.1	23.2	24.2	25.4

Table -3.2: Avg. Peak Loading for M35

M35	OPC	Jute	Polypropylene	Composite
7 Day	16.2	17.9	17.9	19
7 Day	16.0	17.1	18.3	20
7 Day	15.8	17.5	18.7	19.6
AVG	16.0	17.5	18.3	19.6
28 Day	22	25	26.4	27.3
28 Day	23.6	24.7	26.1	27
28 Day	22.8	25.3	25.8	27.6
AVG	22.8	25.0	26.1	27.3

Table -3.3: Avg. Peak Loading for M40

M40	OPC	Jute	Polypropylene	Composite
7 Day	17.1	18.8	19.2	19.8
7 Day	17.4	19.2	19.6	20.4
7 Day	16.8	18.4	20.0	20.8
AVG	17.1	18.8	19.6	20.4
28 Day	24.8	26.8	27.8	28.8
28 Day	24.4	27.3	28.0	29.6
28 Day	24.0	26.3	28.2	29.1
AVG	24.4	26.8	28.0	29.2

Flexural Strength

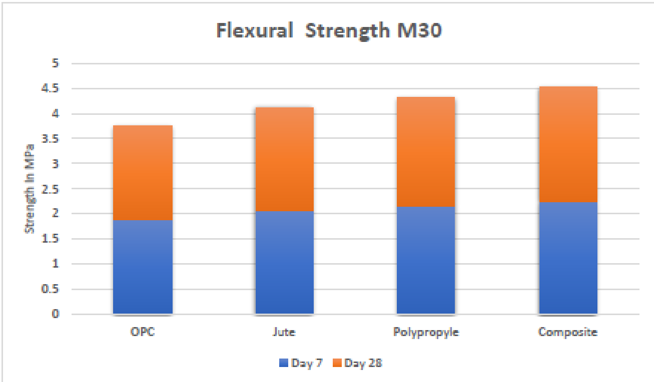

Fig -3.1 Value of Flexural Strength M30

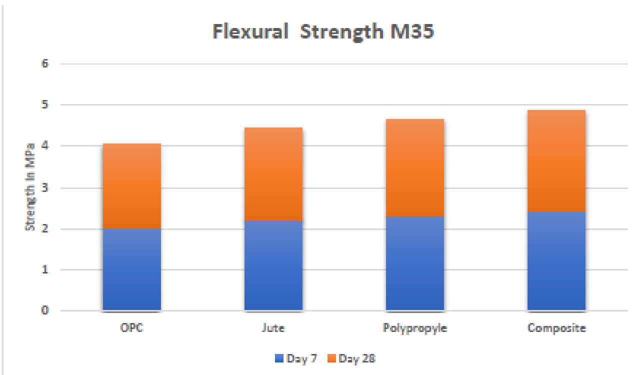

Fig -3.2 Value of Flexural Strength M35

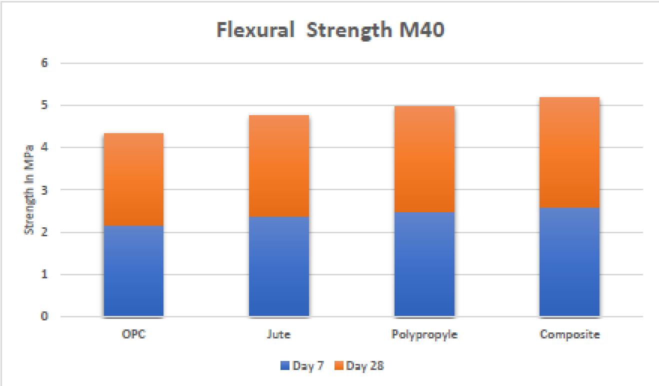

Fig -3.3 Value of Flexural Strength M40

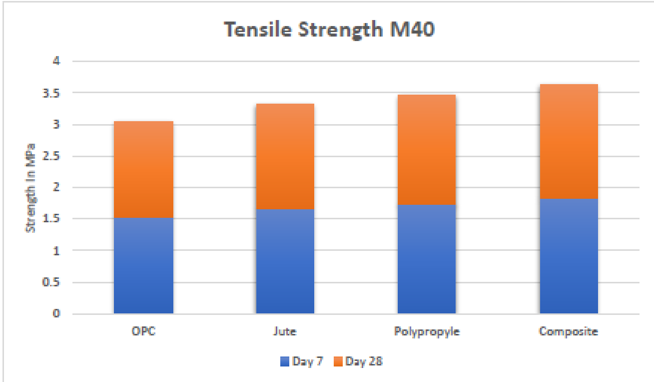

Fig -3.6 Tensile Strength M40

➢ Tensile strength

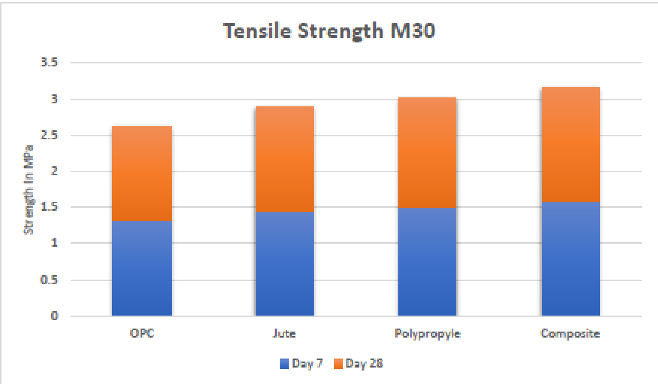

Fig -3.4 Tensile Strength M30

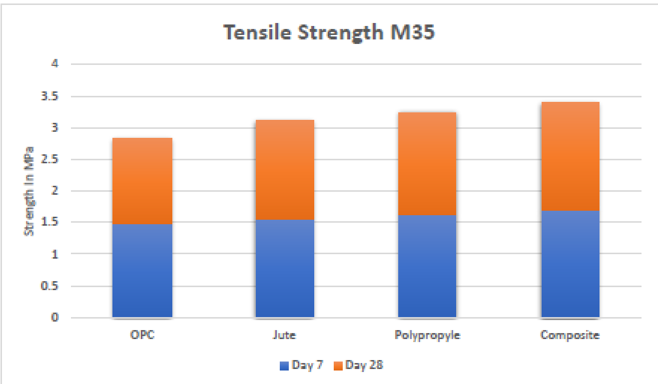

Fig -3.5 Tensile Strength M35

➢ Day 7 observation

Table -3.4: Flexural and Tensile Strength of M30 on day 7

Concrete Grade	Fiber Type	Fiber Volume Fraction	Peak Load *P* [kN]	Flexural Strength f_r $=3PL/2BD^2$ [MPA]	Tensile Strength $F_t=k*f_r$ [MPA]
M30	OPC	-	14.8	1.88	1.31
M30	Jute	0.5%	16.2 (9.46% increase)	2.06 (9.57% increase)	1.44 (9.92% increase)
M30	Poly-propylene	0.1%	16.9 (14.19% increase)	2.15 (14.36% increase)	1.50 (14.50% increase)
M30	Composite	0.75%	17.8 (20.27% increase)	2.26 (20.21% increase)	1.58 (20.61% increase)

Table -3.5: Flexural and Tensile Strength of M35 on day 7

Concrete Grade	Fiber Type	Fiber Volume Fraction	Peak Load *P* [kN]	Flexural Strength f_r $=3PL/2BD^2$ [MPA]	Tensile Strength $F_t=k*f_r$ [MPA]
M35	OPC	-	16.0	2.03	1.48
M35	Jute	0.5%	17.5 (9.38% increase)	2.22 (9.35% increase)	1.55 (4.7% increase)
M35	Poly-propylene	0.1%	18.3 (14.38% increase)	2.32 (14.28% increase)	1.62 (9.45% increase)
M35	Composite	0.75%	19.6 (22.5% increase)	2.42 (19.21%increase)	1.70 (14.86% increase)

Table -3.6: Flexural and Tensile Strength of M40 on day 7

Concrete Grade	Fiber Type	Fiber Volume Fraction	Peak Load *P* [kN]	Flexural Strength f_r $=3PL/2BD^2$ [MPA]	Tensile Strength $F_t=k*f_r$ [MPA]
M40	OPC	-	17.1	2.17	1.52
M40	Jute	0.5%	18.8 (9.94% increase)	2.38 (9.67% increase)	1.67 (9.86% increase)
M40	Poly-propylene	0.1%	19.6 (14.62% increase)	2.49 (14.74% increase)	1.73 (13.8% increase)
M40	Composite	0.75%	20.4 (19.30% increase)	2.60 (19.81% increase)	1.83 (20.39% increase)

Table -3.7: Flexural and Tensile Strength of M30 on day 28

Concrete Grade	Fiber Type	Fiber Volume Fraction	Peak Load *P* [kN]	Flexural Strength f_r $=3PL/2BD^2$ [MPA]	Tensile Strength $F_t=k*f_r$ [MPA]
M30	OPC	-	21.1	3.75	2.62
M30	Jute	0.5%	23.2(9.95% increase)	4.12 (9.86% increase)	2.88 (9.92% increase)
M30	Poly-propylene	0.1%	24.2 (14.69% increase)	4.30 (14.66% increase)	3.01 (14.88% increase)
M30	Composite	0.75%	25.4 (20.37% increase)	4.51 (20.26% increase)	3.15 (20.22% increase)

Table -3.8: Flexural and Tensile Strength of M35 on day 28

Concrete Grade	Fiber Type	Fiber Volume Fraction	Peak Load *P* [kN]	Flexural Strength f_r $=3PL/2BD^2$ [MPA]	Tensile Strength $F_t=k*f_r$ [MPA]
M35	OPC	-	22.8	4.05	2.83
M35	Jute	0.5%	25.0 (9.64% increase)	4.44 (9.62% increase)	3.10 (9.54% increase)
M35	Poly-propylene	0.1%	26.1 (14.47% increase)	4.64 (14.56% increase)	3.24 (14.48% increase)
M35	Composite	0.75%	27.3 (19.73% increase)	4.85 (19.75% increase)	3.39 (19.78% increase)

Table -3.9: Flexural and Tensile Strength of M40 on day 28

Concrete Grade	Fiber Type	Fiber Volume Fraction	Peak Load *P* [kN]	Flexural Strength f_r $=3PL/2BD^2$ [MPA]	Tensile Strength $F_t=k*f_r$ [MPA]
M40	OPC	-	24.4	4.33	3.03
M40	Jute	0.5%	26.8 (9.83% increase)	4.76 (9.93% increase)	3.33 (9.90% increase)
M40	Poly-propylene	0.1%	28.0 (14.75% increase)	4.97 (14.78% increase)	3.47 (14.52% increase)
M40	Composite	0.75%	29.2 (19.67% increase)	5.19 (19.86% increase)	3.63 (19.8% increase)

4. CONCLUSIONS

- Enhanced Strength: Fiber reinforcement in concrete significantly improves its flexural and tensile strengths compared to conventional concrete.
- Optimal Fiber Volume: Composite fibers at a 0.75% of volume fraction showed the highest strength gains among all fiber types tested.
- The Composite Fiber Increases Strength Up to 20% for 7 day and 28days.
- The Jute fiber is the cheapest fiber in our study and it increases strength up to 10%. But You cant add high amount of jute because its effect more on workability compare to Polypropylen.
- Superior Performance of Composite Fibers: Composite fibers consistently outperformed Jute and Polypropylene fibers in both flexural and tensile strength tests.
- Grade Variation: The improvements in mechanical properties were evident across all concrete grades (M30, M35, and M40), demonstrating the versatility of fiber reinforcement.
- Early Strength Gain: Even at 7 days, fiber-reinforced concrete samples showed noticeable improvements in strength, indicating early strength gain.
- Long-term Benefits: At 28 days, the enhancements in strength were more pronounced, suggesting that fiber reinforcement contributes to long-term durability.
- Uniform Distribution: Proper mixing and compaction are crucial to ensure the uniform distribution of fibers within the concrete matrix.
- Cost-Effective Solution: Fiber reinforcement can be a cost-effective way to enhance concrete properties without significantly increasing the material cost.
- Practical Applications: Fiber-reinforced concrete is suitable for structural applications where increased load-bearing capacity and durability are required.
- Environmental Considerations: The use of natural fibers like Jute can be beneficial for environmentally sustainable construction practices.
- Future Durability Studies: Further investigation into the long-term durability of fiber-reinforced concrete under various environmental conditions is recommended.
- Implementation Guidelines: The findings suggest practical guidelines for incorporating fibers into concrete mixes, optimizing both performance and cost-efficiency.

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