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Investigation of the Mechanical Properties and Durability Performance of Jute Fiber Concrete

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ABSTRACT

Concrete, inherently weak in tension and shows brittleness, can be strengthened and made more ductile through the addition of continuous reinforcement like fibers. However, conventional reinforced concrete is costly due to production and transportation expenses. This study explores the feasibility of enhancing concrete properties like mechanical and durability performances using locally sourced jute fibers. Mechanical properties like compressive strength, splitting tensile strength, unit weight of jute fiber concrete (JFC) was observed as well as water absorption capacity was observed as durability performance of JFC. Experiments involved preparing concrete cylinders with 0.6%, 0.8%, and 1.0% of volumetric concentrations of 10 mm and 12 mm jute fibers. Results indicated a significant increase in compressive strength from 14.54% to 30.10% and splitting tensile strength of 12.64% with 0.6%, 12 mm jute fibers concrete compared to plain concrete after 28 days. An increasing trend of water absorption capacity of JFC was observed for larger size jute fiber in the jute fiber concrete. The findings are for jute fiber-reinforced concrete as a cost-effective alternative for sustainable construction.

Keywords: Sustainable Construction, Fibrous Composites, Eco-friendly Housing, Mechanical Properties, Durability Performance

1 Introduction

The key feature of hardened concrete is its strength, which is crucial for different structural applications. Although unreinforced concrete can be utilized for numerous purposes, it is naturally brittle. To overcome this drawback, fibers are added to the concrete matrix, affecting characteristics like compressive strength [1],[2]. This study centers on the use of jute fibers as a cost-effective alternative construction material, with a particular focus on enhancing the mechanical properties of concrete—specifically, its compressive strength. As natural fibers like jute gain traction for their ability to improve energy efficiency, reduce costs, and support environmental sustainability in Fiber-Reinforced Cementitious Composites (FRCC), jute stands out due to its affordability and unique composition of cellulose and lignin. Although research into jute's use in cement-based products dates back to the late 1960s, concerns about long-term durability have persisted, primarily due to interactions between the fibers, cement paste, and moisture. This study seeks to address these challenges by substituting traditional steel reinforcement with jute fibers, thereby reducing issues related to steel corrosion and resulting in lighter, yet mechanically improved, concrete. As the world's second most produced natural fiber, jute offers significant potential for sustainable and economical innovation in civil engineering construction [3]-[6]. The primary objective of this study is to comprehensively evaluate the mechanical and durability properties of jute fiber concrete (JFC) through experimental methods. The research specifically aims to assess the compressive and tensile strengths of JFC in comparison to those of conventional plain concrete. In addition, the study investigates the long-term durability of JFC, providing valuable insights into its sustained performance over time. By addressing these aspects, this research contributes to the advancement of sustainable and cost-effective construction practices in civil engineering. Conceptual definitions established in this study will guide the development of operational definitions in later chapters, providing a foundation for systematic exploration of JFC in construction applications [7],[8]. The development of cementitious composites has evolved from the use of asbestos and synthetic fibers to a growing focus on natural fibers. This historical progression sets the stage for the present exploration of sustainable alternatives in construction materials. Research conducted from the late twentieth century through the early twenty-first century has concentrated on refining fiber properties to enhance performance, thereby expanding the potential applications of natural fibers in modern construction projects [9],[10]. Fiber-reinforced concrete utilizes materials such as steel, glass, and synthetic fibers to significantly improve strength and resistance to cracking. Steel fibers are widely employed in both structural and nonstructural contexts, providing key benefits in applications like tunnel linings, slope stabilization, and excavation support. Although glass fibers may experience some loss of strength over time, they are commonly used in exterior building panels and electrical utility products. Synthetic fibers, made from organic polymers, enhance crack control and increase the overall durability of concrete [11],[12]. Natural fiber concrete, incorporating fibers from plants like sisal, coconut, sugarcane, and jute, aligns with sustainable and eco-friendly construction practices. Unprocessed and processed natural fibers present diverse options, each with unique applications and challenges. Jute fiber concrete, specifically focusing on jute fibers, emerges as a promising avenue for enhancing concrete properties. Jute fiber concrete, a specific type of natural fiber concrete, integrates jute fibers to enhance tensile strength, reduce cracking, and improve durability [13],[14]. Jute, known for its affordability and unique properties, ranks as the second most produced natural fiber globally. This section delves into the uses of jute fiber and explores its application in concrete, providing a foundation for

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the subsequent discussion on the effect of jute fiber concrete on mechanical properties [15],[16]. Jute is a versatile natural material renowned for its wide range of applications, from cloth manufacturing and household products to eco-friendly alternatives in multiple industries. Its minimal environmental footprint and recyclability make it an ideal choice for purposes such as erosion control, seed protection, and soil conservation. This section highlights the many uses of jute, providing a foundation for exploring its potential role in concrete applications [17],[18]. Research by Zakaria et al. [19] and Sofat et al. [20] has shown that incorporating jute fibers can enhance the compressive strength of concrete. Similarly, studies conducted by Liu et al. [21], Sultana et al. [22] and Sabarinathan et al. [23] highlight the beneficial impact of jute fiber reinforcement on split tensile strength. Through the analysis of these findings, this literature review seeks to offer a thorough understanding of how jute fiber incorporation influences the mechanical properties of concrete [18]-[21],[23].

Despite the intrinsic advantages that natural fibers possess compared to synthetic ones, it is important to acknowledge that the literature also points out certain drawbacks linked to natural fibers. For instance, they tend to absorb more moisture and exhibit lower mechanical strength. Although there are numerous studies focused on natural fiber composites, there is a significant lack of research regarding the various manufacturing processes for jute fiber-based composites and how these processes impact the mechanical properties of the composites. This study aims to provide a focused review of JFCs, emphasizing the unique advantages and challenges associated with different manufacturing methods. This study also addresses a notable gap in existing literature by investigating the mechanical and durability properties of jute fiber concrete (JFC). Integrating jute fibers into concrete opens new avenues for enhancing performance while aligning with sustainability goals. The research scope encompasses evaluating JFC's mechanical and durability characteristics relative to plain concrete, considering various fiber fractions, and examining factors that influence these properties.

2 Methodology

2.1 Material Used in this Study

2.1.1 Cement

For this research, cement has been employed as the binding material. Specifically, Ordinary Portland cement (OPC), known as PREMIER cement, has been used, and it was sourced from Dinajpur town. Table 1 contains information about the properties of OPC Cement.

Table 1 Physical properties of OPC

Properties	Values
Specific gravity	3.12
Initial setting time	65 min
Final setting time	275 min

2.1.2 Aggregate

In this investigation, locally sourced materials, specifically Panchagarh crushed stone and sand, were employed as coarse aggregate (CA) and fine aggregate (FA), respectively. The sizes for coarse aggregate were 19 mm downgrade. The physical characteristics of all aggregate groups were determined, and the findings are detailed in Table 2. To establish the particle size distribution of the aggregates, sieve analysis was conducted and the outcomes are shown in Fig. 1 & Fig. 2.

Table 2 Physical properties of aggregates

Specification	Code followed	Coarse Aggregates	Fine Aggregates
Bulk specific gravity	ASTM C127[24] & ASTM C 29 [25]	2.77	2.52
Gradation	ASTM C136[26]	Fineness Modulus = 6.42	Fineness modulus = 2.55
Bulk specific gravity (SSD)	ASTM C127[24] & ASTM C128[27]	2.78	2.56
Absorption (%)	ASTM C127[24] & ASTM C128[27]	0.47	1.83
Bulk density (loose) Kg/m^3	ASTM C29 [25]	1357.53	1679.00
Bulk density (compacted) Kg/m^3	ASTM C29 [25]	1543.21	1526.31

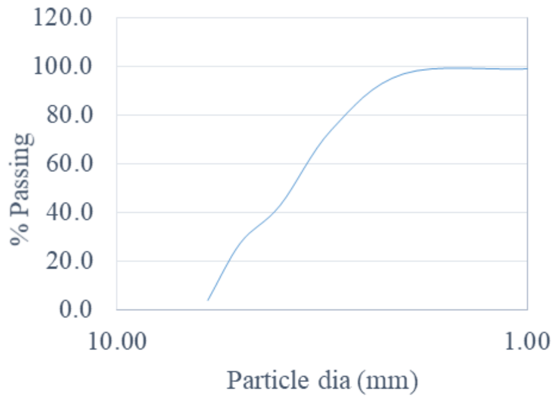

Fig. 1 Gradation curve of coarse aggregate

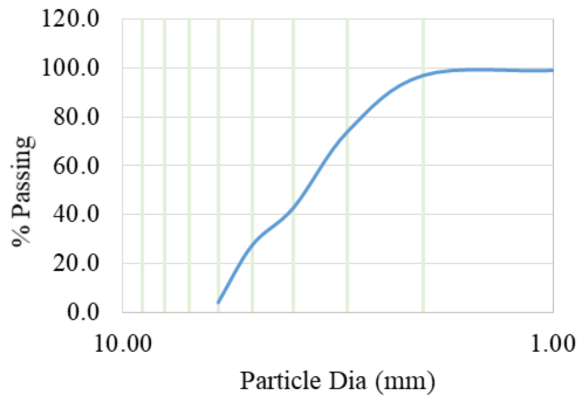

Fig. 2 Gradation curve of fine aggregate

2.1.3 Jute fiber

The fibers examined in this experimental study are jute fibers, specifically sourced from the local region in Dinajpur district and the fibers are shown in Fig. 3. The jute fiber of two different lengths 10 and 12 mm was cut by hand scissors and mixed with concrete mix. Jute fiber formation in concrete is displayed in Table 3.

Table 3 Jute fiber formation in concrete

Jute fiber percentage	Length of jute fiber(mm)
0%	-
0.6%	10,12
0.8%	10,12
1.0%	10,12

Fig. 3 Jute Fiber collected from local market of Dinajpur city

2.1.4 Superplasticizer

A superplasticizer, known as Conplast Sp337, was also used to significantly reduce water demand in concrete, without reducing workability, and allowing high early and ultimate strengths without additional cement. The characteristic of this superplasticizer is that (i) Appearance: dark brown liquid, (ii) Density: 1.205 ± 0.01 kg/L, (iii) pH: 1.08 ± 1.0.

2.2 Concrete mix

Specific mix design with a target strength of 20 MPa was used in this study because common ratios practiced in neighboring countries like India, Pakistan and Nepal was used. For this study, mix ratios of 1:1.5:3 for M20 concrete and water/cement ratio as 0.45 were used to cover the target strength. The concrete mix design is shown in Table 4. The concrete mixing, casting and curing of JFC are shown in Fig. 4.

Table 4 Concrete mix proportion of 1 m^3 of concrete

Concrete Type	Fiber length (mm)	Fiber percentage (%)	Cement (kg)	Sand (kg)	Aggregate (kg)	Water (kg)	W/C ratio
0JFC	N/A	0	360	584	1224	162	0.45
0.6JFC	10	0.6	360	584	1224	162	0.45
0.8JFC	10	0.8	360	584	1224	162	0.45
1.0JFC	10	1.0	360	584	1224	162	0.45
0.6JFC	12	0.6	360	584	1224	162	0.45
0.8JFC	12	0.8	360	584	1224	162	0.45
1.0JFC	12	1.0	360	584	1224	162	0.45

2.3 Experimental test

In the experimental phase, workability tests were carried out for each concrete mix following ASTM C143M-12 [28] standards. The concrete was cast into cylindrical molds (100 mm × 200 mm), adhering to the compaction procedure outlined in ASTM C31/C31-19 [29]. A total of 105 specimens were cast for subsequent tests, including compressive strength, tensile strength, and durability tests. Subsequently, the cured specimens underwent a curing period of 7 and 28 days in accordance with ASTM C31 [29] guidelines. The water absorption examination, a crucial test to evaluate the porosity and durability of concrete, followed ASTM C642-06 [30] standards. Additionally, the unit weight of jute fiber concrete was determined using the ASTM C642-06 [30] procedure. Compressive strength and split tensile strength tests were conducted after 7 and 28 days of curing, adhering to ASTM C39/C3M-18 [31] and ASTM C 496/C 496M – 04 [32] standards, respectively. The modulus of elasticity of JFC was determined per ACI 318-14 [33], employing the specified formula shown in Eq. (1)

$$E_c(MPa) = 4700\sqrt{f_c^/} \tag{1}$$

where $f_c^/$ represents the specified compressive strength of concrete at 28 days. The testing machine setup for compression and tensile strength is shown in Fig. 5.

(a) Concrete mixing

(b) Fresh JFC

(c) Curing of JFC

Fig. 4 (a) Concrete mixing, (b) casting and (c) curing of JFC used in this study

(a) Compression test setup

(b) Splitting tensile test setup

Fig. 5 Compression and tensile strength testing machine

On the other hand, the water absorption test of JFC measures the percentage of water taken up by concrete specimens. In this procedure, the specimens are first oven-dried, then cooled to room temperature. They are subsequently immersed in water for 24 hours. After removal from water, the specimens were wiped with a damp cloth and weighed again. The percentage of water absorption is calculated based on the difference between the dry and wet weights shown in Eq. (2).

$$Water\ absorption\ (\%) = \frac{W_{ssd}-W_d}{W_d} \times 100 \tag{2}$$

where, W_d = mass of a dry specimen in kg and
W_{ssd} = mass in saturated surface-dry (SSD) condition in kg

3 Results and Discussion

3.1 Slump value

The results of the workability tests, as measured by slump values, for different fiber lengths (10mm and 12mm) of JFC with varying fiber content (0.6%, 0.8%, and 1% of volume) and the addition of 1.5% of admixture are presented in Fig. 6 and Fig. 7. Additionally, the slump value for plain concrete (0JFC) is included for comparative purposes.

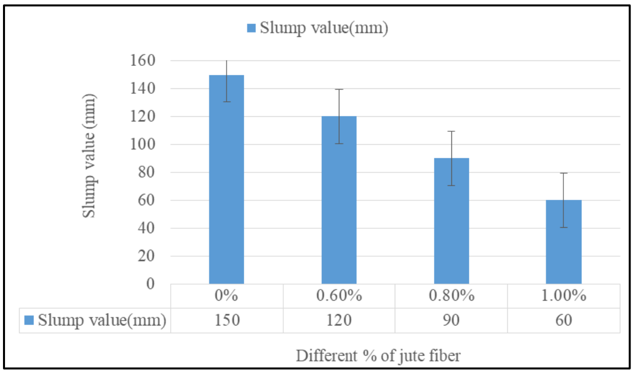

Fig. 6 Slump value for all mixes (10mm length)

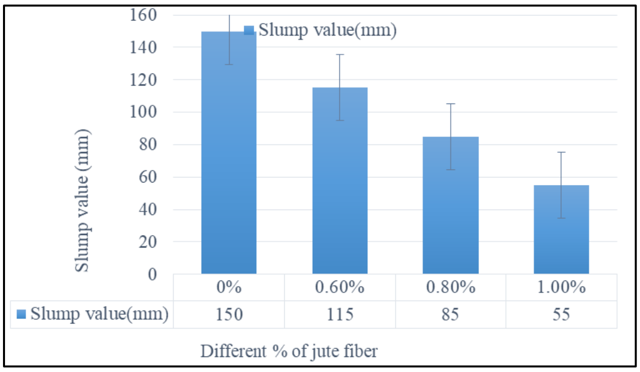

Fig. 7 Slump value for all mixes (12mm length)

The results presented in the Fig. 6 and Fig. 7 illustrated the effects of varying fiber content and admixture on the slump values of different concrete mixtures, specifically 10mm and 12mm fiber lengths. In the case of 0% JFC, where no fibers are added (N/A), the slump value is notably high at 150 mm, indicating a more workable and flowable concrete mixture. As the fiber content increases, the slump values decrease, suggesting a reduction in workability and increased stiffness. For instance, 0.6 % JFC, with 0.6% fiber content and 10mm length, exhibits a slump value of 120 mm, while 0.6% JFC with 12mm length has a slightly lower slump of 115 mm. Similarly, higher fiber contents of 0.8% and 1.0% in JFC lead to further reductions in slump values, with 1.0% JFC recording the lowest slump of 55 mm. This reduction in slump is indicative of the reinforcing effect of fibers, as they enhance the concrete's ability to maintain its shape under load. The results highlight the trade-off between fiber content and workability, which is essential to consider in designing concrete mixtures for specific applications.

3.2 Compressive strength test result

Fig. 8 displays the 7-day compressive strength of JFC with 10mm and 12mm fiber lengths, with various fiber percentages. When no fibers were added (0%), the mean compressive strength was 18.5 MPa. The introduction of 10mm fibers at 0.6%, 0.8%, and 1.0% fiber percentages led to mean compressive strengths of 20.44 MPa, 20.70 MPa, and 19.96 MPa, respectively.

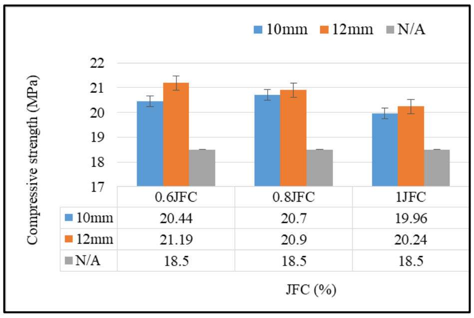

Fig. 8 7-day compressive strength results of JFC with 10 mm and 12 mm length jute fiber.

This represented relative compressive strength gains of 10.49%, 11.89%, and 7.89% compared to the control (N/A or 0%) condition. Similarly, with 12mm fibers, the compressive strength increased. At 0.6%, 0.8%, and 1.0% fiber percentages, the mean compressive strengths were 21.19 MPa, 20.90 MPa, and 20.24 MPa, respectively. These improvements represented relative compressive strength gains of 14.54%, 12.97%, and 9.40% compared to the reference case without fibers. Overall, the results indicate that the addition of jute fibers, particularly at 12mm length and 0.6% fiber percentage, had the most substantial positive impact on the 7-day compressive strength of JFC. The results show that fiber reinforcement contributes to increased strength, with the longer fibers having a more pronounced effect on enhancing the compressive strength. Fig. 9 presents the 28-day compressive strength results of JFC with 10mm and 12mm fiber lengths, at various fiber percentages.

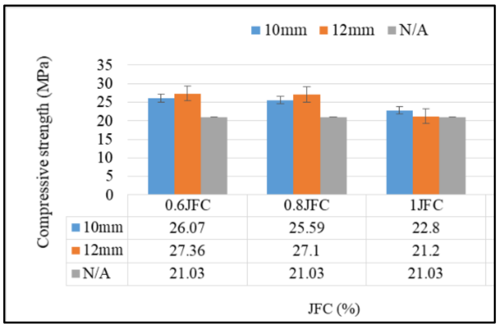

Fig. 9 28-day compressive strength results of JFC with 10mm and 12 mm length jute fiber

Without the inclusion of fibers (N/A or 0%), the mean compressive strength at 28 days was 21.03 MPa. When 10mm fibers were introduced at 0.6%, 0.8%, and 1.0% fiber percentages, the mean compressive strengths at 28 days were 26.07 MPa, 25.59 MPa, and 22.80 MPa, respectively. These results represented relative compressive strength gains of 23.96%, 21.68%, and 8.41% compared to the control condition (N/A). With 12mm fibers, the improvements in compressive strength were even more pronounced. At 0.6%, 0.8%, and 1.0% fiber percentages, the mean compressive strengths at 28 days were 27.36 MPa, 27.10 MPa, and 21.20 MPa, respectively. These results represented remarkable relative compressive strength gains of 30.10%, 28.86%, and 0.80% when compared to the reference case without fibers. In summary, the results demonstrate that the addition of jute fibers significantly enhances the 28-day compressive strength of JFC. The impact is more notable with 12mm fibers, particularly at 0.6% and 0.8% fiber percentages, where substantial strength gains were achieved. However, for 10mm fibers, the best results were seen at 0.6% fiber percentage, highlighting the influence of both fiber length and percentage on the compressive strength of JFC at 28 days.

In the context of improving concrete's compressive strength through the incorporation of jute fiber, our study achieved a notable 30.10% increase for 0.6% fiber, reaching 27.36 MPa at 28 days, employing a specific mix ratio (1:1.5:3), a water-cement (w/c) ratio of 0.45, and a 1.5% superplasticizer. Comparing the results with Rahman and Azad [34], it was observed that a more substantial increase in compressive strength (30.10% compared to 15%) with 0.10% fiber content. A similar trend was seen in these findings compared to Zakaria et al. [19], indicated a 30.10% increase with 0.25% fiber content, slightly exceeding their reported 26.15% increase. Overall, this study demonstrated the effectiveness of jute fiber reinforcement in enhancing concrete's compressive strength, outperforming some previous research and closely aligning with others like Rahman and Azad [34] and Zakaria et al. [19].

3.3 Splitting tensile strength test results

The 7-day split tensile strength results of JFC with 10mm, and 12mm length jute fiber and the relative split tensile strength are presented in Fig. 10.

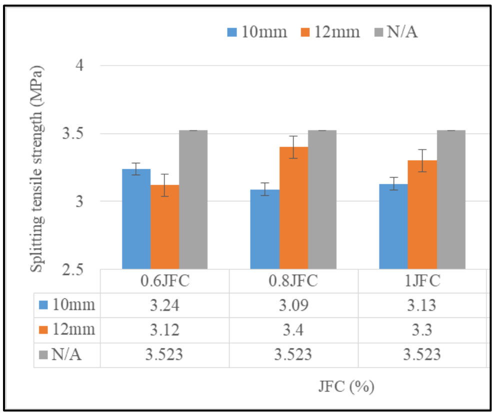

Fig. 10 7-day splitting tensile strength of JFC with 10 mm and 12 mm length jute fiber

Fig. 10 presents the 7-day tensile strength results of JFC with 10mm and 12mm fiber lengths, at varying fiber percentages. In the absence of fibers (N/A or 0%), the mean tensile strength at 7 days was 3.523 MPa. The introduction of 10mm fibers at 0.6%, 0.8%, and 1.0% fiber percentages resulted in mean tensile strengths at 7 days of 3.24 MPa, 3.09 MPa, and 3.13 MPa, respectively. These outcomes represented relative tensile strength losses of 8.73%, 13.36%, and 12.13% compared to the control condition (N/A). For 12mm fibers, at 0.6%, 0.8%, and 1.0% fiber percentages, the mean tensile strengths at 7 days were 3.12 MPa, 3.40 MPa, and 3.30 MPa, respectively. These results showed relative tensile strength losses of 12.43%, 3.80%, and 6.88% when compared to the reference case without fibers. In summary, the inclusion of jute fibers, whether at 10mm or 12mm in length, and at various fiber percentages, generally resulted in a decrease in tensile strength at 7 days. The most significant decrease was observed in the 10mm fiber group at 0.8% and 1.0% fiber percentages. The findings underscore the importance of considering the trade-off between the addition of fibers for other desired properties such as compressive strength and the potential reduction in tensile strength at early ages. Fig. 11 provides the 28-day tensile strength results for JFC with 10mm and 12mm fiber lengths at varying fiber percentages. 12 mm length jute fiber

In the absence of fibers (N/A or 0%), the mean tensile strength at 28 days was 4.27 MPa. When 10mm fibers were introduced at 0.6%, 0.8%, and 1.0% fiber percentages, the mean tensile strengths at 28 days were 4.26 MPa, 3.39 MPa, and 3.87 MPa, respectively.

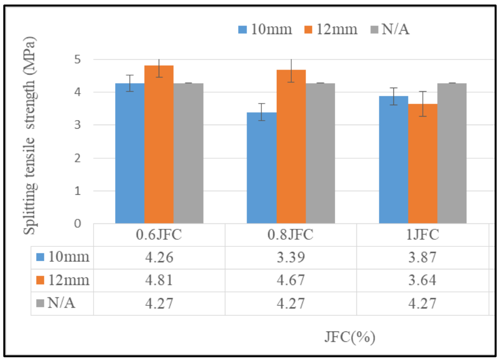

Fig. 11 28-day splitting tensile strength of JFC with 10 mm and

These outcomes represented relative tensile strength declines of 0.23%, 20.60%, and 9.37% compared to the control condition (N/A). For 12mm fibers, at 0.6%, 0.8%, and 1.0% fiber percentages, the mean tensile strengths at 28 days were 4.81 MPa, 4.67 MPa, and 3.64 MPa, respectively. These results showed relative tensile strength changes of 12.64%, 9.36%, and 14.75% when compared to the reference case without fibers. In summary, the addition of jute fibers had varying effects on the 28-day tensile strength of JFC. While some configurations, particularly 12mm fibers at 0.6% fiber percentage, exhibited significant improvements, other combinations, especially 10mm fibers at higher percentages, led to reductions in tensile strength. These results emphasize the importance of selecting the appropriate fiber length and percentage to achieve desired tensile strength outcomes in JFC. These results indicate that the impact of jute fibers on 28-day tensile strength varies based on the fiber length and percentage. The introduction of 10mm jute fibers at 0.6% showed a notable improvement, whereas higher percentages led to reduced tensile strength. In the case of 12mm fibers, lower percentages demonstrated limited effects on tensile strength, while the 0.8% content showed positive results. The loss in tensile strength for 1.0% fiber content may indicate potential fiber clumping or an imbalance in the fiber-matrix interaction. Sultana et al. [22] and Nambiar and Haridharan [35] applied soft computing techniques to predict the mechanical characteristics of jute fiber-reinforced concrete. That investigations experienced a 3.5 N/mm^2 rise in split tensile strength when 0.2% of jute fiber content was added while maintaining a water-cement (w/c) ratio of 0.55. This outcome underscores the beneficial impact of a small quantity of jute fiber reinforcement on the split tensile strength of concrete. So, this study produced similar results, where it was introduced 10mm jute fibers at a 0.6% fiber content. This result showed a noticeable increase in tensile strength to 4.81 MPa, signifying a 12.64% improvement in tensile strength when compared to the control mixture. This aligns with the findings of Sultana et al. [22] and emphasizes the positive influence of incorporating jute fibers on the split tensile strength of concrete. Balancing the improved compressive strength seen in previous discussions with the impact on tensile strength is essential in designing JFC mixes. It's clear that the choice of fiber length and content can significantly affect the tensile behavior of JFC. Further research may be necessary to explore the long-term tensile performance and to determine the optimal fiber parameters for specific JFC applications.

3.4 Durability test

The durability of concrete in this study was determined by water absorption test only. The water absorption characteristics of jute fiber-reinforced concrete were investigated with varying fiber lengths and percentages (0.6%, 0.8%, and 1%). The data obtained from the experiments are presented in Fig. 12.

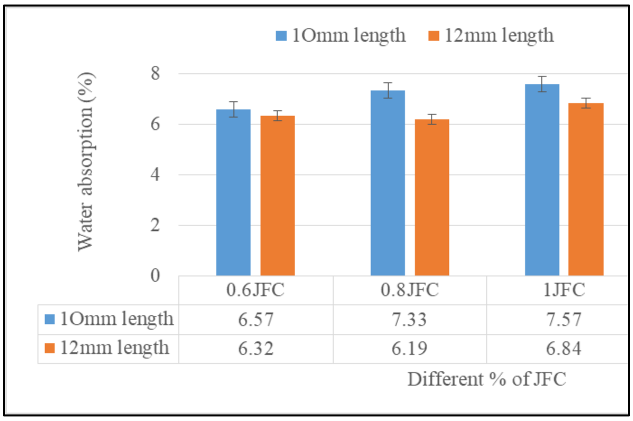

Fig. 12 Water absorption test results

The results in Fig. 12 presented water absorption percentages for JFC with two different fiber lengths (10mm and 12mm) and various fiber percentages (0.6%, 0.8%, and 1.0%). To assess the impact of jute fiber reinforcement, the comparison of these results to the control mix, which contains no jute fibers (N/A) and had a water absorption percentage of 4.8%. For the 10mm fiber length, an increasing trend in water absorption was observed as the fiber percentage rises. At 0.6% fiber content, the water absorption increased to 6.57%, representing an increment compared to the control mix. A further increase to 0.8% fiber content led to 7.33% water absorption, and at 1.0% fiber content, the water absorption reached 7.57%. These findings indicate that the addition of 10mm jute fibers, while improving compressive strength (as seen in the previous discussion), also led to higher water absorption, particularly at the 0.8% and 1.0% percentages. For the 12mm fiber length, the results show a different trend. In this case, the 0.6% fiber content led to a water absorption of 6.32%, which is slightly lower than the control mix. The 0.8% fiber content demonstrated an even lower water absorption of 6.19%, and the 1.0% fiber content increased it to 6.84%. It is interesting to note that the addition of 12mm jute fibers at 0.8% led to a reduction in water absorption compared to the control mix, demonstrating that certain combinations of fiber length and percentage can lead to improvements in water resistance alongside enhanced compressive strength. These results highlight the importance of considering both water absorption and compressive strength when designing JFC mixes. The choice of fiber length and percentage can be tailored to meet specific project requirements, balancing strength improvements with potential changes in water absorption properties. Further research and testing may be needed to explore the optimal combinations for desired performance in JFC.

3.5 Unit weight of JFC

The unit weight of jute fiber concrete was investigated with varying fiber lengths and percentages. The data obtained from the experiments are presented in the Fig. 13 for the unit weight of jute fiber concrete. Fig. 13 shows comparison unit weight for plain concrete and concrete with 0%, 0.6%, 0.8%, 1%jute fiber of 10- and 12-mm lengths respectively. To assess the influence of jute fiber reinforcement on unit weight, the comparison of these values to the control mix (N/A), which contains no jute fibers. The control mix had a dry unit weight of 2442.5 kg/m^3 and a saturated surface-dry (SSD) unit weight of 2560 kg/m^3. When 10mm jute fibers were introduced at a 0.6% fiber content, the dry unit weight reduced to 2200.5 kg/m^3, and the SSD unit weight decreased to 2345.06 kg/m^3. The control mix had a dry unit weight of 2442.5 kg/m^3 and a saturated surface-dry (SSD) unit weight of 2560 kg/m^3.

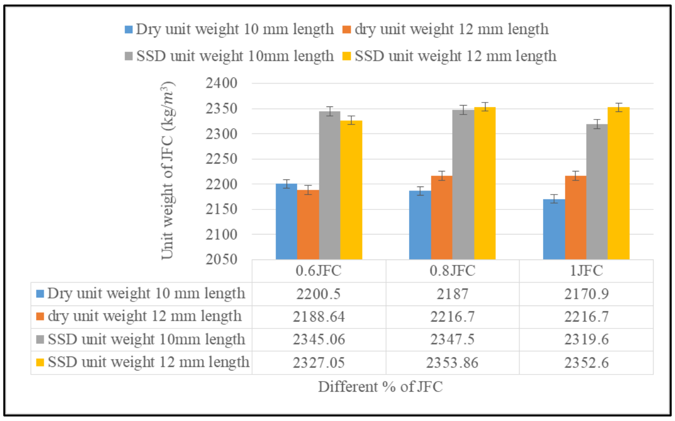

Fig. 13 Unit weight of jute fiber concrete graph.

When 10mm jute fibers were introduced at a 0.6% fiber content, the dry unit weight reduced to 2200.5 kg/m^3, and the SSD unit weight decreased to 2345.06 kg/m^3. Similarly, at 0.6% fiber content with a different batch, the dry unit weight was 2187 kg/m^3, and the SSD unit weight was 2347.5 kg/m^3. These findings suggested that the addition of 10mm jute fibers at 0.6% resulted in a lower unit weight compared to the control mix. For 10mm fibers at a higher 0.8% content, the dry unit weight further decreased to 2170.9 kg/m^3, with the SSD unit weight at 2319.6 kg/m^3. Moving to 12mm length jute fibers, at a 0.8% content, the dry unit weight was 2188.64 kg/m^3, and the SSD unit weight was 2327.05 kg/m^3. At 1.0% fiber content with 12mm fibers, the dry unit weight was 2216.7 kg/m^3, and the SSD unit weight was around 2353.86 kg/m^3, while the second batch with the same parameters resulted in an SSD unit weight of 2352.6 kg/m^3. These results indicate that the introduction of jute fibers, especially at higher fiber percentages and with longer 12mm fibers, led to a decrease in unit weight. The decrease in unit weight may be attributed to the lighter nature of the jute fibers compared to the concrete matrix, which displaces some of the concrete material and reduces the overall density. This can have implications for structural design, as lower unit weight may affect load-bearing capacities. Therefore, when designing JFC mixes, it's essential to carefully consider the trade-off between fiber reinforcement for strength and the potential reduction in unit weight for the intended application.

3.6 Modulus of elasticity of JFC

The test results of the modulus of elasticity of JFC are presented in Fig. 14. The test results for the modulus of elasticity of JFC are shown in Fig. 14. It was obvious that fiber length and percentage influenced the characteristics of JFC. In particular, the highest modulus of elasticity was observed for 12mm fiber length and 0.6% fiber percentage (24.58 GPa), while the lowest is for 12mm length and 1.0% percentage (21.64 GPa).

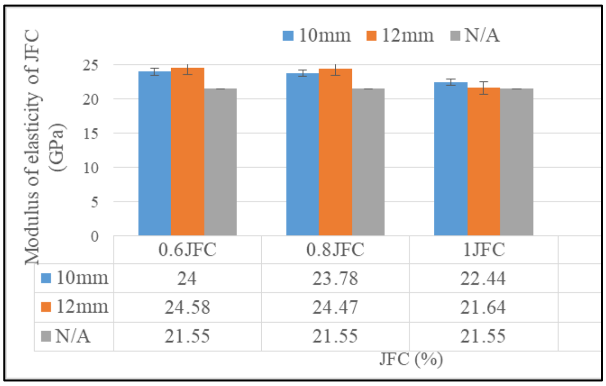

Fig. 14 Modulus of elasticity of JFC

These results demonstrate the importance of selecting appropriate fiber characteristics to achieve desired mechanical properties in JFC. The "N/A" entry suggests that no data is available for that specific condition.

3.7 Mode of failure pattern of the cylindrical specimen

The failure mode of standard concrete and concrete with 0.6%, 0.8% and 1.0 % jute fiber cement exhibit a sudden and explosive pattern. The following section displays the failure modes for conventional concrete and JFC concrete with varying jute fiber percentage (0%, 0.6%, 0,8%, 1.0%) shown in Fig. 15 and Fig. 16. Similarly, the failure pattern of concrete cylindrical specimens under compression load is depicted in Fig. 17 based on ASTM C39 [31].

(a) 0% fiber

(b) 0.6% fiber

(c)0 8% fiber

(d) 1.0% fiber

Fig. 15 Mode of failure pattern of cylindrical specimens under compression load

(a) 0% fiber

(b) 0.6% fiber

(c) 0.8% fiber

(d) 1.0% fiber

Fig. 16 Mode of failure pattern of cylindrical specimens under splitting tensile load

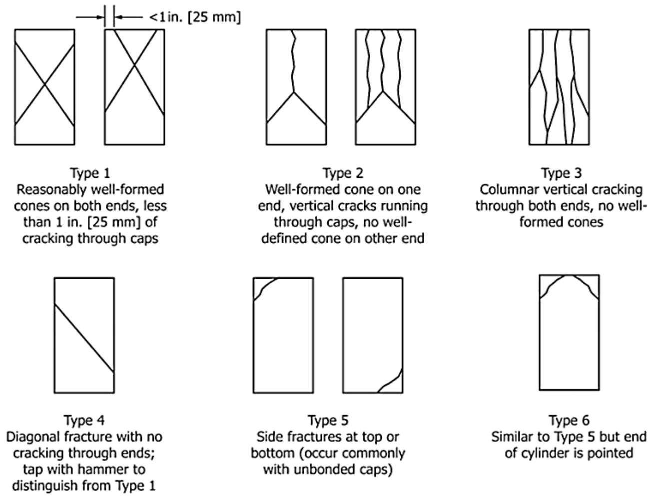

Fig. 17 Schematic diagram of typical fracture pattern under compression load

Based on the Fig. 17, the failure patterns visible in Fig. 15 (a), (c) and (d) most closely resemble the columnar or type 3 fracture pattern as described in the ASTM C39 standard [31]. The cylinders have fractured into columns along vertical planes running the length of the specimen. On the other hand, the failure pattern shown in the Fig. 15 (b) is a well-formed cone, which is classified as a type 2 fracture pattern according to the ASTM C39 standard [31]. This type of failure occurs when the concrete cylinder splits vertically into several columns along its length, as is clearly visible in the Fig. 15.

4 Conclusions

Natural fiber-based cement concrete (NFCC) is getting a lot of attention because it is affordable, lightweight, strong, durable, eco-friendly, good at keeping heat, and can resist damage from rust. This special concrete with fibers in them is a big deal in the world of building things because they can make structures stronger and fix damaged concrete. This study aimed to evaluate the strength enhancement of concrete reinforced with jute fibers (JF). Following a systematic screening, extraction, and analysis of the data, the following conclusions were drawn:

- Increasing the fiber content from 0.6% to 1% alongside a 1.5% superplasticizer causes a substantial reduction in slump values, this indicates a marked decrease in workability with higher fiber content, even in the presence of an admixture.
- Comparing 10mm and 12mm fiber lengths with a constant fiber content of 0.6% and 0.8% and 1% the 12mm fibers generally yield lower slump values, signifying those longer fibers render the concrete less workable.
- The inclusion of 0.6% and 0.8% jute fibers with 12mm lengths leads to substantial increases in compressive strength, with a 30.10% and 28.86% gain, respectively, compared to the control mix. These findings emphasize the effectiveness of 12mm jute fibers at these percentages in significantly enhancing the long-term compressive strength of JFC.
- This study achieved a noteworthy 30.10% increase in compressive strength with 0.6% fiber content.
- This study also confirmed the positive influence of jute fiber reinforcement on split tensile strength, with a 12.64% improvement when using 10mm jute fibers at a 0.6% fiber content.
- The addition of 10mm jute fibers, especially at 0.8% and 1.0% content, increased water absorption. Conversely, the

use of 12mm jute fibers at 0.8% content led to a reduction in water absorption.

- The introduction of 10mm jute fibers at 0.6% content resulted in lower unit weights compared to the control mix. The inclusion of 12mm jute fibers at 0.8% and 1.0% content also led to lower unit weights.
- The optimal modulus of elasticity for JFC was achieved with 12mm fiber length and 0.6% fiber percentage at 24.58 GPa.
- Moreover, other mechanical properties such as flexural strength, stress-strain behavior of JFC as well as other durability assessments of JFC like chemical resistance, water permeability, RCPT etc. may be required for future studies. Also, microstructural analysis may be required for future studies to investigate internal structure of JFC.

Author Contributions

T. Bhushal: Data curation, Formal analysis, Investigation, Methodology, Roles/Writing – original draft; **M. R. Haque:** Supervision, Conceptualization, Methodology, Validation, Visualization, Roles/Writing – original draft, Writing – review & editing; **M. R. Islam:** Data curation, Formal analysis, Investigation, Methodology; **H. Al-Mohmud:** Data curation, Formal analysis, Investigation, Methodology.

Conflict of Interest Statement

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this study.

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Generative AI Statement

No generative AI/LLM was used in any stage of this manuscript. The authors verified all outputs. No AI-generated content, data, or analysis is presented as original work.

Data Availability

Data will be made available on request.

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