Mechanical Properties and Durability Study of Jute Fiber Reinforced Concrete

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Abstract. Natural material/fiber should be used in the construction industry as it finds low cost and improve the properties of the material. Jute fiber is used in research study and carried out an experimental investigation on the mechanical properties of the jute fiber reinforced concrete (JFRC). Natural available jute fiber was chopped to the desired length and it was mixed in concrete to produce JFRC. The chopped jute fiber added in three different percentages i.e. 0.5\%, 1.0\%, & 1.5\% in three various concrete mixes (M25, M30 and M40). Additionally, JFRC concrete specimens cured in the acid medium and examine the compression strength, split tensile strength, and strength reduced under acid curing. Workability results indicated that the slump value (workability) reduced as an increased amount of jute fiber in the concrete specimens. Also, the compressive strength reduced in the acid curing as compared to normal curing. Additionally, Jute fiber increased the compressive and tensile strength of every concrete mix. This research study revealed that natural fiber (jute fiber) can be used as additives to enhance the durability and strength of concrete.

Keywords: Concrete mix, Jute fiber, Compressive strength, Tensile strength, Acid curing, Workability
1. Introduction

Natural fibers are cost-effective with low density, biodegradable, renewable, on-abrasive and readily available worldwide. The natural fiber is mainly composed of cellulose, hemicelluloses and lignin with minor amounts of protein and inorganic. Jute Fiber Reinforced Concrete (JFRC) can be considered as a composite material made of concrete and short discrete natural jute fiber. Therefore, much research has been undergoing to utilize the naturally available jute fiber to use in a concrete matrix, for creating a composite building material. The development of such composite material will increase the strength of the structure and also increases the life span of the structure. Many studies carried out on the concrete mix with addition of jute fiber. Aziz et al. [1] studied the critical estimation and properties of natural fiber reinforced concrete and it was seen that the suitable technology for quality product development was of main importance. Ramakrishna et al. [6] worked on the four different fibers such as coir, sisal, jute and Hibiscus cannabinus using in mortar mix. Results found that coir fiber was significantly improved the initial strength. Sen and reddy [8] investigated the materials chosen for structural up-gradation must, in addition to functional efficiency and increasing or improving the various properties of the structures, should fulfill some criterion, for the cause of sustainability and a better quality.

Zhou et. al. [10] researched fracture and impact properties of short discrete jute fiber reinforced cementitious composites (JFRCC) with various form for developing low-cost natural fiber-reinforced concretes and mortars for construction. Three different process methodologies were adopted to mix the jute fiber homogeneously in the mortar matrix [2]. Out of these three processes, the best dispersion of the fibers was achieved when water-saturated chopped jute fibers were used in mortar sample preparation. Additionally, Oh et al. [5] worked on the jute fiber reinforced concrete with an addition three different percentage of jute fiber. Alkali activator was also used and replaced the blast furnace slag. With the increased amount of jute fiber and alkali activator, void ratio and compressive strength was also increased. Yan et al. [9], studied the flexural strength using two types of concrete such as plain concrete and coir fiber reinforced concrete (CFRC). Flax fabric reinforced epoxy polymer (FFRP) was applied on the beam specimens. FFRP layer and coir exhibited the flexural strength of specimens. Razmi and mirsayar [7] used 20mm length fiber with three different percentages of 0.1%, 0.3% and 0.5% and evaluate the toughness and mechanical
properties of concrete. The results found that concrete mix with jute fibers improved the compressive, tensile and flexural strength as well as higher resistance value. Additionally Islam and Ahmed [4] used three different dosage of jute fiber i.e. 0.25%, 0.5% and 1% with two length of 10 mm and 20 mm. Maximum improvements was observed in jute fiber concrete at the addition of 0.25% jute fiber.

Various research studies were performed on the concrete and mortar mix using jute fiber with different percentages. Therefore, a study needs to be done to examine the effect of chemical/acid on the concrete mix with jute fibers. This research study aims to evaluate the effect of jute fiber (chopped) on the compressive strength and tensile strength of the concrete after 7 days and 28 days. Jute fiber was used with three different percentages of 0.5%, 1% and 1.5% in three concrete mixes (M25, M30 and M40) to prepare the Jute fiber reinforced concrete (JFRC). Also, concrete specimens with jute fiber cured in the acid medium to examine the effect of acid on the mechanical properties of concrete specimens after 28 days.

2. Material used and methods

2.1 Materials

All the materials used in the present study was tested under the IS guidelines. Ordinary Portland cement (OPC-43) was used in the research study. The specific gravity and consistency of the cement was 3.14 and 34% respectively. The compressive strength of the cement was 42.6 MPa after 28 days. The specific gravity, water absorption and fineness modulus of the coarse aggregate (CA) and fine aggregate (FA) was 2.72, 0.7%, 6.9 and 2.48, 1%, 2.44 respectively. Grading zone of the coarse aggregate and fine aggregate lied in II zone. The admixture was also used in this study. CICO C-300 was used as water reducing admixture in the concrete mix as confirmed by IS 9103:1999.

2.2 Jute fiber

Jute fiber is a three-dimensional composite mainly composed of cellulose, hemicelluloses and lignin with minor amounts of protein and inorganic [7]. Jute fiber has high tensile strength as compared to other fiber like sisal, bamboo, coir, & hemp. Apart from the tensile strength jute fiber can easily withstand heat. The different mechanical properties of the jute fiber has-been
briefly described here in Table 1. Raw jute fiber (Figure 1(a)) collected from the manufacturer and chopped (Figure 1(b)) in the concrete laboratory.

Table 1: Properties of jute fiber

| Properties                  | Values    |
|-----------------------------|-----------|
| Specific Gravity [kg/m³]    | 1460      |
| Water Absorption [%]        | 13        |
| Tensile Strength [MPa]      | 400-800   |
| Stiffness [kN/mm²]          | 10-30     |

Figure 1 (a) Raw jute fiber (b) Chopped jute fiber

2.3 Mix Design of three different grade of concrete

Concrete mix design of M25, M30 & M40 is prepared as per IS: 10262-2009 [3]. These grades are selected because beams and column are mainly cast of selected concrete mix proportions on construction site. Several trial mixes has been done to obtain the optimum design mix of concrete for different grades then add the jute fibers. The jute fiber has been added in three different percentages into the cement matrix i.e. 0.5%, 1.0%, & 1.5%. The procedure followed for preparing mix design is given in Table 2 for different grades of concrete mix.

Table 2 Different mix proportions of concrete

| Materials | Mix proportions (kg/m³) |
|-----------|-------------------------|
|           | M25                     |
|           | M30                     |
|           | M40                     |
### 2.4 Preparation and testing of specimens

All the experimental work in the present research has been carried out as per the IS codes. Local available jute fiber was taken in the study and raw jute fiber was chopped up to the length of 25-50mm in length for the preparation of the JFRC. The chopped jute fiber was immersed in water for 24 hour before mixing it in the concrete matrix. The jute fiber was mixed in the concrete, after preparing the cement and jute slurry. 50% of cement and water were taken with the required amount of jute fiber for preparing the slurry. The remaining 50% dry cement mixed with coarse and fine aggregate in the mixture. Once the dry mix properly mixed, the slurry was added into the mixture, and remaining 50% of water with superplasticizer was added. This procedure was selected for the proper mixing of jute fiber with materials as well as jute fiber did not soak the additional water of concrete. In this way, the Jute fiber reinforced concrete was prepared for the three different grades of concrete.

Freshly prepared concrete was then poured in the moulds. The cube and cylinder specimens were de-moulded after 24 hours and were kept for a curing period of 7 and 28 days. The concrete cube and cylinder specimens cured in the acid medium (Sulphuric acid 0.5N) for 28 days as various concrete structures is effected by chemical attack. Also, see the impact of sulphuric acid on jute fiber concrete. Cube and cylinder specimens were prepared to evaluate the compressive and tensile strength of concrete using compression testing machine.

### 3. Result and discussion

Destructive test were conducted on hard concrete after 7 days and 28 days of curing. Whereas, on freshly prepared concrete slump test was done to check the workability of the jute fiber reinforced concrete. To know the effect of acid curing (sulphuric acid) on concrete, a
destructive test was conducted after 28 days of acid curing. The various destructive test has been done on the hardened concrete to check the compressive and split tensile strength of the concrete.

3.1 Workability test results

A slump cone test was done on the freshly prepared concrete to know the workability (slump value) of the concrete mix. The slump value was 110mm, 105mm and 110mm for the conventional concrete grade of M25, M30 and M40 respectively. Less value of slump value (80mm) was observed at 1.5% percentages of jute fiber in M25 and M40 grade of concrete. The slump value was decreased as the percentages of jute fiber increased in the concrete mix due to the two factors. The first factor is when the chopped jute fiber mixed into the concrete matrix the jute got agglomerated which result in non-uniform distribution of jute. Secondly, jute being hydrophilic, it absorbs water from the mix which required to make concrete, hence reduces the workability. Figure 2 shows the bar chat of slump value reduction with the addition of jute fiber into the cement matrix.

![Figure 2 Slump values of control mix and JFRC](image)

3.2 Compressive strength test results

Testing of hardened concrete is important for determination of mechanical properties of concrete as it can give a reasonable estimation of the fundamental physical behavior of concrete such as compressive strength, hardness and homogeneity of concrete for quality
control aspect.

The compressive strength results of the cube specimens with the addition of different percentage of jute fiber for concrete grade M25, M30 and M40 after 7 days & 28 days under normal and acid curing is presented in Figure 3, Figure 4 and Figure 5 respectively. The compressive strength result of control mix was 20.3 MPa, 26.8 MPa and 21.35 MPa at 7 days, 28 days and in acid curing respectively. Highest compressive strength was observed as 23.2 MPa, 32.1 MPa and 21.20 MPa after 7 days, 28 days and in acid curing respectively at 1.5% addition of jute fiber however lowest compressive strength was observed as 20.9 MPa, 27.7 MPa and 21.20 MPa at 7 days, 28 days and in acid curing respectively at 0.5% addition of jute fiber. The compressive strength of the concrete increased with the addition of jute fiber into the concrete matrix. As fiber bridges the micropores and fills the voids in the concrete which helps to enhance the strength of concrete. The present study revealed that maximum strength was achieved as 19.7 percentage increased with the addition of 1.5% jute fiber into the concrete matrix for M25 grade of concrete after 28 days of curing due to proper uniformity distribution of fiber inside in the concrete matrix. Whereas the percentage in reduction of strength after 28 days acid curing, was maximum at 1.5% jute fiber, which is found to be 37.8%.

The compressive strength values were 26 MPa, 34 MPa and 28.4 MPa of the control mix (M30) at 7 days, 28 days and in acid curing. The maximum compressive strength was observed as 29.1 MPa and 37.3 MPa after 7 days and 28 days which is found to be increased by 11.9% and 9.7% respectively. The strength of concrete keeps on increased with addition of fiber as shown in Figure 4.3. Whereas the reduction of strength after 28 days in acid curing, was maximum at 1.5% jute fiber, which is found to be 31.06%. The results indicated that addition of jute fiber slightly increased the compressive strength in acid curing up to 1% of jute fiber however; it was reduced at 1.5% of jute fiber.

A similar trend of results was observed in the M40 grade of concrete as observed in M25 and M30 grade of concrete. Figure 4.4 shows the results for the M40 grade of concrete. 27.2 MPa, 44.1 MPa and 36.70 MPa strength was found in the control mix at 7 days, 28 days and in acid curing after 28 days. The maximum increase in strength after addition of jute fiber was achieved at 1.5% which was found as 35.1 MPa and 47.7 MPa at 7 days and 28 days respectively. The compressive strength was observed minimum at 0.5% addition of jute fiber.
Acid curing showed negative impact on the strength of concrete and the compressive strength decreased in the acid curing as compared to normal curing.

Figure 3 Compressive strength results of control mix and JFRC for concrete (M25)

Figure 4 Compressive strength results of control mix and JFRC for concrete (M30)
3.3 Split tensile strength result

Split tensile test has been conducted to observe the brittle nature of the concrete specimens that consisted of natural aggregate and jute fiber in differing percentage. The split tensile test is carried out on cylinder specimens (150mm diameter, 300 mm depth) according to IS: 5816-1999.

The concrete mix with 0% jute fiber (CM) showed tensile strength as 2 MPa, 2.6 MPa and 2.1 MPa at 7 days, 28 days and in acid curing as presented in Table 3. Concrete mix with fiber dosage at 1.5%, achieved maximum strength as 3.4 MPa which was found to be increased by 30.8% as compared to control sample. However, the mixes with fiber dosage of 0.5% and 1% showed minimum tensile strength as 3 MPa and 3.3 MPa respectively after 28 days. The split tensile strength increased with the addition of jute fiber, which shows that the brittle nature of concrete can be overcome by addition of jute fiber for M25 Grade of concrete. This improvement in the tensile strength of JFRC was observed due to the jute fiber. Besides, the cylinder specimens cured in the acid curing to examine the tensile strength. The tensile strength gradually decreased in acid curing as compared to normal curing because acid medium accelerates the rate of decomposition for the jute fiber. Additionally, it is a natural fiber which has the natural tendency to undergo decomposition with time.

Similar observations of tensile strength were obtained in M30 and M40 grade of concrete. Incorporation of jute fiber with three different percentages in both concrete mixes (M30,
M40) increased the tensile strength after 7 days and 28 days. Also, jute fiber increased the tensile strength of cylinder specimens in acid curing but not significantly improved as compared to normal curing. The tensile strength was slightly low in acid curing as compared to normal curing. The maximum increment in strength was 19.35% (3.7 MPa) as compared to the control mix at 1.5% content of jute fiber for M30 concrete. The strength in acid curing showed reduction in strength was minimum at 0.5% jute addition, which was found to be 26.92% (2.6 MPa) as presented in Table 4. For the M40 grade of concrete, highest tensile strength was observed as 4.6 MPa (21.1%) at 1.5% jute fiber however lowest strength was observed as 4.1 MPa (7.9%) at 0.5% jute fiber at 28 days presented in Table 5. 2.97 MPa strength (1.5% jute fiber) was observed maximum in acid curing. Inclusion of jute fiber content (0.5%, 1%, and 1.5%) in the concrete mixes did not effectively increased the tensile strength of cylinder specimens cured in acid medium after 28 days as compared to normal curing.

Table 3 Split tensile strength result of JFRC concrete (M25)

| Grade with Jute fiber percentage | Strength after 7 D | % Increase | Strength after 28 D | % Increase | After Acid Curing | % Reduction after Acid Curing |
|---------------------------------|-------------------|------------|---------------------|------------|-------------------|-------------------------------|
| M25 @ 0%                         | 2.0               | -          | 2.6                 | -          | 2.1               | 23.8                          |
| M25 @ 0.5%                      | 2.2               | 10         | 3.0                 | 15.4       | 2.3               | 30.43                         |
| M25 @ 1.0%                      | 2.4               | 20         | 3.3                 | 26.9       | 2.6               | 26.92                         |
| M25 @ 1.5%                      | 2.5               | 25         | 3.4                 | 30.8       | 2.97              | 30.76                         |
Table 4 Split tensile strength result of JFRC concrete (M30)

| Grade with jute fiber percentage | Strength after 7 D | % Increase | Strength after 28 D | % Increase | After Acid Curing | % Reduction after Acid Curing |
|----------------------------------|-------------------|------------|-------------------|------------|------------------|-----------------------------|
| M30 @ 0%                         | 2.4               | -          | 3.1               | -          | 2.5              | 24                          |
| M30 @ 0.5%                       | 2.7               | 12.5       | 3.3               | 6.4        | 2.6              | 26.92                       |
| M30 @ 1.0%                       | 2.9               | 20.8       | 3.6               | 16.12      | 2.78             | 29.5                        |
| M30 @ 1.5%                       | 3.1               | 29.1       | 3.7               | 19.35      | 2.8              | 32.14                       |

Table 5 Split tensile strength result of JFRC concrete (M40)

| Grade with jute fiber percentage | Strength after 7 D | % Increase | Strength after 28 D | % Increase | After Acid Curing | % Reduction after Acid Curing |
|----------------------------------|-------------------|------------|-------------------|------------|------------------|-----------------------------|
| M40 @ 0%                         | 2.5               | -          | 3.8               | -          | 3.1              | 22.5                        |
| M40 @ 0.5%                       | 3.0               | 20         | 4.1               | 7.9        | 3.3              | 24.2                        |
| M40 @ 1.0%                       | 3.3               | 32         | 4.3               | 13.15      | 3.3              | 30.3                        |
| M40 @ 1.5%                       | 3.4               | 36         | 4.6               | 21.1       | 3.5              | 31.42                       |

4. Conclusion

Jute fiber has been added in three different percentages i.e. 0.5%, 1.0%, & 1.5% in M25, M30, and M40 grade of concrete for making concrete better in its mechanical property. Furthermore, the durability of concrete is studied to know the effect of acid curing on JFRC. While studying, every aspect has been deeply observed and following conclusions are deduced from the present investigation:

- The workability of the JFRC reduced with the addition of jute fiber in the concrete matrix. The maximum workability was achieved at 0% of jute fiber addition in all grades of concrete. Whereas minimum workability was observed with 1.5% addition of jute fiber.
This reduction in workability is due to hydrophilic nature of jute fiber. The jute fiber absorbs the water from the concrete mix which is required for its strength, heat of hydration and workability. Therefore, the JFRC mix had less water content, which reduced the workability.

- The compressive strength M25, M30 & M40 of concrete is increased with the addition of jute fiber. Maximum compressive strength was achieved at 1.5% addition of jute fiber in M25, M30 & M40 grade of concrete which amount to be 19.7%, 9.7% and 8.1% respectively. However, the compressive strength of specimen cured in acid medium showed maximum reduction in strength was also observed at 1.5% addition of jute fiber. This is due to the natural decay of jute fiber and one major drawback of jute fiber as the JFRC specimens placed in acid medium so it starts to accelerate the decomposition process of jute fiber.

- The split tensile strength results were similar to the compressive strength of concrete specimens and maximum tensile strength was obtained in all concrete mixes after 28 days of curing at 1.5% jute fiber content. Improvement in tensile strength was observed as 30.8%, 19.35% and 21.1% in M25, M30 and M40 grade of concrete respectively. Whereas, the maximum reduction in strength is observed for JFRC with 1.5% addition of jute fiber after 28 days in acid curing.

- Jute fiber binds the materials inside into the concrete matrix and enhances the compressive and tensile strength of concrete. However, JFRC did not show any significant results in acid curing and cannot use this concrete in coastal/marine areas.

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