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MECHANICAL PROPERTIES OF CONCRETE INCORPORATING NaOH TREATED JUTE FIBER

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ABSTRACT

The incorporation of short discrete fibers in concrete has become popular nowadays due to its versatile advantages over plain concrete. Jute is cheap and abundant in Bangladesh. Thus, the combination of jute fiber and concrete may be one of the important approaches to the development of concrete technology. The aim of this study is to investigate the mechanical properties of jute fiber reinforced concrete (JFRC) for different combinations of fiber volume and length and compare the results with plain concrete. Cylinders and prisms of standard sizes containing JFRC were prepared for compressive, split tensile and flexural strength tests and all the tests were carried out after 28 days moist curing. Before mixing with concrete, jute fibers were cut into two different lengths and treated with NaOH solution. It was observed that NaOH treatment reduced the water absorption capacity of fibers. Though the compressive strength of JFRC was found slightly incremental for some combinations of fiber length and volume, significant increment was not observed for other combinations. Moreover, the strength was found decreased for long length and large volume of fibers. It was demonstrated that fibers had no or very little influence on split tensile strength of concrete. Improvement of flexural strength was found by about 10~20% for JFRC specimen as compared to plain concrete. Due to the incorporation of fibers restriction to the catastrophic failure of the FRC specimens was also observed.

Keywords: *Fiber Reinforced Concrete, Jute Fiber, NaOH Treatment, Water Absorption*

1. INTRODUCTION

It is well known that concrete is strong in compression but very weak in tension. Generally, the tensile strength of concrete is only about 10% of its compressive strength. This variation in strength of concrete is analogous to the brittle failure of concrete. Thus, transverse reinforcement needs to be provided to counteract the brittleness in the region where tensile stress develops. But provision of such reinforcement in some cases might arise difficulties in associated with labor, cost etc. Fiber Reinforced Concrete (FRC) can play an important role in this context. FRC is a concrete composite in which short distinct fibers are incorporated as a reinforcing agent.

Different fibers originating from different materials can be used in concrete as reinforcement. Fibers can be produced from steel, plastic, glass, carbon, synthetic etc. and varied in sizes and shapes. Fiber length, aspect ratio and fiber dosage play vital role in concrete strength (Naraganti *et al*., 2019). Steel fiber is widely used fiber for different structural purposes and is available in different shapes like- straight, end hooked, end knobs, deformed and crimped, irregular etc. (Flakk and Tordal, 2012). Many researchers carried out numerous studies on the benefit of using fibers as reinforcement in concrete. It is well established that addition of fibers in concrete imparts improved strength, fatigue resistance, toughness, ductility, post cracking resistance, impact resistance etc. (Manikandan *et al*., 2017; Saxena and Saxena, 2015; Suksawang and Mirmiran, 2014). Due to its versatile properties, FRC is now widely used in airport and highway pavement construction, construction of earthquake resisting building, construction of tunnel, lining of mine, construction of hydraulic structures etc. (Manikandan *et al.*, 2017; Meddah and Bencheikh, 2009; Saxena and Saxena, 2015; Seo, 2010).

Neves (2005) studied compressive characteristics of SFRC. It was observed that both compressive strength and toughness index was increased for concrete containing steel fibers as compared to plain concrete. Khanlou *et al.* (2012) reported that the shear contribution of steel fiber reinforced concrete (SFRC) is 70% higher than that of plain concrete. SFRC is also used to produce ultrahigh performance concrete. As concrete shows higher brittleness with increased strength, addition of steel fiber makes the composite ductile. Thus sudden failure tendency of high strength concrete can be eliminated (Flakk and Tordal, 2012). Moreover fibers contribute to the compressive and tensile properties of concrete (Wahba, 2012). But using of steel fibers in concrete has some demerits also. Exposed steel fibers are susceptible to be attacked by corrosion that may affect the strength as well as aesthetic. Thus, the use of SFRC in coastal region should be limited.

Glass fibers was also used in preparing FRC and precast concrete segment by some researchers (Kasagani and Rao, 2018; Meda *et al.*, 2019). It was found that the strength, energy absorption capacity, hardness was higher for glass fiber reinforced concrete as compared to plain one and the results showed increased strength where the grading of fibers had done. Similar response was observed for nylon fiber as the reinforcing agent in concrete

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(Manikandan *et al*., 2017; Saxena and Saxena, 2015). It was evident that synthetic fibers are not efficient in improving toughness of concrete. The major problem associated with steel, glass and synthetic fibers is that these fibers are very costly and has some negative impact on environment. Use of natural fibers like- jute, hemp, sisal, coir etc. may be advantageous in that case.

Jute is a kind of bast fiber that is extracted from the stems of jute plant. Jute grows plenty in Bangladesh. Thus, jute fiber is cheap and abundant in Bangladesh. Jute possesses many important properties like high tensile strength and stiffness, low density, environment friendliness, biodegradability etc. (Pickering *et al*., 2016). These properties will be advantageous over other types of fibers when jute is incorporated in concrete. Limited number of research has been published on the effect of incorporation of treated and untreated jute fibers in concrete. Islam and Ahmed (2018) studied the effect of untreated jute fibers on concrete properties. It was reported that the incorporation of smaller fibers in concrete improved both compressive strength and flexural strength. But inclusion of fibers had no significant effect on the split tensile strength of concrete. Zakaria *et al.* (2017) found improved compressive, flexural and split tensile strength of JFRC for low cut fibers with smaller volumetric content. It was observed that long fibers with high volume were responsible for inhomogeneous mixing of composite.

Major problem of using natural fibers in different composite is the durability of fibers in aggressive environment (Wei and Meyer, 2015). Jute fiber has hydrophilic character that will make the concrete stiff by absorbing water from the wet mix. Thus modification of jute fiber is required prior to apply in concrete. Kundu *et al*. (2012) produced non pressure concrete pipes by using JFRC. But jute fiber was treated with alkaline and was modified by polymer latex before applying in the composite. Treated jute composite exhibited improved mechanical properties. Alkali treatment of jute is effective in reducing the water absorption capacity of fibers (Adhikari *et al*., 2011).

In this research, mechanical properties of jute fiber reinforced concrete were investigated. Alkali treated jute fiber was used as reinforcing agent. Different JFRC specimens were prepared for compressive, tensile and flexural tests and the tests were carried out after 28 days moist curing. The effect of fiber length, fiber volume and alkali dosage on the strength of JFRC specimen was also observed.

2. METHODOLOGY

2.1 Materials

In this study 19 mm downgrade black stone chips having a specific gravity of 2.83 were used as coarse aggregates and sand having a specific gravity of 2.41 with a fineness modulus of 2.47 was used as fine aggregate. Ordinary Portland cement (ASTM Type I) with initial setting time of 140 minutes and final setting time of 275 minutes was used in all concrete mixtures as binding material. Locally available raw jute fiber was used in different volumetric percentages as the reinforcing agent of Jute Fiber Reinforcement Concrete (JFRC). But prior to applying in the mix, jute fiber was cut into two different lengths, 10 mm and 20 mm respectively (Figure 1) and chemical modification of the cut fiber was made by alkali treatment.

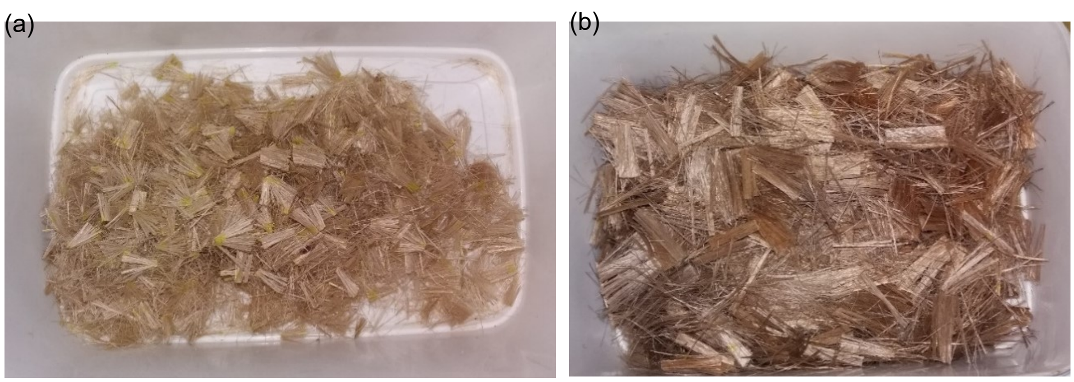

Figure 1: Cut Jute Fibers (a) 10 mm fiber length, (b) 20 mm fiber length

2.2 Alkali Treatment of Fibers

To reduce the hydrophilic character of jute fiber chemical treatment of fibers (Figure 2) is required and alkali treatment of jute fibers was carried out in this study. The cut fibers (10 mm, 20 mm) were immersed in 1% and 5% (w/v) NaOH solution for 48 hours at room temperature. The liquor ratio used in the treatment was 1:30. The treated fibers were then washed several times with water and air dried at room temperature. Finally the fibers were oven dried at 55 ^{0}C for 24 hours.

Figure 2: Alkali treatment of jute fiber (a) Fiber immersion in NaoH solution, (b) Extraction of jute fibers from NaOH Solution, (c) Air drying of jute fibers, (d) Oven drying of jute fibers.

To test the efficiency to the treatment water absorption test was carried out both for treated and untreated jute fibers. The water absorption calculation was as follows-

Water absorption (%) = $[(w_2-w_1)/w_1]$ x 100

Where, w_1 = oven dried weight of fiber; w_2 = weight of fibers after water soaking

It was observed that water absorption of untreated jute fibers was 163% whereas the absorption value for 1% NaOH treated jute fiber was 149%.

2.3 Concrete Mix Ratio

By concrete mix design, the proportions of different ingredients are selected to achieve target strength. But in this study no target strength was considered. Thus, a mix ratio of 1 (cement):2.5 (sand):3 (stone chips) was selected with a water cement ratio of 0.59. Fibers were incorporated in the mixture in two volume dosages i.e. 0.1% and 0.25% and the quantity of other ingredients were adjusted consequently. The quantity of different materials required for preparing a single prism block for different fiber dosages is shown in Table 1.

Table 1: Quantity of different materials for preparing a prism block with a mix ratio of 1:2.5:3 for different fiber volume

Sample No.	% of fiber	Total volume (cm^3)	Volume of cement and aggregates (cm^3)			Volume of fiber (cm^3)	Density of fiber (gm/cm^3)	Weight of fiber (gm)
			Cement	Sand	Stone chips			
01	0.0		2336.54	5841.35	7009.62	0.00		0.00
02	0.1	15187.5	2334.20	5835.50	7002.60	15.19	1.45	22.02
03	0.25		2330.70	5826.74	6992.10	37.97		55.06

2.4 Specimen Preparation

12 cylinders of size 100 mm (diameter) x 200 mm (height) and 6 prism blocks of size 450 mm (length) x 150 mm (width) x 150mm (depth) were prepared as reference concrete specimens in which no fiber content was

used. Specimens with fiber content were prepared for different combinations of fiber length, fiber volume and % of NaOH solution. The combinations are summarized in Table 2. For each combination, 3 cylinders for compressive strength test, 3 cylinders for split tensile strength test and 3 prism blocks for flexural strength test were prepared.

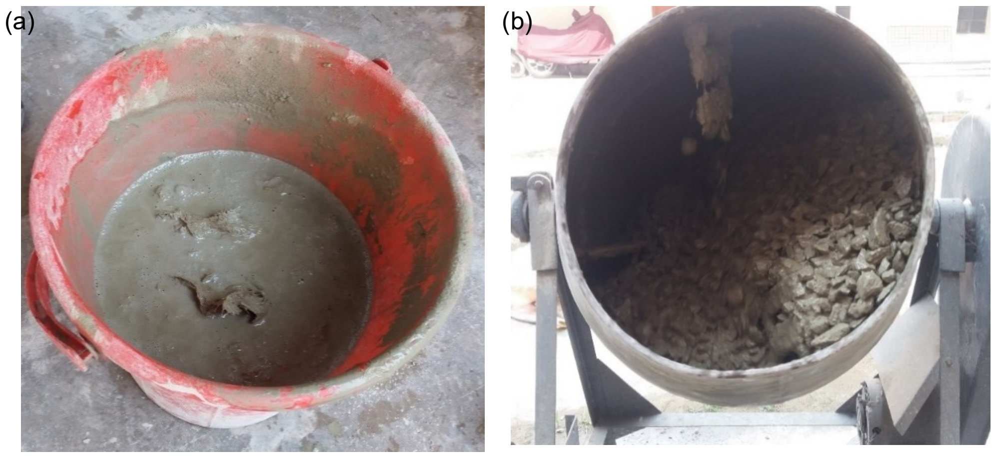

Figure 3: (a) Jute-cement slurry, (b) Mixing of slurry with remaining ingredients

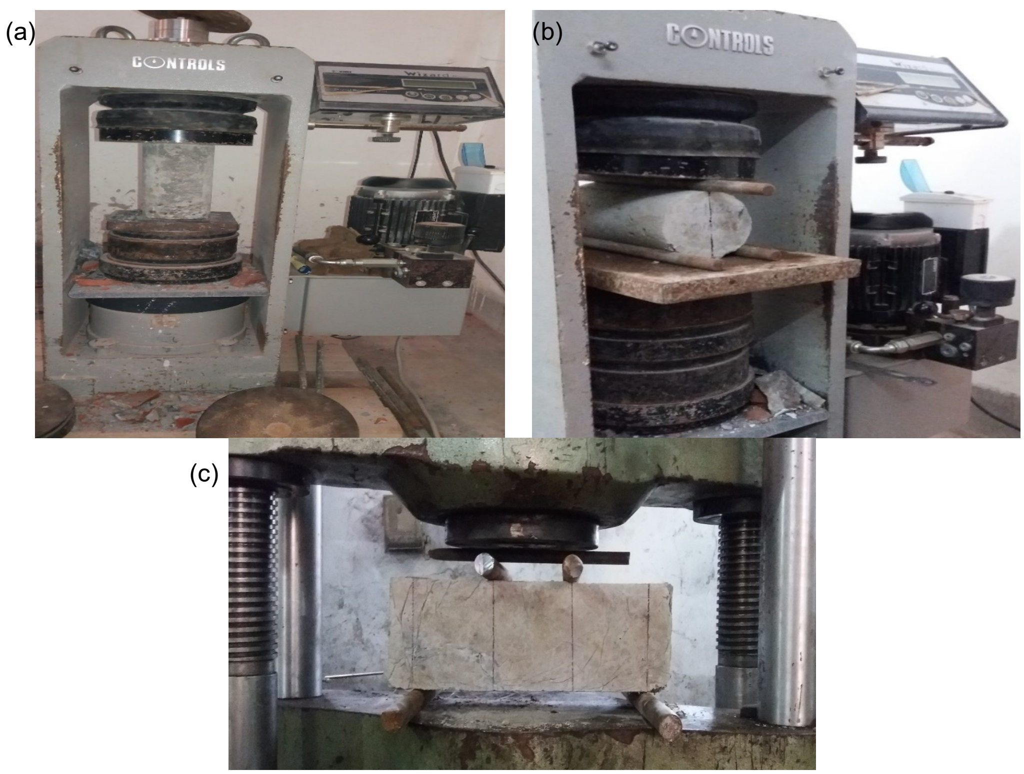

Figure 4: (a) Compressive Strength Test for Cylindrical Concrete Specimens, (b) Splitting Tensile Strength Test for Cylindrical Concrete Specimens, (c) Flexural Strength Test for Prism Block Specimens

A major problem associated with jute fiber as a reinforcing element in the concrete mix is that the non-homogeneous dispersion of the fibers throughout the mix. To overcome this shortcoming, a scheme was followed in which jute-cement slurry [Figure 3(a)] was prepared prior to apply in the mixture. Half of the required amount of cement and water were mixed with jute fiber in a container followed by continuous stirring. Then the jute-cement slurry was poured into the concrete mixture containing remaining amount of cement, water, sand and stone chips as illustrated in Figure 3(b). The mixture was then run for standard mixing time and the specimens were casted from the freshly mixed concrete. The slump value was found 131mm for plain concrete and 103mm for concrete containing 0.1% fiber. All the specimens were cured in water for 28 days.

Table 2: Combinations for Casting of JFRC Specimen

SL No.	NaOH % (w/v)	Fiber Length (mm)	Fiber Volume (%)
01	1	10	0.10
02	1	10	0.25
03	1	20	0.10
04	1	20	0.25
05	5	10	0.10
06	5	10	0.25
07	5	20	0.10
08	5	20	0.25

2.5 Experimental Program

The aim of this research was to evaluate the mechanical properties of jute fiber reinforced concrete (JFRC). Thus, the compressive, tensile and flexural property of the JFRC specimens was tested as shown in Figure 4. Compressive strength test was performed according to ASTM C39. 24 cylinders containing JFRC along with reference concrete cylinders were tested. Tension test was carried out by split tensile strength test which is an indirect method of tensile strength measurement covering ASTM C496 standard. Flexural strength was determined by third point loading according to ASTM C78 standard.

3. RESULTS AND DISCUSSION

3.1 Compressive Strength

Percentage difference of compressive strength of JFRC with respect to plain concrete for different fiber lengths and volumes are shown in Figures 5(a) and 5(b). Strength variation for 1% NaOH treated fibers are illustrated in Figure 5a. Strength increment was observed for both 10 mm and 20 mm fiber length when fiber content was limited to 0.1%. It was also visualized that although the strength increment for 10 mm fiber was about 4.5%, this increment was reduced to 2% for 20 mm fiber for the same fiber content. This reduction was increased with the increase of fiber content. Similar results were found from the study of Zakaria *et al.* (2017).

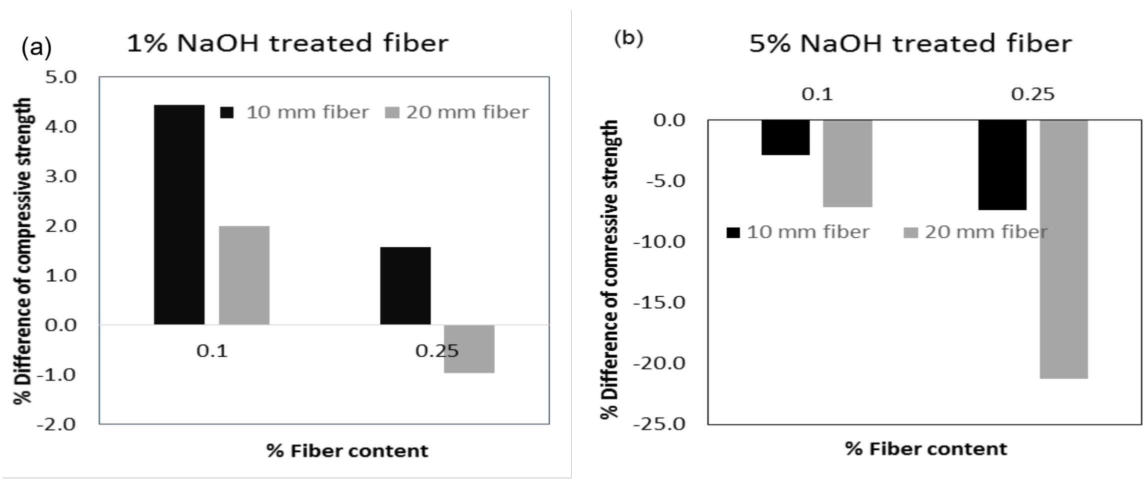

Figure 5: % difference of compressive strength of JFRC specimen with respect to plain concrete specimen (a) 1% NaOH treated fiber, (b) 5% NaOH treated fiber.

It was found from various research that the behavior of fibers in the concrete composite is rather like a coarse aggregate than a fine aggregate. This phenomenon is responsible for creating high porosity in the concrete that results in low compressive strength. But the slight increment for low fiber content can be explained in this manner that the short fiber length with smaller content made the composite an intact material by firmly binding the constituents of the composite. Another factor is that although the fiber is treated by NaOH to reduce the water absorption by the fibers, total reduction is not possible. Thus, fibers might absorb some amount of mixing water and thus reduce the water cement ratio. For this reason, compressive strength might has slightly increased as compared to plain concrete.

Reduction of strength was observed both for 10mm and 20 mm fiber when the fiber was treated with 5% NaOH solution. And maximum strength reduction was observed for 20 mm fiber length with 0.25% fiber content. This trend of strength reduction can be explained that the addition of fibers into the concrete mix results in the lower specific gravity of the composite. Thus, higher porosity occurs in the composite. It was observed that larger length and higher volume of fibers tended to ball up during mixing due to low specific gravity of fibers. And this phenomenon was also observed by other researchers Zakaria *et al.* (2017). The balling process as shown in Figure 6 is responsible for making concrete stiff which leads to reduction of compressive strength.

Figure 6: Dispersion of fibers in concrete (a) Homogeneous mixing (b) Inhomogeneous mixing or ball formation

In this study compressive strength was also found lower when the fiber treatment was conducted with increased percentage of alkaline. Similar results were observed from the study of Adhikari *et al.* (2011). Alkali modification of fiber makes the surface of fibers rougher which is helpful for creating bond with other constituents. But in this study, it was observed that the ball formation was more frequent for 5% NaOH treated fibers as the fibers might create strong cohesive bond between them and could not be separated.

The failure pattern of the specimens under compressive load was observed during testing. The specimens without fiber experienced a catastrophic failure [Figure 7(a)] while the specimens containing jute fibers had a multidirectional failure as the stresses were uniformly transferred by the fibers [Figure 7(b)].

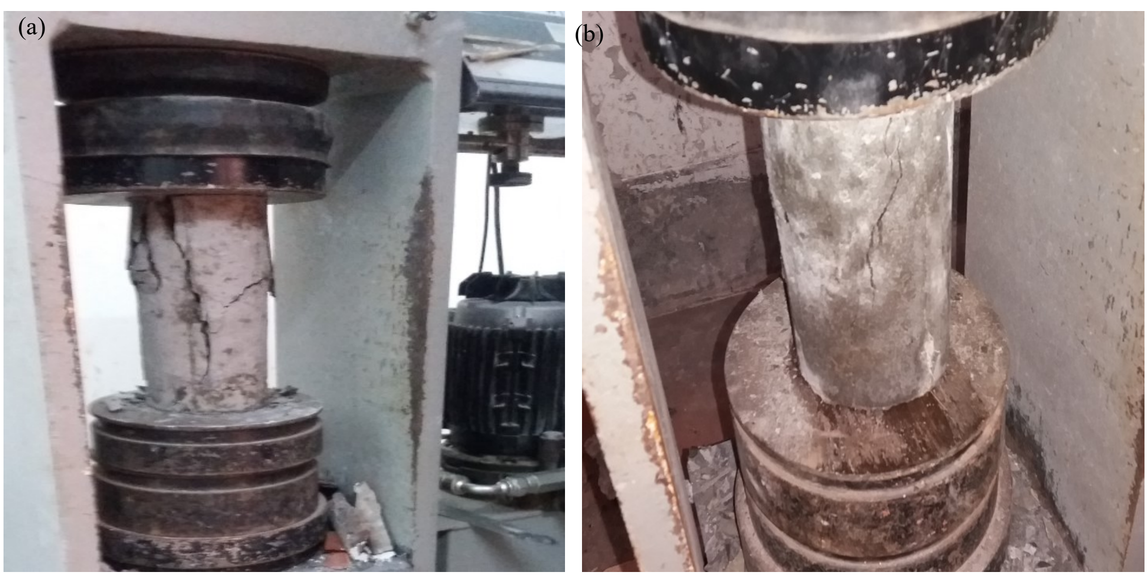

Figure 7: (a) Catastrophic failure of cylinder specimen without fiber (b) Failure pattern of JFRC specimen

3.2 Split Tensile Strength

The effects of fiber length, fiber volume and NaOH dosage on split tensile strength are illustrated in Figure-8 (a) and Figure 8 (b). It shows that fiber has no significant effect on the split tensile strength of the JFRC specimens. This result is identical with the study carried by Islam & Ahmed (2018). This may be explained as the fiber length and fiber volume might not be enough to arrest the crack propagation. In most of the cases reduction of strength was observed. This might be due to the ball formation of the fibers during mixing. As stated earlier that the inhomogeneous mixing of fibers is the reason for making the concrete stiff.

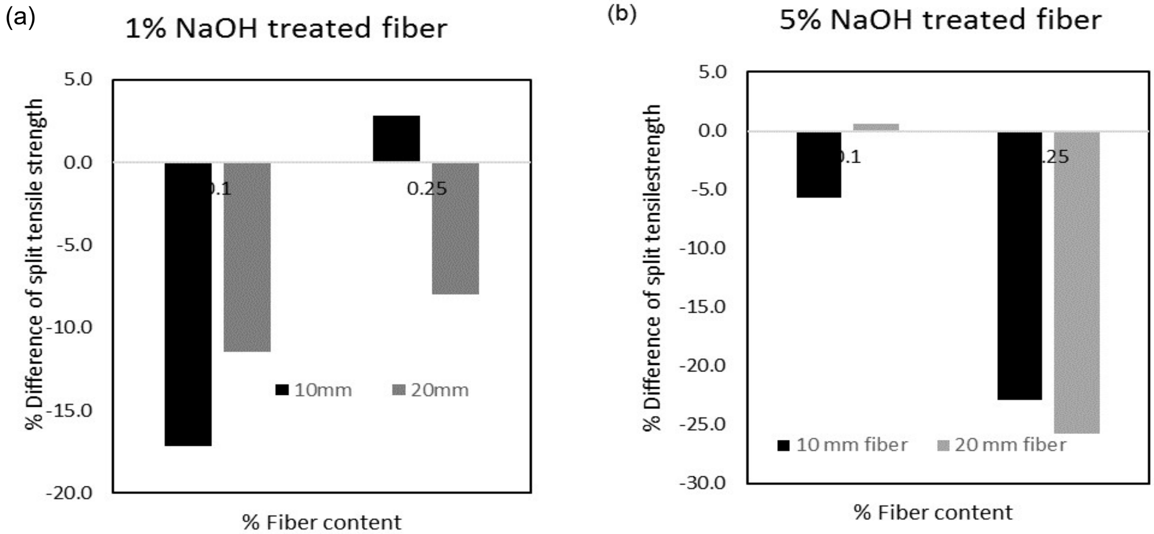

Figure 8: % difference of split tensile strength of JFRC specimen with respect to plain concrete specimen (a) 1% NaOH treated fiber, (b) 5% NaOH treated fiber.

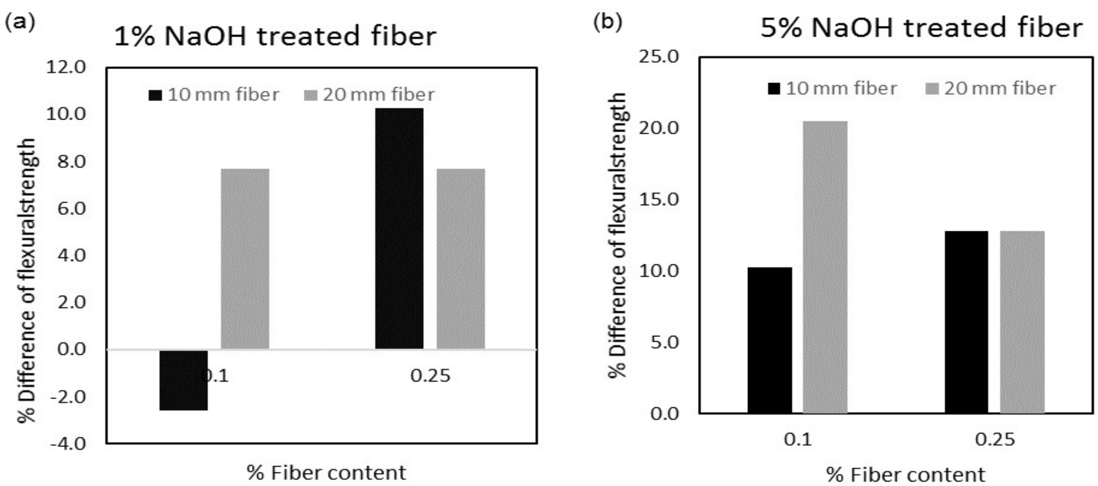

Figure 9: % difference of flexural strength of JFRC prism block with respect to plain concrete prism block (a) 1% NaOH treated fiber, (b) 5% NaOH treated fiber.

3.3 Flexural Strength

Figure-9 (a) and (b) represent the flexural strength variation of JFRC with plain concrete. Flexural strength had increased significantly for concrete specimen containing jute fiber as compared to plain concrete. About 10~20% strength increment was reported for all the JFRC specimens except for 10 mm fiber with 0.1% volume content. Due to the incorporation of fibers in concrete the crack propagation was retarded by the fibers whereas the crack propagation was rapid for plain concrete specimen. This retardant of crack propagation increased the flexural strength of JFRC beam specimens. Long fiber length served better in this regard. Short fibers are helpful to knit the micro cracks together. However long fibers are effective for transferring stresses across the micro cracks (Meddah and Bencheikh, 2009). Thus, the post-cracking failure of JFRC containing long fibers is delayed. The decrease in strength might result from improper mixing (ball formation) and casting of specimens.

4. CONCLUSIONS

Jute is cheap and abundant in Bangladesh. So, the combination of jute and concrete will be a promising footstep towards the development of concrete technology if the composite is sustainable. The aim of this work was to study the behavior of jute fibers mixed in concrete as a reinforcing material by observing the mechanical properties of concrete. More precisely, the compressive, split tensile and flexural properties of jute fiber reinforced concrete were observed in this study. Compressive strength was found slightly incremental for short length with small volumetric dosages of fibers whereas long fibers with large volumetric dosages caused strength reduction in most of the cases due to the ball formation of fibers. Split tensile strength for fiber incorporated concrete did not increase. Rather fiber caused the strength reduction for most of the cases. Flexural strength was found to increase for almost all the combinations and long fibers served better in this context. Alkali treatment of fibers reduced the water absorption capacity but at the same time the percent dosages of treatment need to be considered as it might have influence on compressive strength. Thus, chemically modified jute fibers can be used in concrete as a reinforcing agent in the construction of pavement slabs, concrete pipes and manholes, concrete poles etc. where higher flexural strength is desirable with lower compressive and tensile strength.

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