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STUDY ON THE EFFECT OF JUTE TO THE MECHANICAL PROPERTIES OF CONCRETE IN BANGLADESH

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Graphical abstract

Abstract

Concrete, the prevailing construction material globally, is a composite blend comprising cement, sand, coarse aggregate, and water. Nevertheless, concrete as a structural material faces certain limitations that curb its widespread application, including brittleness, limited ductility, inadequate resistance to impact strength, fatigue, and diminished durability. Fiber reinforced concrete, blending concrete with natural fibers like jute, offers promise in overcoming these challenges, particularly due to its enhanced tension detection capabilities. This study investigates how the freshly state properties and strength of concrete are affected by jute fiber. Raw jute fibers were cut to 10 mm and 15 mm and mixed with cement, fine aggregate, and coarse aggregate in different proportions in this work with varying volumes of jute fibers (1%, 2%, 3%, 4% and 5%) and cured for 7, 14 and 28 days with 0.50 water-cement ratio. The study found that compressive strength was increased 7.77% by using 1% proportion with 10 mm length and split tensile strength was increased 15.14% by same percentage and length of jute fiber content at 28 days. However, the mechanical properties of concrete decrease by the increasing fiber content resulting in poor workability of concrete.

Keywords: Natural fiber, Jute, Concrete, Compressive strength, Tensile strength, Bangladesh.

1.0 INTRODUCTION

Concrete has long been a favored construction material for building infrastructure due to its durability and versatility. Its composition typically includes binder, aggregates, and a carefully balanced amount of water. However, concrete is inherently brittle and possesses lower tensile strength compared to materials like metals and polymers. Steel exhibits approximately 100 times greater resistance to crack formation compared to concrete, as determined by fracture toughness measurements [1]. According to Balaguru et al.,(1992) reinforcing fiber has been shown to be a highly effective way to solve the drawbacks of plain concrete [2]. To use of fiber in concrete is not new, it has started since the 1900s [3]. Fiber reinforced concrete (FRC) is the result of this addition, featuring a random distribution of short, dispersed fibers throughout the material. Over time, FRC has gained recognition as a standard building material, offering improved toughness and durability. According to ACI 544.4R-88 (1999), FRC is defined as a composition comprising aggregate, Portland cement, and carefully integrated fibers. This controlled incorporation of fibers contributes to the enhancement of concrete's performance, making it more resistant to cracking and improving its overall structural integrity [4]. The inclusion of fibers in the concrete not just enhances the durability, also serves to mitigate crack formation [5]. This reinforcement helps to regain strength after cracking and enhances the concrete's resistance to shear and punching forces. FRC is characterized by the uniform dispersion of small, discontinuous fibers throughout the concrete body. FRC incorporates fibers of various materials, including steel, galvanized iron, carbon, aramid, polypropylene, glass, asbestos, and jute among others. These fibers provide significant improvement of the overall performance and properties of concrete, imparting added strength and resilience against cracking and other forms of structural damage.

Numerous researchers have explored the application of steel fibers to upgrade the properties of concrete. A study conducted by Mohd Muzammil Ahmed et al.,(2015) reported that the flexural behavior of beams was found to significantly improve with the incorporation of fibers. Specifically, the flexural strength of the beams increased by approximately 21.58% [6]. Consequently, Arunakanthi et al.,(2016) conducted experimental research on steel fiber-reinforced concrete, noting that incorporating 1.5% of steel fiber led to significant improvements. Specifically, the split tensile strength increased by 14-36% and 15-39% for 7 and 28 days, respectively, while the compressive strength increased by 8-21% and 6-12% [7]. Numerous studies have looked into the impact of fibers on concrete, highlighting a common technological challenge for both developing and advanced nations: producing cost-effective and robust FRC. Concerns regarding cost-effectiveness and environmental impact have limited the widespread adoption of carbon fiber in cementitious composites, primarily remaining at the commercial level. Additionally, artificial fibers pose drawbacks such as higher costs and potential health and environmental risks. To address these challenges, natural fibers emerge as a promising solution [8]. Derived from readily available resources like banana trees, coconut trees, cotton, jute, and other natural sources, these fibers offer several advantages. They are biodegradable, inexpensive, and environmentally friendly. By incorporating natural fibers into plain cement concrete, it is possible to mitigate the shortcomings associated with polymer-based fibers while maintaining cost-effectiveness and ecological sustainability [9]. A number of researches have been found the effect of different types of natural fibers on the concrete properties like mechanical, physical, chemical, durability properties through various test methods.

According to Reis JML et al., (2004) incorporating coconut fiber resulted in an approximately 25% increase in flexural strength compared to conventional unreinforced concrete. Additionally,they noted a slight enhancement (3.5%) in flexural strength with the use of sugarcane bagasse[10]. As reported by Kriker AG et al.,(2005) under water curing conditions, vegetable fiber-reinforced concrete exhibits a modest advantage in compressive strength [11].

Furthermore, jute fiber is one of the most environment friendly, affordable, non-toxic, and biodegradable materials. It is a resilient, quick-growing sustainable, and light-reactive crop that takes about 120–150 days to convert from seed to fiber state [12]. Currently, Bangladesh is the second-largest jute producer in the world with an estimated annual production of 1.6 million tons in 2019 but has a very small local market for fiber and its products as from the beginning of the industry, the sector has been heavily dependent on exports [13]. For the emergence of inexpensive synthetic substitutes, bulk handling, containerization, and soil storage, it is also losing market share in key countries. So, it must be used in a variety of ways (like fiber in concrete mix) to prevent the jute industries from further collapsing. Numerous researchers have already begun integrating jute fiber into conventional concrete.

Mansur et al., (2022) examined that the compressive strength of concrete increased by 64.34% compared to natural concrete after 28 days by using 0.1% jute fiber in concrete with water cement ratio was 4% [14]. Gupta et al., (2021) undertook a study to evaluate the performance of jute fiber-reinforced concrete in comparison to normal concrete, examining different fiber proportions (0.1%, 0.2%, and 0.3%) at a water-cement ratio of 0.38. Their findings revealed enhancements in compressive strength of up to 2.03% [15]. Pramodini Sahu et al., (2020) reported a comprehensive study with different fiber percentages (0.15%, 0.25%, 0.35%, and 0.5% by weight) of M30 grade concrete mix and observed that the 28-day concrete strength was optimal with 0.25% of jute fiber mix [16].

Accordingly, Ahmed et al., (2020) investigated the impact of jute fiber content on concrete compressive strength, finding increases of 1.8% and 2.5% with respective fiber proportions of 0.1% and 2.5%, while maintaining a water-cement ratio of 0.35 [17]. Islam et al., (2018) conducted research on the effects of untreated jute fibers on concrete characteristics and they observed that integrating finer fibers resulted in improvements in both compressive and flexural strength [18]. Furthermore, Zakaria et al., (2017) suggested an increase in compressive, flexural, and split tensile strength with lower cut jute fibers and smaller volumetric content. They also noted that long fibers with higher volume contributed to the inhomogeneous mixing of the composite [19]. Mostak et al., (2024) carried out an investigation using jute fiber of 15 mm and 20 mm length of different volumetric proportions of 0.1%, 0.2% and 0.3% in conventional concrete having w/c ratio 0.50. The study found that jute fibers improved compressive strength 7.77% and 4.66% at 0.1% content for 15mm and 20mm jute fibers respectively but increasing the fiber content further reduced compressive strength with poor workability of concrete [20].

In contrast, a survey conducted by the United Nations suggests that the consumer market's inclination towards natural products is increasing by 2% to 3% annually [21]. The global demand for various jute products is experiencing significant growth due to the rising popularity of environmentally friendly options. With the surge in demand for eco-friendly products, Bangladesh holds considerable potential to rebrand its jute products. Consequently, aligning with the go-green movement, jute emerges as a cost-effective alternative to composite materials. Furthermore, the inherent shortage of cementitious materials could potentially be addressed by utilizing jute fiber as reinforcement [21].

Most of the researchers have considered the usage of fiber contents up to 1% and more than that was rarely attempted. This study aims to explore the feasibility of incorporating high propotion of jute fibers into concrete for assessing their mechanical properties. Therefore, the main objective of the study is to investigate the effect of raw jute on the strength characteristics of FRC, including compressive strength and tensile strength, experimentally and compare it with ordinary concrete in developing a low -cost construction material.

2.0 METHODOLOGY

2.1 Material Properties

2.1.1 Cement

In this investigation, Ordinary Portland Cement (OPC) acts as the principal binding agent for the preparation of concrete. Due to its chemical reactivity upon hydration, OPC significantly influences the desired properties of concrete in an economically viable manner. It is essential to select the appropriate type of OPC and utilize it correctly to achieve optimal results. According to ASTM C150 standards, the initial setting time of OPC should not be less than 45 minutes, and the final setting time should not exceed 375 minutes. However, in this experiment, the initial setting time was observed to be 75 minutes, while the final setting time was 225 minutes. The specific gravity of the cement used was measured 3.17. Additionally, the fineness of cement was determined to be 8.57%.

2.1.2 Coarse Aggregate

Incorporating aggregates into concrete serves to enhance its durability and capacity to withstand impacts. Achieving uniformity in aggregate size and grading is pivotal for ensuring satisfactory workability of the concrete. In this study, brick chips (Figure 1) sourced from the local market are used as coarse aggregates. These brick chips exhibit a specific gravity of 3.15 and a fineness modulus of 7.17. Additionally, absorption capacity of coarse aggregate was found 4.78%, aggregate crushing value (ACV) was 32% and aggregate impact value (AIV) was 16%.

Figure 1 Coarse Aggregate

2.1.3 Fine aggregate

In this research, locally sourced sand (Figure 2) with particle sizes below 4.75 mm is used as the fine aggregate, primarily chosen for its ready accessibility. The fine aggregate exhibits a fineness modulus of 2.67 and a specific gravity of 2.67. Furthermore, absorption capacity of this aggregate was found 1.15%.

Figure 2 Fine Aggregate

2.1.4 Jute fiber

Jute fibers are characterized by their smooth texture, typically appearing in off-white or brown color, and are renowned for their eco-friendly nature with tensile strength and low extensibility. In this investigation, locally sourced raw jute fibers (Figure 3) were utilized in their untreated form. These jute fibers were manually cut into two distinct lengths - 10 mm and 15 mm. The quantity of jute fibers incorporated into the concrete specimens was determined based on their volume. Various percentages ranging from 1% to 5% were used in the experimental concrete mixtures. The characteristics of jute fibers used in this study are provided in Table 1.

Table 1 characteristics of jute fibers [12]

Length **Length**	**10 mm** **15 mm**
Diameter (mm)	0.05 (mm)
Aspect Ratio (l/d) Aspect Ratio (l/d)	200 300
Density	1400 (kg/m^3)
Tensile Strength	400 (MPa)
Color	Off white or brown
Specific Gravity	1.3
Elongation at break %	1.6

Figure 3 Jute Fiber

2.1.5 Water

For the casting and curing of the specimens, only tap water sourced from the Dhaka Water Supply and Sewerage Authority was utilized. This tap water falls within the pH range of 6.5 to 9.5. Moreover, the water adheres to the standards outlined in BDS ISO 12439:2011 for mixing water in concrete, as stipulated by BNBC-2020 [22].

2.2 Methods

2.2.1 Mix Proportion of Concrete

In this investigation, the materials utilized included coarse aggregate, fine aggregate, ordinary Portland cement (OPC), and natural fiber (Jute). The selection of materials and their proportions was guided by the concrete mix design standards outlined in the American Concrete Institute (ACI, 211.1-91) [23]. These standards dictated the required quantities of cement, fine aggregate, coarse aggregate (brick chips), and the water-cement ratio. For this study, the mix ratios of cement, sand and brick chips were maintained (by volume) = 1:2:4, with a water/cement ratio (by weight) of 0.5.

2.2.2 Mixing of Concrete

The mixing process shown in Figure 4 entailed employing a pan mixer to achieve comprehensive amalgamation of the constituents. Jute fibers were gradually and evenly introduced into the concrete mix to guarantee uniform dispersion of the yarns throughout the concrete. The workability of the concrete mixtures was evaluated using slump tests, adhering to ASTM C143-90a (1990) standards [24]. Subsequently, the freshly mixed concrete was poured into cylinder molds measuring 100 mm in diameter and 200 mm in height.

Figure 4 Mixing of Concrete

2.2.3 Curing of Concrete Specimen

After pouring, the specimens were left unmold for a duration of 24 hours. Each specimen was clearly labeled with pertinent information, including the casting date and a unique specimen identification number, prior to the curing process. According to the standards outlined in ASTM C 192-90a, the specimens underwent curing in a water bath (Figure 5) for durations of 7, 14, and 28 days to optimize strength development. Following these steps ensured that the concrete cylinders were appropriately prepared and cured, rendering them suitable for subsequent testing and analysis. Upon completion of the curing period, the specimens were allowed to air dry for an additional 24 hours before undergoing testing.

Figure 5 Curing of Concrete Specimen

2.2.4 Test plan of Specimen

The required number of cylindrical specimens for compressive strength and splitting tensile strength tests are presented in Table 2.

Table 2 Test Plan for Compressive Strength and Tensile Strength test

Criteria	% of Jute (Volumetric Weight)	Length of Fiber (mm)	Diameter of Cylinder (mm)	Height of Cylinder (mm)	Number of Cylinder for Compressive Strength Test	Number of Cylinder for splitting Tensile Strength Test
Normal Concrete	0	--	100	200	9	3
	1				9	3
	2				9	3
	3	10	100	200	9	3
	4				9	3
JFRC	5				9	3
	1				9	3
	2				9	3
	3	15	100	200	9	3
	4				9	3
	5				9	3

3.0 RESULTS AND DISCUSSION

3.1 Slump Test

In Figure 6, it has been observed that the value of slump decreases with an increase in fiber content. Specifically, the slump was measured at 100 mm with 1% of Jute Fiber Reinforced Concrete (JFRC), decreasing to 85 mm with 2% of JFRC, 75 mm with 3% of JFRC, 65 mm with 4% of JFRC, and 50 mm with 5% of JFRC. Consequently, the amount of concrete slump gradually decreases with an increase in fiber percentage.

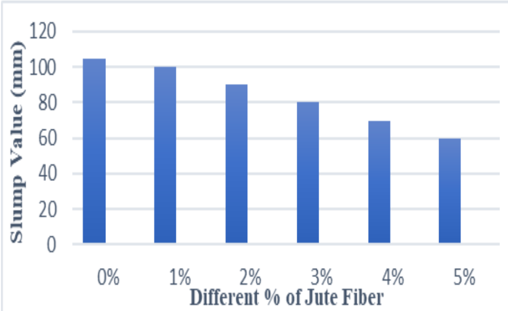

Figure 6 Slump value with fiber content

3.2 Compressive Strength Test

Compressive strength assessments were performed utilizing a Universal Testing Machine (UTM) on concrete cylinder samples subjected to treatments lasting 7, 14, and 28 days. These specimens were reinforced with varying volumetric percentages of jute fiber, namely 1%, 2%, 3%, 4%, and 5%. Two different lengths of jute fiber were considered: 10 mm and 15 mm. The compressive strength of the concrete was evaluated and compared across the different combinations of jute fiber percentages and lengths in Table 3. This comparative analysis aimed to assess the impact of jute fiber reinforcement on the compressive strength of the concrete mixtures over the specified curing periods.

Table 3 Compressive Strength of Normal Concrete and JFRC

Jute Fiber Length (mm)	Specimen Name	Fiber Content (%)	Compressive Strength for 7 Days (MPa)	Average Value of Compressive Strength for 7 Days (MPa)	Compressive Strength for 14 Days (MPa)	Average Value of Compressive Strength for 14 Days (MPa)	Compressive Strength for 28 days (MPa)	Average Value of Compressive Strength for 28 Days (MPa)
			9.35		14.08		18.52	
--	Normal Concrete	0	9.25	9.46	13.65	13.85	18.74	18.67
			9.78		13.82		18.75	
			10.97		15.64		20.01	
	JFRC 1	1	11.30	11.5	15.69	15.65	19.97	20.12
			12.23		15.62		20.38	
			10.65		15.36		19.45	
	JFRC 2	2	11.01	10.78	15.28	15.33	19.32	19.34
			10.68		15.35		19.25	
			10.05		14.90		18.04	
10	JFRC 3	3	10.35	10.06	14.71	14.65	18.27	18.16
			9.78		14.34		18.17	
			9.48		14.25		17.67	
	JFRC 4	4	9.74	9.58	14.38	14.45	18.02	17.94
			9.52		14.72		18.13	
			8.56		14.42		17.44	
	JFRC 5	5	8.67	8.66	14.45	14.33	17.56	17.44
			8.75		14.12		17.32	
			9.61		14.67		19.12	
	JFRC 1	1	9.56	9.62	14.70	14.62	19.20	19.16
			9.69		14.49		19.16	
			9.51		13.92		18.84	
	JFRC 2	2	9.42	9.43	14.36	14.32	19.03	18.96
			9.36		14.68		19.01	
			9.08		12.65		17.87	
15	JFRC 3	3	9.15	9.10	12.65	12.62	17.90	17.96
			9.07		12.56		18.11	
			8.74		11.79		16.38	
	JFRC 4	4	8.90	8.95	11.89	11.82	16.54	16.41
			9.21		11.78		16.31	
			8.30		10.35		14.45	
	JFRC 5	5	8.42	8.38	10.78	10.54	14.56	14.48
			8.42		10.49		14.43	

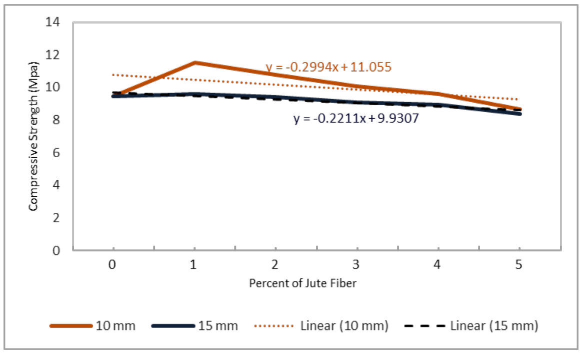

Figure 7 Compressive strength for 7 days

Figure 7 illustrates data on the compressive strength of concrete specimens for 7 days which were reinforced with varying percentages of jute fiber at different fiber lengths (10 mm and 15 mm). Serves as a baseline, indicating the compressive strength of concrete without any jute fiber reinforcement with the strength value recorded as 9.46 MPa. For the 10 mm jute fiber length, as the percentage of jute fiber increases from 1% to 4%, there is a slight improvement in compressive strength compared to normal concrete. However, with further increases in fiber content (5%), the compressive strength decreases compared to the 1% to 4% range. While, For the 15 mm jute fiber length, the compressive strength appears to decrease consistently with increasing fiber content from 2% to 5% compared to normal concrete. In addition, the compressive strength of 15 mm jute fiber mix is less than the other length (10 mm) for (1% to 5%) mix content. These observations suggest that the effectiveness of jute fiber reinforcement on compressive strength varies depending on both the percentage of fiber used and the length of the fibers.

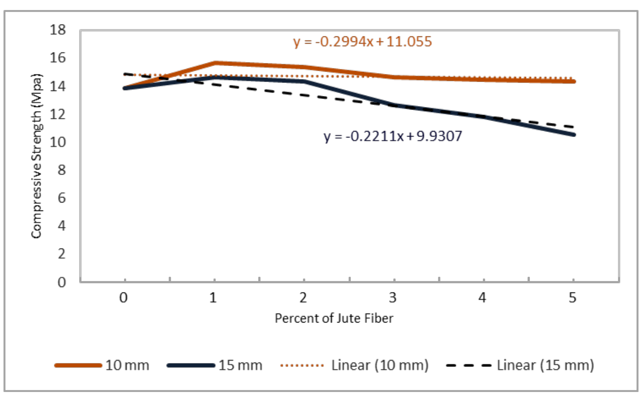

Figure 8 Compressive strength for 14 days

Figure 8 displays the compressive strength data after 14 days, serving as a reference for concrete without any jute fiber reinforcement, with a recorded strength of 13.85 MPa. For 10 mm jute fiber length, the compressive strength generally exhibits an upward trend with increasing fiber content. In particular, there is a noticeable enhancement from 1% to 3% fiber content, with the 1% mixture demonstrating the highest strength (15.65 MPa). However, at 4% and 5% fiber content levels, the compressive strength either remains relatively steady or slightly declines compared to the 3% range. However, for the 15 mm jute fiber length, the compressive strength demonstrates more significant fluctuations with varying fiber content. A notable rise is observed from 1% to 2% fiber content. However, at 3%, 4% and 5% fiber content levels, there is a considerable decrease in compressive strength compared to the lower percentages, with the 5% jute fiber mixture recording the lowest strength at 10.54 MPa.

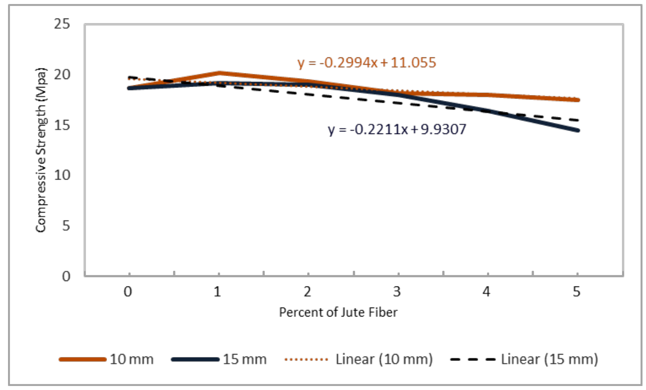

Figure 9 Compressive strength for 28 days

Figure 9 illustrates the ultimate strength of normal concrete and various jute fiber-mixed concrete specimens after 28 days. The line graph provides a reference point, indicating the compressive strength of concrete without any jute fiber reinforcement, with a recorded strength of 18.67 MPa. For the 10 mm jute fiber length, the compressive strength generally demonstrates an increasing trend with the addition of jute fiber. Particularly, there is a notable enhancement from 1% to 2% fiber content, with the 1% mixture exhibiting the highest strength at 20.12 MPa. However, at the greater fiber content levels, the compressive strength gradually decreases compared to the 1% range, and it remains relatively consistent at 5%. Similarly, for the 15 mm jute fiber length, the compressive strength increases with the fiber content mix from 1% to 2%, with the 1% mixture also demonstrating the highest strength. However, at 3%, 4%, and 5% fiber content levels, there's a decrease in compressive strength compared to the lower percentages. Overall, after 28 days, the 1% (10 mm) jute fiber mixture shows the maximum strength value compared to other fiber percentages and lengths.

3.3 Splitting Tensile Strength Test

The splitting tensile strength test of concrete is a method used to determine the tensile strength of cylindrical concrete specimens. Unlike compressive strength, which measures the material's ability to withstand axial loads, tensile strength assesses its resistance to being pulled apart or cracked under tension. The test involves applying a diametrical force to the cylindrical specimen along its longitudinal axis, causing it to split or fracture. Tensile strength is determined by considering the maximum force exerted and the cross-sectional area of the specimen. In this study, the splitting tensile strength test was exclusively carried out after 28 days for various mix proportions of jute fiber and the results are shown in Table 4.

Table 4 Tensile Strength of Normal Concrete and JFRC at 28 days curing

Jute Fiber Length (mm)	Specimen Name	Fiber Content (%)	Tensile Strength for 28 Days (MPa)	Average Value of Tensile Strength for 28 Days (MPa)
--	Normal Concrete	0	3.12 3.20 3.19	3.17
10	JFRC 1	1	3.60 3.56 3.79	3.65
	JFRC 2	2	3.45 3.48 3.33	3.42
	JFRC 3	3	3.34 3.43 3.28	3.35
	JFRC 4	4	3.21 3.18 3.30	3.23
	JFRC 5	5	3.11 3.20 3.14	3.15
15	JFRC 1	1	3.38 3.45 3.40	3.41
	JFRC 2	2	3.38 3.29 3.38	3.35
	JFRC 3	3	3.22 3.34 3.31	3.29
	JFRC 4	4	2.94 2.98 3.05	2.99
	JFRC 5	5	2.85 2.95 2.81	2.87

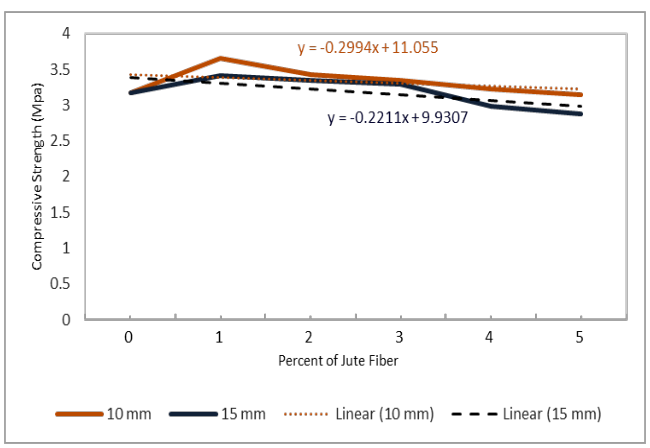

Figure 10 Splitting tensile strength test for 28 days

Figure 10 illustrates the splitting tensile strength values after 28 days. The line graph includes a reference point, denoting the tensile strength of concrete without any jute fiber reinforcement, which is recorded at 3.17 MPa. For both 10 mm and 15 mm jute fiber lengths, there is a general increase in splitting tensile strength with the addition of jute fiber, up to a certain percentage. Specifically, a notable enhancement is visible from 1% to 2% fiber content for both lengths. The 1% jute fiber mixture demonstrates the highest strength, with 3.65 MPa for 10 mm fiber length and 3.41 MPa for 15 mm fiber length. However, at higher fiber content levels (3% to 5%), the splitting tensile strength tends to decrease compared to the 1% range, with some fluctuations observed. Notably, the 4% and 5% fiber content levels exhibit lower strengths compared to other percentages, indicating a potential negative effect of higher fiber content on splitting tensile strength. Overall, it is evident that the 1% jute fiber mixture for 10 mm length demonstrates the ultimate strength compared to other percentages and fiber lengths.

4.0 CONCLUSION

The incorporation of jute fiber in concrete signifies a significant step towards sustainable development in Bangladesh, a region abundant in jute cultivation. This research reveals that, while there may be a reduction in workability for specific fiber lengths and quantities, the addition of jute fiber enhances the mechanical characteristics of concrete.

- The results of the slump test demonstrated that as the volume fraction of jute fibers increases, the workability of concrete progressively decreases.
- After 28 days, 1% (10 mm) jute fiber resulted in a maximum compressive strength of 20.12 MPa, marking a 7.77% improvement over conventional concrete.
- In addition, the maximum tensile strength recorded was 3.65 MPa with a 1% (10 mm) fiber mix for 28 days, showcasing a 15.14% increase compared to normal concrete.
- However, mechanical properties were negatively impacted by higher fiber percentages and longer fiber lengths, with both compressive and tensile strength declining accordingly.

Drawing upon the insights gleaned from testing and analyzing jute fiber reinforced concrete, there lies the opportunity to seamlessly integrate it into the production of fiber reinforced concrete composites, thereby offering substantial potential for enhancing concrete performance. Considering the promising nature of this subject within the construction sector, there is ample scope for continued exploration and investigation. Future research endeavors may delve into exploring the incorporation of admixtures alongside jute fiber in concrete.

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Conflicts of Interest

The author(s) declare(s) that there is no conflict of interest regarding the publication of this paper

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