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Article

Enhancing the Mechanical Properties of Concrete Using Natural Fiber Reinforcement: A Comparative Study of Bamboo, Banana, and Jute Fibers

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Abstract: With the construction industry seeking to mitigate its carbon footprint, utilizing agricultural by-products as reinforcement offers a promising pathway toward eco-friendly infrastructure. While previous studies have explored synthetic fibers, there remains a critical research gap in the comparative performance and statistical consistency of diverse natural fibers like banana, jute, and bamboo within a concrete matrix. This study investigates the mechanical properties of concrete mixes incorporating these fibers at varying volume fractions (0.5%–2.0%). The evaluation focuses on compressive, split tensile, and flexural strengths at 7-day and 28-day curing intervals. Key findings reveal that banana fiber at 0.5% achieved the highest absolute compressive and flexural strengths of 37.32 MPa and 6.12 MPa, respectively, after 28 days. However, performance for banana and jute fibers generally declined at higher dosages due to increased porosity. Conversely, bamboo fiber demonstrated superior reliability and consistency, reaching a peak split tensile strength of 5.02 MPa at 2.0% loading and maintaining steady growth across all proportions. This suggests that while banana fiber provides maximum load-bearing capacity at low volumes, bamboo fiber is preferable for applications requiring predictable mechanical scaling. These results provide foundational data for the implementation of natural fiber-reinforced concrete in sustainable structural applications, highlighting a viable strategy for reducing reliance on carbon-intensive materials while enhancing the energy absorption and ductility of cementitious composites.

Keywords: Natural Fiber; Bamboo Fiber; Banana Fiber; Jute Fiber; Enhance; Properties of Concrete; Strength.

1. Introduction

Low-rise concrete buildings are a staple of the built environment in developing nations. However, due to economic constraints and material scarcity, many residential structures in South Asia are constructed without adequate reinforcement. The catastrophic seismic events of 2025 in Myanmar and Thailand, which resulted in approximately 1,700 fatalities and widespread destruction, underscore the vulnerability of non-engineered structures. Statistics indicate that 60% of earthquake-related deaths over the last century were attributed to the collapse of unreinforced or poorly reinforced masonry and concrete structures. In this context, natural fiber reinforcement emerges as a viable, cost-effective solution for enhancing seismic resilience and preventing the sudden, brittle collapse of dwellings, potentially saving thousands of lives [1].

Sustainability has become a primary directive in modern civil engineering. The production of conventional construction materials, particularly cement, is a carbon-intensive process that contributes significantly to global CO_2 emissions. Given that concrete is the most consumed material globally after water, the industry's environmental footprint is immense. Consequently, researchers are increasingly investigating the inherent tensile strength of various natural fibers as a sustainable alternative to traditional reinforcement [2].

While concrete is prized for its high compressive strength and durability, its inherent brittleness and low tensile strength necessitate reinforcement. Although traditional methods—ranging from steel rebars to synthetic fibers—are structurally effective, they are often characterized by high costs, resource-intensive production, and significant environmental impacts. These drawbacks have catalyzed the search for renewable, carbon-neutral reinforcement materials [3].

Among the available natural fibers, bamboo, banana, and jute are prominent candidates due to their abundance, low cost, and favorable mechanical properties. These fibers have demonstrated high flexibility and durability across various industrial sectors. However, the integration of natural fibers into concrete matrices presents specific challenges, including non-uniform distribution, long-term durability concerns, and variability in fiber quality. Furthermore, there remains a lack of comprehensive, comparative research evaluating the relative performance of different natural fiber types within the same experimental framework.

This study investigates the effectiveness of bamboo, banana, and jute fibers when incorporated into a concrete matrix. The objective is to address existing research gaps through a comparative analysis of the mechanical performance and developmental challenges of these selected fibers. While natural fibers may mitigate shrinkage, they can also increase water absorption and reduce the workability of the fresh mix. Additionally, excessive fiber loading is known to potentially decrease compressive strength [4]. This research aims to optimize these mixtures to validate their potential as sustainable, high-performance materials for the modern construction industry.

2. Literature Review

Concrete is made from a mixture of a few things using water as a focal point and one of the most used materials in construction and it has great endurance and strength. On the other hand, it has weak tensile strength and becomes very fragile. Thus, various researchers are seeking more effective ways for enhancing its mechanical properties. The traditional metal reinforcements which include steel and synthetic fibers are the common ones showing good results, but their cost and negative environmental effect are the major concerns. The Organic fibers such as bamboo, banana, jute are tangible environmental-friendly fiber sources which is also can be obtained continuously from renewable sources. A significant number of studies have investigated natural fibers as sustainable construction materials, owing to their cost-effectiveness, unique physical characteristics, and mechanical properties. The properties of bamboo, banana, and jute fibers are investigated and reported that while bamboo fibers enhanced Tensile strength, the other fibers offered more flexibility [5]. Jute fibers on the other hand, were identified as the ones which would give the toughness of concrete and higher capacity for energy absorption which in turn would raise the strength of the structure. These results are the evidence of iterations on different fibers for different applications comparing from their unique properties to their compositions [6].

M. Hasan et al. (2025) investigated the influence of low-alkali-treated betel nut husk fiber (BNHF) on the fresh, mechanical, and durability characteristics of natural fiber-reinforced concrete (NFRC). The study examined several parameters, including workability, density, compressive and split tensile strengths, and water absorption, while also developing a predictive regression model. By incorporating 45 mm BNHF at dosages of 0.50%, 0.75%, 1%, and 1.25% by binder weight, the researchers observed a progressive decline in both workability and density. However, the 1% BNHF dosage was identified as the optimal threshold, yielding maximum 28-day compressive and split tensile strength enhancements of 43.36% and 51.61%, respectively, over the control specimens [7].

The mechanical behavior of Kenaf Fiber-Reinforced Concrete (KFRC) was examined using 150 mm cubes and 350 mm beams at fiber concentrations of 1%, 3%, and 5%. Comparative testing of the KFRC and control specimens focused on parameters such as the modulus of rupture, direct shear, and flexural strength. The results demonstrated a positive correlation between Kenaf fiber loading and improved toughness, although a simultaneous increase in water absorption was observed. Based on these outcomes, the research validates Kenaf fiber as a suitable material for concrete enhancement [8].

As a composite material, concrete consists of a cement-water paste that bonds aggregates into a coherent mass. Its properties are a function of both its constituent quality and its mix design proportions [9]. Furthermore, the final performance is highly dependent on standardized construction practices, including proper placement, mechanical compaction, and adequate curing, which ensure the development of the desired mechanical strength and durability.

Rabbani et al. (2024) investigated the mechanical performance of natural fiber-reinforced concrete (NFRC) using jute and coconut fibers. In this study, compressive, split tensile, and flexural strengths were evaluated, and the effects of fiber addition on workability and microstructural characteristics were also examined. It was found that the incorporation of jute and coconut fibers improved the tensile and flexural properties compared to conventional concrete, although a slight decrease in compressive strength was observed. Furthermore, enhanced ductility and better crack resistance were achieved in the fiber-reinforced concrete [10].

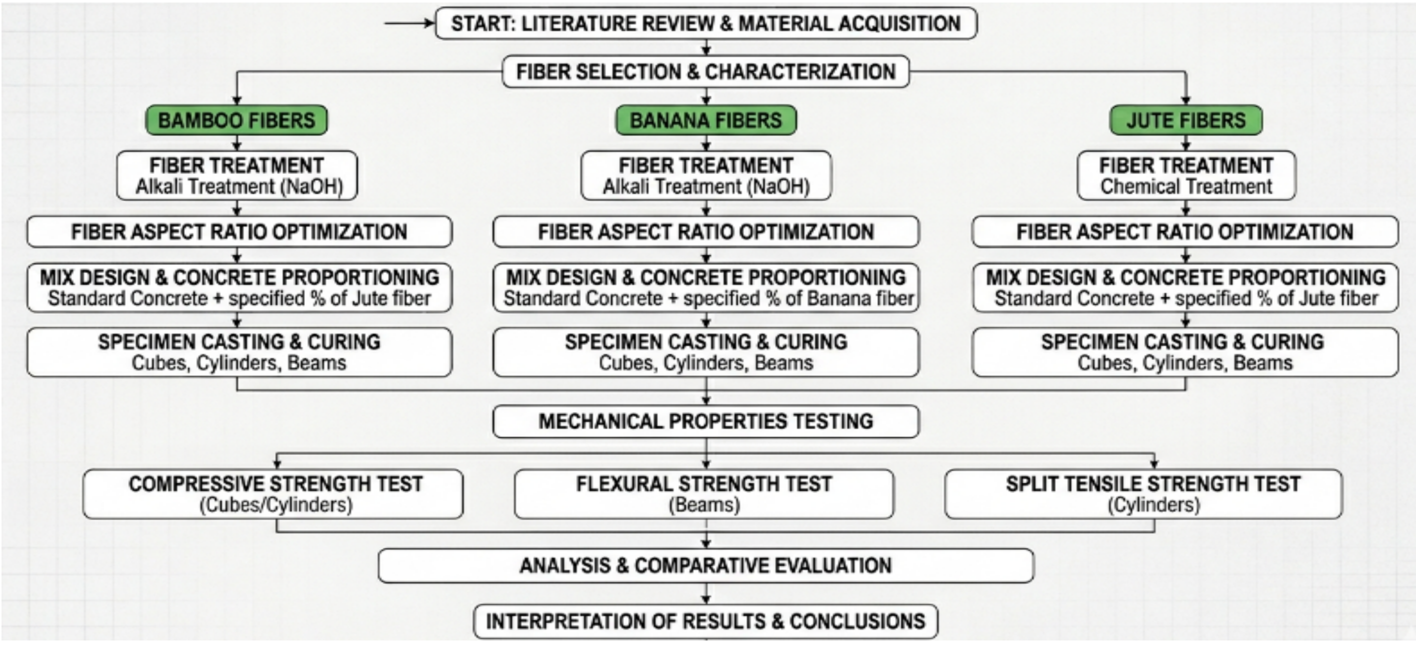

Figure 1. Research flow diagram.

Occupying 65–75% of the total volume, aggregates are essential to concrete production and are classified by size: fine (up to 9.5 mm) and coarse (retained on a 1.18 mm sieve, typically up to 25 mm) [11], [12]. Proper gradation may require intermediate sizes to ensure matrix density, with aggregate suitability determined by rigorous quality testing [13].

The binder, hydraulic cement, facilitates a chemical hydration reaction that yields a stable, water-resistant solid mass [14]. Although international nomenclature varies—referring to the material as OPC or Type I Portland Cement—its function as a general-purpose construction binder remains consistent [15]. This study utilizes Ordinary Portland Cement due to its representative nature in the construction industry.

Banana fibers are known for their good tensile strength and flexibility. Several studies have reported that incorporating banana fiber in small percentages (typically up to 0.5%) can enhance both the tensile and flexural strength of concrete. However, at higher concentrations, issues like fiber clustering and poor dispersion may reduce overall strength.

3. Materials and Methodology

This subsection describes the material properties and the research methodology applied. This study investigates the effect of adding natural fibers such as Bamboo, Banana and Jute fibers to concrete. The methodology adopted for conducting this research is illustrated in Figure 1.

3.1. Materials

3.1.1. Cement

Portland cement that meets the requirements of ASTM C150 [16] was the material of choice for all mixes. The chemical composition, physical, and mechanical properties of cement are shown in Tables 1 and 2, respectively.

3.1.2. Aggregate

The crushed granite stone and river sand were the coarse and fine aggregates, respectively. Aggregate's particle size distribution and physical properties meet the requirement of the ASTM C33 [17], [18] and are shown in Table 3.

3.1.3. Banana Fibers

Banana fiber (Figure 2) is a natural fiber obtained from the pseudo-stem of banana plant. It is a bast fiber with high strength and low elongation. It is similar to bamboo and ramie fiber in appearance, but finer and more spinnable. It is lightweight, biodegradable and has strong moisture absorption quality.

3.1.4. Bamboo Fibers

Bamboo fiber (Figure 3) is a material derived from the pulp of bamboo plants. It enhances the tensile strain thus avoiding undesirable brittle failure. Bamboo fibers are also biodegradable and offer high flexibility. Bamboo fibers are eco-friendly alternative to synthetic materials. FRC made using Bamboo fibers enhances mechanical properties of concrete, including increased compressive strength and improved crack resistance.

3.1.5. Jute Fibers

Jute fibers (Figure 4) are cheap among all the fibers and are abundantly available in severable developing countries. It can be used in concrete to improve its strength and durability performance. These fibers are biodegradable, abundant, and possess high tensile strength.

Figure 2. Banana fiber.

Figure 3. Bamboo fiber.

Figure 4. Jute fiber.

3.2. Fiber Extraction Process

3.2.1. Banana Fibers

Banana fibers used were obtained by manually scraping them off from the banana sheath of the harvested pseudo stems and then cut into different sizes. To avoid the remake shortage related to the durability of natural fibers made of organic substance like waxes, lignin, and pectin, treatment of fibers with immersion in a 5% sodium hydroxide solution for 60 minutes at room temperature. Before this, fibers went through a thorough wash with tap water for at least 10 minutes in order to take out hemicellulose, lignin, and wax the cellulose was enclosed in [19]. Now, this step is not only the exposing of the cellulose but also increasing the surface roughness of the fibers, along with a better interface with the resin.

3.2.2. Bamboo Fibers

Bamboo fibers are obtained through a mechanical and chemical process. Mature bamboo culms are selected, cleaned, and split into smaller strips. These strips undergo mechanical crushing to separate the fibers, which are then boiled in alkaline solution (e.g., sodium hydroxide) to remove lignin, hemicellulose, and impurities [20], [21]. The treated fibers are washed thoroughly with water and dried under controlled conditions to achieve the desired quality.

3.2.3. Jute Fibers

Jute fibers are obtained from the bark of the jute plant, The process begins with retting, where the harvested stalks are submerged in water to allow microbial action to loosen the fibers After retting, the fibers are extracted manually or mechanically by stripping the stalks, The fibers are then washed to remove dirt and non-fibrous matter, sun-dried, and bundled for use [22]. Treatment with an alkaline solution may be performed to improve with the cement matrix.

3.3. Mix Proportions

Normal-strength concrete of M15 grade was prepared using Ordinary Portland Cement (OPC) and crushed stone with a nominal maximum size of 20 mm. Key parameters were kept constant across all mixtures, including a water–cement ratio of 0.50 and fiber contents of 0.5%, 1%, 1.5%, and 2% by volume (based on the weight of cement). The mix proportions were determined in accordance with ACI standards [23]-[25].

3.4. Mixing procedure

The concrete was mixed following ACI guidelines using an electrically operated mixer. Aggregates, sand, and cement were first introduced into the mixer. For fiber-reinforced mixes, the fibers were manually dispersed and dry-mixed for 60 seconds to ensure uniform distribution. Water was then added, and mixing continued for an additional 90 seconds. Test specimens for compressive, split tensile, and flexural strength were cast in triplicate. After casting, the specimens were kept in air for 24 hours before being transferred to a water tank for curing at 20 ± 2 °C for 28 days.

Table 1. Chemical composition of cement.

Chemical composition	SiO_2	CaO	Fe_2O_3	MgO	Al_2O_3	SO_3	LOI	LR
Percentage (%)	22.86	65.08	4.07	1.95	5.05	2.41	1.12	1.33

Table 2. Physical and Chemical properties of cement.

Type	Blaine fitness (0.08mm) % (m2 /g)	Specific surface area (m2 /g)	Standard consistency	Soundness (mm)	Setting time(min)		Compressive strength (MPa)	
					Initial	Final	2d	28d
CEM I 42.5N	2.2	349.9	27.8	.5	154	293	20.9	48.1

Table 3. Physical and Mechanical properties of fibers.

Property	Banana Fiber	Jute Fiber	Bamboo Fiber
Fiber Length	92 cm	3.3 m	2.9 m
Fiber Diameter (µm)	227.9 µm	168.7 µm	150 µm
Moisture Absorption (%)	11%	10.5%	11%
Specific Gravity	1.35	1.46	1.50
Water Absorption	High	Moderate	Moderate
Compressive Strength	45 – 65 MPa	50 – 70 MPa	60 – 80 MPa
Tensile Strength (g/tex)	18.25 g/tex	27 g/tex	20 – 50 g/tex
Density	1.35 g/cm³	1.46 g/cm³	1.20 – 1.50 g/cm³

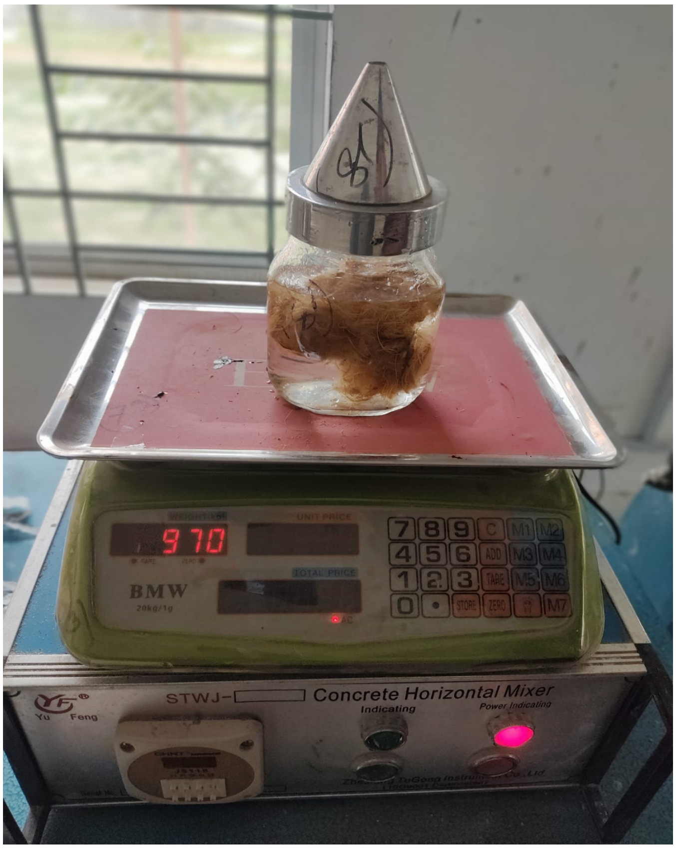

Figure 5. Specific Gravity Test.

3.5. Tests on fibers

3.5.1. Specific Gravity tests of fibers

To determine the density of natural fibers in relation to water, the specific gravity test is crucial [26], [27]. It aids in figuring out whether the fiber is appropriate for reinforcing materials like concrete (Figure 5).

Procedure:

Fiber Sample

Preparation:

To get rid of contaminants, grease, or dust, thoroughly clean the fibers. To maintain a consistent weight, dry the fibers in an oven set to 105°C.

Measurements of weight:

- Empty pycnometer weight (W_1): Determine the weight of the dry, clean pycnometer.
- The water-filled pycnometer's weight (W_2): Avoid creating air bubbles while adding distilled water to the pycnometer. Weigh it.
- Weight of pycnometer with fibers and water (W_3): Fill the pycnometer with fibers of a known weight. Weigh again after adding water.
- Weight of Dry Fiber: The dry fibers used (W_4) should be weighed.

The specific gravity is calculated using the formula:

Specific Gravity (SG) = weight of the dry fibers (W4) / (W2-W1) – (W3-W1-W4).

3.5.2. Water Absorption test of fiber

To determine the water absorption capacity of natural fibers such as bamboo, banana, and jute fibers.

The process involves preparing the fibers:

To get rid of dust or other contaminants, clean the natural fibers. The fibers should be dried at 105°C in an oven until their weight remains consistent. In a desiccator, let them cool to ambient temperature (Figure 6).

Figure 6. Water Absorption Test.

Table 4. Physical properties of aggregates.

Material Properties	Coarse aggregate	Fine aggregate
Type	Crushed	River sand
Maximum size (mm)	20	.75
Fineness modulus, FM	2.86	-
Water Absorption (%)	0.61	0.37
Apparent density (g/m3)	2800	2850
Mica content (%)	0.0	-
Fines<0.075 mm (%)	2.74	-
Flakiness index (%)	-	9.5
Elongation index (%)	-	11.6

Measurement of Dry Weight:

Accurately weigh the dry fibers. The notation for this weight is W dry.

- Fibers Submerged: At room temperature, put the dry fibers in a jar with distilled water. Make sure all of the fibers are submerged. If required, use a mesh or light weight.
- Duration of Soaking: For full absorption, let the fibers soak for a regular amount of time, usually 24 hours. For initial evaluations, shorter soaking times (such as 30 minutes or an hour) might also be used.
- Drying the Surface: To get rid of extra surface water without squeezing the fibers, take them out of the water and blot them with a towel or blotting paper.

Wet Weight Calculation:

Weigh the fibers as soon as they are surface-dried. Make a note of this as W moist.

The Water Absorption is calculated using the formula:

Percent Water Absorption = [(Wet weight - Dry weight)/ Dry weight] x 100.

3.6. Sieve analysis

Sieve analysis is used to determine particle size distribution of aggregate using a series of square or round openings starting with largest opening at top [28], [29]. Sieve analysis also allows engineers to plot gradation curves for better assessment It helps to determine fineness modulus, uniformity and suitability for use in construction. Coarse aggregates are those between 75 and 4.75 mm in size (Ethiopian Standard). In construction, normally those that retains in 4.75 mm sieve after sieve analysis are used. The physical properties of the aggregates are presented in Table 4.

3.7. Mixing and casting

Mixing is an important aspect of any successful experiment and to avail the desired results. The mixing and casting process was done with utmost care. All materials are mixed with the standard (M15 standard) practice of mixing them and natural fibers (Banana fiber, Bamboo fiber and Jute fiber) are added in varying ratio to the mix. Specimens were prepared by using cubes, cylinders, flexure beams. The Cubes (100mm*100mm*100mm), cylinders (100mm in diameter and 200mm in height) and prisms (100mm*100mm*500mm) were casted to determine the compressive strength, split tensile strength and flexural strength respectively, as shown in Figure 7.

3.8. Curing

Curing is the process of maintaining adequate moisture, temperature in newly casted concrete to ensure proper hydration of the cement. It is essential for the development of the concrete’s strength, durability, and surface quality. Concrete may develop cracks, lose strength, and suffer from poor durability over time if curing is not done properly. Methods of curing includes water curing (keeping the surface wet), covering with wet fabrics made up of jute or other plants that holds moisture for a long time, applying curing compounds, and steam curing in precast concrete (Figure 8). The curing period typically ranges from 7 to 28 days depending on the type of cement and environmental conditions.

3.9. Testing

Compressive strength test: All cubes should be tested for crushing strength in compression after 7 and 28 days of curing in a testing machine **(**Figure 9**).** The load should be applied progressively until the specimen collapses. The final load should be noted as the collapse load and crushing strength can be measured.

Split Tensile strength test: Diametrical lines should be drawn on the two ends of the cylindrical specimen to

Figure 7. Cylindrical and Cubic Specimens.

Figure 8. Cube and cylindrical samples casted for testing.

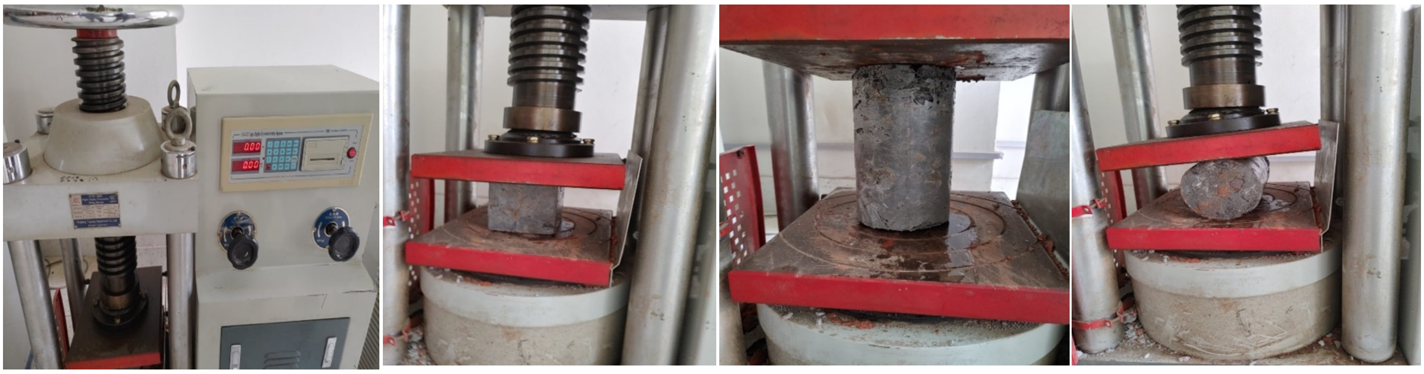

Figure 9. Sample testing in Strength testing Machine.

ensure that they are on the same axis. The load should be applied gradually until the specimen collapses. The final load before collapse should be noted. The split tensile strength can be determined. The test was conducted according to standard procedures such as ASTM C496 or IS 5816, using cylindrical specimens typically measuring 100 mm in diameter and 200 mm in height.

Flexural strength test: Cylindrical shaped samples should be placed horizontally on testing machine and the load should be applied slowly on the beam until the sample breaks down completely in the middle of the beam. The final load before the break down should be noted. And finally, the flexural strength can be determined. The test was conducted in accordance with standard procedures (such as ASTM C78 or IS 516) using a two-point loading method on prism specimens, typically measuring (100mm*100mm*500mm).

The cube specimen (100*100*100 mm) was put over the compression testing machine and the load was applied progressively until the specimen abortive. The final load was noted as the collapse load and the crushing strength was measured as (load/area). The cylinder specimen (100mm diameter & 200mm height) be located in compression testing machine with horizontal position to determine

Table 5. Compressive strength (MPa) after 7 days.

Types of Fiber	Percentages of Fiber	Failure load (kN)	Compressive Strength (Mpa)
Banana Fiber	0.5%	243.1	24.31
	1%	212.7	21.27
Jute Fiber	0.5%	210.4	21.04
	1%	226.7	22.67
Bamboo fiber	0.5%	246.2	24.62
	1%	249.2	24.92

Table 6. Compressive strength (MPa) after 28 days.

Types of Fiber	Percentages of Fiber	Failure load (kN)	Compressive Strength (Mpa)
Banana Fiber	0.5%	373.2	37.32
	1%	323.7	32.37
	1.5%	310.2	31.02
	2%	322.5	32.25
Jute Fiber	0.5%	237.0	23.70
	1%	245.9	24.59
	1.5%	215.6	21.56
	2%	190.4	19.04
Bamboo fiber	0.5%	362.4	36.24
	1%	367.3	36.73
	1.5%	368.2	36.82
	2%	369.1	36.91

Table 7. Split tensile strength (MPa) after 7 days.

Types of Fiber	Percentages of Fiber	Failure load (kN)	Split tensile Strength (Mpa)
Banana Fiber	0.5%	23.16930	2.95
	1%	19.39938	2.47
Jute Fiber	0.5%	21.04872	2.68
	1%	22.30536	2.84
Bamboo fiber	0.5%	26.93922	3.43
	1%	26.07528	3.32

Table 8. Split tensile strength (MPa) after 28 days.

Types of Fiber	Percentages of Fiber	Failure load (kN)	Split tensile Strength (Mpa)
Banana Fiber	0.5%	24.66156	3.14
	1%	25.68258	3.27
	1.5%	22.69806	2.89
	2%	21.67704	2.76
Jute Fiber	0.5%	23.40492	2.98
	1%	24.74010	3.15
	1.5%	24.42594	3.11
	2%	22.85514	2.91
Bamboo fiber	0.5%	37.85628	4.82
	1%	37.38504	4.76
	1.5%	38.40606	4.89
	2%	39.42708	5.02

the split tensile strength of concrete. Concrete prisms (100mm*100mm*500mm) were tested in the universal testing machine to determine the flexural strength of concrete. The failure load was noted down. The compressive strength was then calculated using the formula: Compressive Strength (MPa) = Failure Load (N)/ Loaded Area (mm²). Split Tensile strength can be calculated using the formula: Split Tensile Strength (MPa) = $2P/\pi DL$. And flex-

Table 9. Flexural strength (MPa) after 7 days.

Type of Fiber	Percentages of Fiber	Failure load (kN)	Flexural Strength (Mpa)
Banana Fiber	0.5%	99.8	4.99
	1%	43.8	4.38
Jute Fiber	0.5%	41.5	4.15
	1%	43.8	4.38
Bamboo fiber	0.5%	40.5	4.05
	1%	44	4.40

Table 10. Flexural strength (Mpa) after 28 days.

Type of Fiber	Percentages of Fiber	Failure load (kN)	Flexural Strength (Mpa)
Banana Fiber	0.5%	122.4	6.12
	1%	112	5.60
	1.5%	103.4	5.17
	2%	98.8	4.94
Jute Fiber	0.5%	102.6	5.13
	1%	109.8	5.49
	1.5%	100.2	5.01
	2%	104.8	5.24
Bamboo fiber	0.5%	112.6	5.63
	1%	117.2	5.86
	1.5%	117.8	5.89
	2%	120.2	6.01

ural strength can be calculated using formula: Flexural Strength (MPa) = P/DL, where *P* is the failure load, *D* is diameter, *L* is length of the specimen. These values were used to quantify the mechanical behavior of fiber-reinforced concrete mixes.

4. Results and Discussions

The results obtained from the comparative analysis of concrete samples reinforced with natural fibers—bamboo, banana, and jute. This study was to evaluate the influence of these fibers on the mechanical properties of concrete, specifically compressive strength, split tensile strength, and flexural strength. The results are systematically analyzed to highlight the performance differences among the three types of fiber-reinforced concretes and to assess the effect of fiber in reinforced concrete. Variations in strength, failure modes, and overall behavior are interpreted in relation to physical and chemical characteristics of each fiber.

4.1. Test results

4.1.1. Compressive Strength Test

The cubes were tested for varying percentages of fiber by volume of concrete for 7 days and 28 days. Two different percentage (0.5%, 1%) addition of fibers were taken for 7 days and four different percentage addition (0.5%, 1%, 1.5%, 2%) of fibers were taken for 28 days. Here, compressive strength of three different types of fiber specifically-bamboo, banana, and jute were determined. Compressive strength of 7 days is presented in the Table 5 and compressive strength of 28 days is presented in Table 6.

4.1.2. Split tensile Strength Test

The split tensile strength test indirectly evaluates the tensile capacity of concrete. In this method, a standard cylindrical specimen is placed horizontally and subjected to diametral compression. In split tensile strength test, two percentage addition of fiber for 7 days and four different percentage addition of fiber for days were taken similar to compressive strength test. A detailed test results of split tensile strength for 7 days are shown in Table 7 and results for 28 days are shown in Table 8.

4.1.3. Flexural Strength Test

The flexural strength test provides an alternative method for assessing the tensile capacity of concrete. Under bending conditions, a structural member experiences internal stresses, including shear, tension, and compression. When a simply supported beam is subjected to a downward load, the region above the neutral axis is predominantly under compression, while the region below it is subjected to tensile stresses. In this loading configuration, areas close to the supports tend to experience higher shear stresses compared to tensile stresses. Similarly, two percentage addition of fiber were taken for 7 days and four percentage addition of fiber were taken for 28 days. A detailed test results of flexural strength for 7 days are shown in Table 9 and results for 28 days are shown in Table 10.

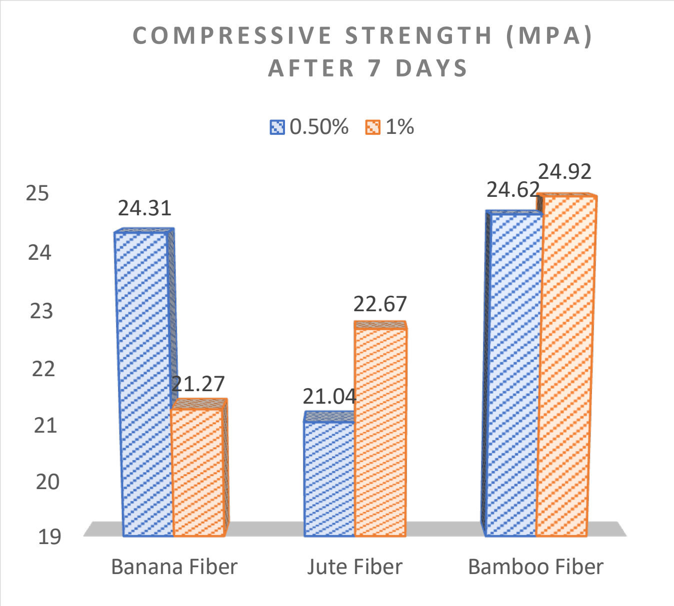

Figure 10. Compressive Strength (MPa) after 7 days Bar Chart.

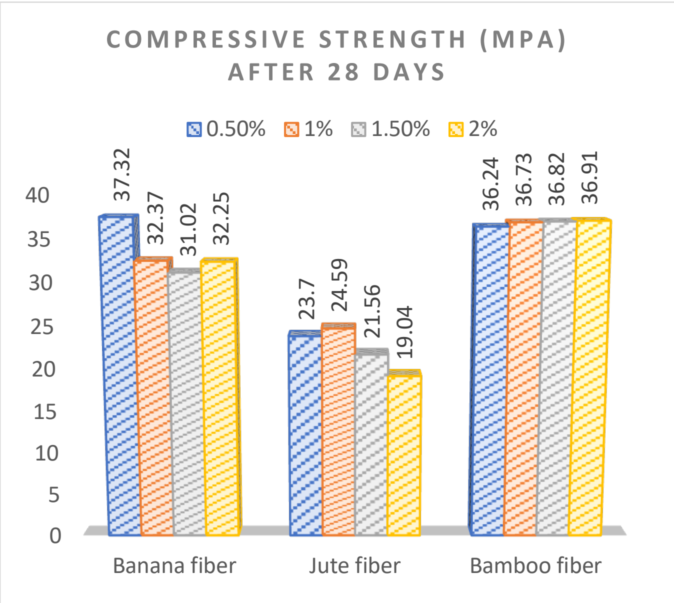

Figure 11. Compressive Strength (MPa) after 28 days Bar Chart.

4.2. Discussions

4.2.1. Variability of test results

In this study, a strength test result is the average strength of all specimens of the same age, cast from a single concrete batch. To maintain a high confidence level in the findings, a test result is never based on a single specimen; a minimum of two samples is required for each test. Consequently, the data presented in this research represents the mean value derived from two test samples. Despite standardized testing, fluctuations were observed in the compressive, tensile, and flexural strength values across specimens, even within the same fiber group. This variability is attributed to several critical factors. Variations in fiber percentage, spatial distribution, and orientation within the concrete matrix. The moisture content of the fibers and the quality of the bond between the fiber surface and the cement paste. The use of manual mixing and hand placement during specimen preparation, which can lead to non-uniform fiber dispersion and impact result accuracy. These findings emphasize the necessity for standardized fiber treatment and mechanical mixing procedures. Implementing more rigorous preparation protocols is essential to minimize inconsistencies and enhance the reliability of Natural Fiber-Reinforced Concrete (NFRC) for practical engineering applications.

4.2.2. Compressive Strength Test

The 7-day compressive strength of concrete reinforced with banana, jute, and bamboo fibers at two fiber contents (**0.5%** and **1%** by weight of cement) indicate that the mechanical performance of fiber-reinforced concrete at early ages is significantly influenced by both the type and the proportion of natural fiber used.

At a fiber content of **0.5%** (see Figure 10), bamboo fiber-reinforced concrete exhibited the highest compressive strength, reaching **24.62 MPa**, followed closely by banana fiber-reinforced concrete at **24.31 MPa**, while jute fiber-reinforced concrete recorded the lowest strength at **21.04 MPa**.

When the fiber content was increased to 1%, the compressive strength of bamboo fiber-reinforced concrete increased slightly to **24.92 MPa**, indicating consistent performance and strong compatibility between bamboo fibers and the cementitious matrix. Jute fiber-reinforced concrete also showed an improvement in strength, rising to **22.67 MPa**, which reflects better internal stress distribution and crack control at higher fiber volumes. In contrast, banana fiber-reinforced concrete demonstrated a noticeable reduction in compressive strength at **1%**, decreasing to **21.27 MPa**. This decline may be attributed to the higher water absorption capacity of banana fibers and their tendency to cause poor dispersion or clumping within the mix at elevated contents.

As for 28-day compressive strength tests for concrete reinforced with banana, jute, and bamboo fibers, four different percentage of variation is considered respectively **0.5%**, **1%**, **1.5%**, and **2%** (see Figure 11). Among the three types of natural fibers, banana fiber exhibited the highest compressive strength at **0.5%**, reaching **37.32 MPa**. However, a noticeable decline was observed as the fiber percentage increased to **1%** and **1.5%,** where compressive strengths dropped to **32.37 Mpa** and **31.02 MPa**, respectively. Interestingly, at **2%,** the strength slightly recovered to **32.25 MPa**, although still considerably lower than at **0.5%**. This trend suggests that while a small addition of banana fiber can enhance the compressive strength of concrete, excessive amounts may lead to a decrease in strength, possibly due to poor fiber dispersion or increased porosity within the matrix.

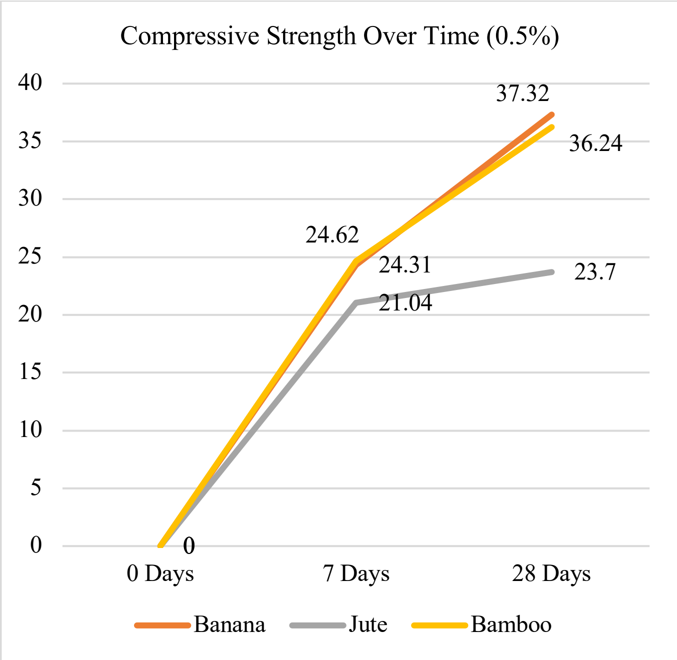

Figure 12. Compressive Strength Graph over time (0.5%).

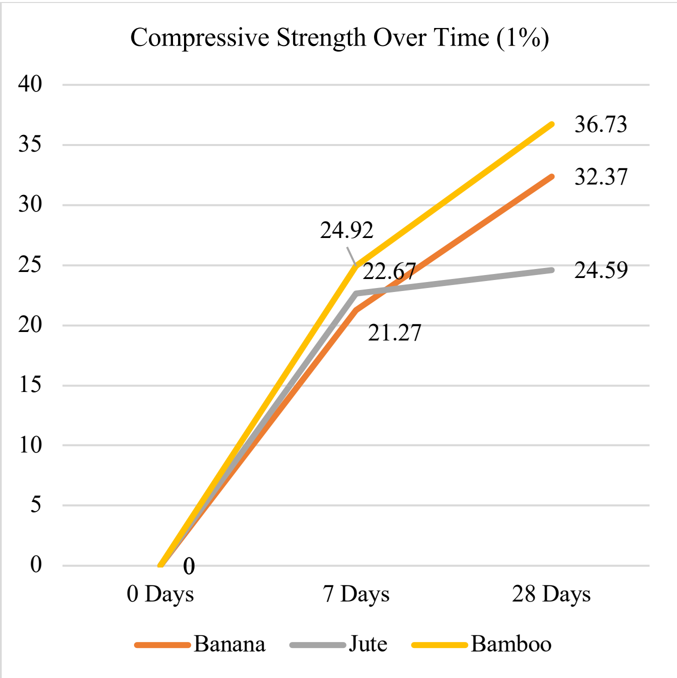

Figure 13. Compressive Strength Graph over time (1%).

In contrast, jute fiber-reinforced concrete showed the lowest overall compressive strength values across all fiber percentages. The maximum strength achieved was **24.59 Mpa** at **1%** fiber content, followed by a steady decline to **21.56 Mpa** and **19.04 Mpa** at **1.5%** and **2%**, respectively.

Bamboo fiber, on the other hand, demonstrated the most stable and consistent results. The compressive strength values ranged from **36.24 Mpa** at **0.5%** to **36.91 Mpa** at **2%**, with a gradual and almost linear increase. Although the variation is minor, bamboo fiber enhances compressive strength regardless of the percentage used. This stability could be linked to the relatively higher stiffness, strength, and compatibility of bamboo fibers with the cementitious material.

The development of compressive strength over time for concrete reinforced with 0.5% natural fibers—banana, jute, and bamboo—demonstrated clear differences in performance based on fiber type (see Figure 12). At 7 days, all three fiber-reinforced mixes exhibited a substantial gain in compressive strength, with banana and bamboo fibers showing higher early strength than jute fiber. As curing progressed to 28 days, both banana and bamboo fiber mixes continued to show significant increases in compressive strength, eventually reaching closely aligned peak values just below 40 MPa. In contrast, the jute fiber mix exhibited a slower rate of strength gain, with a more modest increase from 7 to 28 days, ultimately achieving a lower overall strength compared to the other two fibers. This trend suggests that both banana and bamboo fibers contribute more effectively to early and long-term compressive performance at 0.5% content, likely due to better fiber-matrix interaction and crack resistance. Bamboo fiber, in particular, displayed slightly better consistency and long-term strength development, reinforcing its potential as a favorable reinforcement material for compressive applications in fiber-reinforced concrete.

At 1% fiber content (see Figure 13), the development of compressive strength over time for banana, jute, and bamboo fiber-reinforced concrete displayed distinct trends. All mixes showed a significant increase in compressive strength from 0 to 7 days, with bamboo fiber-reinforced concrete achieving the highest early-age strength among the three. By the 28-day mark, the bamboo fiber mix continued its upward trajectory, reaching the highest overall compressive strength of approximately 37 MPa, suggesting strong fiber-matrix bonding and effective crack-bridging properties that contributed to its long-term mechanical performance. The banana fiber mix also showed considerable strength development, reaching around 33 MPa at 28 days, indicating its viability for structural applications at this dosage. In contrast, the jute fiber mix, while showing an initial gain from 0 to 7 days, exhibited a more gradual increase afterward, reaching only about 25 MPa at 28 days. This slower strength gain may indicate less effective fiber dispersion or weaker interfacial bonding with the cementitious matrix compared to the other two fibers. These results highlight bamboo fiber's superior performance in compressive strength enhancement at 1% dosage, with banana fiber offering moderate benefits and jute fiber showing limited long-term strength development under similar conditions.

A comparative analysis across all samples highlights bamboo fibers as the most effective in sustaining or enhancing compressive strength, followed by jute fibers, while banana fibers were the least effective at higher fiber

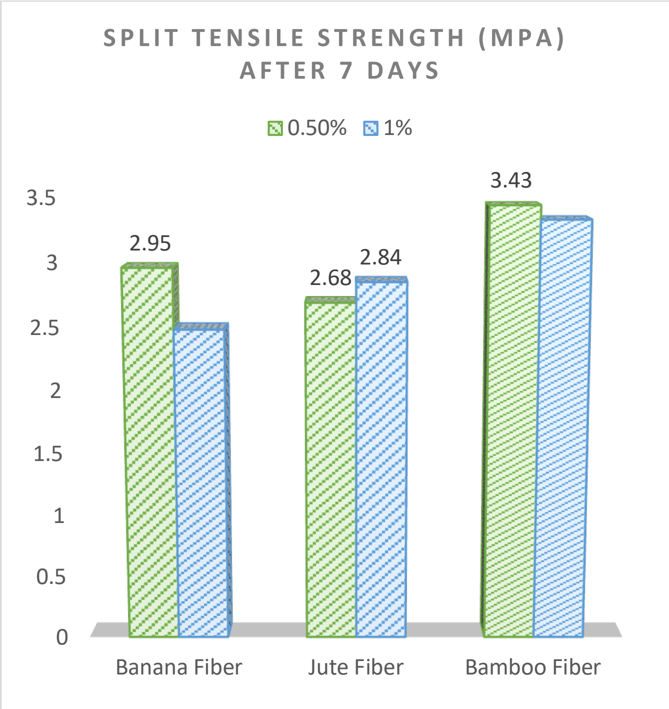

Figure 14. Split Tensile Strength (MPa) after 7 days Bar Chart.

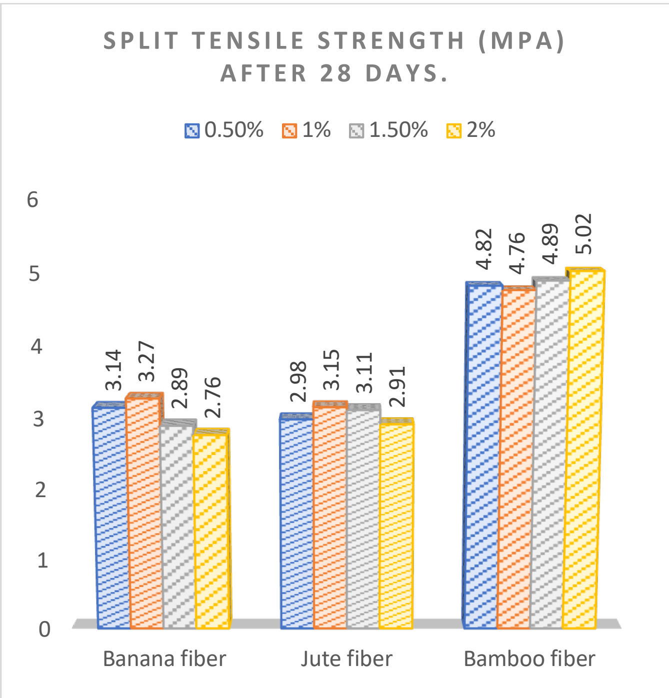

Figure 15. Split Tensile Strength (MPa) after 28 days Bar Chart.

content. These results suggest that the mechanical performance of fiber-reinforced concrete is not only depends on fiber-type but also strongly influenced by the percentage of fiber used.

4.2.3. Split Tensile Strength Test

The 7-day split tensile strength provide valuable insight into the early-age tensile behavior of fiber-reinforced concrete (see Figure 14). Among the three types of natural fibers tested—banana, jute, and bamboo—bamboo fiber consistently exhibited the highest tensile strength values, while banana and jute fibers showed more variable performance depending on the fiber dosage.

For banana fiber, the tensile strength was **2.95 Mpa** at **0.5%** fiber content, but it declined to **2.47 Mpa** at **1%**. This reduction suggests that while a small percentage of banana fiber contributes positively to tensile performance, an increase in fiber content may disrupt the homogeneity of the concrete matrix.

In contrast, jute fiber showed an improvement in tensile strength with increased fiber content. The strength rose from **2.68 Mpa** at 0.5% to **2.84 Mpa** at 1%, indicating that jute fibers can contribute positively to tensile performance when used in moderation. However, even at its best performance, jute fiber still falls short of the strength achieved by bamboo fiber.

Bamboo fiber clearly demonstrated the highest split tensile strengths among all tested samples. At **0.5%**, the strength reached **3.43 MPa**, and slightly decreased to **3.32 Mpa** at **1%**. This slight drop is negligible and suggests that bamboo fiber maintains its effectiveness even when the fiber content is increased. Its performance could be linked to its higher stiffness, tensile strength, and better compatibility with the cement matrix.

At 28 days (see Figure 15), the split tensile strength shows a clear distinction in performance across the three natural fibers tested—banana, jute, and bamboo—highlighting how fiber type and dosage affect long-term tensile behavior in concrete.

Banana fiber-reinforced concrete exhibited its highest tensile strength at **1%** fiber content **(3.27 MPa)**, showing a slight improvement over **0.5% (3.14 MPa)**. However, strength values dropped at higher fiber additions, falling to **2.89 Mpa** at 1.5% and **2.76 Mpa** at 2%.

For jute fiber, the performance was relatively stable across the tested dosages. The tensile strength increased from **2.98 Mpa** at 0.5% to **3.15 Mpa** at 1%, and remained nearly consistent at **3.11 Mpa** for 1.5%. A slight decrease to **2.91 Mpa** at 2% was observed, but the variation is modest.

In contrast, bamboo fiber showed both the highest strength values and the most consistent upward trend. Starting from **4.82 Mpa** at 0.5%, the strength increased slightly with each increment—**4.76 Mpa** at 1%, **4.89 Mpa** at 1.5%, and peaking at **5.02 Mpa** at 2%. This progressive enhancement suggests bamboo fiber's superior ability to improve tensile properties due to its higher mechanical strength and better interfacial bonding with the cement matrix.

The variation of split tensile strength over time for concrete incorporating 0.5% banana, jute, and bamboo fibers reveals distinct performance patterns among the fiber types (see Figure 16). All specimens showed a rapid increase in tensile strength from 0 to 7 days, indicating early

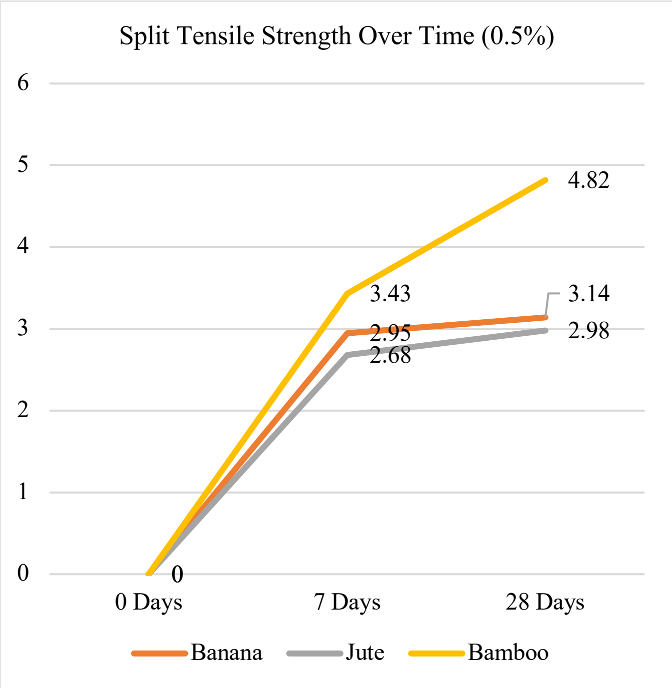

Figure 16. Split Tensile Strength Graph over time (0.5%).

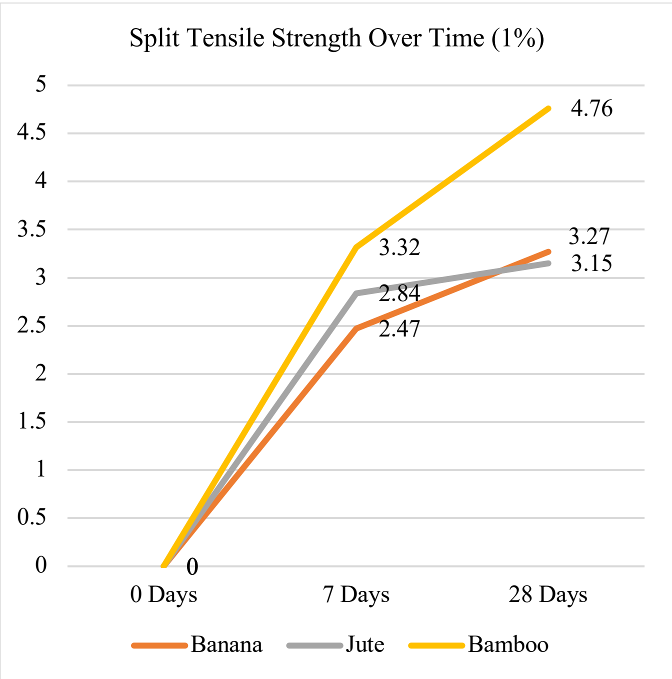

Figure 17. Split Tensile Strength Graph over time (1%).

fiber-matrix interaction and improved crack resistance during initial hydration. Among the three, bamboo fiber-reinforced concrete exhibited the highest tensile performance throughout the curing period. At 7 days, it achieved a strength around 3.5 Mpa, further increasing to approximately 5 Mpa by 28 days. This substantial gain reflects bamboo fiber's effectiveness in bridging cracks and enhancing tensile stress distribution, even at a relatively low dosage. Banana and jute fibers showed similar trends but with lower absolute values. Banana fiber reached just over 3 Mpa at 28 days, while jute fiber trailed slightly behind, with a strength close to 2.8 Mpa. The smaller improvement in jute fiber may be attributed to less efficient bonding or alignment within the concrete matrix. Overall, the results demonstrate that even at 0.5% fiber content, bamboo fiber contributes significantly to tensile strength development over time, making it a favorable reinforcement option for enhancing the ductility and crack resistance of concrete.

At a fiber content of 1% (see Figure 17), the split tensile strength of fiber-reinforced concrete showed noticeable variation based on the type of natural fiber used. All three fiber types contributed to a significant early-age gain in tensile strength from 0 to 7 days. Among them, bamboo fiber-reinforced concrete displayed the most pronounced strength development. At 7 days, it achieved approximately 3.4 Mpa and continued to increase steadily, reaching a peak of about 4.8 Mpa at 28 days. This trend highlights bamboo fiber's ability to enhance tensile stress resistance through effective crack-bridging and load transfer mechanisms, particularly when used at this dosage. Jute fiber also performed reasonably well, reaching around 2.9 Mpa at 7 days and increasing to about 3.4 Mpa by day 28. In contrast, banana fiber started slightly lower, at around 2.5 Mpa after 7 days, but closely followed jute fiber in final performance, ending near 3.3 Mpa. While both banana and jute fibers improved tensile strength over time, their effect was less significant compared to bamboo. Overall, the results confirm that increasing bamboo fiber content to 1% leads to a substantial improvement in split tensile strength, making it a strong candidate for enhancing the tensile performance and durability of concrete in structural applications.

To summarize, **bamboo fiber** stands out as the most effective reinforcement in terms of tensile strength development**. Banana fiber** offers a notable but limited benefit, especially at lower percentages, while **jute fiber** provides a modest and relatively balanced performance. These trends align with the material properties of each fiber and highlight the importance of optimizing fiber content for maximum benefit in fiber-reinforced concrete.

4.2.4 Flexural Strength Test

The flexural strength of concrete for natural fibers—banana, jute, and bamboo—was examined after 7 days of curing at two fiber volume fractions**: 0.5% and 1%** (see Figure 18).

In the case of jute fiber, the flexural strength increased from **4.15 Mpa** at 0.5% to **4.38 Mpa** at 1%. A similar trend was observed with bamboo fiber, where the strength improved from **4.05 Mpa** at 0.5% to **4.40 Mpa** at 1%. These results indicate that both jute and bamboo fibers contribute more effectively to enhancing flexural properties when their content is increased, likely due to improved crack-

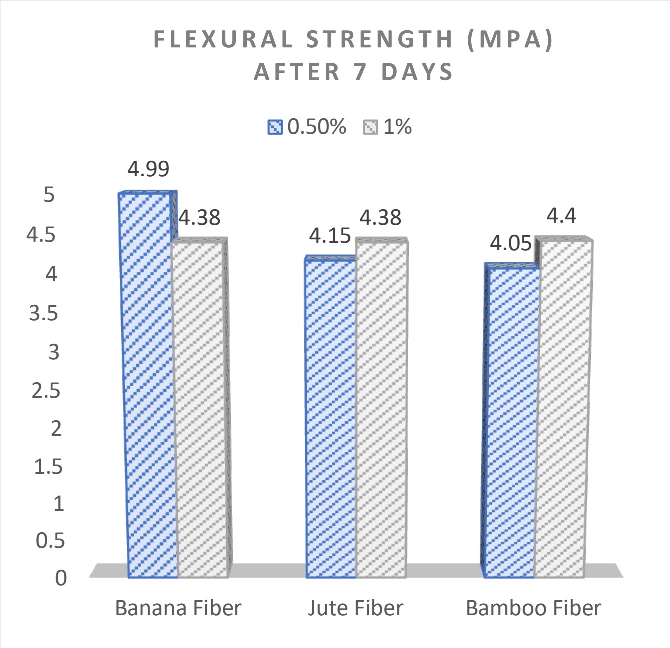

Figure 18. Flexural Strength (MPa) after 7 days Bar Chart.

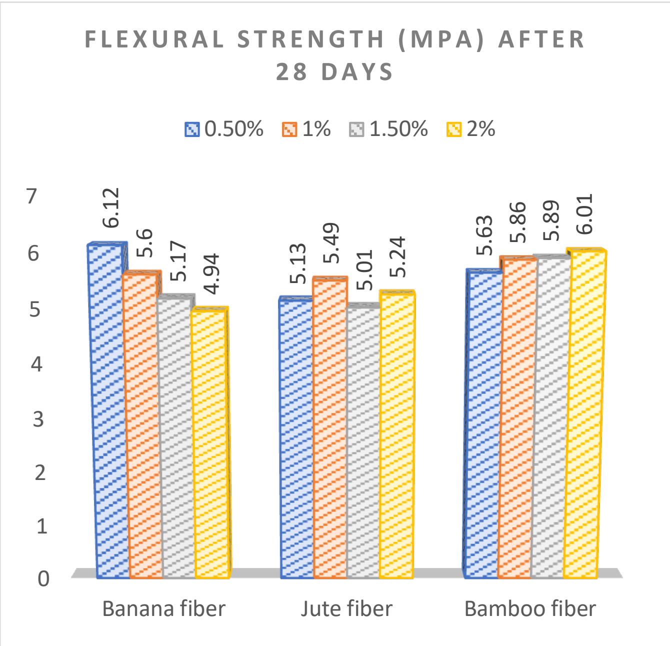

Figure 19. Flexural Strength (Mpa) after 28 days Bar Chart.

bridging capability and energy absorption. Interestingly, at 1% fiber content, all three fibers yielded comparable strengths—banana at **4.38 Mpa**, jute also at 4.38 MPa, and bamboo slightly higher at **4.40 Mpa** suggesting that, beyond a certain threshold, the type of fiber becomes less influential than its overall presence and distribution within the concrete matrix. These findings highlight the importance of selecting the appropriate fiber type and percentages: banana fiber and jute fiber is most effective at lower content, while bamboo fiber show better performance at both lower and higher concentration.

At 28 days (see Figure 19), the flexural strength behavior of concrete reinforced with banana, jute, and bamboo fibers revealed significant variations depending on both the fiber type and its dosage. Banana fiber showed a clear decline in flexural performance with increasing fiber content. The highest strength for banana fiber was recorded at 0.5%, reaching **6.12 Mpa**. However, as the fiber dosage increased to 1%, 1.5%, and 2%, the flexural strength gradually dropped to **5.60 Mpa**, **5.17 Mpa**, and **4.94 Mpa**, respectively. This trend suggests that while banana fiber provides excellent reinforcement at lower content, its higher concentrations may negatively affect the mix, likely due to reduced workability and non-uniform fiber distribution that hinder proper stress transfer.

In the case of jute fiber, the flexural strength initially improved from **5.13 Mpa** at 0.5% to a peak of **5.49 Mpa** at 1%. However, beyond this point, a reduction was observed, with values decreasing to **5.01 Mpa** at 1.5%, before slightly increasing again to **5.24 Mpa** at 2%. This non-linear trend indicates that jute fiber can enhance flexural strength up to an optimal dosage, after which its effectiveness diminishes, possibly due to fiber clustering or poor bonding with the cement matrix.

Bamboo fiber, in contrast, exhibited a consistent improvement in flexural strength across all dosages. Starting at **5.63 Mpa** for 0.5% fiber content, the strength increased progressively to **5.86 Mpa** at 1%, **5.89 Mpa** at 1.5%, and reached its maximum of **6.01 Mpa** at 2%. This steady increase reflects bamboo fiber's ability to integrate efficiently within the concrete mix, offering effective crack-bridging and tensile resistance without compromising the workability or homogeneity of the composite material.

The flexural strength development of fiber-reinforced concrete with 0.5% fiber content was monitored over a 28-day curing period, revealing clear performance differences between banana, jute, and bamboo fibers (see Figure 20). Among the three, banana fiber showed the highest flexural strength throughout the entire duration. At 7 days, it reached approximately 5.0 Mpa and continued to increase, achieving around 6.2 Mpa at 28 days. This indicates strong early-age crack-bridging capabilities and continued improvement in the post-cracking behavior of the mix. Bamboo fiber also demonstrated a steady increase in flexural strength, starting close to 4.0 Mpa at 7 days and rising to about 5.6 Mpa at 28 days. While slightly lower than banana fiber, this improvement reflects bamboo's effective reinforcement properties, especially in terms of its compatibility with the cement matrix and ability to resist flexural stress. Jute fiber, on the other hand, exhibited the lowest flexural strength among the three, increasing from roughly Mpa at 7 days to just above 5.0 Mpa at 28 days. Although all fiber types enhanced flexural behavior over time, banana and bamboo fibers clearly outperformed jute at this dosage, with banana fiber being particularly effective at increasing both early and long-term flexural capacity.

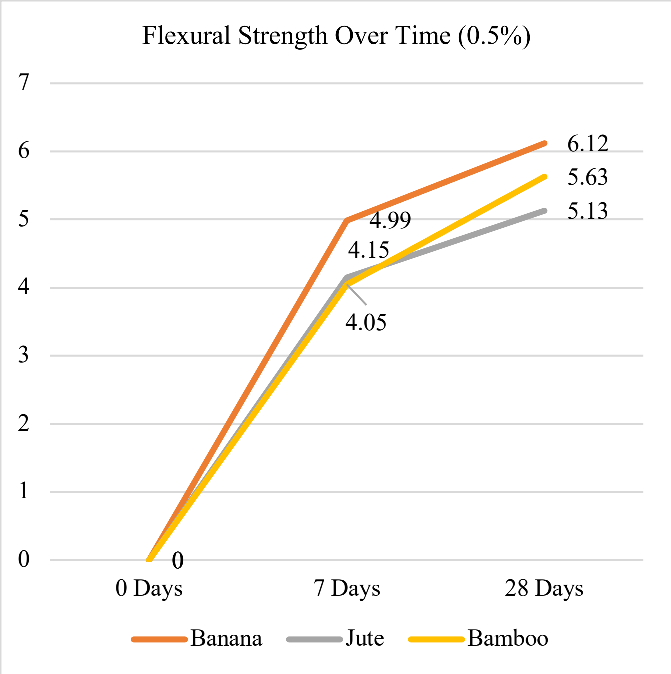

Figure 20. Flexural Strength Graph over time (0.5%).

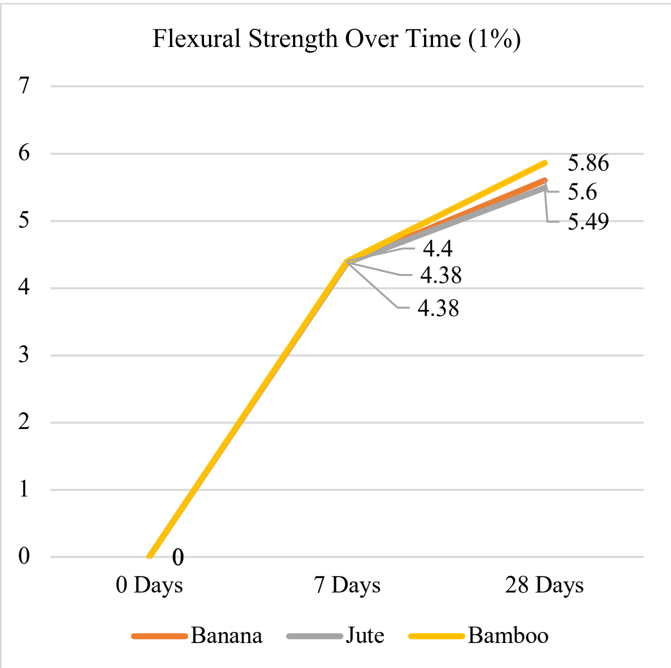

Figure 21. Flexural Strength Graph over time (1%).

With an increased fiber content of 1% (see Figure 21), the flexural strength of concrete exhibited significant gains across all three natural fiber types. By day 7, each mix had developed a flexural strength of approximately 4.5 Mpa showing a strong early-age contribution of fibers to resisting bending stress. Over time, all three fiber-reinforced concretes continued to gain strength, with final values ranging between 5.3 and 5.7 Mpa at 28 days. Notably, bamboo fiber achieved the highest flexural strength, peaking around 5.7 Mpa, closely followed by banana and jute fibers. The convergence in flexural performance at this dos-age suggests that, at 1% content, all fiber types provided effective crack-bridging, stress redistribution, and resistance to failure under bending loads. Compared to the 0.5% dosage, the improvement in strength at 1% was more uniform across all fiber types, indicating an optimal saturation level for fiber efficiency in terms of flexural behavior. Bamboo's slightly superior performance may be attributed to its higher tensile strength and modulus, which enhance its effectiveness in delaying crack propagation. These results affirm that increasing natural fiber dosage to 1% can substantially enhance flexural strength, with bamboo fibers offering the most consistent benefit.

Overall, Banana fiber performs best at low content, while bamboo fiber continues to enhance flexural strength even at higher dosages. Jute fiber offers moderate improvement, with optimal performance observed around 1%. These findings demonstrate that bamboo fiber, in particular, holds promise for applications where long-term flexural strength is critical.

5. Conclusions

Based on the laboratory investigations into the mechanical properties of natural fiber-reinforced concrete (NFRC) specifically focusing on compressive, flexural, and splitting tensile strengths conclusions have been established regarding the impact of incorporating natural fibers such as banana, jute, and bamboo. Consequently, recommendations are provided concerning the effects of these fiber additions on concrete performance.

1) Bamboo emerged as the most reliable and consistent reinforcement. It achieved the highest overall mechanical values at a 2.0% volume fraction after 28 days, including a peak compressive strength of 36.91 Mpa, split tensile strength of 5.02 MPa and flexural strength of 6.01 MPa. Its superior performance is attributed to high stiffness and strong interfacial bonding with the cement matrix.
2) **Banana fiber** performed best at low dosage, with 0.5% content reaching the highest compressive strength of 37.32 Mpa. However, strength declined at higher percentages, with compressive strength dropping to 32.25 Mpa and tensile strength to 2.76 Mpa at 2%. This reduction may result from poor fiber dispersion and reduced workability, suggesting banana fiber is most effective at lower concentrations.
3) **Jute fiber** moderately improved tensile and flexural strength but performed poorly in compressive strength. At 1%, it achieved 3.15 Mpa (tensile) and 5.49 Mpa (flexural), but compressive strength peaked at only 24.59 Mpa, falling to 19.04 Mpa at 2%. Higher dosages likely reduced concrete density and bond quality, limiting its use in load-bearing applications.

4) The effect of **fiber content** varied by type. While bamboo fiber showed improved performance up to 2%, banana and jute fibers declined beyond 0.5–1%. This trend is likely due to poor workability and fiber clumping, emphasizing the need to identify optimal dosages for each fiber type.
5) **Bamboo fiber at 1.5%–2%** is the most effective reinforcement among the three, offering consistent strength gains without drawbacks. Its strong bonding and high tensile resistance make it ideal for structural elements under tension and bending, such as beams and slabs.

6. Recommendations

1) Bamboo fiber should be prioritized as the most effective natural reinforcement for concrete. Based on the experimental results, bamboo fiber at 1.5% to 2% dosage provided consistent improvement in compressive, tensile, and flexural strengths. Its use is highly recommended for structural applications where enhanced mechanical performance and durability are required.
2) Banana fiber is suitable for improving early compressive strength but should be used in limited amounts. The highest compressive strength was achieved with 0.5% banana fiber at 28 days. However, higher dosages resulted in reduced performance, likely due to poor dispersion and increased porosity. Therefore, banana fiber should be restricted to 0.5% content and is more appropriate for non-load-bearing or low-strength concrete components.
3) Jute fiber is most effective when used in non-load-bearing elements or structures where tensile resilience and crack control are more critical than high compressive strength (e.g., pavements, thin-walled elements, or plastering).
4) Proper fiber content and mixing techniques are essential for optimal performance. Overuse of fiber especially banana and jute can reduce concrete workability, cause clumping, and lead to strength loss. Uniform mixing methods and possibly pretreatment of fibers (e.g., alkali treatment) should be considered to improve fiber dispersion and bonding with the cement matrix.
5) Further research is recommended to explore long-term durability and environmental benefits. Future studies should focus on the aging behavior, chemical resistance, shrinkage, and environmental performance of fiber-reinforced concrete. Additionally, life-cycle assessments can support the promotion of natural fibers as a sustainable alternative in the construction industry.

7. Declarations

7.1. Author Contributions

Md. Liton Rabbani: Writing – review and editing, validation, supervision; **Md. Rashedul Islam:** data curation, methodology, writing—original draft; **Md. Shahoriar Pulok:** data curation, methodology, writing—original draft; **Rakibul Hasan:** conceptualization, Visualization; **Md. Shaheen Al Mamun:** methodology; **Dhruboraj Roy:** methodology; **Rafaun Sultana Shiuly:** methodology; **Md. Atiqul Hasan:** Writing - Review & Editing.

7.2. Institutional Review Board Statement

Not applicable.

7.3. Informed Consent Statement

Not applicable.

7.4. Data Availability Statement

The data presented in this study are available on request from the corresponding author.

7.5. Acknowledgment

Not applicable.

7.6. Conflicts of Interest

The authors declare no conflict of interest.

8. References

[1] B. Munshi, "Failure analysis, seismic policy, and non-engineered construction: A South Asian perspective with Indian reconstruction models.", *ResearchGate*, 2025. https://doi.org/10.13140/RG.2.2.12126.91202.

[2] A. Majumder, M. Valdes, A. Frattolillo, E. Martinelli and F. Stochino, "Natural fiber TRM for integrated upgrading/retrofitting". *Buildings*, vol. 15, no. 16, art. No. 2852, 2025. https://doi.org/10.3390/buildings15162852.

[3] M. Hosseini, M. Gaff, P. Konvalinka, D. Hui, Y. Wei, P. Ghosh, A. Hosseini and P. K. Pandey, "Natural fiber-reinforced composites in precast modular construction: A critical review of structural viability and durability considerations for high-rise applications." *Journal of Natural Fibers*. Vol. 23, no. 1, 2026. https://doi.org/10.1080/15440478.2026.2629567.

[4] Y. Millogo, J.-E. Aubert, E. Hamard, J.-C. Morel, "How properties of kenaf fibers from Burkina Faso contribute to the reinforcement of earth blocks," *Materials*, vol. 8, no. 5, pp. 2332–2345, 2015. https://doi.org/10.3390/ma8052332.

[5] K. Annamalai, T. Shanmugam, H. Sundaram, V. Jagadeesan, "Enhancing concrete properties with bamboo and jute fibers: a response surface methodology approach." *Matéria (Rio de Janeiro)*, vol. 30, no. 1, 2025. https://doi.org/10.1590/1517-7076-RMAT-2024-0759.

[6] M. A. Hossain, S. D. Datta, A. S. M. Akid, M. H. R. Sobuz, M. S. Islam, "Exploring the synergistic effect of fly ash and jute fiber on the fresh, mechanical and non-destructive characteristics of sustainable concrete." *Heliyon*, vol. 9, no. 11, e21708, 2023. https://doi.org/10.1016/j.heliyon.2023.e21708.

[7] M. Hasan, F. H. Tushar, K. Hasan, F. M. Yahaya, R. P. Jaya, R. Hasan, S. H. Sohan, and M. L. Rabbani, "Performance analysis of sustainable reinforced concrete using chemically treated betel nut fiber," *Journal of Building Engineering*, vol. 105, 2025. https://doi.org/10.1016/j.jobe.2025.112456.

[8] M. R. M. Asyraf *et al.*, "Mechanical properties of oil palm fibre-reinforced polymer composites: a review", *Journal of Materials Research and Technology*, vol. 17, pp. 33-65, 2022, https://doi.org/10.1016/j.jmrt.2021.12.122.

[9] M. L. Rabbani, "A study on low-cost roof (Masonry Slab)," *American Journal of Engineering Research*, vol. 6, no. 3, pp. 32–36, 2017. https://www.ajer.org/papers/v6(03)/F06033236.pdf.

[10] M. L. Rabbani, M. M. Islam, M. S. Hossain, A. H. Tusar, and M. A. Hasan, "Mechanical properties and performance analysis of natural fiber reinforced concrete using jute and coconut fibers," *International Journal of Sustainable Rural Development*, vol. 2, no. 1, pp. 30-38. 2024. https://doi.org/10.54536/ijsrd.v2i1.3577.

[11] A. Dinku, "The need for standardization of aggregates for concrete production in Ethiopian construction industry," in *International Conference on African Development Archives*, 2005. https://scholarworks.wmich.edu/africancenter_icad_archive/90.

[12] T. D. Utsha, I. I. Reza, N. Zaman, and M. L. Rabbani, "Enhancing recycled concrete performance by using chemical activators," *American Journal of Innovation in Science and Engineering*, vol. 3, no. 3, pp. 19–30, 2024. https://doi.org/10.54536/ajise.v3i3.2497.

[13] C. K. Nmai *et al.*, *Materials for Concrete Construction*, ACI Education Bulletin E1-99. https://id.scribd.com/document/703085390/ACI-E1-99.

[14] A. M. Neville, *Properties of Concrete*, 5th ed. Longman Scientific & Technical, 2011. https://books.google.co.id/books?id=mmygngEACAAJ.

[15] H. F. W. Taylor, *Cement Chemistry*. London: Academic Press, 1997. https://books.google.co.id/books?id=1BOETtwi7mMC.

[16] ASTM C150/C150M-20, *Standard Specification for Portland Cement*. West Conshohocken, PA, USA: ASTM International, 2020. https://store.astm.org/c0150_c0150m-20.html.

[17] ASTM C33/C33M-18, *Standard Specification for Concrete Aggregates*. West Conshohocken, PA, USA: ASTM International, 2018. https://store.astm.org/c0033_c0033m-18.html.

[18] A. Fahad, N. H. Nayem, M. N. Hossain, M. L. Rabbani, R. K. Opu, S. M. A. Al Shuaeb, "Sand fineness modulus prediction in construction sector using convolutional neural network," *Asian Journal of Civil Engineering*, vol. 25, pp. 443–450, 2024. https://doi.org/10.1007/s42107-023-00786-z.

[19] E. Trujillo, M. Moesen, L. Osorio, A.W. Van Vuure, J. Ivens, I. Verpoest, "Bamboo fibres for reinforcement in composite materials: Strength Weibull analysis" *Composites Part A: Applied Science and Manufacturing*, vol. 61, pp. 115-125, 2014. https://doi.org/10.1016/j.compositesa.2014.02.003.

[20] H. Song, J. Liu, K. He, W. Ahmad, "A comprehensive overview of jute fiber reinforced cementitious composites", *Case Studies in Construction Materials*, vol. 15, 2021, e00724, https://doi.org/10.1016/j.cscm.2021.e00724.

[21] ACI 211.1-91, *Standard Practice for Selecting Proportions for Normal, Heavyweight, and Mass Concrete*. Farmington Hills, MI, USA: American Concrete Institute, 2002. https://id.scribd.com/document/358202789.

[22] ACI 544.1R-96, *Report on Fiber Reinforced Concrete*. Farmington Hills, MI, USA: American Concrete Institute, 2002. https://id.scribd.com/document/367321644/544-1R-96-pdf.

[23] M. Saifullah, M. Hasan, T. Debnath, M. A. Rob, A. H. Tusar, and M. L. Rabbani, "Investigation the Use of Waste Glass and Waste Paper as an Alternative Construction Binding Material: An Approach Towards Sustainable Environment," *American Journal of Environmental Economics*, vol. 3, no. 1, pp. 116–129, 2024. https://doi.org/10.54536/ajee.v3i1.3266.

[24] R. Kumar, R. V. P. Kaviti, L. Mahesh, M. Babu, "Water absorption behavior of hybrid natural fiber reinforced composites," *Materials Today: Proceedings*, vol. 54, no. 2, pp. 187-190, 2022. https://doi.org/10.1016/j.matpr.2021.08.281.

[25] ASTM C642-13, *Standard Test Method for Density, Absorption, and Voids in Hardened Concrete*. ASTM International, 2013. https://store.astm.org/c0642-13.html.

[26] J. A. Abdalla, R. A. Hawileh, A. Bahurudeen, G. Jyothsna, A. Sofi, V. Shanmugam, B.S. Thomas, "A comprehensive review on the use of natural fibers in cement/geopolymer concrete: A step towards sustainability", *Case Studies in Construction Materials*, vol. 19, e02244, 2023. https://doi.org/10.1016/j.cscm.2023.e02244.

[27] T. Debnath, M. A. Rob, S. B. Pranta, and M. L. Rabbani, "Properties evaluation and suitability assessment for construction applications of sand of Kirtankhola River in Bangladesh," *American Journal of Geospatial Technology*, vol. 3, no. 1, pp. 91–100, 2024. https://doi.org/10.54536/ajgt.v3i1.3178.

[28] M. Maier, A. Javadian, N. Saeidi, C. Unluer, H. K. Taylor, C. P. Ostertag "Mechanical properties and flexural behavior of sustainable bamboo fiber-reinforced mortar," *Applied Sciences*, vol. 10, no. 18, p. 6587, 2020. https://doi.org/10.3390/app10186587.

[29] K. Zhang, F. Wang, W. Liang, Z. Wang, Z. Duan and B. Yang "Thermal and mechanical properties of bamboo fiber reinforced epoxy composites," *Polymers*, vol. 10, no. 6, p. 608, 2018. https://doi.org/10.3390/polym10060608.