EXPERIMENTAL EVALUATION OF FLEXURAL BEHAVIOR IN CONCRETE BEAMS REINFORCED WITH WASTE HUMAN HAIR FIBERS

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Abstract- Concrete is the most widely used construction material globally, but it faces inherent challenges such as low tensile and flexural strength and a tendency to crack under stress. Traditional fibers like steel and polypropylene are used to mitigate these issues; however, they are often costly and nonbiodegradable, prompting the search for sustainable alternatives. This study explores the innovative use of human hair, a natural, biodegradable, and high tensile waste material as a reinforcing additive in concrete beams. The novelty lies in evaluating the structural and durability performance of concrete beams reinforced with human hair, an underexplored fiber in flexural applications. An experimental program was carried out where four concrete beams were cast, two with 1% human hair by cement volume and two without hair as control specimens. Tests conducted included a three-point flexural test, water absorption test, and surface hardness test using the Schmidt hammer. Specimens were cured for 28 days before testing. Results showed that human hair reinforced beams exhibited 23.84% higher flexural strength compared to controls, reduced water absorption, and increased surface hardness. These findings suggest that human hair can be effectively utilized as a sustainable and efficient fiber additive to enhance concrete performance.

Keywords- Human Hair, Concrete, Flexural Strength, Schmidt Hammer, Water Absorption

1. Introduction

Concrete remains the most extensively utilized construction material globally, primarily due to its high compressive strength, durability, and adaptability to diverse structural forms. Nevertheless, it is inherently deficient in tensile and flexural capacities, which predisposes it to brittle failure modes when subjected to bending and tensile loads [16][14]. This fundamental limitation frequently results in the early initiation and propagation of cracks within structural members such as beams and slabs, thereby compromising both strength and serviceability over time. The ingress of moisture and deleterious agents through these microcracks exacerbates the risk of steel reinforcement corrosion, which progressively undermines structural integrity [6]15]. The compounded effects of crack development and reinforcement degradation can significantly reduce the lifespan and safety margins of concrete infrastructure. Consequently, addressing the flexural vulnerability of concrete is imperative for ensuring the long term performance and resilience of structural systems. This necessity underscores the importance of innovative materials and techniques aimed at mitigating crack formation and enhancing the overall durability of concrete structures.

Fiber reinforced concrete (FRC) has emerged as an effective solution for enhancing the tensile and flexural performance of conventional concrete by incorporating fibers such as steel, polypropylene, and glass, which bridge microcracks and improve ductility and energy absorption [11][12][17] has shown that fiber orientation, dispersion, and dosage significantly influence fracture resistance and mechanical response. Despite extensive studies on synthetic and natural fibers, the structural potential of human hair as reinforcement remains largely underexplored. Composed mainly of keratin, human hair offers high tensile strength, elasticity, and biodegradability, making it a promising sustainable alternative [8]. To address this gap, the present study incorporated 1% human hair by cement volume into concrete beams and assessed flexural strength, water absorption, and surface hardness. Four beams were cast, two with hair reinforcement and two controls and tested under four point bending to evaluate load deflection behavior and durability performance.

The results of this experimental investigation demonstrate a significant enhancement in the mechanical and durability characteristics of concrete beams reinforced with human hair fibers. This study aimed to explore the novel use of human hair as a sustainable and cost effective reinforcement material for structural concrete applications. Four beams were prepared, including two control specimens and two reinforced with 1% human hair by volume of cement, and were tested under standardized four point bending, water absorption, and surface hardness procedures. The hair reinforced beams exhibited a 23.84% increase in flexural strength compared to the controls, indicating a notable improvement in their load bearing capacity. Additionally, these beams showed higher surface hardness and reduced water absorption rates, suggesting enhanced resistance to abrasion and moisture ingress. Visual inspection confirmed that the hair fibers effectively bridged microcracks and delayed crack propagation, thereby improving energy dissipation during flexural loading. These findings underscore the viability of human hair as an innovative reinforcement material that contributes both structural benefits and environmental value through the reuse of biodegradable waste.

2. Research Methodology

2.1 Raw Material

The concrete mix followed a 1:2:4 ratio using OPC 43 grade cement, Lawrencepur sand as fine aggregate, and 20 mm coarse aggregate. Clean drinking water was used to ensure proper hydration and curing. Human hair fibers (30–60 mm) (fig 1a), collected from barber shops (fig 1b), were added at 1% by cement volume to enhance crack resistance and flexural performance as shown in figure 1. The selection of 1% human hair fiber by cement volume was based on prior studies indicating that low-volume natural fibers can effectively improve flexural properties without severely compromising workability [3][7]. The 30–60 mm fiber length range was chosen to ensure sufficient crack-bridging capability while maintaining manageable mixing consistency. These parameters provided a practical balance between dispersion, reinforcement effect, and workability. Future studies are encouraged to explore a broader dosage range (2–5%) to identify the optimal content for structural-scale applications. The data in table 1 indicates that human hair possesses moderate tensile strength and high elongation, making it effective for crack bridging and energy absorption. Its biodegradable nature, coupled with surface roughness and adequate modulus, makes it a compelling alternative for sustainable fiber reinforcement in concrete.

a) b)

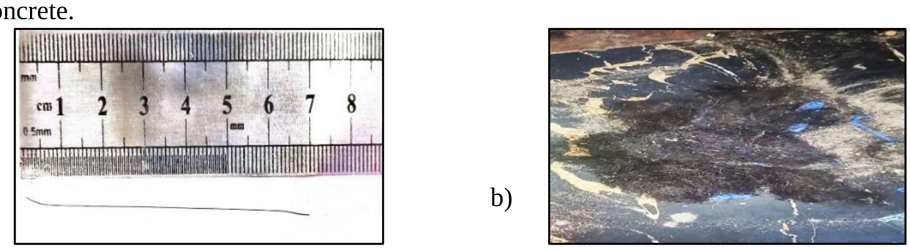


Figure 1: Hair Reinforced Concrete

Table 1 Physical and Mechanical Properties of Human Hair Fibers

Sr	Property	Value/Range	Unit	Remarks
1	Fiber Length	30 – 60	mm	Naturally variable; selected for crack bridging
2	Diameter	60 – 80	µm	Measured under optical microscope
3	Specific Gravity	1.32	—	Slightly lower than conventional aggregates
4	Tensile Strength	200	MPa	Comparable to low-grade synthetic fibers
5	Elongation at Break	30 – 50	%	High ductility helps dissipate energy
6	Modulus of Elasticity	1.5 – 2.0	GPa	Lower than steel or glass fibers
7	Surface Morphology	Rough (scaly cuticle)	—	Promotes mechanical interlocking with cement
8	Thermal Decomposition Point	230 – 250	°C	Degrades before concrete exposure to high heat

2.2 Mix Design and Casting of Concrete Specimen

A 1:2:4 mix ratio was adopted with water cement ratio of 0.5%. Hair was mixed using a four layer approach to ensure even distribution. 4 x beams (2 x control, 2 x reinforced) were cast and cured for 28 days. Table 2 illustrates mix design of PCC and FRC.

Table 2: Mix *Design* of PCC & FRC

Sr	Parameter	Plain Cement Concrete	Hair Reinforced Concrete
1	Mix Ratio	1:2:4	1:2:4
2	Cement	6.5 kg	6.5 kg
3	Sand	13 kg	13 kg
4	Coarse aggregate	26 kg	26 kg
5	W/C Ratio	3.25 Liters	3.25 Liters
6	Hair Fiber Addition	Nil	30 60 mm long fibers (Naturally variable) 1% by cement mass (65 grams)
7	Mixing Method	Combine – add water – mix	Combine – add water – mix
8	Batching Time	5 minutes	5 Minutes

a) b)

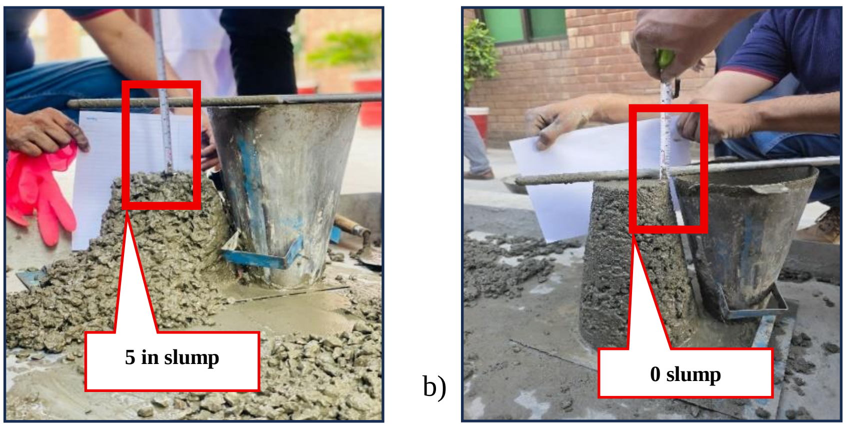


Figure 2: a. Slump Tests for PCC and b. HRC

Slump tests were conducted on Plain Reinforced Concrete (PRC) and Hair Reinforced Concrete (HRC) using the standard slump cone method to evaluate workability. Fresh concrete was filled into the slump cone mold in three layers, each tamped 25 times with a rod for compaction. After leveling the top surface, the cone was lifted vertically, and the slump was measured as the vertical drop. The PRC mix showed a 5inch slump (figure 2a), indicating moderate workability. In contrast, the HRC mix incorporating human hair fibers had a zero slump, reflecting very low workability (figure 2b). The fibers restricted the concrete's flow and deformation significantly. Table 3 illustrates comparison of PCC and HRC based on achieved slump.

Table 3: Comparison of PCC & HRC

Sr	Parameter	Plain Cement Concrete	Hair Reinforced Concrete
1	Workability	Good	Reduced due to fiber presence
2	Slump (in)	5	0
3	Placement	Easy	Requires more effort due to reduce flowability
4	Use of admixtures	Not required	Superplasticizer may be required to improve workability
5	Curing Period	28 days	28 days

2.3 Testing

The experimental evaluation included flexural strength assessment through a 3-point bending test (figure 3a) conducted in accordance with ASTM C78/C78M-22 to measure beam performance under transverse loading. Water absorption (figure 3b) was determined per ASTM C642-21 to evaluate porosity and durability. Surface hardness was measured using a Type N Schmidt rebound hammer following ASTM C805/C805M-18 (figure 3c).

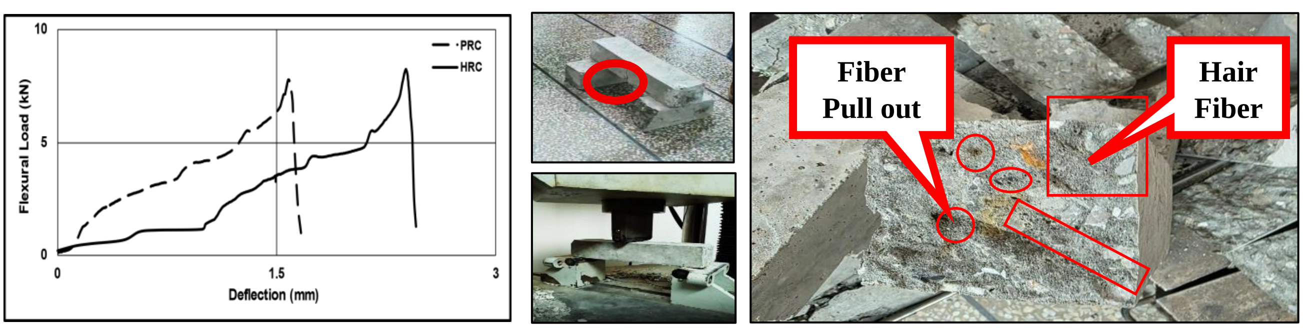
a) b) c)

Figure 3: a) Beam under flexural load test, b) water absorption test c) Schmidt hammer test

3. Experimental Results and Analysis

3.1 Flexural Behavior

The comparison of the flexural load deflection curves as demonstrated in figure 4a illustrates the superior performance of the human hair reinforced beams relative to the control specimens. The reinforced beams exhibited higher peak loads and sustained greater deflection, reaching 2.4 mm before failure, indicating improved ductility and energy absorption. In contrast, the control beams failed abruptly at lower deflection levels around 1.5 mm, reflecting a more brittle response. The smoother post peak behavior of the reinforced beams suggests that hair fibers effectively delayed crack propagation and contributed to a more gradual failure mechanism. These observations confirm that incorporating human hair enhances both load bearing capacity and deformation resilience in concrete beams.



a) b) c)

Figure 4: a) Load vs Deflection Graph for HRC & PRC b) Fractured surface c) Cross Section Hair Infused

Figures 4b and 4c illustrate the fracture behavior and internal characteristics of the tested concrete beams incorporating human hair fibers. In the first image of Figure 4b, the beam exhibits a pronounced bridging effect immediately prior to collapse, where visible cracks had formed but the fibers continued to transfer stress across the fracture plane, delaying sudden failure. The second image shows the beam during flexural testing under applied load at the point of failure, highlighting the location and pattern of the fracture. Figure 4c presents a cross-sectional view of a hair infused beam after testing, clearly revealing embedded hair fibers distributed within the concrete matrix. The exposed fibers and evidence of fiber pullout indicate that the hair reinforcement contributed to crack bridging and energy dissipation, confirming their active role in enhancing ductility and toughness. Collectively, these images provide visual confirmation of the mechanical mechanisms observed in the experimental results and support the effectiveness of human hair fibers in improving post cracking performance. Table 4 compares the maximum flexural load and flexural strength of control and hair reinforced concrete beams, demonstrating enhanced flexural performance with the addition of human hair fibers.

Table 4: Flexural Load and Strength of Plain Cement Concrete (PCC) and Hair Fiber Reinforced Concrete (FRC) Beams

Sr	Beam	Type	Load (KN)	Flexural Strength (MPa)
1	A	Control	5.264	0.649
2	B	Control	7.792	3.342
3	Average		6.528	1.995
3	C	Hair Reinforced	8.248	3.539
4	D	Hair Reinforced	6.318	1.995
5	Average		7.283	2.767

3.2 Flexural Properties

The comparative data in Table 5 highlight notable differences in mechanical behavior between Hair Reinforced Concrete (HRC) and Plain Reinforced Concrete (PRC). While both beams shared identical geometric properties, HRC exhibited a higher deflection of 2.38 mm under load, indicating reduced stiffness relative to PRC. The modulus of rupture for HRC reached 3.67×10^6 MPa, surpassing PRC and suggesting enhanced cracking resistance. However, PRC demonstrated superior stiffness (5194.67 N/mm) and a higher elastic modulus (1.166 GPa), reflecting greater rigidity and elastic performance. Importantly, the Flexural Toughness Index of HRC (19640.55 N mm) was more than three times that of PRC, indicating significantly improved energy absorption and ductility. These findings imply that incorporating human hair fibers enhances flexural toughness and crack resistance but may reduce overall stiffness and elastic modulus, with toughness increasing by 236%, while stiffness and elastic modulus decrease by about 33%. Table 6 indicates the comparative analysis which reveals that while human hair fibers offer slightly lower flexural strength than synthetic counterparts like steel or polypropylene, they significantly enhance toughness and crack resistance at a lower cost and with the added benefit of biodegradability. These attributes position human hair as a viable, sustainable alternative for semi-structural applications where moderate strength and high ductility are desired.

Table 5: Flexural mechanical properties of control and hair reinforced concrete beams B and C.

Sr	Parameter	HRC	PRC	Unit
1	Span	18	18	In
2	Width	4	4	In
3	Depth	4	4	In
4	Deflection	2.38	1.5	Mm
5	Modulus of Rupture (MOR)	3.67×10^6	3.398×10^6	MPa
6	Load	8248	7792	N
7	Stiffness	3463.73	5194.67	N/mm
8	Initial Modulus (E1)	7.77×10^8	1.166×10^9	Pa
9	Elastic Modulus (E)	0.78	1.166	GPa
10	Flexural Toughness Index (FTI)	19640.55	5844	N mm
11	Flexural Stiffness (K)	3.46×10^6	5.19×10^6	N/m

Table 6: Comparison of Mechanical Performance of Different Fiber Types in Concrete

Sr	Fiber Type	Flexural Strength (MPa)	Toughness Improvement (%)	Modulus of Rupture (MPa)	Notable Characteristics

1	Human Hair	2.77	+236%	3.67×10^6	Readily available waste; moderate bonding
2	Polypropylene	3.5 – 5.0	+150–200%	4.0×10^6	Chemically inert; good dispersion
3	Steel Fiber	5.0 – 8.0	+300–500%	5.5×10^6	Very high strength; prone to corrosion
4	Glass Fiber	4.0 – 6.5	+200–300%	4.5×10^6	High strength but brittle

3.3 Durability and Non-Destructive Testing (NDT) Characteristics

The durability and non-destructive characteristics of the concrete beams were evaluated through water absorption and in situ strength testing. As shown in Table 7, Beam C and Beam D exhibited low water absorption rates of 0.97% and 0.95%, respectively, indicating reduced porosity and enhanced resistance to moisture ingress and chemical attack. Corresponding compressive strength values, measured via NDT, were 3345 psi and 3328 psi, demonstrating consistent structural performance. The close alignment of these parameters suggests that both beams possess satisfactory durability and mechanical integrity, making them suitable for long term structural use.

Table 7: Water Absorption & NDT Test

Sr	Beam	Water Absorption (%)	Average Strength (psi)
1	Beam C	0.97%	3345
2	Beam D	0.95%	3328

4. Practical Applications

The incorporation of human hair into concrete offers significant practical applications that align with sustainability and structural efficiency objectives. As a natural protein fiber typically considered waste, human hair provides an innovative means to reduce environmental impact by repurposing biowaste within construction materials. Its high tensile strength and inherent flexibility enable it to bridge microcracks in the concrete matrix, improving flexural resilience and enhancing the ability of beams to withstand deformation under applied loads. In regions where conventional fiber reinforcements are prohibitively expensive or difficult to access, human hair emerges as a cost effective, locally available alternative. This approach can be especially advantageous in rural or low income construction projects by reducing dependence on synthetic or industrial materials. The improved crack resistance offered by hair fibers also contributes to the long term durability and structural integrity of concrete elements. However, potential challenges include ensuring uniform dispersion of human hair fibers within the concrete matrix and addressing scalability for large-scale construction projects, which may require specialized mixing techniques or quality control measures. As a result, human hair reinforced concrete holds potential for semi structural applications, including pavements, partitions, and precast components.

From a sustainability perspective, the average barbershop produces up to 0.5–1 kg of waste hair per day, which often ends up in landfills. Repurposing this biowaste in construction could divert thousands of kilograms annually per city from waste streams. Additionally, using human hair in place of synthetic fibers reduces embodied energy by an estimated 60–80%, contributing to lower carbon footprints in green construction projects. Furthermore, integrating human hair into concrete aligns with contemporary green building practices and broader waste reduction strategies. By leveraging this abundant and renewable resource, construction projects can support global initiatives aimed at promoting sustainable development. Projects seeking environmental certifications, such as LEED, may benefit from the inclusion of innovative materials like hair fibers to strengthen their sustainability credentials. Additionally, the use of human hair addresses pressing environmental concerns by diverting waste from landfills and reducing the ecological footprint of construction activities. The enhanced durability performance achieved through fiber reinforcement further underscores its practical value in improving service life and reducing maintenance needs. Overall, human hair reinforced concrete presents a promising pathway for creating environmentally conscious and structurally reliable building materials. Its adoption can contribute meaningfully to advancing sustainable construction practices worldwide.

5. Conclusion

This research has demonstrated a sustainable strategy to improve concrete beams by incorporating human hair fibers as reinforcement. The findings highlight both mechanical and durability benefits compared to conventional concrete and prior studies using synthetic fibers. Following conclusions can be drawn from the study:

- The experimental results demonstrated that incorporating 1% human hair by cement volume led to a 23.84% improvement in flexural strength, a 0.96% decrease in water absorption and an increase in surface hardness to 3345 psi.
- The inclusion of human hair fibers in concrete increased the flexural toughness index by 236%, while reducing stiffness and elastic modulus by about 33%, highlighting a tradeoff between enhanced ductility and reduced structural rigidity.
- Incorporating human hair as a reinforcement in concrete provides an effective and eco-friendly solution that enhances mechanical properties while contributing to waste reduction and decreasing dependence on traditional construction materials.

A key limitation of this study is the use of only two specimens per concrete type, which constrains the statistical robustness of the results. To improve the reliability and generalizability of findings, future studies should incorporate a larger sample size with replicates to allow for rigorous statistical analysis. Future research should also focus on evaluating the long-term behavior of hair reinforced concrete under diverse environmental exposures and load cycles. Additional studies are also recommended to determine the optimal fiber content within the 2–5% range for structural use. Such efforts will help validate and refine this innovative approach for broader adoption in sustainable construction.

Acknowledgements

The author gratefully acknowledges the invaluable guidance and support of Engr. Dr. Majid Ali, whose supervision was instrumental in the successful completion of this research. Moreover, the careful review and constructive suggestions by the anonymous reviewers are gratefully acknowledged.

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