Effect of Fly Ash in Fiber Reinforced Concrete Composites

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ABSTRACT

The use of fibers to strengthen materials, which are weak in tension, goes back to ancient times. Nowadays, many types of commercially available corrosion free fibers are being used to reinforce cement concrete, thereby improving the behaviour of structural elements. Even though extensive investigations have been conducted to study the behaviour of steel fiber reinforced concrete (SFRC) and polypropylene fiber reinforced concrete (PFRC), the use of jute fibers, which are locally available in large quantities, has not received much attention and studies reported so far are old and few. The present study focuses on the use of jute fibers in improving flexibility and ductility properties in concrete and has been carried out to investigate the feasibility of developing jute fiber reinforced concrete (JFRC) using jute fibers varying from 0.15 to 0.6, by volume. To improve the concrete toughness, a small fraction of short fibers and fly ash (0 to 30% by weight of cement) was added to the concrete mix. fibers provide resistance to crack propagation and crack widening before being pulled out or stressed to rupture. Tests were conducted on different specimens with optimum fiber parameters and results are compared with those normally used for reinforced concrete specimens.

KEYWORDS: Fiber reinforced concrete, Fly ash.

INTRODUCTION

Fiber reinforced concrete is not a new material for construction. During the past decades, published works on fiber reinforced concrete using different types of fibers, ranging from steel fibers to synthetic ones, have been reported on the enhancement of material properties. Steel is a very commonly used fiber for reinforcing the concrete matrix (Swamy, 1974; ACI, 1973; Zollo, 1997; Job and Syam Prakash, 1999; Ramakrishnan, 1987). However, in India, the availability of locally used materials, like jute or coconut, which are spun into threads or strands, has prompted the study of fiber reinforced concrete using jute fibers. Use of fibers in concrete ensures effective bridging of fibers across the inherent micro-flaws and improves the strength and behaviour of cement concrete. Steel fiber reinforced concrete is being used in many engineering applications, where the formation and propagation of cracks are to be controlled. But, the application of steel fiber reinforced concrete is limited, due to the corrosion possibilities of the partially exposed fiber filaments on surface. In such a situation, non-corrosive fiber seems to be appropriate. In this work, the behaviour of cement concrete reinforced with locally available jute fiber, a typical non-corrosive and non-biodegradable fiber, has been studied.

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EXPERIMENTAL PROGRAMME

To bring into focus the use of jute fibers in concrete, an experimental programme was planned to study the material characteristics and structural components like beams. In this paper, work on material properties is reported. In this experimental investigation, the structural properties of jute fiber reinforced concrete have been determined. The fiber concrete was prepared in various combinations of fiber length, fiber content and fly ash percentage parameters. Specimens were prepared to study structural properties, such as: compressive strength, tensile strength, modulus of elasticity and modulus of rupture.

Materials Used

The constituents of materials used for making the concrete were tested and the results are furnished in Table 1. Tensile strength of jute fiber reinforced concrete was also tested. The cement, fine aggregate, course aggregate and fly ash were tested prior to the experiments and checked for conformity with relevant Indian standards. Jute fiber and fly ash were also tested to find their tensile strength and compressive strength. Figure 1 shows the view of jute fiber used and the specimens tested.

Table 1. Details of constituent materials

Materials	**Description**
Cement	Type - OPC43 grade
Fly ash & %	Coal Ash (Neyveli Lignite), 10, 15, 20, 25, 30
Fine aggregate	River sand falling on zone III having a Fineness Modulus of 2.5
Coarse aggregate	20mm nominal size aggregate, Fineness Modulus = 8.75
Jute fiber	Diameter = 1mm,Tensile strength of Jute fiber = 442N/mm^2
Fiber length	20,40,60,80 ϕ = 1mm (Aspect ratio – (20), (40), (60), (80))
Steel reinforcement	High yield strength deformed (HYSD) bars of 6mmϕ and 8mmϕ
Grade of concrete and W/C ratio	M20 & 0.45

Figure (1): Typical view of jue fiber

Specimen Details

A mix proportion of 1:1.49:1.79 with a water to cement ratio of 0.45 was considered for this study to attain M20 grade strength. The exact quantity of materials for each mix was calculated. The parameters varied were: fiber length, fiber content and fly ash percentage. The designations given for various mixes corresponding to fiber length, fiber content and fly ash percentage used for that particular mix are given in Table 2. Specimens were fabricated for various parameters to study their effect on the structural properties of concrete. The number of specimens fabricated, for studying various structural properties, is described in Table 3. Modulus of elasticity was computed from the load deformation characteristics of the cylinder specimens of 300 mm height and 150 mm diameter.

Table 2. Details of fiber and fly ash parameters used in batches

Jute fiber length	Fly ash %	Fiber content in percentage by weight				
		0.00	0.15	0.30	0.45	0.60
20	10	J10F0	J10F0.15	J10F0.30	J10F0.45	J10F0.60
40	15	J15F0	J15F0.15	J15F0.30	J15F0.45	J15F0.60
60	20	J20F0	J15F0.15	J15F0.30	J15F0.45	J15F0.60
80	25	J25F0	J15F0.15	J15F0.30	J15F0.45	J15F0.60

Table 3. Details of specimens

Properties Tested	Size in mm	Number of specimens
7-day cube compressive strength	150x150x150	3
14-day cube compressive strength	150x150x150	3
28-day cube compressive strength	150x150x150	3
Cylinder compressive strength	300x150ϕ	3
Split tensile strength	300x150ϕ	3
Modulus of rupture [prism]	500x100x100	3

Testing Specimens

All the specimens were cast in oiled moulds, compacted using needle vibrators and cured for the required period. These specimens were whitewashed before testing and tested under surface dry condition. Cubes and cylinders were tested using compression testing machine. Prisms were tested using universal loading frame. Figure 2 shows a typical setup and Figure 3 shows the pattern of failure of the specimens tested.

RESULTS AND DISCUSSION

The structural properties studied in this work are compressive strength, tensile strength, modulus of elasticity and modulus of rupture. The test results of fiber reinforced concrete have been compared with those of plain concrete.

Figure (2): Testing setup

Cube Compressive Strength

The cubes and cylinders were tested for the ages of 7 days, 14 days and 28 days. The test results are given in Table 4. The variation of cube compressive strength with respect to fiber content, fiber length and fly ash percentage is given in Figure 4. The maximum compressive strength was obtained for a mix having a fiber length of 40mm, 10% fly ash and a fiber content of 0.30% by weight and the increase in strength over plain cement concrete was found to be about 17%.

The 7-day compressive strength of the fly ash-based fiber concrete was found to be as high as 19.05 N/mm^2, which is about 31% more than that of ordinary concrete. Similarly, the 28-day compressive strength was found to be about 31.48 N/mm^2 and is 17% more than that of ordinary concrete. The increase in cube compressive strength for fly ash-based fiber concrete with respect to age is generally less than that of ordinary concrete. This is because the bonding action of fiber concrete is very effective even at 7days and this action is not getting improved after 28 days.

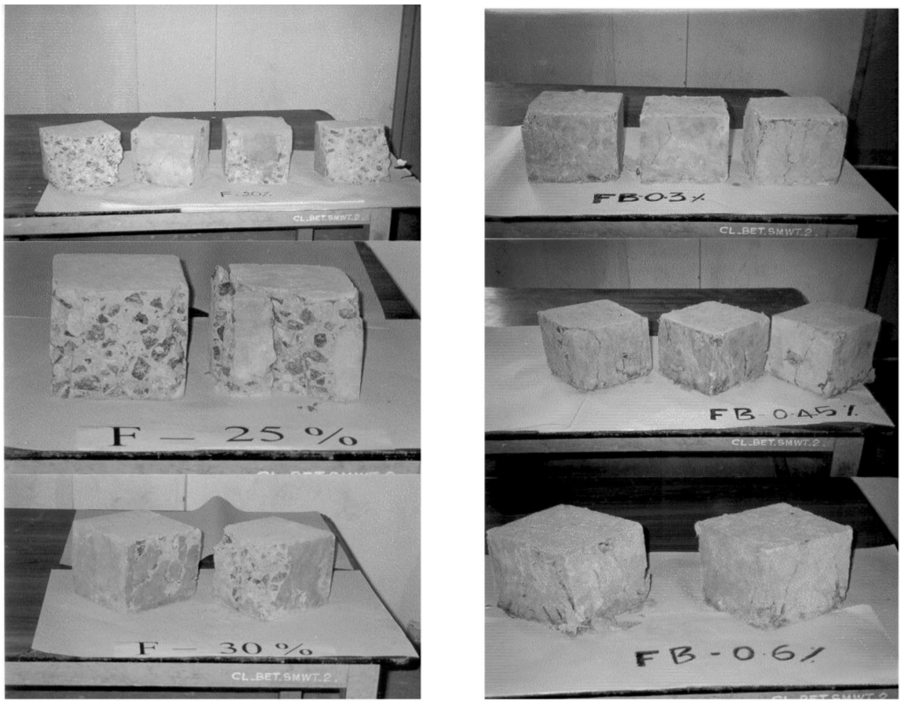

Figure (3): Pattern of failure of the specimens tested

As the fiber content increases, the strength of the composite also increases. It is found that the loss due to introduction of fly ash could be easily compensated through the fibers. However, at the age of 28 days, the increase in pozzolonic activity of the fly ash was sufficient to contribute to the compressive strength. Thus, the efficiency of fly ash to act as a cementitious material has substantially increased at the age of 28 days.

Cylinder Compressive Strength

The variation of cylinder compressive strength with respect to fly ash percentage, fiber length and fiber content is given in Figure 7.The results of cylinder compressive strength are given in Table 5. The maximum cylinder compressive strength is 21.43 N/mm^2, which is about 30% more than that of ordinary concrete. It is observed that the variation of cylinder compressive strength is very much similar to that of cube compressive strength. This shows that the fiber bonding action during the failure of the cylinder specimens is identical to that of the cube specimens and that fly ash-based fiber concrete specimens maintained their structural integrity at all stages of loading.

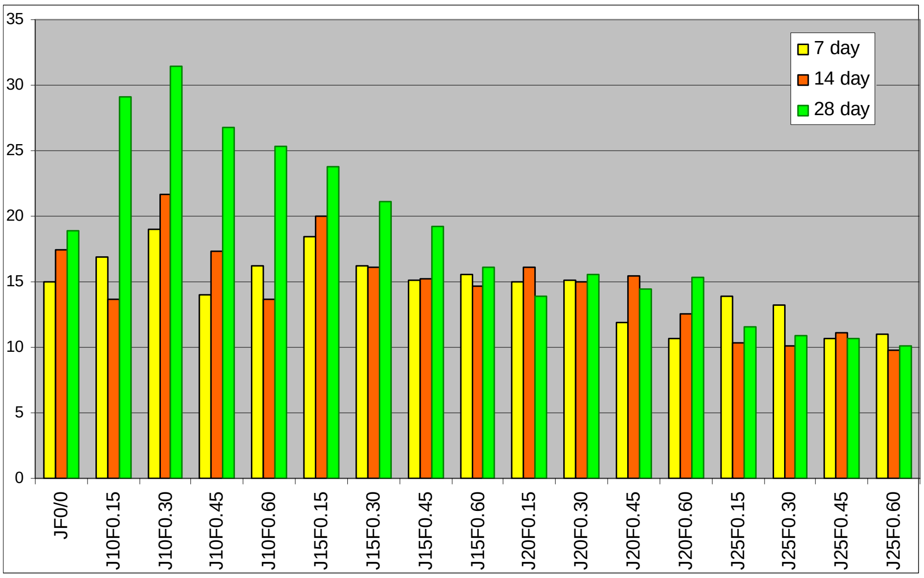

Figure (4): Effect of variation of fiber content and fly ash% on 7-, 14- and 28-day cube strength

Table 4. Results of 7-, 14-and 28- day cube compressive strength test for jute fiber composite

Designation	7-day Average	14-day Average	28-day Average	Strength Ratio		
				7-day	14-day	28-day
JF0/0	15.05	17.47	18.86	1	1	1
J10F0.15	16.93	13.63	29.16	1.13	0.77	0.71
J10F0.30	19.05	21.62	31.48	1.27	1.08	1.14
J10F0.45	13.99	17.28	26.79	0.91	0.97	1.01
J10F0.60	16.26	13.69	25.38	1.08	0.77	0.86
J15F0.15	18.48	20.01	23.82	1.22	1.13	0.99
J15F0.30	16.22	16.13	21.11	1.08	0.93	1.08
J15F0.45	15.06	15.25	19.21	1.039	0.87	1.02
J15F0.60	15.58	14.62	16.16	1.05	0.83	1.09
J20F0.15	15.04	16.13	13.91	1	0.92	0.72
J20F0.30	15.09	15.03	15.52	1	0.86	0.74
J20F0.45	14.66	15.41	14.39	0.74	0.83	0.74
J20F0.60	14.13	12.51	15.28	0.64	0.6	0.6
J25F0.15	13.86	10.28	11.52	0.92	0.53	0.5
J25F0.30	13.3	10.12	10.83	0.92	0.58	0.6
J25F0.45	10.61	11.11	10.62	0.71	0.74	0.5
J25F0.60	11	10.78	10.07	0.7	0.55	0.5

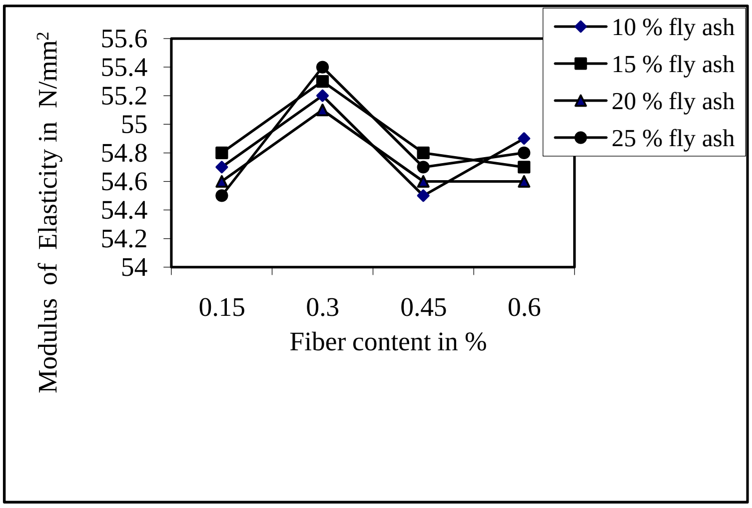

Figure (5): Effect of fiber content and fly ash% on the modulus of elasticity

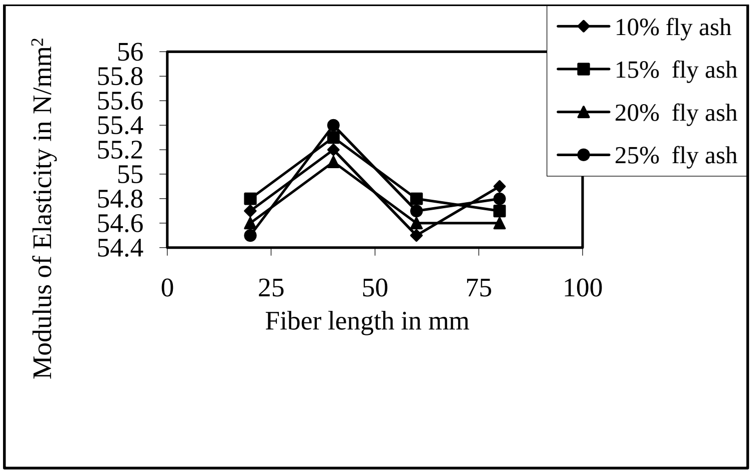

Figure (6): Effect of fiber length and fly ash% on the modulus of elasticity

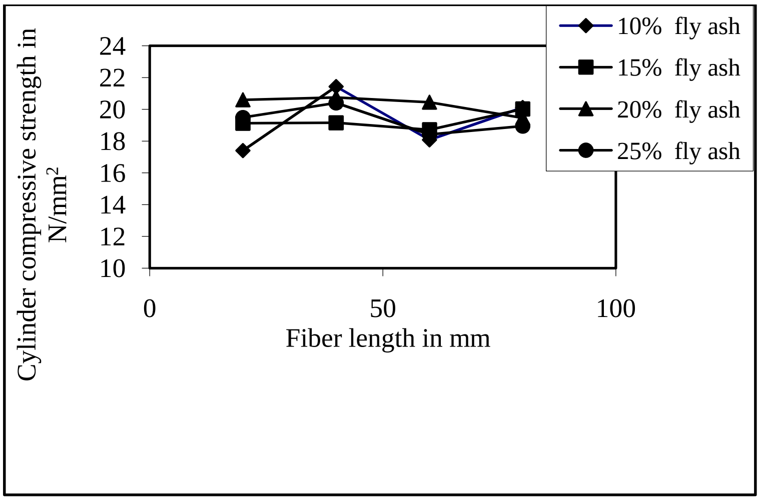

Figure (7): Effect on cylinder compressive strength with respect to fly ash%, fiber length and fiber content

Table 5. Results of 28 - day cylinder compressive strength test

Designation	28-day cylinder compressive strength in N/mm^2				Strength ratio
	Specimen 1	Specimen 2	Specimen 3	Specimen 4	
JF0/0	17.56	15.80	16.40	16.60	1.00
J10F0.15	16.40	18.35	16.45	18.35	1.05
J10F0.30	21.02	22.25	22.34	20.13	1.11
J10F0.45	16.54	18.68	17.25	19.85	1.09
J10F0.60	19.25	20.38	20.99	19.82	1.21
J15F0.15	18.68	19.25	19.06	19.52	1.15
J15F0.30	18.23	18.95	19.60	19.85	1.13
J15F0.45	18.12	19.32	19.28	18.13	1.12
J15F0.60	19.32	19.82	20.38	20.57	1.20
J20F0.15	19.82	22.08	20.35	20.05	1.24
J20F0.30	20.95	20.95	20.57	20.54	1.25
J20F0.45	19.82	20.38	20.65	20.95	1.23
J20F0.60	19.52	19.25	19.26	19.82	1.17
J25F0.15	19.65	18.85	19.82	19.65	1.17
J25F0.30	19.35	19.56	21.21	21.51	1.23
J25F0.45	18.65	18.68	17.85	18.49	1.11
J25F0.60	18.68	20.35	16.55	20.20	1.14

Split-Tensile Strength Tests

In each mix, four standard cylinder specimens were tested to determine the splitting tensile strength. The results are given in Table 6. The variation of split tensile strength with respect to fly ash percentage, fiber length and fiber content is given in Figure 8. The maximum value of splitting tensile strength obtained is 4.5N/mm^2, which is about 44% more than that of ordinary concrete. The maximum strength was obtained for a mix with a fiber length of 20 mm, a fiber content of 0.30 % by weight and 15% fly ash replacement of cement. It is observed that because of fly ash percentage, the split tensile strength may have been increased.

Modulus of Rupture

The maximum flexural strength obtained for jute fiber reinforced concrete was 4.56 N/mm^2 and that for plain cement concrete was 2.80 N/mm^2 .The corresponding strength improvement is 62%. It is observed during testing that ordinary concrete specimens failed without any warning, while jute fiber reinforced concrete specimens showed a ductile failure, giving ample warning. The flexural stress determined for both ordinary concrete and fiber reinforced concrete is given in Table 6.

Modulus of Elasticity

Modulus of elasticity was determined from the load deformation observation of the cylinder specimens. The variation of the modulus of elasticity value with respect to fly ash percentage, fiber length and fiber content is shown in Figures 5 and 6. The value of modulus of elasticity in compression of each mix is shown in Table 6. The modulus of elasticity of this composite is very low, but the specific modulus is in increasing order.

Based on these test results, normalized curves were drawn for different materials over normal concrete. Figure 9 shows the normalized values of stress *versus* strain. It can be observed that even though the specimens show less E values, their sustainability in terms of larger strains without failure prompts one to use these jute fibers appropriately in specimens requiring larger flexibility or ductility.

Table 6. Results of 28-day splitting tensile strength test

Designation	Splitting tensile strength in N/mm^2	Strength ratio	Flexural tensile strength in N/mm^2	Strength ratio	Modulus of elasticity N/mm^2
JF0/0	3.50	1.00	4.00	1.00	55.5
J10F0.15	3.25	0.93	3.75	0.94	54.2
J10F0.30	3.00	0.85	4.25	1.06	54.5
J10F0.45	2.75	0.79	4.50	1.13	55.6
J10F0.60	4.00	1.14	4.50	1.13	55.7
J15F0.15	4.50	1.29	4.25	1.06	56.8
J15F0.30	3.75	1.07	4.75	1.19	53.7
J15F0.45	3.50	1.0	4.00	1.0	54.8
J15F0.60	2.75	0.78	3.75	0.94	52.6
J20F0.15	2.40	0.68	3.50	0.90	54.4
J20F0.30	1.75	0.50	3.00	0.80	55.6
J20F0.45	2.50	0.71	3.25	0.81	55.8
J20F0.60	2.50	0.71	2.75	0.69	55.6
J25F0.15	2.25	0.64	3.00	0.75	52.6
J25F0.30	2.75	0.78	2.50	0.63	54.8
J25F0.45	1.75	0.50	2.75	0.69	55.5
J25F0.60	2.00	0.60	2.75	0.69	54.3

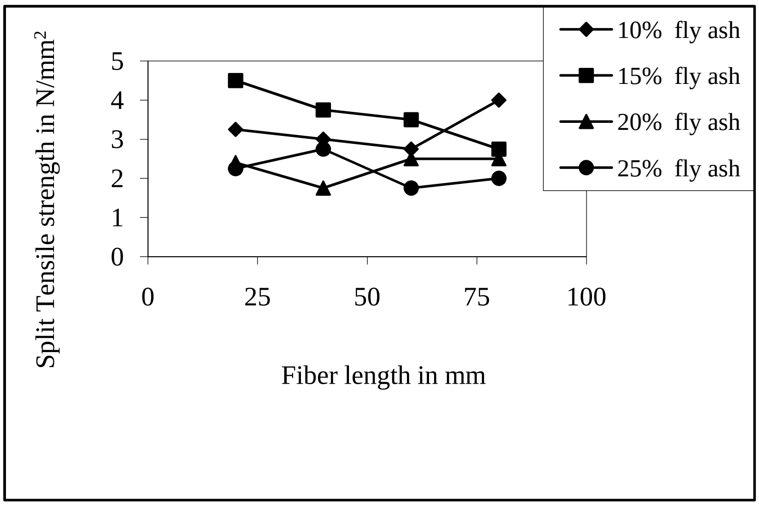

Figure (8): Effect of fiber length and fly ash% on split tensile strength

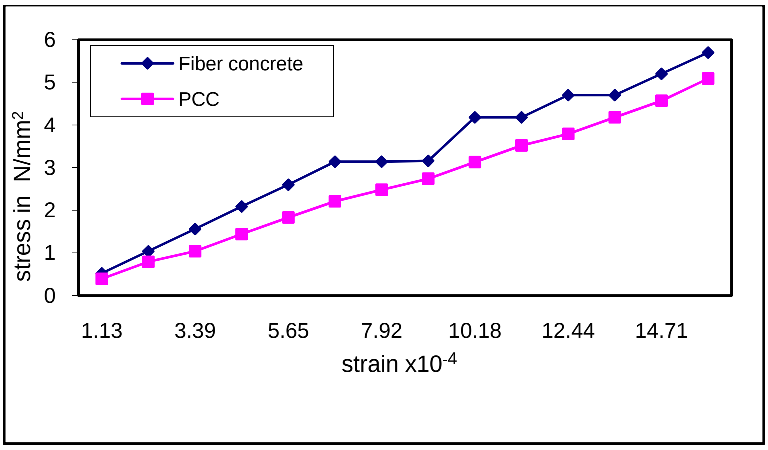

Figure (9): Stress and strain variations of fiber concrete composite

CONCLUSIONS

Based on the results of investigation reported in this paper, the following conclusions are drawn

- Fly ash-based jute fiber reinforced concrete shows a better performance than ordinary concrete.
- The replacement of fly ash up to 25% resulted in a better performance under compression.
- The 7-day compressive strength of the composite having fly ash up to 25% is slightly less than that of the control concrete mix. But, the compressive strength is marginally more than that of the control concrete mix at the age of 28 days.
- The maximum 7-day cube compressive strength obtained was 19.05N/mm^2, for the mix with a fiber length of 40mm, 10% fly ash and a fiber content of 0.30% (14.50N/mm^2).
- The maximum 14-day cube compressive strength obtained was 19.76N/mm^2, for the mix with a fiber length of 20mm, 15% fly ash and a fiber content of 0.15% (14.50N/mm^2).
- The maximum 28-day cube compressive strength obtained was 31.48 N/mm^2, for the mix with a fiber length of 40mm, 10% fly ash and a fiber content of 0.30% (21.95N/mm^2).
- The maximum compressive strength obtained for the cylinder specimens was 21.43N/mm^2, for the mix with a fiber length of 40mm, 10% fly ash and a fiber content of 0.30% (15.06N/mm^2).
- The maximum splitting tensile strength obtained for the cylinder specimens was 4.50N/mm^2, for the mix with a fiber length of 60mm, 15% fly ash and a fiber content of 0.15% (15.06N/mm^2).
- The maximum value of modulus of elasticity obtained was 56.8N/mm^2, for the mix with a fiber length of 20mm, 15% fly ash and a fiber content of 0.15% (15.06N/mm^2). It is observed that even though the specimens show less E values, their sustainability in terms of larger strains without failure prompts one to use these jute fibers appropriately in specimens requiring larger flexibility or ductility.
- The maximum value of flexural strength obtained was 4.75N/mm^2, for the mix with a fiber length of 60mm, 15% fly ash and a fiber content of 0.15%.

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