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Exploring the Potential of Jute Fiber Reinforcement in Concrete for Enhanced Strength and Durability

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Abstract

The use of natural fibers in concrete reinforcement has gained significant attention in recent years as a sustainable alternative to synthetic materials. Among the various natural fibers, jute has emerged as a promising option due to its low cost, high availability, and favorable mechanical properties. This paper presents a comprehensive review of recent research on the use of jute fiber as a reinforcing material in concrete. The study examines the mechanical properties of concrete reinforced using jute fibers (10 mm and 20 mm) with various mix proportions of 0%, 0.10%, 0.15%, 0.20%, 0.25% and 0.30% respectively by volume of concrete. The results showed that the addition of jute fibers improved both the compressive and tensile strength of the concrete. The research suggests that using the small length (10 mm) and a low content (0.15%) of reinforcing materials can enhance the mechanical properties of jute fiber reinforced concrete (JFRC). The optimum percentage of jute fiber (10 mm) was found to be 0.15%, which resulted in a 12% increase in compressive strength and a 27% increase in tensile strength compared to the control concrete. In conclusion, this paper provides valuable insights into the use of jute fibers as a sustainable and effective reinforcement material for enhancing the strength and durability of concrete.

Keywords: *Tensile strength; Jute fiber; Compressive Strength; Concrete; Ecofriendly.*

1 Introduction

Concrete is a durable, strong, and versatile construction material made from a mixture of cement, water, and aggregates such as sand, gravel, or crushed stone. It is one of the most widely used construction materials in the world and is used in a variety of structures such as buildings, bridges, roads, dams, and many other infrastructure projects. Concrete has several advantages over other construction materials. It is strong and durable, able to withstand heavy loads and harsh weather conditions. It is also fire-resistant and has excellent thermal mass, making it ideal for energy-efficient buildings. Additionally, concrete is readily available, cost-effective, and can be produced in a range of colors and finishes to suit various aesthetic requirements. Despite its many benefits, concrete also has some limitations. Concrete is relatively fragile and its tensile strength is low in comparison to its compressive strength (Sivakumeret *al.,* 2007). It can also crack over time due to changes in temperature and moisture levels.

Fiber reinforced concrete (FRC) is a type of concrete that incorporates fibers into the mix to improve its strength, durability, and toughness. The fibers used in FRC can be made from various materials such as steel, glass, synthetic polymers, and natural fibers such as jute or coconut. The addition of fibers to concrete improves its strength, impact resistance, and ductility, making it more resistant to cracking and spalling. This makes FRC ideal for use in structures that are subjected to high stresses and loads such as pavements, bridges, tunnels, and industrial floors. The process of making FRC is similar to that of traditional concrete, but with the addition of fibers. FRC has several advantages over traditional concrete. It can be used to reduce the amount of steel reinforcement required in a structure, which can help to lower construction costs. FRC is also more resistant to cracking and can be used to create thinner, lighter structures.

Jute fiber is a natural fiber that is derived from the stem of the jute plant. It is a long, soft, and shiny fiber that is composed primarily of cellulose, the same material found in cotton and other plant fibers. Jute fiber has a high tensile strength, which makes it strong and durable. Jute fiber has a low thermal conductivity, which makes it a good insulator. It is often used in the production of insulation materials for buildings and other structures. Jute fiber is biodegradable, which means it can be broken down naturally by microorganisms. Jute fiber is relatively inexpensive compared to other natural and synthetic fibers, which makes it a cost-effective material for a variety of applications. Overall, jute fiber is a versatile material that offers several useful properties. Its strength, durability, and low thermal conductivity make it useful in a variety of applications, while its biodegradability and affordability make it an attractive option for environmentally conscious consumers.

Concrete reinforcing with jute fibers is more promising for increasing concrete strength while minimizing environmental impact and making better use of available natural resources. Numerous researchers have successfully used fiber and yarn as concrete reinforcing materials to attain this goal (Nemati, 2013). This study delves further into the properties of jute fiber reinforced concrete, such as tensile and compressive strength. This study discusses the effects of jute fiber reinforcement on concrete.

2 Materials and Methods

2.1 Material

In this experiment, Ordinary Portland Cement (OPC) had been used. The OPC used in the study consisted of 95 - 100% portland clinker and 0-5% gypsum, and had a strength class of 52.5 N. For the fine aggregate, sand (FM: 2.65, Sp. Gr.: 2.55) was used while crushed stone chips (Sp. Gr.: 2.70) were used as the coarse aggregate. The use of jute fiber (Diameter: 0.05 mm, Tensile strength: 400MPa, Density: 1400 kg/m^3, Elongation at break: 1.7 %) with different lengths (10 mm and 20 mm) was evaluated in this research. The fibers were added to a mix of cement, coarse aggregate, and sand in a specific proportion with a water-cement ratio of 0.38. In this experiment, specimens were created using two different lengths of jute fibers, measuring 10 mm and 20 mm with varying volumetric contents of 0%, 0.10%, 0.15%, 0.20%, 0.25%, and 0.30%. These specimens were then cured for a period of 28 days.

The mix design in this study was conducted in accordance with the American Concrete Institute (ACI, 2009) guidelines. The objective was to achieve a target strength of 35 MPa at 28 days, while maintaining a slump value of 75-100 mm. Before the testing process, all aggregates were brought to a saturated surface dry (SSD) condition. The content of cements and aggregates remained constant for all mixtures, while the water content was adjusted to obtain the desired slump value. The ratios of the constituent materials and jute fiber used in the concrete mix for the research are presented in Table 1.

Table 1. Mix proportions of the concretes used in experimental work.

Mix	Water (kg/m^3)	Cement (Kg/m^3)	Coarse Aggregate ((kg/m^3) [SSD (OD)]	Fine Aggregate ((kg/m^3) [SSD (OD)]	Jute Fiber (kg/m^3)
J_1 (0%)	213	567	1000 (993)	565 (559)	0
J_2 (0.10%, 10 mm)	215	567	1000 (993)	565 (559)	2.345
J_3 (0.15%, 10 mm)	216	567	1000 (993)	565 (559)	3.518
J_4 (0.20%, 10 mm)	217.5	567	1000 (993)	565 (559)	4.690
J_5 (0.25%, 10 mm)	219	567	1000 (993)	565 (559)	5.863
J_6 (0.30%, 10 mm)	220	567	1000 (993)	565 (559)	7.035
J_7 (0.10%, 20 mm)	216	567	1000 (993)	565 (559)	2.345
J_8 (0.15%, 20 mm)	217.5	567	1000 (993)	565 (559)	3.518
J_9 (0.20%, 20 mm)	219	567	1000 (993)	565 (559))	4.690
J_{10} (0.25%,	220.5	567	1000 (993)	565 (559)	5.863

20 mm)					
J_{11} (0.30%, 20 mm)	222	567	1000 (993)	565 (559)	7.035

2.2 Concrete Mixing

This study utilized varying fiber lengths of 10 mm and 20 mm and different proportions ranging from 0% to 0.30% by volume of concrete. A rotary machine is employed to facilitate the mixing process. The initial mixing involved a suitable quantity of coarse aggregate (CA), fine aggregate (FA), and cement for 2 minutes, ensuring that both coarse and fine aggregate were in a saturated surface dry (SSD) condition before dry mixing. Next, jute fibers were added at a slow rate to ensure even distribution and water was added to the mixture for a total mixing time of 4 minutes using a concrete machine mixer. The workability of the concrete composite was assessed through a slump test, and a 150 x 150 x 150 mm concrete mold was prepared to evaluate the concrete's performance under compression and tension loading. Tamping was done using an appropriate tamping rod during the placement of concrete in the mold, and a steel trowel was used to achieve a smooth surface finish. The specimens were left in the mold for 24 hours after casting, and then the concrete samples were removed from the molds and immersed in clean water for the curing process. It is also important to note that the curing process (Ponding method) is be carried out under controlled conditions (Water temperature: 28 to 30°C, Humidity: 80 to 90%) as the strength and durability of the concrete can be affected by factors such as the temperature and humidity levels during curing.

2.3 Strength Testing

To determine the strength of the concrete accurately, it is necessary to perform certain procedures. Firstly, 6-inch cube specimens are cast, which should be made with the same materials and proportions that are used in the actual construction. The cubes should also be cured under the same conditions as the concrete in the structure to ensure that the specimens are representative of the actual concrete strength. After the 28-day curing period, the specimens should be tested in a universal testing machine, which is capable of applying a gradual load at a controlled rate. In this case, a rate of 2.5 mm/min was used because testing concrete at a strain rate of 2.5 mm/min yields crucial information regarding the material's strength, durability, and response to real-world loading conditions. It is important to note that the rate of loading should be selected based on the specific requirements of the project and the type of concrete being tested.

3 Results and Conclusions

3.1 Compressive and Tensile Strength

The paper presents a comprehensive analysis of the use of jute fiber in concrete compared to plain concrete. The experimental results obtained were analyzed and presented in detail in Table 2, which provides data on the compressive and tensile strength of the concrete. Figure 1 illustrates the correlation between the proportion of jute fiber (both 10mm and 20mm) used in concrete and the resulting compressive strength of the composite material. The figure provides a graphical representation of how changes in the content of jute fiber can affect the strength of the concrete. By analyzing this relationship, it is possible to determine the optimal amount of jute fiber to use in order to achieve the desired level of strength for a given application.

Table 2. Strength characteristics of jute fiber reinforced concretes.

Type of Concrete	Compressive Strength (MPa)	Tensile Strength (MPa)
J1 (0%)	36.40	2.67
J2 (0.10%, 10 mm)	38.63	3.08
J3 (0.15%, 10 mm)	40.77	3.40
J4 (0.20%, 10 mm)	40.65	3.19
J5 (0.25%, 10 mm)	39.39	3.06
J6 (0.30%, 10 mm)	38.48	2.98
J7 (0.10%, 20 mm)	37.60	3.13
J8 (0.15%, 20 mm)	38.42	3.29

J9 (0.20%, 20 mm)	39.05	3.18
J10 (0.25%, 20 mm)	39.53	2.99
J11 (0.30%, 20 mm)	38.55	2.80

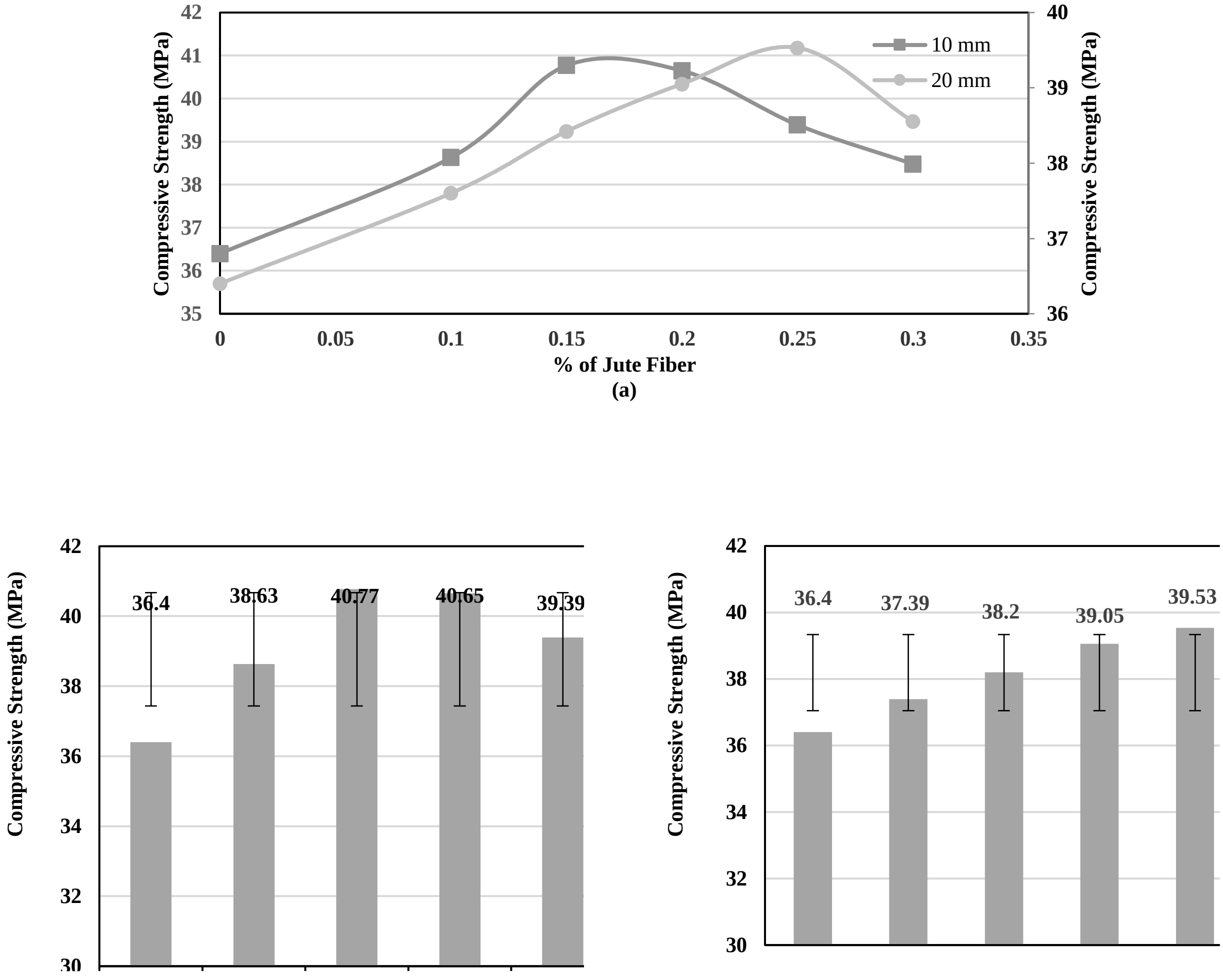

Figure 1. (a) Relationship between compression strength and percent of jute fiber (10 mm and 20 mm). (b) Compression strength comparison between plain concrete and jute fiber reinforced concrete (10 mm). (c) Compression strength comparison between plain concrete and jute fiber reinforced concrete (20 mm)

In Figure 1 it is observed that, for the fiber length of 10 mm, the addition of 0.1%, 0.15%, 0.2%, 0.25%, and 0.3% jute fiber led to increases in compressive strength of approximately 6.13%, 12.0%, 11.68%, 8.21%, and 5.71%, respectively with respect to the plain concrete. For the fiber length of 20 mm, similar trends were observed, with compressive strength increasing by approximately 2.72%, 4.95%, 7.28%, 8.57%, and 5.91% for the same respective increments of fiber percentage. These findings suggest that the length of the fiber may have some impact on the strength improvement achieved through fiber reinforcement, although the overall trend of increasing strength with increasing fiber content holds true for both fiber lengths examined in the study. The reason for this is that the interlocking effect of the concrete matrix has been enhanced, resulting in a stronger bond between the fibers and the concrete. In addition, the addition of fibers can also improve other aspects of concrete performance, such as reducing cracking, increasing durability, and enhancing the resistance to impact and abrasion. This makes fiber-reinforced concrete a popular choice in a variety of construction applications, including bridges, tunnels, and high-rise buildings.

Overall, the interlocking effect plays a crucial role in determining the effectiveness of fiber-reinforced concrete, and enhancing this effect can lead to significant improvements in the overall performance and durability of concrete structures.

It has been noted that the fiber length of 10 mm produces the highest compressive strength increase of 12% (Figure 1b) when reinforced with 0.15% fiber, compared to the control mixture without fiber reinforcement. On the other hand, a fiber length of 20 mm results in an 8.21% (Figure 1c) increase in compressive strength with 0.25% fiber reinforcement, which is considered the optimal fiber percentage for this length.

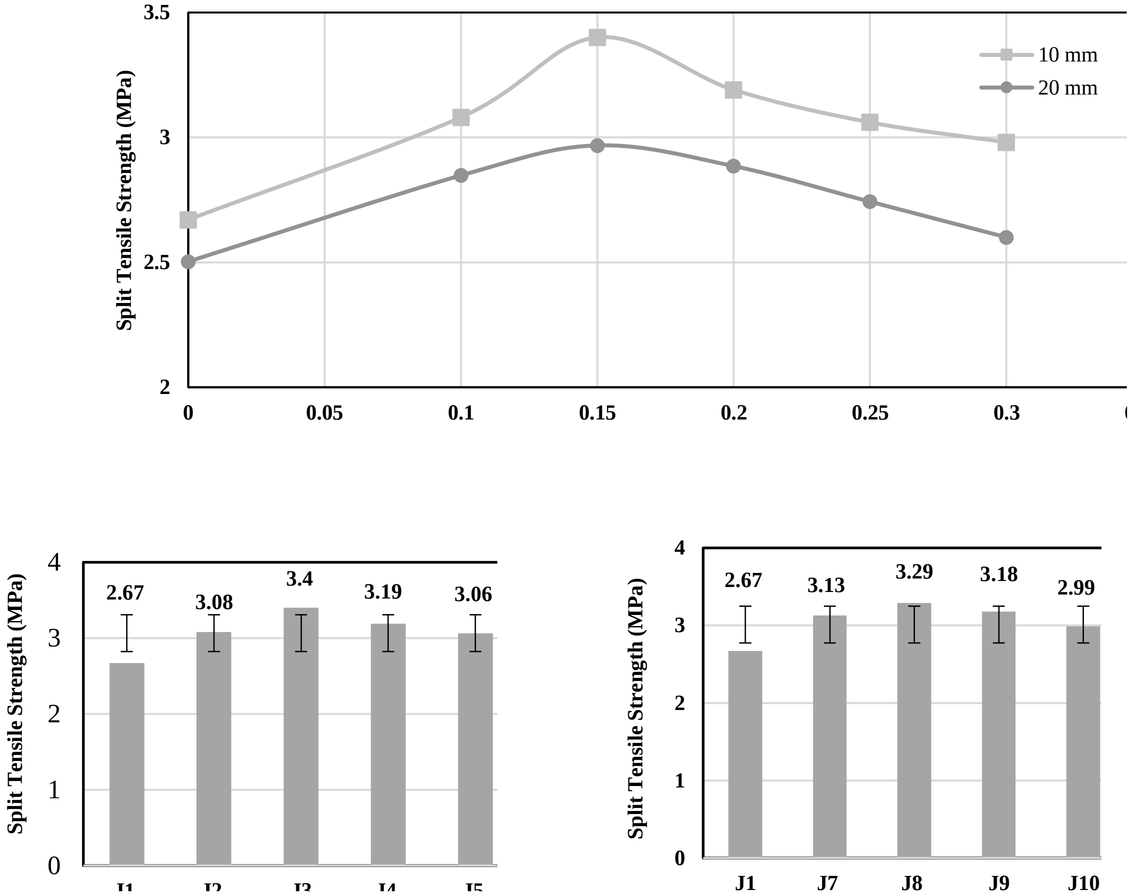

Figure 2. (a) Relationship between split tensile strength and percent of jute fiber (10 mm and 20 mm). (b) Split tensile strength comparison between plain concrete and jute fiber reinforced concrete (10 mm). (c) Split tensile strength comparison between plain concrete and jute fiber reinforced concrete (20 mm)

In Figure 2, the relationship between the quantity of fibers added and the resulting tensile strength is presented. The graph demonstrates that, as the quantity of fibers added is increased, the tensile strength of the material improves. This is because the fibers are able to distribute the load and provide additional support to the material. However, beyond a certain threshold, adding more fibers does not have a significant impact on the tensile strength.

It can be observed from Figure 2 that the introduction of jute fiber in quantities of 0.10%, 0.15%, 0.2%, 0.25%, and 0.3% resulted in increases in tensile strength of roughly 15.36%, 27.34%, 19.48%, 14.61%, and 11.61% respectively for a fiber length of 10 mm with respect to the plain concrete. Similarly, for a fiber length of 20 mm, comparable patterns were noted, with the tensile strength increasing by roughly 17.23%, 23.22%, 19.10%, 11.99%, and 4.87% for the same corresponding fiber percentages.

It has been noted that the fiber length of 10 mm produces the highest tensile strength increase of 27.34% (Figure 2b) when reinforced with 0.15% fiber, compared to the control mixture without fiber reinforcement. On the other hand, a fiber length of 20 mm results in an 23.22% (Figure 2c) increase in tensile strength with 0.25% fiber reinforcement, which is considered the optimal fiber percentage for this length.

3.2 Conclusion

Based on the experimental results presented in the paper, several conclusions can be drawn regarding the use of jute fiber in concrete:

1. The inclusion of jute fiber with a length of 10 mm in the concrete mixture has been shown to result in a notable improvement in the compressive strength of the material. The increase in compressive strength,

relative to plain concrete, ranges from 5.71% to 12.0% depending on the amount of fibers added to the mixture.

2. The experimental results showed that using jute fiber with a length of 20 mm in the concrete mixture resulted in a significant improvement in compressive strength when compared to plain concrete. The increase in compressive strength ranged from 2.72% to 8.57%.
3. The study found that the optimal fiber content for achieving the highest compressive strength in jute fiber-reinforced concrete with a length of 10 mm was 0.15%.
4. According to the study, the optimal fiber content for achieving the highest compressive strength in jute fiber-reinforced concrete with a length of 20 mm was determined to be 0.25%.
5. By incorporating jute fiber with a length of 10 mm into the concrete mixture, the experimental results show that the tensile strength increases by a range of 11.61% to 27.34%, when compared to plain concrete.
6. The inclusion of 20 mm jute fiber in concrete results in a 4.87% to 23.22% increase in its tensile strength compared to plain concrete.
7. The greatest improvement in tensile strength was observed when 0.15% jute fiber was added to the concrete.
8. To make future research more accurate, consider including a wider range of jute fiber percentages in the study.

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