Tuijin Jishu/Journal of Propulsion Technology
ISSN: 1001-4055
Vol. 44 No. 5 (2023)

Experimental Study On Mechanical Behaviour Of Human Hair Reinforced Concrete

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Abstract:
Fibre-reinforced concrete offers a practical and cost-effective solution for addressing micro-cracks and similar structural weaknesses in concrete. Traditional concrete is inherently weak in tension, necessitating measures to enhance its performance in this regard. One unconventional yet promising option for reinforcement is human hair due to its impressive tensile strength. Human hair fibres (HF) are readily available, affordable, and do not degrade quickly, which can contribute to environmental concerns. This study aims to investigate the impact of incorporating human hair fibres into plain cement concrete, with a focus on enhancing compressive strength, tensile strength, flexural strength, and crack prevention while promoting economic and eco-friendly concrete practices.
Prior to incorporating human hair fibres into the concrete mix, a meticulous cleaning process involving acetone is carried out. Experimental assessments were conducted on concrete beams, cubes, and cylinders, utilizing various proportions of human hair fibres (0%, 1%, 1.5%, and 2% by weight of cement). The findings reveal that the introduction of human hair fibres as reinforcement leads to a noteworthy enhancement in concrete performance. Specifically, with a 2% inclusion of human hair fibres, we observed a 3.29% upsurge in compressive strength, a 10.87% increase in tensile strength, and a 12.69% improvement in flexural strength in comparison to traditional concrete.
Keywords: Fibre reinforced concrete, hair fibre, compressive strength, flexural strength, split tensile strength, acetone.

1. Introduction

Fibre-Reinforced Concrete (FRC) is a type of concrete in which fibres are incorporated to enhance its property and behaviour under structural load. These fibres are typically short, discrete strands that are evenly distributed and randomly oriented within the concrete matrix. The practice of using fibres for reinforcement has a long historical background, dating back to ancient times. In historical applications, materials like horsehair were added to mortar, and straw was utilized in the construction of mud bricks.

During the early years of 1900s, asbestos fibres were introduced as a means of reinforcing concrete. However, composite materials gained prominence during 1950s, and fibre-reinforced concrete began to attract interest. Consequently, the use of asbestos in concrete reinforcement was discouraged due to associated health risks. Instead, new materials such as steel, glass, and synthetic fibres began to replace asbestos for reinforcement

Ongoing research continues to explore and advance this crucial technology, with a focus on developing new types of fibre-reinforced concrete. Broadly defined, FRC is a composite material that combines cement, mortar, or concrete with discontinuous, uniformly dispersed fibres. It's important to note that continuous meshes, woven fabrics, long wires, or rods are not considered discrete fibres. Common fibre types include steel, glass, synthetic, and natural fibres.

Human hair is one unconventional choice for fibre reinforcement in concrete, and its effects on compressive, crushing, flexural strength, and crack control are being studied. This research aims to promote more cost-effective and environmentally friendly concrete practices by utilizing a readily available and abundant resource.

Concrete, a widely used building material, consists of three primary components: cement, sand, and fillers, bound together by cement to form a man-made stone. While it possesses acceptable compressive strength, its tensile strength is relatively low, approximately ten percent of its compressive strength. This inherent weakness leads to various issues, including concrete shrinkage and cracking. The extent of concrete shrinkage depends on

numerous factors, such as ingredient composition, temperature, relative humidity, concrete age, size, and structure.

FRC offers enhanced performance in comparison to conventional concrete and many other construction materials with similar costs. As a result, the utilization of FRC has steadily expanded over the past two decades, finding applications in highway pavements and airport runways, seismic-resistant and explosion-resistant structures, tunnel and mine linings, hydraulic structures, rock-slope stabilization, and more.

Extensive research has shown that the incorporation of various fibre types, including metallic and non-metallic options like steel, glass, synthetic, and carbon fibres, significantly improves the strength, toughness, ductility, and post-cracking resistance of plain concrete.

2. Literature Studies

M. Manjunatha et al., (2021)

In this research, the authors have explored the utilization of naturally available chopped human hair (HH) as a reinforcement material in concrete to enhance its performance. Human hair is a non-biodegradable material found in nature. The primary objective of this study is to determine the optimal quantity of HH as a fibre additive in concrete, with varying percentages ranging from 0%, 0.5%, 1%, 1.5%, 2%, to 3% by weight of cement in the concrete mixture. The authors conducted a comprehensive investigation into the effects of HH on various concrete properties, including fresh, hardened, and durability characteristics.

The experimental findings of this investigation indicate that incorporating HH as a fibre reinforcement improves the bonding between the concrete components, resulting in property enhancements of up to 2.5% HH dosage. In summary, the study establishes that the optimal utilization of HH as a concrete fibre is within the range of 2% to 2.5%. Furthermore, ultrasonic pulse velocity test results demonstrate that the introduction of human hair into the concrete mixture enhances the quality criteria of the concrete up to the 2.5% dosage; however, beyond this dosage (3%), the quality of the concrete begins to deteriorate.

Additionally, mechanical tests on concrete properties, such as flexural strength, compressive strength, and split tensile strength, corroborate the optimal usage of human hair as a concrete fibre, which falls within the 2% to 2.5% range, particularly for structural applications.

Dr. A. S. Kanagalakshmi et al., (2021)

Human hair fibre is employed as a natural reinforcement material to enhance the strength characteristics of both concrete and mortar. Human hair possesses notable tensile strength, making it a suitable choice for fibre reinforcement. Additionally, human hair is readily available in large quantities and is cost-effective.

The inclusion of human hair fibres in concrete results in several improvements, including enhanced micro-crack control, enhanced binding properties, increased ductility, and improved resistance to swelling. In a study, it was observed that the addition of 0.5% hair fibres led to a 7% increase in compressive strength, and further incorporation of 0.5% yielded a 12.8% increase. However, beyond this point, additional hair fibre caused a reduction in strength.

Furthermore, the study revealed that the introduction of 0.5% hair fibres resulted in a 2% increase in flexural strength, and a further addition of 0.5% led to a significant 22% increase. During a Sulphate attack test, it was observed that the percentage of strength loss and weight loss decreased as the percentage of human hair fibre increased. The study's findings indicated that the minimum weight loss and strength loss were achieved at 1% and 1.5% hair fibre by weight of cement, respectively.

Hummaira Kanwal et al., (2020)

Human hair exhibits notable tensile strength, making it a viable option for reinforcement purposes. This non-degradable material is also readily available at a cost-effective rate.

Experimental trials were conducted on cylindrical specimens of fibre-reinforced concrete (FRC) containing different proportions of human hair—namely, 0%, 0.5%, 1%, and 1.5% by weight relative to the cement content. In total, seventy-two cylinders were prepared, each with varying hair content.

Workability, compressive strength, and split tensile strength were assessed at three different curing periods: 7 days, 14 days, and 28 days. Over time, both compressive strength and split tensile strength increased

for all concrete mixtures. Notably, the concrete mixture labeled "M4," which contained 1.5% human hair, exhibited higher strength compared to "M2" (0.5% hair) and "M3" (1.0% hair). This outcome underscores the effectiveness of human hair as a fibre reinforcement material for achieving superior strength in concrete beyond that of normal concrete.

Geeta Batham (2019)

Human hair serves as a natural fibre to augment the strength characteristics of both concrete and mortar. Numerous studies have been conducted to assess the performance of human hair in this regard. This study presents a parametric experimental investigation conducted in a laboratory setting to assess the impact of human hair on cement concrete.

Concrete of M-25 grade was produced and reinforced with varying percentages of human hair content. Various concrete specimens were cast in the laboratory, with human hair content ranging from 0%, 0.5%, 1.0%, 1.5%, 2.0%, to 2.5% by weight relative to the cement used.

The utilization of human hair content as a natural fibre resulted in an increase in compressive strength. Among the concrete cubes tested, those containing 2.0% and 2.5% human hair content demonstrated superior performance in terms of strength. However, it was determined that a human hair content of 2.0% represented the optimum percentage for both strength and workability.

Navneet Singh et al., (2019)

Concrete stands as one of the most extensively utilized building materials. Comprising three primary components—cement, sand, and aggregates—it binds together under the influence of cement, forming concrete, essentially a man-made stone. While its compressive strength meets acceptable standards, its tensile strength remains considerably lower, at approximately ten percent of its compressive strength.

To explore potential enhancements, experiments were conducted using concrete cubes with varying proportions of human hair fibre—specifically, 1%, 2%, and 3% by weight relative to the cement content. The testing outcomes revealed notable improvements across various concrete properties and strengths due to the incorporation of human hair as a fibre reinforcement material. This suggests its suitability as an alternative additive for concrete, enhancing its mechanical properties.

Furthermore, hair fibre-reinforced concrete offers a promising approach to hair waste management. The compressive strength of the concrete specimens was determined through testing using a universal testing machine, with the results indicating that the highest compressive strength was achieved with a 2% addition of human hair fibre.

Er. Chinnadurai et al., (2017)

Human hair fibre serves as a reinforcement material. Human hair fibres (HF), being non-degradable and readily available at a low cost, present an alternative option. However, their slow decomposition can pose environmental concerns.

This study was conducted to investigate the impact of human hair on plain cement concrete, focusing on compressive, crushing, flexural strength, and crack control. The objective is to promote cost-effective concrete practices while mitigating environmental issues.

For each concrete mix, three cubes were tested to evaluate their mechanical properties. The test results revealed a notable enhancement in concrete properties corresponding to varying percentages of hair by weight of cement in the concrete mixture. Specifically, there was an overall increase of 1% to 12% in compressive strength and up to 5% in flexural strength for concrete test specimens due to the addition of hair fibres in different quantities. This increase was most pronounced when adding 1.5% to 3% of hair fibre, by weight of concrete, in all the mixtures.

T. Naveen Kumar et al., (2015)

This study aims to investigate the impact of human hair on M-40 grade plain cement concrete, with a focus on its mechanical properties—specifically, compressive, flexural, and split tensile strength. Additionally, the study seeks to address environmental concerns.

Experiments were conducted using concrete cubes, beams, and cylinders of standard sizes, with varying percentages of human hair fibre (1%, 1.5%, 2%, 2.5%, and 3%) added by weight relative to the cement content. The results were then compared to those of plain M-40 grade cement concrete.

The experimental findings revealed that the optimal content of human hair fibre to be added to M-40 grade concrete is 1.5%. This addition led to notable improvements in the properties of M-40 grade concrete, particularly in terms of its compressive strength, flexural strength, and split tensile strength, with the degree of improvement corresponding to the percentage of hair by weight of cement in the concrete mixture.

Jain D et al., (2012)

The project's objective is to examine the impact of human hair on plain cement concrete, with a focus on its compressive, crushing, flexural strength, and cracking control. This investigation aims to promote cost-effective concrete practices while addressing environmental concerns.

Experimental trials were conducted on concrete beams and cubes, incorporating varying percentages of human hair fibre (0%, 1%, 1.5%, 2%, 2.5%, and 3%) relative to the weight of cement. Each concrete proportion was tested using one beam and three cubes to evaluate their mechanical properties.

The results, when compared to plain cement concrete, revealed an increase in both compressive and flexural strength up to a certain percentage. Specifically, the addition of 1.5% human hair by weight of cement led to improvements in compressive and flexural strength across different concrete grades (M10, M15, M20, and M25).

3. Motivation

- Exploring the inclusion of human hair as a reinforcing material in concrete supports sustainable construction practices, utilizing an abundant and renewable resource.
- Analysing the mechanical behaviour of hair-reinforced concrete may uncover economical alternatives to conventional reinforcement materials, potentially leading to cost savings in construction projects.
- The use of human hair in concrete remains an underexplored area, rendering it a captivating and innovative research avenue with the potential to advance the field of materials science.

4. Problem Domain

Alternative Construction Materials and Technologies

Problem Definition

In the realm of construction materials and engineering, there is a growing interest in the exploration of alternative and sustainable reinforcement materials for concrete. Conventional reinforcement options, such as steel, come with environmental challenges and costs. Human hair, often considered a waste product and abundantly available, presents an innovative opportunity for reinforcing concrete. However, there exists a significant knowledge gap regarding the mechanical properties, structural performance, and durability of human hair-reinforced concrete.

The primary objective of this study is to bridge this knowledge gap by conducting comprehensive experimental investigations. These investigations aim to assess the feasibility and effectiveness of employing human hair as a reinforcement material in concrete. The research encompasses the evaluation of tensile strength, flexural strength, compressive strength, and durability characteristics of hair-reinforced concrete. These findings will be compared to those of conventional concrete. In doing so, this study aims to offer valuable insights into the potential benefits, limitations, and practical applications of human hair as a sustainable and cost-effective reinforcement material in the realm of concrete construction.

Problem Statement

Experimental Study on Mechanical Behaviour of Human hair reinforced concrete.

Innovative Content

The use of human hair in concrete is relatively unexplored, making it an interesting and innovative research topic with the potential to advance the field of materials science.

5. Solution Methodologies

A. Materials used

Cement – In this project ordinary Portland cement of grade 43 is used confirming to IS: 12269-1987.

Fine Aggregate – Manufactured sand of size less than 4.75mm, conforming to IS 383 – 2016, has been used in this study in place of natural river sand. Manufactured sand or artificial sand is produced by crushing of hard granite stone. The crushed sand produced using this technology are of cubicle shape.

Coarse aggregates – In the present experimental investigation locally available coarse aggregate i.e., crushed granite stone aggregate of size 20mm passing and retained on 16mm IS sieve is used.

Water – Potable water free of carbonic content, sulphates and chlorides has been used.

Human hair – Washed and dried hair were sorted and used as fibres in this study.

B. Preliminary Material Properties

Table 1: Material Properties

PROPERTY	RESULT
Ordinary Portland cement	
Specific gravity	3.18
Normal consistency	30%
Manufactured Sand	
Specific gravity	2.35
Water absorption	4.25%
Fineness modulus	3.53
Properties of Coarse Aggregate	
Specific gravity	2.89
Water absorption	0.75%

In this study, M25 grade human hair reinforced concrete has been design using IS 10262: 2019, samples of cubes, cylinders and prisms were casted to test compression, tensile and flexural strengths of the concrete.

For the purpose of this study human hair was collected from beauty parlours and salons. It was treated before adding it to the concrete specimens.

M25 grade human hair reinforced concrete samples were cast in 4 different proportions, as tabulated below,

Table 2: Mix Proportion

Sl. No.	Mix proportion	Percentage of Human hair
1.	MP1	0% (Control group)
2.	MP2	1%
3.	MP3	1.5%
4.	MP4	2%

Fig. 1: Casting and Testing of Specimen

6. Result Analysis

Slump Flow Test

The concrete slump test, also known as the slump cone test, is conducted to assess the workability or consistency of a concrete mix, whether it is prepared in a laboratory or at a construction site during ongoing construction work. This test is performed batch by batch to ensure consistent concrete quality throughout the construction process.

Table 3: Average Slump value

Mix Proportion	Slump Value (mm)
MP1	150
MP2	150
MP3	145
MP4	135

Compressive Strength

The test was performed in accordance with IS 516-1959 standards. Specimens in the form of cubes and cylinders, each measuring 150mm x 150mm x 150mm, were prepared. These specimens were positioned on the compression testing machine's bearing surface, and a consistent rate of loading was applied until the cube failed. Subsequently, the maximum load was recorded, and the compressive strength was determined through calculations.

Table 4: Average Compressive Strength at different curing periods

Mix Proportion	7^{th} Day Strength (N/mm^2)	14^{th} Day Strength (N/mm^2)	28^{th} Day Strength (N/mm^2)
MP1	15.63	22.82	27.34
MP2	15.90	23.12	27.42
MP3	16.13	23.34	27.78
MP4	16.46	23.64	28.25

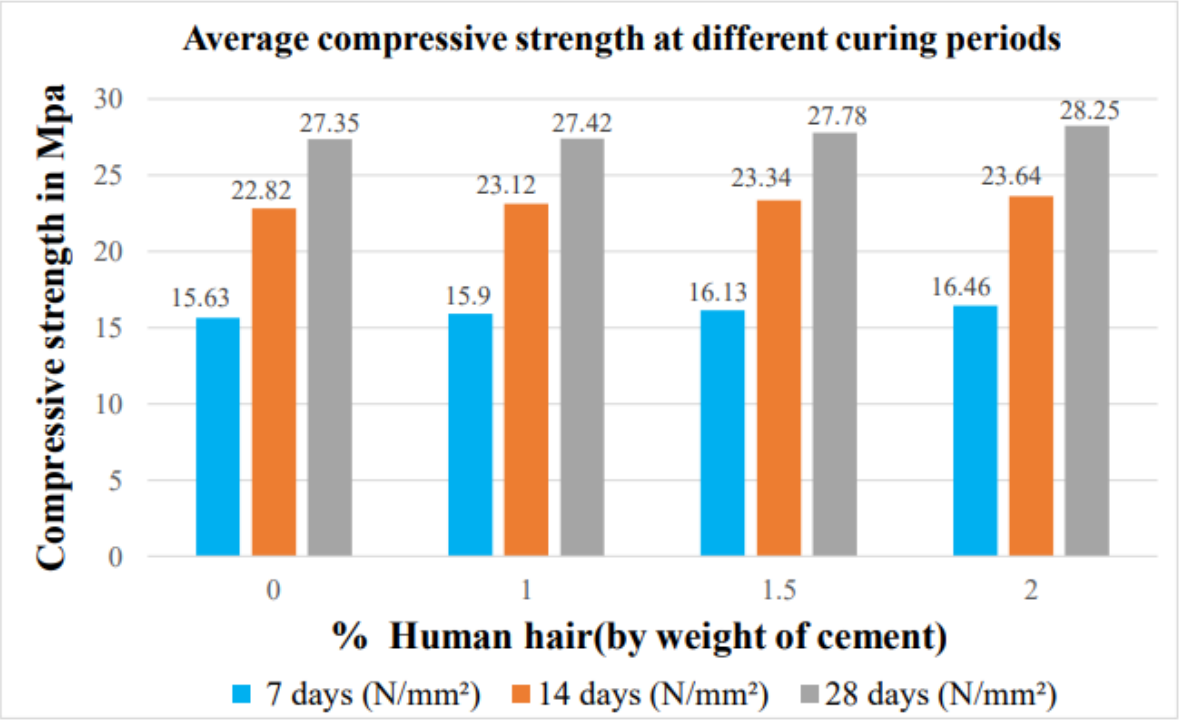

Fig. 2: Average Compressive Strength

Split Tensile Strength

Tensile strength is a fundamental and crucial property of concrete. Concrete, owing to its low tensile strength and brittle nature, is typically not expected to withstand direct tension. However, determining the tensile strength of concrete is essential to ascertain the load at which concrete members might develop cracks.

This test was conducted following IS 5819:1999 specifications. Cylinders of standard dimensions and cylinders made from human hair-reinforced concrete (150mm in diameter and 300mm in height) were cast and subjected to the curing process. The test involved placing a cylindrical specimen horizontally between the compression testing machine's loading surface and applying a load until the cylinder failed, along its vertical diameter.

Table 5: Average Split Tensile Strength at different curing periods

Mix Proportion	7^{th} Day Strength (N/mm^2)	14^{th} Day Strength (N/mm^2)	28^{th} Day Strength (N/mm^2)
MP1	2.25	2.62	3.12
MP2	2.34	2.68	3.26
MP3	2.38	2.72	3.38
MP4	2.45	2.86	3.46

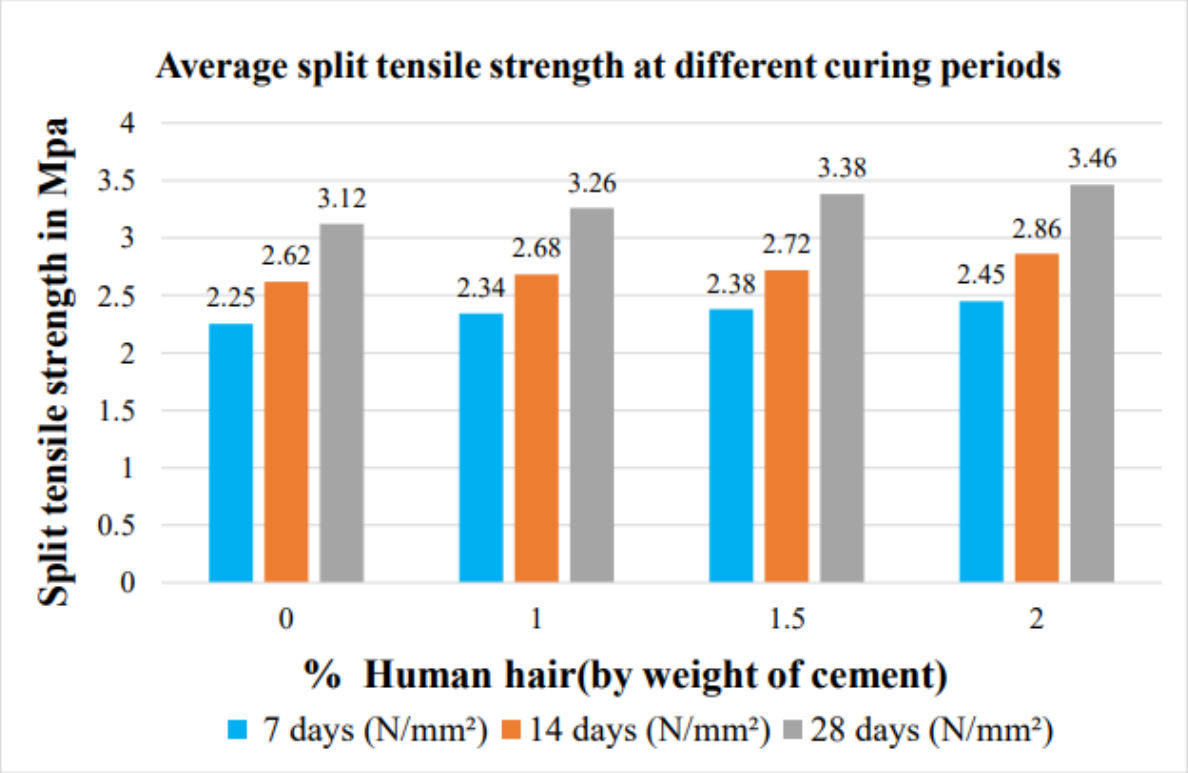

Fig. 3: Average Split Tensile Strength

Flexural Strength

When concrete undergoes bending, it experiences both tensile and compressive stresses due to bending, and in some cases, direct shear stresses may arise. In many plain concrete structures, particularly those found in highway pavements, the strength of the concrete is commonly assessed through a bending test.

The flexural test is designed to determine the flexural strength of concrete in tension. It is often more practical and convenient than the crushing test, especially when conducted in the field, as it requires significantly smaller loads. Flexural strength serves as an indicator of concrete's tensile strength, specifically its ability to withstand failure when subjected to bending forces. This measurement is typically obtained by loading 100 x 100 x 500mm concrete beams.

Table 6: Average Flexural Strength at different curing periods

Mix Proportion	7^{th} Day Strength (N/mm^2)	14^{th} Day Strength (N/mm^2)	28^{th} Day Strength (N/mm^2)
MP1	2.40	3.16	3.78
MP2	2.56	3.28	3.92
MP3	2.62	3.34	4.10
MP4	2.68	3.42	4.26

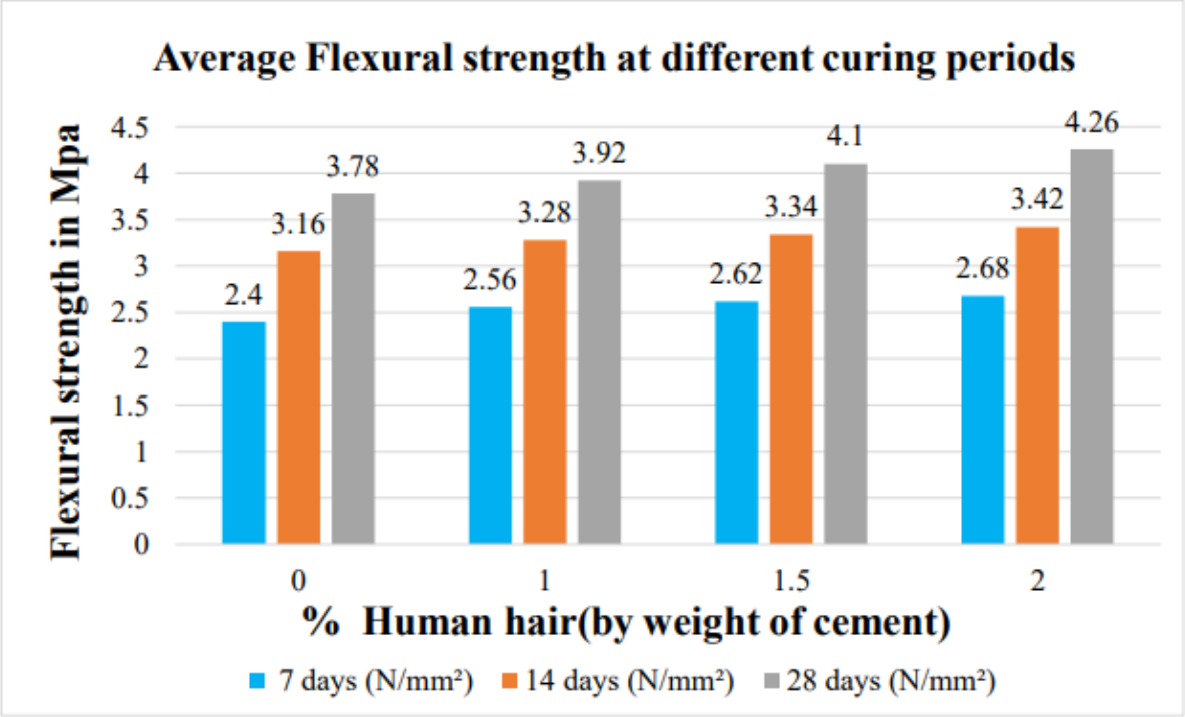

Fig. 4: Average Flexural Strength

Comparison Of Results

- The compressive strength of the concrete increases with the percentage increase of human hair.
- The tensile strength of concrete has been found to increase with the increase in the percentage of human hair in the concrete.
- The flexural strength of concrete increases with increasing percentage of human hair in the concrete.

Justification Of The Results

The addition of human hair as fibres to concrete has demonstrated an enhancement in its mechanical characteristics. This enhancement can be attributed to the unique structural composition of hair strands, characterized by an organized cylindrical structure formed by keratin, which comprises inert cells following a precise arrangement.

From a chemical standpoint, hair typically consists of approximately 20.85% oxygen, 50.65% carbon, 17.14% nitrogen, 5.0% sulfur, and 6.36% hydrogen. Keratin is primarily responsible for imparting flexibility, strength, and durability to hair. Specifically, the cortex keratin plays a vital role in these properties, as its long chains compact to form a robust yet flexible structure.

Hair exhibits various physical properties, including elasticity, resistance to stretching, and hydrophilic characteristics. The resistance to breakage depends on the thickness of the hair strand and the condition of the cortex. Hair fibres possess an elastic quality and can undergo significant stretching, whether in a dry or wet state. In a dry state, a hair strand can stretch by 20-30% of its length, and when exposed to water, this elongation capacity may increase to as much as 50%.

7. Conclusion

The experimental results yield the following conclusions:

- Over time, the compressive strength increased for all mixtures. Specifically, the concrete (MP4) containing 2% human hair demonstrated higher strength compared to the concrete mixtures (MP2

and MP3) containing 1% and 1.5% human hair, respectively. This suggests that human hair, when used as a fibre, can enhance the strength of concrete beyond that of regular concrete (MP1).

- The highest compressive strength was achieved when using 2% human hair.
- The split tensile strength also increased with the addition of different percentages of human hair. Notably, the concrete (MP4) containing 2% human hair exhibited superior strength compared to the concrete mixtures (MP3 and MP2) containing 1.5% and 1% human hair, respectively.
- Similarly, the flexural strength of all mixtures improved with the incorporation of varying percentages of human hair. Once again, the concrete (MP4) containing 2% human hair outperformed the concrete mixtures (MP3 and MP2) containing 1.5% and 1% human hair, respectively.
- Given that MP4 exhibits the highest strength, it can be concluded that treated human hair is a viable material for mixing and curing concrete.

8. Future Work

- Through durability studies can be conducted on human hair reinforced concrete.
- Structural Behaviour of this concrete can also be studied to check its application as structural concrete.

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