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Fiber Reinforced Concrete (FRC)

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Abstract: A detailed experimental investigation was conducted on the use of natural fibers—bamboo fiber, coconut fiber, and human hair fiber—as reinforcing agents in concrete. The primary aim was to explore their feasibility as sustainable, cost-effective, and eco-friendly alternatives to synthetic fibers like polypropylene or steel. Natural fibers are biodegradable, readily available, and contribute to environmental protection by reducing non-biodegradable construction waste. The experimental program involved the preparation of concrete specimens with different dosages of each fiber type. Tests were conducted to evaluate key mechanical properties such as workability (slump test), compressive strength (cube test), and split tensile strength (cylinder test). Additionally, the effects of fibers on crack propagation and post-cracking behavior were observed and analyzed. The results indicated that all three natural fibers contributed positively to the enhancement of concrete performance. Bamboo fiber, owing to its high cellulose content and tensile strength, improved the bonding within the concrete matrix and delayed crack formation. Coconut fiber, known for its high lignin content and natural toughness, significantly improved impact resistance and tensile strength. Human hair fiber, a protein-based keratinous material, proved especially effective in controlling microcracks and shrinkage due to its high tensile strength and elasticity. Among the three, coconut fiber showed the most substantial increase in tensile strength, while bamboo fiber excelled in maintaining the structural integrity of concrete under compression. Human hair fiber was particularly beneficial in reducing plastic shrinkage cracks. The study also found that a fiber content of around 1% by volume provided the most balanced improvements in strength and workability without compromising the mix's consistency. This study highlights the viability of using waste or agricultural by-products as reinforcement materials in concrete, contributing both to structural performance and sustainability goals. The incorporation of such fibers not only enhances mechanical properties but also addresses issues of solid waste disposal and reduces dependency on industrially manufactured materials. Furthermore, the use of natural fibers supports the global movement towards green construction practices and aligns with the principles of sustainable development.

Keywords: Fiber Reinforced Concrete, bamboo fiber, coconut fiber, human hair fiber, sustainable materials, mechanical properties.

I. INTRODUCTION

Concrete, as the backbone of modern infrastructure, plays a crucial role in the development of buildings, bridges, highways, dams, and other essential structures due to its high compressive strength, versatility, and availability. Despite these advantages, conventional concrete possesses inherent weaknesses—particularly its low tensile strength, poor resistance to cracking, and brittle failure under stress—which often necessitate additional reinforcement to improve its performance. Traditionally, this reinforcement has been achieved through the use of steel bars or synthetic fibers like polypropylene, glass, or carbon fibers. While effective, these materials are associated with high manufacturing costs, energy-intensive production processes, and adverse environmental impacts due to their non-biodegradable nature. With the increasing awareness of global environmental issues, such as climate change, depletion of natural resources, and the accumulation of industrial and synthetic waste, the construction industry is under mounting pressure to transition toward more sustainable and eco-friendly alternatives. This shift has led researchers and engineers to explore the potential of using natural, renewable, and biodegradable materials as substitutes or supplements in traditional construction techniques. In this context, Fiber Reinforced Concrete (FRC) emerges as an innovative solution, wherein discrete fibers are added to the concrete matrix to enhance its tensile strength, ductility, crack resistance, and durability. Among the various types of fibers explored, natural fibers such as bamboo, coconut, and human hair are gaining increasing attention due to their sustainable origin, wide availability, cost-effectiveness, and positive impact on the environment. Bamboo fiber, derived from the fast-growing bamboo plant, is rich in cellulose and known for its high tensile strength and stiffness, making it an excellent candidate for reinforcing brittle materials like concrete. Coconut fiber, or coir, obtained from the husk of coconuts, is abundant in tropical regions and is appreciated for its toughness, resilience, and resistance to water absorption, making it particularly suitable for applications subjected to dynamic and impact loads.

Human hair fiber, an unconventional yet innovative material, is composed primarily of keratin, a protein known for its high tensile strength and elasticity; human hair is often discarded as waste in salons and households, creating a disposal challenge. Utilizing it in concrete not only helps enhance the material's mechanical behavior but also addresses a significant environmental waste problem. The use of these natural fibers in concrete mixes provides a two-fold benefit: it improves the material properties of concrete and promotes sustainability by recycling agricultural and organic waste. Moreover, the inclusion of natural fibers in concrete has shown potential in controlling shrinkage cracks, improving post-crack load-bearing capacity, and enhancing the longevity of structures under varying environmental conditions. In developing countries, where the availability of industrial fibers may be limited and construction costs need to be minimized, natural fibers provide a locally available, low-cost, and environmentally sound reinforcement alternative. Given these promising prospects, this study investigates the mechanical and durability performance of concrete reinforced with bamboo fiber, coconut fiber, and human hair fiber, aiming to provide scientific validation for their use in modern construction and contribute to the ongoing efforts to make the built environment more sustainable and resilient. The construction industry plays a crucial role in global infrastructure development but is also one of the largest contributors to environmental pollution and resource depletion. Rigid pavements, commonly used in highways, airports, and industrial flooring, require large quantities of cement and aggregates, leading to high carbon emissions and excessive consumption of natural resources. The production of Portland cement, a key component of concrete, is responsible for nearly 8% of global CO_2 emissions, making it imperative to explore alternative materials that can reduce the environmental footprint of pavement construction. The increasing demand for sustainable construction practices has driven research into the use of alternative materials, such as natural fibers , which can enhance the durability and performance of rigid pavements while reducing reliance on non-renewable resources. Among the promising materials, bamboo fiber, coconut fiber, and human hair fiber stand out due to their natural availability, high tensile strength, and biodegradable nature. These fibers improve the mechanical properties of concrete, enhancing its tensile strength, crack resistance, and overall durability. Bamboo fiber has gained attention for its high strength-to-weight ratio, flexibility, and biodegradability. It has been successfully incorporated into concrete to improve tensile strength and reduce crack formation. Coconut fiber, another natural fiber, possesses excellent toughness and resistance to water absorption, making it a valuable reinforcement material in rigid pavement construction. Human hair fiber, often regarded as waste, has been found to enhance bonding in concrete while offering additional tensile reinforcement, which can help in reducing the brittleness of conventional concrete. These materials contribute to sustainability by minimizing waste disposal issues and reducing the carbon footprint of cement production.

II. AIM AND OBJECTIVES

A. Aim Of The Study

The aim of this study is to evaluate the feasibility of using bamboo Fiber, coconut fiber and human hair fiber in rigid pavement construction to enhance environmental sustainability and resource efficiency. The study focuses on analysing their impact on mechanical properties and durability compared to conventional materials.

B. Objectives Of The Study

The objectives of this study are:

1) To investigate the mechanical and durability properties of rigid pavement incorporating bamboo fiber, coconut fiber and human hair fiber.
2) To compare the environmental impact of sustainable materials with conventional pavement materials.
3) To recommend guidelines for implementing sustainable materials in rigid pavement design.
4) Conduct field trials and monitor the long-term performance of sustainable material-based pavements in real-world conditions.

III. PROPOSED METHODOLOGY

A. Materials Used

This study utilizes a combination of traditional and sustainable materials in the construction of rigid pavement. The primary materials used include:

1) Cement: The base material providing strength and binding properties. IS 1489 1991 Part I defining PPC as "An intimately inter ground mixture of Portland clinker and pozzolana with the possible addition of gypsum (natural or chemical) or an intimate and uniform blending of Portland cement and fine pozzolana". Portland-pozzolana cement can be produced either by grinding together Portland cement clinker and pozzolana with addition of gypsum or calcium sulphate, or by intimately and uniformly blending Portland cement and fine pozzolana. The pozzolanic materials generally used for manufacture of PPC are calcined

clay or fly ash. Portland-pozzolana cement produces less heat of hydration and offers greater resistance to the attack of aggressive waters than normal Portland cement. Moreover, it reduces the leaching of calcium hydroxide liberated during the setting and hydration of cement.

2) Aggregates: Fine and coarse aggregates ensuring stability and strength.

a) *Fine Aggregate:* Aggregates are the important constituents in concrete. They give body to the concrete, reduce shrinkage and effect economy. They occupy about 70-80 percent of the volume of the concrete. Aggregates shall consist of naturally occurring (crushed or uncrushed) stones, gravel and sand or combination thereof. They shall be hard, strong, durable, clear and free from veins and adherent coating, and free from injurious amounts of disintegrated pieces, alkali, vegetable matter and other deleterious substances. As far as possible, flaky, and elongated pieces should be avoided. Aggregates can be mainly classified into fine aggregates and coarse aggregates. IS 383- 1970 defining fine aggregates as "Aggregate most of which passes 4.75mm IS sieve and contains only so much coarser material as permitted." It may be:

- Natural sand: Fine aggregate resulting from the natural disintegration of rock, and which has been deposited by streams or glacial agencies.
- Crushed stone sand: Fine aggregate produced by crushing hard stone.
- Crushed gravel sand: line aggregate produced by crushing natural gravel.

In this research work we use Crushed stone sand or M sand. There are four grading zones for fine aggregates such as grading zone I, II, III, and IV. It is recommended that fine aggregate conforming to Grading Zone IV should not be used in reinforced concrete unless tests have been made to ascertain the suitability of proposed mix proportions.

b) *Coarse Aggregate:* IS 383-1970 defines coarse aggregates as Aggregates most of which is retained on 4.75 mm IS Sieve and containing only so much finer material as is permitted for the various types described in this standard Figure 3.2.

Coarse aggregates may be described as:

- Uncrushed gravel or stone which results from natural disintegration of rock,
- Crushed gravel or stone when it results from crushing of gravel or hard stone, and
- Partially crushed gravel or stone when it is a product of the blending of uncrushed gravel stone and crushed gravel or stone.

3) Water: Used for hydration and chemical reactions in concrete. According to IS 456: 2000, water used for mixing and curing shall be clean and free from injurious amounts of oils, acids, alkalis, salts, sugar, organic materials, or other substances that may be deleterious to concrete or steel. Potable water is generally considered satisfactory for mixing concrete. The pH value of water shall be not less than 6.

4) Bamboo Fiber: A natural fiber known for its high tensile strength and flexibility, incorporated to enhance crack resistance. Processed coconut Fiber is used in this research. They are properly washed and drawn into strands before use. Treatment of fibres removes dust and other residual particles left on the fibre to augment the surface of contact between the fibre and mix resulting in better binding between the reinforcement and concrete and ultimately higher strength. The fibre is washed in tap water for 30 minutes to loosen the fibres and to remove the coir dust. Fibres are then washed and soaked again for 30 minutes. This process is to be repeated three times The softened fibres are straightened manually and combed with a steel comb. To accelerate the drying process, the wet long fibres will be then put in oven at 30°C for 10–12 in which most of the moisture will be removed. The fibres are then completely dried in the open air, combed again and finally cut into the required length of 5cm and soaked in oil for 15-20 min and dried in sun for 24 hours.

Fig.3.1: Preparation of Bamboo Fiber

5) Coconut Fiber: Provides enhanced durability and prevents shrinkage cracks. Bamboo fibres with size of varying length from 2 to 4 cm, breadth from 1 to 2 cm, and thickness of 1 cm is also used as a partial replacement of coarse aggregate at the replacement levels of 0%, 2%, 4% and 5%. The physical properties of all these materials were tested as per IS 383-1970.

Fig.3.2: Preparation of Coconut Fiber

6) Human Hair Fiber: Improves tensile strength and enhances bonding within the concrete matrix. Human hair made up from the human being. Human hair was about 65%-95% of its weight its proteins, more than 32% of water, lipid pigment and other component they made it by processing of chemical synthesis. The human hair fiber controls the crack because of drying and plastic shrinkage. The hair fiber is low at cost and its form in huge quantity. In the study the effect of RHA as a partial cement replacing material with addition of human hair fiber were carried out the experiment were conducted on concrete cube, beam, and cylinder of standard sizes.

Fig.3.3: Preparation of Human Hair Fiber

Table 3.1: Properties of Sustainable Materials

Material	Physical Properties	Mechanical Properties	Chemical Properties
Bamboo Fiber	Lightweight, high tensile strength, biodegradable	High flexibility, good impact resistance, enhances crack resistance	Resistant to alkalis, absorbs moisture, decomposes over time
Coconut Fiber	High lignin content, low-density, high-water absorption	Good toughness, durable, improves ductility	Naturally resistant to fungi, alkali resistance
Human Hair Fiber	High tensile strength, lightweight, natural flexibility	Enhances load-bearing capacity, improves resistance to shrinkage cracks	Composed of keratin, resistant to environmental degradation

IV. RESULTS AND DISCUSSION

The experimental investigation was designed to evaluate the performance of bamboo fiber, coconut fiber, and human hair fiber when incorporated into rigid pavement concrete. A series of tests were conducted to assess key characteristics such as the mechanical properties, durability, and workability of the concrete mixtures modified with these natural fibers. Through these tests, comprehensive data were gathered to understand how each type of fiber influences the overall behaviour and quality of the concrete. The results provided valuable insights into the potential benefits of using these sustainable materials, demonstrating improvements in concrete performance that could contribute to more durable, resilient, and environmentally friendly rigid pavements. This study highlights the promising role of natural fibers in enhancing traditional concrete properties while supporting sustainable construction practices.

A. Human Hair Fiber

Human hairs have been utilized as fibers in this study, undergoing a careful preparation process before incorporation into the concrete mix. After collection, the hairs were thoroughly washed to remove any dust particles or undesirable impurities that could affect the quality and performance of the concrete. Following the washing process, the hairs were properly dried either under sunlight or in an oven to ensure complete moisture removal. To maintain uniformity and achieve an even distribution of fibers within the concrete, the hairs were preferably sorted to have a consistent length. This sorting helps in achieving better bonding and homogeneous mixing. Once dried, the human hairs can be stored without any concerns regarding odor or decay, making them suitable for practical use over time. The diameter of the hairs used ranges from 100 to 120 micrometers (µm), while their length is standardized at 60 millimeters. The aspect ratio, defined as the length to diameter ratio, was maintained between 500 and 600. Mechanical testing shows that human hair fibers possess a tensile strength of approximately 380 MPa, with an ultimate tensile strain of 50.16%, indicating their significant capacity to withstand tensile stresses and deformation. These properties make human hair a promising natural fiber reinforcement in concrete applications.

Fig.4.1: Selecting the hair fibres by measuring its length and Diameter

1) Treatment of Hair Fiber

The hair needed for the preparation of concrete cubes was collected from salons and beauty parlours. It needs treatment before to be added in the concrete specimens. It is carried out as in the following steps:

a) Separating hair from other waste: Depending on the source, the collected hair may contain wastes. This must be removed.
b) Washing: After sorting, the hair is washed with acetone to remove impurities.
c) Drying: The hair is then dried under sun or in oven. After drying, the hair can be stored without any concern for decay or odor.
d) Sorting: The hair is then sorted according to length, color, and quality. The hair fibres are checked at random for its length and diameter.

2) Physical and Mechanical Properties of Human Hair fibres

1. Hair physical proprieties:
   a. Physical proprieties of hair depend mostly on its geometry. Caucasian hair is oval; Asian hair is circular; Afro hair is elliptic.
   b. Several mechanical proprieties are directly related with fibres.
2. Hair mechanical properties:
   a. Hair is surprisingly strong. Cortex keratin is responsible for this propriety and its long chains are compressed to form a regular structure which, besides being strong, is flexible (Dias, 2004; Robbins, 1994).
   b. The physical proprieties of hair involve resistance to stretching, elasticity and hydrophilic power.
3. Resistance to stretching:
   a. In general, the weight needed to produce a natural hair thread rupture is 50-100 g. An average head has about 120,000 threads of hair and would support about 12 tons.
   b. The resistance to breakage is a function of the diameter of the thread, of the cortex condition, and it is negatively affected by chemical treatments.

4. Hair elasticity:
   a. Hair fibre has an elastic characteristic, and it may undergo moderate stretching either wet or dry.
   b. Stretching is a hair attribute under the action of a distal force (length) and the thread returns to the original status when this force stops acting.
   c. When dry, the hair thread may stretch 20-30% of its length; and, in contact with water, this may reach up to 50%.
   d. In contact with ammonia, it becomes more elastic. Chemical and physical treatments, sun exposition and use of electric dryers and heated plates affect this property.
5. Absorption:
   a. Hair surface retains the thread natural oils (sebum) composed by tensoactive ingredients and some dyers.
   b. Absorption of fatty substances is due to a physical process of surface tension. The sebum absorption over the hair occurs by contact with the scalp and transference from a thread to each other.
   c. Chemical treatments enhance the surface anionic nature of the hair thread, which becomes electronegative, causing its physical-chemical affinity with cationic components, as tensoactive and dyeing ingredients.
6. Friction:
   a. Friction is the force resisting the movement when a body slide over another one. The cuticle surface has high friction coefficient due to its scale shape and it depends on the cuticle geometry and on the physical chemical status of the hair.
   b. The continuous attrition of a thread over another one damages the cuticle. From the roots to the extremities the friction coefficient differs in the dry and wet hair thread, and it is enough combing to damage the hair.

3) Preparation of Specimen

The compressive strength test is one of the most commonly performed tests on hardened concrete due to its simplicity and the critical role it plays in evaluating the overall quality and performance of concrete. This test is widely regarded as a fundamental assessment because many of the desirable properties of concrete, such as durability, load-bearing capacity, and resistance to environmental stresses, are qualitatively related to its compressive strength.

Typically, the compression test is conducted on cubic specimens that measure 150 mm on each side, which are carefully prepared to ensure accuracy and repeatability of results. The process begins with the use of a mould, preferably made of cast iron due to its strength and durability, designed to produce a specimen exactly 150 × 150 × 150 mm in size. When placing the concrete mix into these moulds, care must be taken to compact the concrete thoroughly to remove any entrapped air, which could otherwise weaken the specimen and affect the test results.

Compaction is achieved by tamping the concrete with a tamping bar, ensuring no fewer than 25 strokes per layer are applied. This step is crucial as it ensures uniform density throughout the specimen, reducing voids and improving structural integrity. Following tamping, the moulds containing the concrete specimens are placed on a vibrating table, where vibration continues until the concrete achieves the specified compaction criteria, further aiding in the elimination of air pockets and settling of the mix. After these steps, the specimens are left undisturbed for 24 hours, allowing the initial setting of the concrete to occur. Once the curing period of 24 hours is complete, the specimens are carefully removed from the moulds and immediately submerged in clean, fresh water to continue the curing process under controlled moisture conditions.

This curing process is critical for the hydration of cement particles and directly influences the final strength and durability of the concrete. After 28 days of curing, which is the standard period to allow concrete to achieve its design strength, the specimens are subjected to compressive loading in a compression testing machine. During the test, the load is gradually applied to the specimen until failure occurs, and the maximum load sustained by the specimen is recorded. This maximum load is then used to calculate the compressive strength of the concrete, providing valuable information about its suitability for structural applications. The entire procedure, from mould preparation and compaction to curing and testing, is carefully standardized to ensure that the results are reliable and consistent across different batches of concrete, making the compressive strength test an indispensable tool in concrete quality control and research.

Fig.4.2: Cube Specimen

4) Casting and Compaction

- For casting, all the moulds were cleaned and oiled properly. These were securely tightened to correct dimensions before casting. Care was taken that there is no gaps left from where there is any possibility of leakage out of slurry. The fresh concrete was filled in the moulds with the help of trowel. The care was taken in to fill all moulds simultaneously to avoid segregation and to maintain uniformity. The moulds were filled and placed on the vibrating table and vibrated. As needed, concrete was added, and vibrations were stopped as soon as the cement slurry appeared on the top surface of mould.
- The present experimental study of fibre includes testing of specimens for Compressive strength. For testing of Compressive strength 150mm x 150mm x 150mm metallic mould was used, for the casting of concrete cube specimen, for testing of concrete 150mm x 150mm x 150mm cube mould was used.
- Casting of concrete cubes, beams were done as per IS code recommendations (IS Code 10262: 2009, Concrete Mix Design). The proportioning of concrete mixes consists of determination of the quantities of respective ingredients necessary to produce concrete having adequate, but not excessive, workability and strength for the loading and durability for the exposure to which it will be subjected.

Fig.4.3: Casting of cube specimen

Fig.4.4: Compaction with Tamping bar

5) Demoulding and Curing

The specimens were allowed to remain in the steel mould for the first 24 hours at ambient condition. After that these were demoulded with care so that no edges were broken and were placed in the curing tank at the ambient temperature for curing. The ambient temperature was the room temperature during casting.

Fig.4.5: Curing of test specimens

Fig.4.6: Experimental setup. a Human hair fibre; b concrete mixture; and c HF concrete cube

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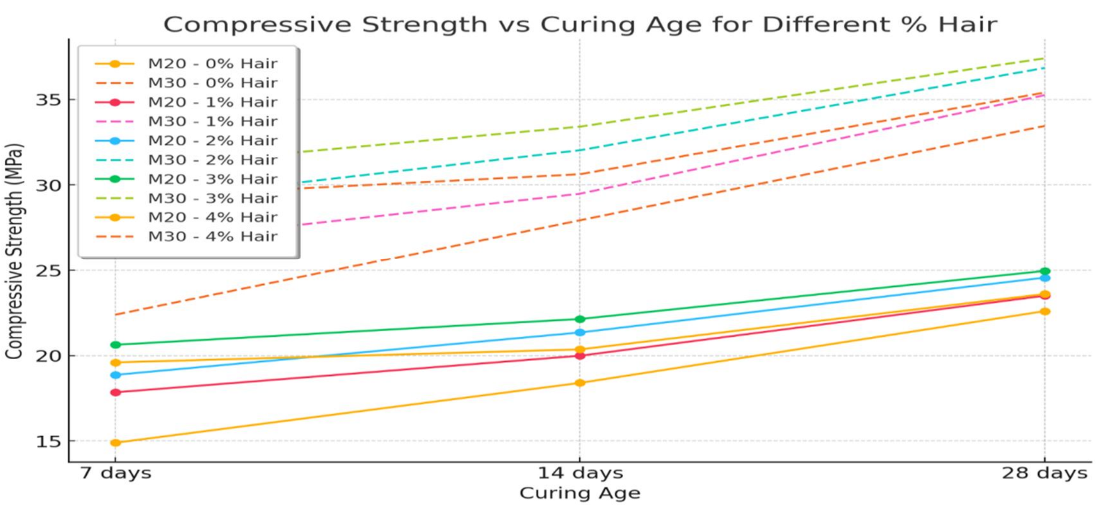
6) Compressive Strength by Cube Test

The compressive strength of concrete is determined in batching plant laboratories for every batch to maintain the desired quality of concrete during casting. The strength of concrete is required to calculate the strength of the members. Concrete specimens are a cast and tested under the action of compressive loads to determine the strength of concrete. In very simple words, compressive strength is calculated by dividing the failure load with the area of application of load, usually after 28 days of curing. The strength of concrete is controlled by the proportioning of cement, coarse and fine aggregates, water, and various admixtures. The ratio of the water to cement is the chief factor for determining concrete strength. The lower the water-cement ratio, the higher is the compressive strength. Average 28 days compressive strength of at least three 150 mm concrete cubes prepared with water proposed to be used shall not be less than 90% of average of strength of three similar concrete cubes prepared with distilled water. For quality control in case of mass concreting, the frequency of testing of compressive strength by cube test. As per Indian standard concrete cube of size 150X150X150mm was casted and curing was done for 7days 14days and 28days, Test were performed by using compressive strength testing machine. The percentage of human hair were taken as 0%, 1%, 2%,3% and 4%. Three cubes of each percentage of human hair are casted. After the test results were taken are shown in below tabular form.

Table 4.1 Compressive Strength of Concrete

SN	Curing Age	% Hair	M20 Strength (MPa)	M30 Strength (MPa)
1	7 days	0%	14.90	22.39
2	14 days	0%	18.40	27.94
3	28 days	0%	22.60	33.45
4	7 days	1%	17.85	26.48
5	14 days	1%	19.99	29.49
6	28 days	1%	23.50	35.25
7	7 days	2%	18.87	28.91
8	14 days	2%	21.35	32.03
9	28 days	2%	24.56	36.84
10	7 days	3%	20.63	30.95
11	14 days	3%	22.14	33.41
12	28 days	3%	24.95	37.40
13	7 days	4%	19.60	29.25
14	14 days	4%	20.36	30.63
15	28 days	4%	23.60	35.40



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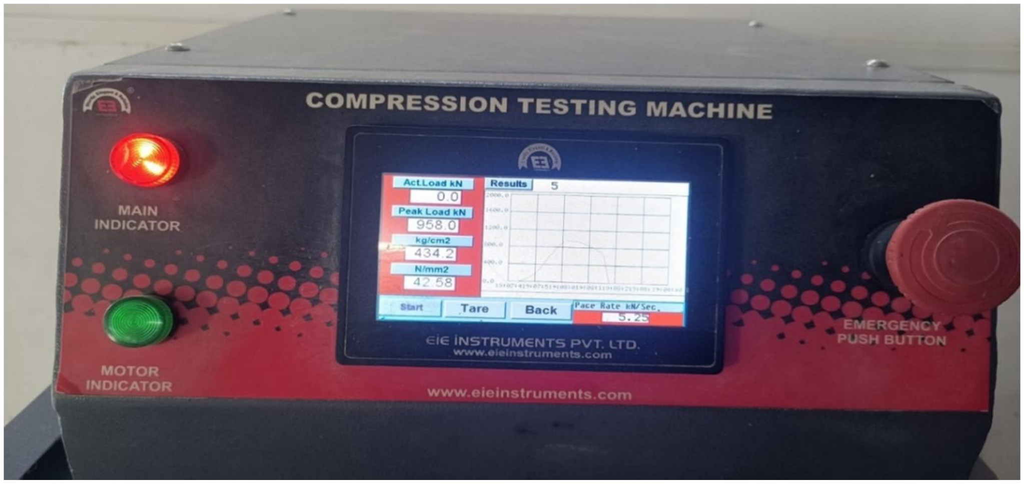

Fig.4.7: Compressive strength of M30 grade concrete at various % of human hair

7) *Observations from the Graph*

a) Strength Increases with Curing Age: Both M20 and M30 concrete mixes show a consistent increase in compressive strength as the curing age progresses from 7 to 28 days, regardless of the percentage of hair used.

b) Effect of Hair Content on Strength: The inclusion of human hair fibers positively influences compressive strength up to a certain percentage. In general:
   - 1% to 3% hair content shows improved strength compared to 0% (control).
   - Maximum strength is observed at 3% hair content for both M20 and M30 grades at 28 days.
   - 4% hair content shows a slight reduction in strength compared to 3%, suggesting an optimal fiber dosage limit around 3%.

c) Higher Grade Shows Higher Gain: M30 mix consistently shows greater compressive strength than the corresponding M20 mix at all curing ages and hair percentages.

d) Most Significant Gain at 28 Days: The greatest increase in compressive strength for all mixes is observed at 28 days, highlighting the importance of extended curing for strength development.

e) Fiber Reinforcement Improves Early Strength: Even at early curing ages (7 and 14 days), the presence of hair fibers contributes to an increase in strength compared to the control mix, indicating enhanced bonding and micro-crack control.

These observations indicate that controlled addition of hair fibers can enhance the performance of concrete, especially at 3% dosage, while also contributing to sustainability through the use of waste material.

B. *Bamboo*

1) *Pieces of bamboo*

Bamboo fibres with varying sizes—lengths ranging from 2 to 4 cm, breadths between 1 to 2 cm, and a consistent thickness of 1 cm—have been utilized as a partial replacement for coarse aggregate in concrete mixtures. The replacement was carried out at different levels of 0%, 2%, 4%, and 5% to evaluate their effect on the concrete's performance. Prior to their incorporation, the physical properties of the bamboo fibres, as well as the other constituent materials, were rigorously tested in accordance with the standards specified in IS 383-1970. This ensured that the materials met the required quality benchmarks for use in concrete production. By partially substituting coarse aggregate with bamboo fibres of these specific dimensions, the study aims to explore sustainable alternatives that may enhance certain characteristics of the concrete, such as crack resistance and durability, while also promoting eco-friendly construction practices.

Table 4.2: Compressive Strength (N/mm^2) for Bamboo Fiber Concrete

Bamboo %	7 Days (MPa)	28 Days (MPa)	56 Days (MPa)
0%	25.045	48.648	54.893
2%	22.439	43.354	50.655
4%	18.417	39.293	45.698
5%	15.966	35.564	42.935

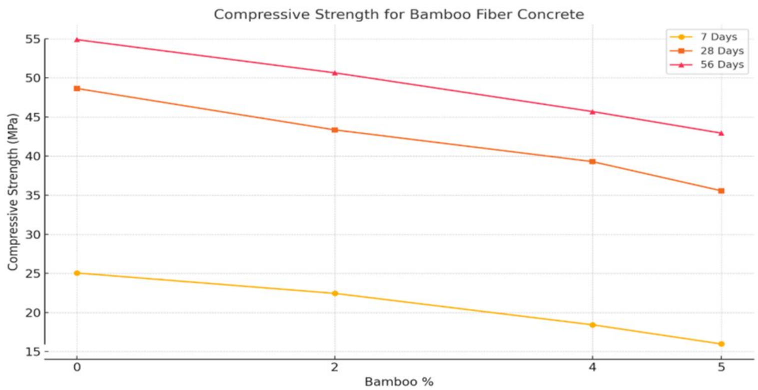

Fig.4.8: Compressive strength of M30 grade concrete at various % of Bamboo

2) *Observations from the Graph (M30 Grade Concrete)*

a) Decrease in Strength with Increased Bamboo Content: The compressive strength of concrete decreases consistently as the percentage of bamboo fiber increases from 0% to 5%. This trend is observed across all curing ages — 7, 28, and 56 days.

b) Maximum Strength at 0% Bamboo Fiber: The highest compressive strength values are recorded at 0% bamboo fiber:
   a. 7 Days: 25.045 MPa
   b. 28 Days: 48.648 MPa
   c. 56 Days: 54.893 MPa

c) Reduction at 5% Bamboo Fiber: At 5% bamboo content, the compressive strength is at its lowest:
   a. 7 Days: 15.966 MPa
   b. 28 Days: 35.564 MPa
   c. 56 Days: 42.935 MPa

d) Strength Gain with Age: For all bamboo percentages, compressive strength increases over time (from 7 to 56 days), confirming continued hydration and strength development.

e) Optimum Range Observation: Although bamboo fiber enhances certain properties of concrete (like crack resistance or ductility), its excess inclusion (beyond 2%) negatively impacts compressive strength in M30 grade.

f) Practical Implication: For structural applications where high compressive strength is essential, bamboo fiber content should be minimized or optimized below 2% to avoid significant strength loss.

C. *Coconut Fiber*

This study aimed at analyzing the variation in strength of coconut fiber (oil coated raw and oil coated processed fibres) reinforced concrete at varying fibre contents and to compare it with that of conventional concrete. The various strength aspects analyzed are the compressive strength of the coconut fiber reinforced concrete at varying percentages (4%,5%,6% by the weight of cement) of fibre. The influence of shape of fibre on strength is also studied by testing on coconut fibre mesh of predetermined dimensions. The optimal percentage of both the processed fibre strands and raw fibre meshes were found out by trial and error and the optimum percentage of superplasticizer needed for the required workability was also determined.

Fig.4.9: Coconut Fiber Strands

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The calculated amount of cement and fine aggregate are mixed till a uniform mix is obtained. The amounts of fibre adopted are 4%, 5% and 6% of cement. Coir fibre strands are cut into a length of 5cm washed, oil coated with coconut oil and dried in sunlight for 24 hours. It is then added to the mix until a uniform colour is obtained. Coarse aggregates are then added to the same and mixed followed by addition of water. Care should be taken to add water slowly in stages to prevent bleeding which may affect the strength formation of concrete rising of water required for hydration to the surface. Admixture is added towards the last stage of addition of water to avail sufficient time for mixing before the concrete hardens. It is placed in the mould, compacted, and finished cubes each of the same are prepared and cured. The compressive strength for 7day and 28 day is determined.

1) Compressive Strength of CFRC (Processed)

Coconut fibre reinforced concrete was added to concrete at varying proportions (4%, 5%, 6% of that of weight of cement) at a water cement ratio of 0.5 The desired slump value and compressive strength was obtained for conventional concrete at this ratio. However, when fibre is added to the mix low workability was observed. Hence superplasticizer was added at different proportions of cement to get a concrete mix of suitable workability.

Table 4.3: Compressive Strength of M30 CFRC (PROCESSED)

Specimen	W/C Ratio	% Coconut Fibre	% Superplasticizer	Slump (mm)	7-Day Strength (N/mm²)	28-Day Strength (N/mm²)
1	0.38	4%	0.3%	110	22.69	38.98
2	0.36	5%	0.4%	105	24.76	40.57
3	0.35	6%	0.8%	105	23.46	39.16

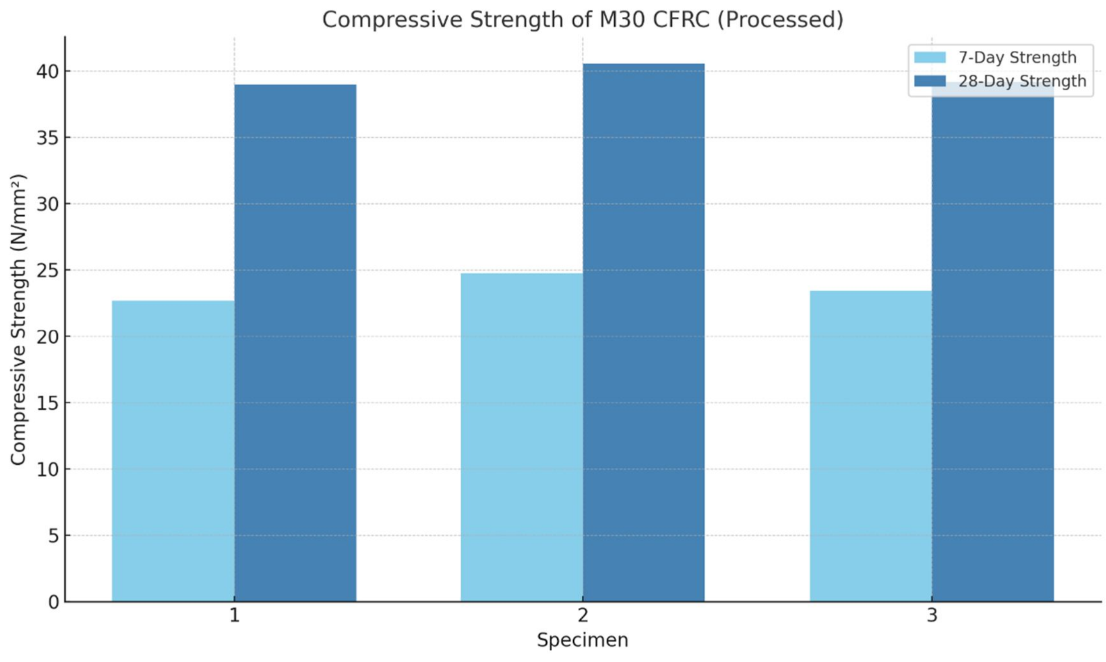

Fig.4.10: Compressive strength of M30 grade concrete at various % of Coconut

2) Observations from Graphs

a) Increase in Strength with Coconut Fibre and SP Adjustments: Compressive strength generally improves when the percentage of coconut fiber and superplasticizer (SP) is optimized.

b) Specimen 2 Achieved Maximum Strength:
7-Day Strength: 24.76 N/mm².
28-Day Strength: 40.57 N/mm².
This specimen (with 5% coconut fibre, 0.4% SP, and 0.36 W/C ratio) performed best overall in both curing durations.

c) Lowest Strength in Specimen 1: Specimen 1 (4% coconut fibre, 0.3% SP, W/C 0.38) showed the least compressive strength:
   a. 7-Day: 22.69 N/mm²
   b. 28-Day: 38.98 N/mm²

d) Effect of Water-Cement Ratio (W/C): A lower W/C ratio (from 0.38 in Specimen 1 to 0.35 in Specimen 3) helps enhance strength, provided fibre and SP contents are balanced.

e) Balance Between Fibre and Workability: Slump values show that workability remains acceptable (105–110 mm), suggesting that coconut fibre additions (up to 6%) and SP (up to 0.8%) can be managed without severely compromising fresh concrete properties.

f) 28-Day Strength Is Significantly Higher Across All Specimens: As expected, 28-day compressive strength is consistently higher than 7-day strength, confirming normal hydration development in CFRC mixtures.

g) Optimization Potential: The results indicate that 5% coconut fibre with 0.4% SP and moderate W/C ratio (0.36) gives the best strength-performance combination in M30 grade CFRC.

V. CONCLUSION

This study evaluated the compressive strength development of concrete with various natural fibers — human hair, bamboo fiber, and coconut fiber — across different grades (M20 and M30), curing ages, and material compositions.

1) Effect of Human Hair Fiber:
- Compressive strength increases with the inclusion of human hair up to 3%, beyond which a slight decline is observed.
- The optimum fiber content for strength enhancement in both M20 and M30 grades is 3% at 28 days:
  - M20: Increased from 22.60 MPa (0%) to 24.95 MPa (3%)
  - M30: Increased from 33.45 MPa (0%) to 37.40 MPa (3%)
- Strength gain is consistent with age (7, 14, and 28 days), indicating normal hydration and effective bonding with fibers.

2) Effect of Bamboo Fiber
- Unlike human hair, bamboo fiber addition shows a reduction in compressive strength as the fiber content increases.
- The highest strength is recorded at 0% bamboo, and it steadily decreases at 2%, 4%, and 5% fiber content.
  - 28-day strength drops from 48.648 MPa (0%) to 35.564 MPa (5%)
  - 56-day strength drops from 54.893 MPa (0%) to 42.935 MPa (5%)
- Although bamboo fibers may improve other concrete properties (e.g., ductility or crack resistance), they adversely affect compressive strength in higher percentages.

3) Effect of Coconut Fiber (Table 4.3 - CFRC Processed)
- Coconut fiber concrete (CFRC) shows moderate strength improvements, particularly when superplasticizer and W/C ratios are optimized.
- Specimen 2 (5% coconut fiber, 0.4% SP, 0.36 W/C) gave the best results:
  - 7-day strength: 24.76 MPa
  - 28-day strength: 40.57 MPa
- Workability remained acceptable (slump: 105–110 mm), suggesting that fiber dosage and admixtures were well-balanced.
- Coconut fiber presents a viable alternative to synthetic fibers when properly proportioned.

A. Conclusion
- Human hair proves to be the most effective among the three fibers in enhancing compressive strength, especially at 3% content.
- Bamboo fiber negatively affects compressive strength when used in high quantities and is less suitable for load-bearing applications.
- Coconut fiber performs moderately well, with potential for structural use when combined with proper mix design and chemical admixtures.
- The optimum use of natural fibers in concrete depends significantly on type, percentage, curing time, and mix proportions. Proper optimization can lead to sustainable and high-performance concrete for modern construction needs.

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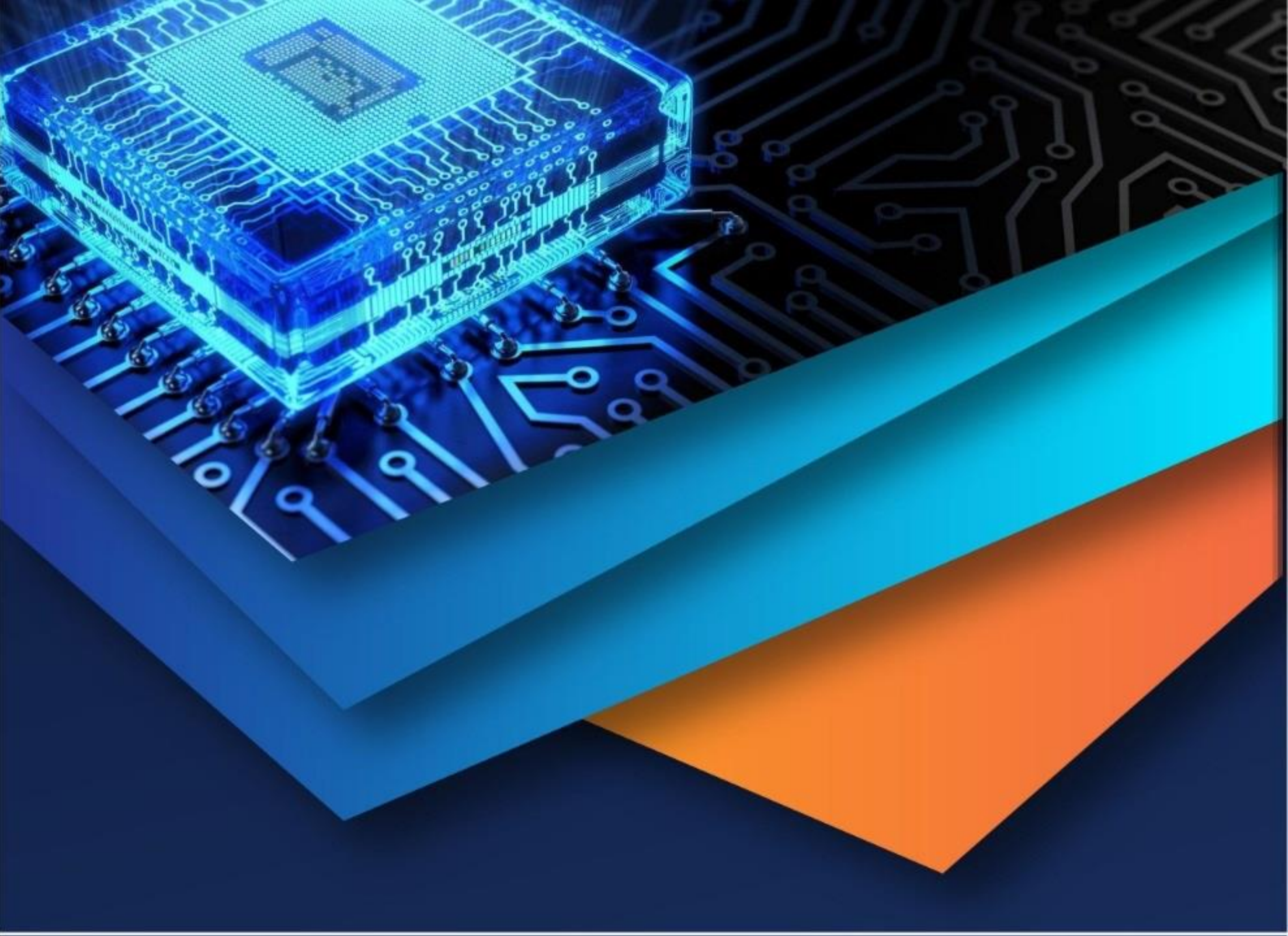

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