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Improving Concrete Strength using Jute Fiber Reinforcement with Surface Treatments

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Abstract: The significance of concrete in the construction sector may include strength and durability, but because of the low tensile strength and the cracking tendencies, its applicability is severely limited on many occasions. Fibers are also finding their way into concrete to counter such problems by enhancing their tensile strength, crack-bridging capacity, and general durability. This paper reflects on the effects of jute fiber reinforcement on the mechanical properties of concrete, in this case, compressive strength, split tensile strength, and workability. M20-grade concrete was mixed with jute fibers at 0.1%, 0.2%, and 0.4% volume fractions and treated with three different methods: alkali (6% NaOH), acidic (2% HCl), and hot water (80–100°C). Workability of the concrete was determined by carrying out a slump test, and the mechanical behavior of the concrete by the compressive and split tensile strength tests. It was found that by the addition of the jute fibers, there was a decrease in the workability of the mixture, such that an increase in fiber content resulted in a decrease in the slump. The alkali treatment enhanced workability and fiber dispersion, whereas the acidic treatment had the greatest impact on the reduction of workability since the fibers are degraded in the acidic treatment. As far as strength is concerned, alkali-treated jute fibers resulted in the best improvements on compressive and split tensile strength, especially for low fiber contents. Untreated and acidic-treated fibers, on the other hand, were weaker, especially at higher contents, because fibers did not disperse well and were weakly bonded to the matrix. It can be concluded that alkali treatment on jute fiber reinforced concrete improves strength and durability to a significant extent.

Keywords: Concrete Strength, Fiber Dispersion, Jute Fiber Reinforcement, Surface Treatments, Sustainable Construction.

1 INTRODUCTION

The most utilised building material in the world is concrete since it is strong, adaptable, and lasting [1]. Nevertheless, despite the benefits, there are some severe downsides to utilising typical concrete, specifically its poor values of tensile strength and workability [2]-[4]. Adding fibers to the concrete has proven a promising way to solve these limitations [3]. Fibers have the potential to improve the mechanical characteristics of concrete to highlight its cracking resistance and the ability to offer the concrete with post-cracking performance, thereby adopting it in scenarios where the concrete is subjected to dynamic loading conditions [5][6]. The addition of fiber boosts the concrete's overall performance, particularly under dynamic loads, giving it a more trustworthy alternative for many structural applications [7].

Of all forms of fibers, natural fibers (including jute) have acquired attractiveness due to their good environmental impact and availability as well as cost-effectiveness [8]. Jute is a plant-based fiber that has the possibility of replacing synthetic fibers; nevertheless, it must be utilized in concrete with steps to control the concerns associated with the hydrophilic character and degrading nature of the fiber [9]. The pre-treatment of the surface, including alkali, acidic, and hot water treatments, has been tried to raise the interfacial resistance between the fiber and cement matrix, thereby enhancing the function of the fiber in supplying the mechanical properties of the concrete [10]. The inclusion of jute fibers in concrete has been demonstrated to greatly enhance compressive and splitting tensile strengths, boosting overall durability and performance [9]. This makes jute fiber-reinforced concrete an attractive solution for sustainable construction methods.

It may be mentioned that although the literature on jute fiber-reinforced concrete is rising over time, there is still a lack of understanding of the influence jute fiber has on critical mechanical parameters, especially in practice [11], [12]. Namely, the influence of jute fiber on the compressive strength, split tensile strength, and the workability of concrete has not been properly studied concerning diverse fiber treatments. These features play a vital role in establishing the applicability of jute fiber-strengthened concrete in structural applications, where the strength of the material and applicability are important factors in establishing structural performance in the long term [13][14]. Future studies should focus on researching the appropriate fiber treatment methods and their effect on the mechanical characteristics of jute fiber-reinforced concrete to increase its practical uses in building.

This research will aim to fill these gaps by performing a comprehensive analysis on the impact that diverse surface treatments have on jute fiber-confined concrete. Three important factors have been considered: compressive strength, split tensile strength, and workability. Alkaline, acetic, and hot water treatments of concrete mixes with various jute fiber rates (0.1%, 0.2%, and 0.4%) were examined for their mechanical characteristics and workability. This study contributes to the creation of high-performance and sustainable concrete materials by combining the impacts of surface treatment and fiber content before and after the concrete mixture and presents potential guidance for understanding how best to utilize jute fibers to achieve high-performance concrete mixtures that are also sustainable.

2 Materials and Methodology

2.1. Materials

The materials that were used in this study to suit the demands of the relevant national and international standards in the production of concrete have been chosen with much care. To be relevant in real-life situations, all the materials used were locally found materials to portray everyday construction habits.

1. Cement: The cement, as the chief bond, was Ordinary Portland Cement (OPC) by IS 269:2015, which is like ASTM C150 Type I cement. The cement had 3.15 specific gravity and there were neither visible contaminants nor clumps.
2. Fine Aggregate: Natural river sand (with no silt or organic matter) was utilized as fine aggregate. The specific gravity and the fineness modulus of the sand were 2.362 and 2.67, respectively. The gradation of particles was verified as in ASTM C136 and passed the test of meeting the specifications of ASTM C33 as zone II sand.
3. Coarse aggregate: Coarse aggregate was crushed granite whose maximum nominal size is 20 mm. The bulk density of the material was 1593 kg/m^3 with a specific gravity of 2.35 and a water absorption rate of 0.02 per cent.
4. Jute Fiber: Raw jute fibers were supplied by a local supplier, and the raw fibers improved their bonding characteristics to the cement matrix by treating them with raw fibers. After the treatment, the fibers were cleaned with distilled water to destroy the remaining chemicals, then dried in the sunlight before they were cut to a length of 15 mm. The density of the fiber was 1.42 g/cm^3.

2.2. Preparation of Concrete Mix

The mix design was based on IS 10262:2019 to provide the concrete of M20 grade (compression strength of 20 MPa at 28 days). All mixes were made in ratios of water-to-cement 0.48. The mixes were prepared to have varying levels of jute fiber, 0.1%, 0.2% and 0.4% by the volume of concrete. The proportions of the cement, fine aggregate, coarse aggregate, and water were kept constant in all the batches, and the proportion of jute fiber varied as indicated in Table 1.

Table 1. Preparation of Concrete Mix

Mix ID	Cement (kg/m³)	Water (kg/m³)	FA (kg/m³)	CA (kg/m³)	Jute Fiber (kg/m³)
Control	337	163	617	1020	0
U1	337	163	617	1020	14.2
U2	337	163	617	1020	28.4
U4	337	163	617	1020	56.8
A1	337	163	617	1020	14.2
A2	337	163	617	1020	28.4
A4	337	163	617	1020	56.8
H1	337	163	617	1020	14.2
H2	337	163	617	1020	28.4
H4	337	163	617	1020	56.8
AC1	337	163	617	1020	14.2
AC2	337	163	617	1020	28.4
AC4	337	163	617	1020	56.8

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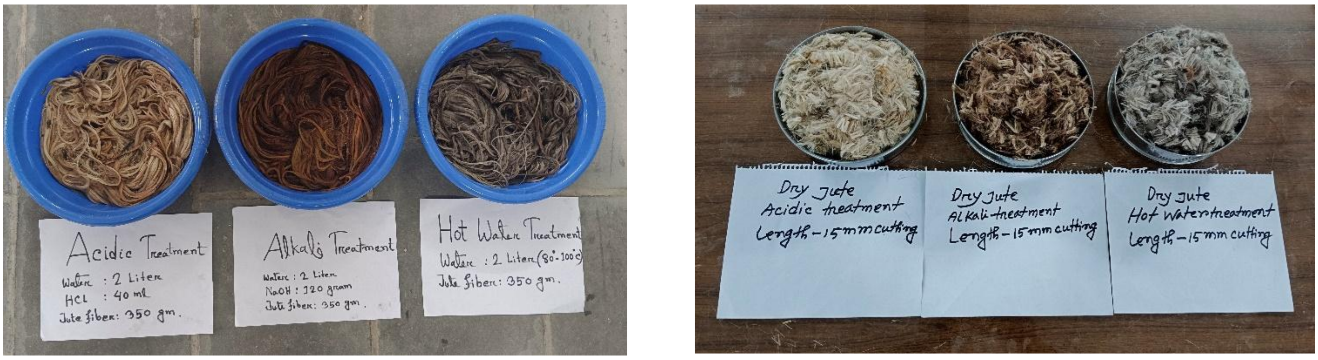
2.3. Methods of Treatment of Fiber

The jute fibers underwent three different surface treatments to alter interaction with the cement matrix, as shown in Fig. 1, and these include:

- Alkali Treatment: Fibers were submerged in 6 per cent NaOH solution and then kept at room temperature for 2 hours; this worked to remove lignin and hemicellulose and enhanced fiber surface character, thereby enhancing fiber bonding with the matrix.
- Acidic Treatment: The fibers were placed in a HCl 2% solution for 2 hours. This treatment eliminated non-cellulosic compositions, cleaned the fiber faces, and improved compatibility with the cement matrix.
- Hot Water Treatment: The fibers were immersed in hot water (80-100 °C) for 2 hours to remove soluble impurities and to enhance flexibility, but at the same time not distort fiber structure.



(a) (b)

Fig. 1. (a) Various treatments of fiber, (b) Sample of 15mm jute fiber after treatment.

2.4. Preparation of Specimen

The mixing of concrete was performed manually in a clean tray on a flat surface. The mixing of the dry materials (cement, fine aggregate, and coarse aggregate) took place in 2 minutes. After that, jute fibers, which had been pretreated, were incorporated and mixed for 1-2 minutes to avoid clumping of fibers. Gradually, the required quantity of water was added, and the mixture was stirred briskly for another 3 minutes. This was cast in cylindrical moulds (150 mm diameter and 300 mm height) that were filled in two layers and compacted by 25 tamping rod strokes, as per ASTM C192. Demoulding was performed after 24 hours by covering the moulds with plastic paper, and the specimens were then cured in a room-temperature water tank after 28 days.

2.5. Procedure of Testing

Each test was done on three repeats of specimens of each mix, and the average values were the basis of evaluating the performance of the concrete:

- Slump Test (ASTM C143): The fresh concrete workability was determined according to the standard slump cone. The height of the slump was determined as soon as the cone was lifted.
- Compressive Strength (ASTM C39): A Compressive strength test was done on the concrete cylinder after 28 days of curing by using a universal testing machine. The cylinders were documented and analysed regarding their failure modes.
- Split Tensile Strength (ASTM C496): The split tensile strength was determined based on the diametral loading technique through which concrete cylinders were loaded up to breakage. The observation and recording of the failure modes were done.

3 Results and Discussion

3.1. Workability

Each concrete mix was evaluated for workability by the slump test (ASTM C143). The control mix (devoid of jute fiber) showed a slump of 88mm, which indicated satisfactory workability. The drop diminished with an increase in the content of the jute fiber, as indicated in Fig. 2. In comparison to the untreated blends, slump decreased: 78 mm (U1) with 0.1 per cent fiber content to 58 mm (U4) with 0.4 per cent fiber content. This shortcoming is essentially due to the fibrous texture of jute, which absorbs part of the water used in the mixing process and aids in inward friction, making the mix relatively unfluid [15].

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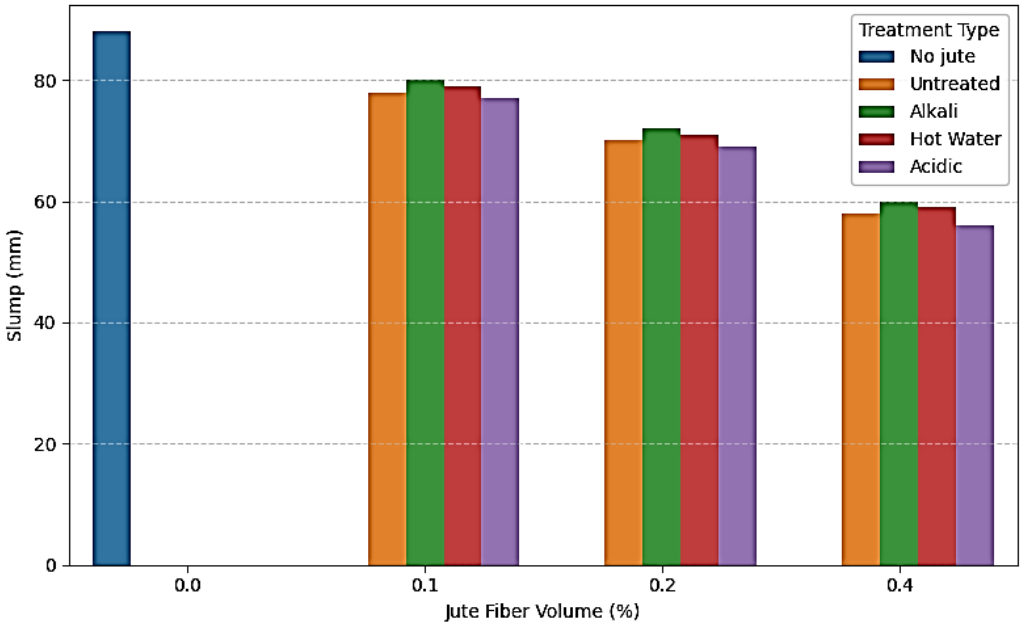

Fig. 2. Slump values of concrete mixtures with varied jute fiber percentage and treatment method

The condition of the fibers contributed substantially to the mix's workability. The most practical alkali-treated fibers were discovered to be (A1, A2, A4) and had a slump of 0.1% mix (A1) of 72 mm, which is greater than the untreated mix (U1) having the same quantity of fibers. Bonding between the fibers and the cement matrix was enhanced, minimizing fiber clumping, and greater dispersion led to increased flow, which was contributed to by alkalinity treatment [16]. In a similar way, there were moderate improvements in the workability of the hot water-treated mixtures (H1, H2, H4), of which the lowest was 71 mm at 0.1% fiber (H1). This treatment improves fiber flexibility, however, not to the level of alkali treatment.

Conversely, the acid-treated mixtures (AC1, AC2, and AC4) recorded the least workability with a slump of 56 mm with 0.4% addition of fiber (AC4). The flexibility of the fibers was presumably limited by the acidic treatment, which removes the non-cellulosic elements of the fibers; hence, the latter found it difficult to blend with the cement matrix. This resulted in increased resistance to flow, particularly with larger dosages of fiber. The workability diminished with an increase in fiber content, as was seen in past investigations on fiber-reinforced concrete. Nevertheless, alkali treatment did the most in keeping or boosting workability since it promoted the dispersion of the fibers and decreased cell clustering of the fibers. Workability was increased by hot water treatment, but to a modest extent, followed by acidic treatment, which resulted in the highest loss in workability [17]. These findings show that although bigger doses of fiber may have to be employed, alkali treatment would be preferable to guarantee that the workability of the mix is not lost at the price of performance.

3.2. Compressive Strength

Compressive strength is regarded as one of the essential aspects in assessing the structural strength of concrete. The compressive strength of concrete mixes was determined at 28 days of age using the technique given in ASTM C39 [18]. The outcomes of each of the mixes, including mixes with varying fiber contents and mixes with different treatments, are tabulated in Fig. 3. The control mix (lacking jute fiber) increased compressive strength to the level of 24.8 MPa, which relied upon the basis of comparison. The strength of the twelve specimens containing jute fiber exhibited a general tendency to rise or decrease somewhat in strength with the fiber content and treatment. In the untreated jute fiber blends, the compressive strength decreases with the increase in the fiber. The combination with 0.1% fiber (U1) had a strength of 25.2 MPa, which was just a little bit greater than in the control, but reduced to 21.3 MPa at the concentration of 0.4% fiber (U4). This reduction in strength has been related to poor dispersion of untreated fibers and the weak connection they have with the cement matrix, thereby leading to the creation of holes, giving it low strength.

The best performance with relation to compressive strength was found in the alkali-treated jute fiber mixtures (A1, A2, A4). The fiber fraction of 0.1 per cent (A1) attained a compressive strength of around 26.3 MPa, about 6 per cent stronger than the standard mix. The alkali-treated mix showed good compressive strength of 23.0 MPa as compared to 21.3 MPa of the untreated mix, even at the highest percentage of fiber content of 0.4% (A4), which is unusually high. The fiber and cement interface treatment reaction were good due to the removal of lignin and hemicellulose during the alkali treatment, which increased stress transmission and decreased clustering of the fibers.

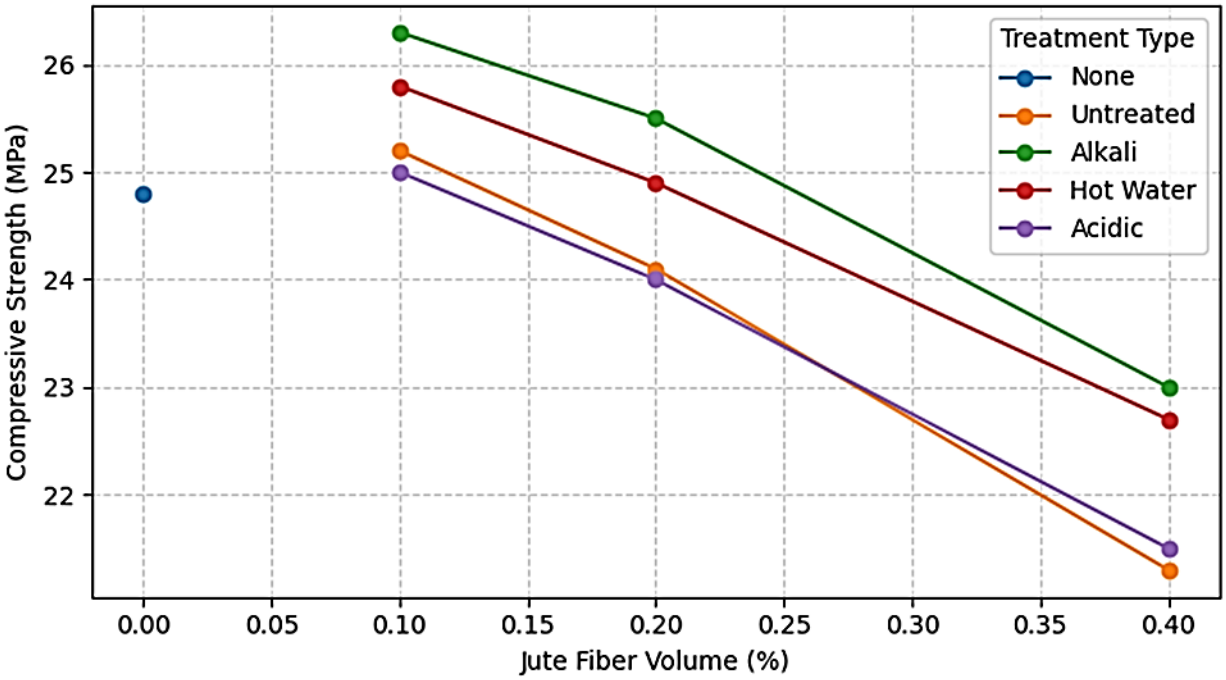

Fig. 3. Variation of 28-Day Compressive Strength with Jute Fiber Volume and Treatment Type

The mixtures treated with hot water (H1, H2, H4) also provided encouraging outcomes, especially at lower dosages. The 0.1% fiber mix (H1) along with a fiber fraction of 0.2 (H2) indicated the strengths of 25.8 and 24.9 MPa, respectively. Nevertheless, the strength of the fiber fell to 22.5 MPa at a greater fiber concentration (0.4% H4). This indicates that although hot water treatment boosted flexibility and dispersion of the fibers, it performed poorly in contrast with alkali treatment in preserving compressive strength. The acidic-treated mixtures (AC1, AC2, AC4) revealed mild benefits at lower levels than at the higher fiber levels, but they had a more significant loss of strength at greater doses as well. The 0.1 per cent fiber mix (AC1) reached a compression strength of 25.0 MPa, matching the non-treated mix, and at a fiber level of 0.4 per cent (AC4), the strength was lowered to 21.5 MPa. This might presumably be a result of a severe breakdown of the fiber structure in the acid treatment procedure, resulting in a weak fiber-matrix bond.

The difference in compressive strength of the various blends is seen in Fig. 3. It is also obvious that alkali treatment delivers the optimal outcome in terms of strength preservation, even at a large volume of fibers. Untreated and acidic-treated fibers, on the other hand, reported reduced compressive strengths, especially at a larger fiber quantity. The compressive strength of concrete can be enhanced with the inclusion of treated jute fibers, specifically alkali-treated jute fibers, especially when the content of the fiber is low. Increased levels of fiber diminish the strength, presumably because of insufficient dispersion of the fibers and their poor assimilation in the matrix. The most efficient treatment of jute fiber-reinforced concrete to preserve or increase the compressive strength consists of the alkali treatment.

3.3. Split Tensile Strength

The split tensile strength is a highly essential feature and is used to measure the ability of the concrete to withstand cracking in the presence of indirect tensile stress. Split tensile strength was also evaluated on a 28-day basis in compliance with ASTM C496, and the results of all mixtures of varied fiber compositions and treatments are reported in Fig. 4. Using the split tensile strength of the control mix (without jute fiber) as the baseline, 2.28 MPa, the other mixes (with jute fiber) had split tensile strengths of 1.76, 1.90, 2.54, and 2.89 MPa, respectively. The addition of jute fibers to the concrete resulted in enhanced concrete, with the improvement levels dependent on the fiber content and treatment. In the untreated jute fiber blends, a slight boost in tensile strength was documented at lower fiber concentrations, but the strength was lowered with higher fiber content.

The 0.1% fiber (U1) mix attained 2.42 MPa of split tensile strength, and the strength fell to 2.20 MPa when the fiber concentration approached 0.4% (U4). This loss in strength with increasing fiber content is due to incomplete dispersion of the fibers and the creation of grouts and empty spaces in the matrix, weakening the tensile performance. The largest effect on an increase in split tensile strength was reported in the alkali-treated jute fiber mixtures (A1, A2, A4). The 0.1% fiber blend (A1) had a strength of 2.60 MPa, which was the strongest of all, demonstrating a considerable increase compared to the control. Even when 0.4% of this fiber was employed (A4), the alkali-treated mix showed greater split tensile strength of 2.38 MPa, compared to its untreated (U4) and control mixes.

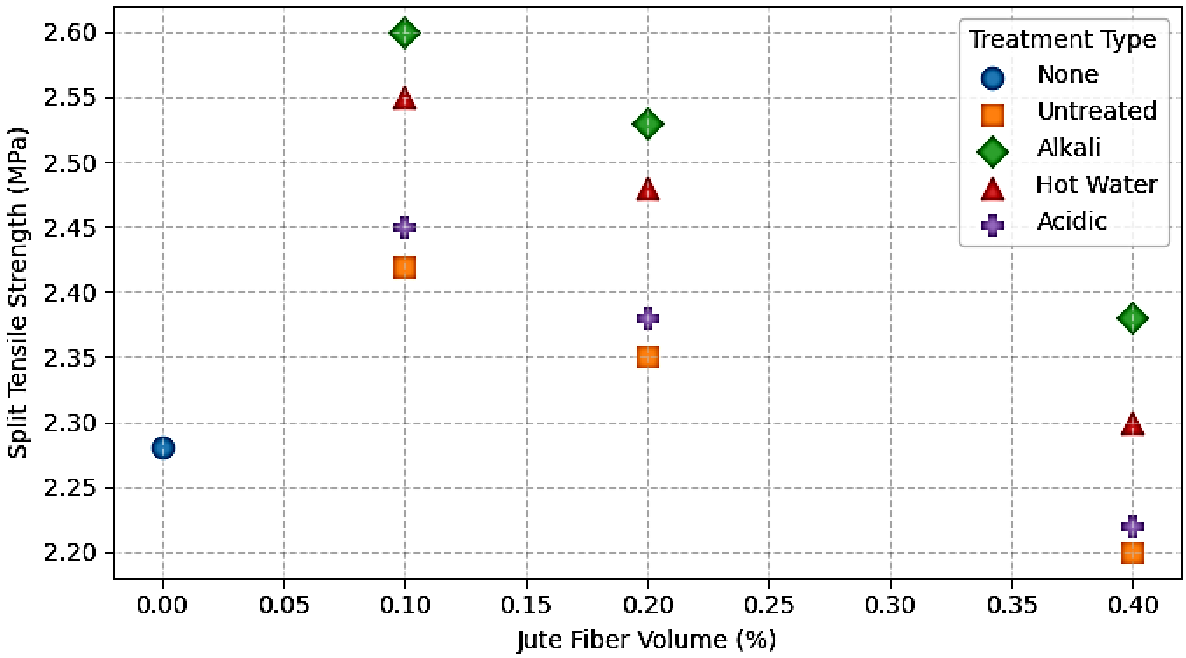

Fig. 4. 28-day split tensile strength for various jute fiber volumes, grouped by treatment type.

The alkali treatment enhances the link between the fiber and the matrix by removing lignins and hemicellulose, consequently enhancing the ability of stress transfer between the fiber and the cement matrix, resulting in increased tensile strength. The hot water-treated mixes (H1, H2, H4) exhibited a moderate improvement in tensile strength, with the 0.1% fiber mix (H1) having a strength of 2.55 MPa, and the 0.2% fiber mix (H2) having a strength of 2.48 MPa. However, with increased fiber concentration (0.4%, H4), the strength was lowered to 2.30 MPa. The hot water treatment promoted the dispersion of the fibers, but its performance in tensile strength retention was not as favourable as that of alkali treatment.

Consistent, but modest, benefits were noted in the acidic-treated mixes (AC1, AC2, AC4), in contrast to the alkali-treated mixes. With the 0.1% fiber mix (AC1), split tensile strength was determined to be 2.45 MPa, and with 0.4% fiber (AC4), the strength was 2.22 MPa. The acidic treatment did not appreciably influence the flexibility of the fibers or the bonding between the fibers and the matrix, resulting in minor gains in tensile strength, especially at the higher fiber concentrations. Fig. 4 illustrates the variation in split tensile strength across all combinations. The results suggest that alkali treatment has a favorable effect on tensile strength, with the highest strength at a lower fiber dose (0.1%). Increased fiber contents resulted in reduced tensile strength for all treatments, but alkali-treated blends fared the best.

The inclusion of treated jute fibers, especially those exposed to alkali treatment, leads to a huge improvement in the split tensile strength of concrete. Alkali treatment increases the connection between the fiber and the matrix, resulting in greater tensile strength, even at larger fiber doses. Comparatively, untreated and acidic-treated fibers do not improve as well, and tensile strength falls with higher fiber content since the fibers do not distribute properly and stick together.

4 Conclusions

This study assessed the effects of jute fiber reinforcement on the mechanical characteristics and workability of concrete, primarily focused on compressive strength, split tensile strength, and workability. The findings indicate that incorporating jute fibers often decreases workability, with more fiber content causing more significant reductions in slump. The surface treatment of the fibers is essential in alleviating this decrease. Alkali treatment markedly enhanced workability and fiber dispersion, whereas acidic treatment resulted in the most considerable reduction in workability due to fiber destruction. Alkali-treated jute fibers demonstrated the most substantial enhancements in compressive and split tensile strengths, particularly at reduced fiber content levels. The treated fibers established a more robust link with the cement matrix, hence augmenting the material's strength and longevity. Conversely, untreated and acid-treated fibers exhibited diminished compressive and tensile strengths, especially at elevated fiber doses, attributable to inadequate dispersion and weak adhesion between the fibers and the matrix. The research validates that jute fiber-reinforced concrete, especially when subjected to alkali treatment, is a viable alternative for enhancing concrete performance in diverse structural applications. Alkali treatment is the most effective approach for improving the strength and workability of jute fiber-reinforced concrete, rendering it a viable and sustainable option for contemporary construction practices.

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ETHICS STATEMENT

This study did not involve human or animal subjects and, therefore, did not require ethical approval.

STATEMENT OF CONFLICT OF INTERESTS

The authors declare no conflicts of interest related to this study.

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