Investigation on the Mechanical Property and Crack Arresting Mechanism of Natural Jute Fiber used as Reinforcement for Lightweight Concrete Masonry Prism

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Abstract. Concrete being the widely used material in construction work is strong in compression and brittle in nature. Addition of fibres to the cementitious mix helps to improve the tensile property of the material, particularly after reaching the yield load. In addition, fiber reinforced cement composites exhibit better toughness, crack resistance, flexural capacity, and ductility than non-reinforced cement materials. In developing countries natural fibers are used in the cement composites to produce a low-cost building construction. Previous research works, carried out using sugarcane, hemp, jute, banana and coconut were found to improve the tensile and compressive strength of concrete composite elements. Main aim of this work is to study the performance of jute fiber reinforcement in lightweight foam concrete masonry structure. To study the load deformation pattern, jute fiber reinforced masonry prism were subjected to axial compression load. From the stress-strain behaviour it can be concluded that jute fiber reinforcement in foam concrete help to improve the pre cracking behaviour and prevents the formation of major crack plane in masonry unit. Masonry unit with different dosages of fiber were tested and results were plotted. From the study it can be concluded that light weight foam concrete with fiber reinforcement can be used as a better alternative to clay bricks and aerated concrete blocks.

Key words: lightweight concrete, CLC prism, Jute fiber, CLC mortar, Micro fiber

1. Introduction

Cellular Lightweight Concrete (CLC) are formed by mixing, cement and fly ash with appropriate amount of water and foaming agent. Addition of foaming agent does not produce any hazardous chemical reaction; it only involves in the generation of tiny air bubbles which will not make the concrete to expand. The concrete product after hardening does not expand and maintain its density. Nowadays CLC blocks have replaced conventional clay bricks in building construction. The energy consumed in the production of lightweight blocks is only a fraction of amount when compared to the red bricks and it does not emit pollutants or any toxic products or by-products [1]. CLC blocks has less dead weight, good thermal insulation and also good mechanical strength. In seismic region, application of lightweight concrete without reinforcement have only less ability to dissipate energy, which is really a concern. A large number of non-reinforced masonry buildings are constructed around the world, such unreinforced building has limited ability to withstand seismic load and undergoes sudden failure. The mode of failure is brittle in nature and sudden, which leads to loss of life and property. In order to minimise such failures and prevent sudden collapse of buildings it is really important to focus on low-cost lightweight masonry structure with better tensile and shear resistance.

In developing countries like India, natural fibre reinforced construction products are much effective, for the development of low-cost building construction [2]. Naturally available fibres such as Roselle, sugar-cane bagasse, sisal, coconut, hemp, and jute are reported to yield improved compressive and tensile strength of the cement-based composites [3-5]. During early days, the naturally available fibers were used for improving the tensile and shear strength of construction. When compare to synthetic fibers, natural fibers are low cost, easily available, highly flexible and produces less health hazards.
On the other hand, synthetic fibers have high strength, absorbs less amount of water and available in low density. From the literature it can be concluded that a considerable amount of work has been carried out in synthetic fiber reinforced light weight concrete, but only a handful amount of work has been done on natural fiber reinforced light weight foam concrete. Therefore, the main aim of this work is to develop a low cost fiber reinforced masonry unit, suitable for construction in seismic region.

2. Literature study

Oraimi and Seibi [6] conducted experiments using nonwoven coir mesh matting in mortar and concluded that coir mesh mortar showed improved performance in composite post-cracking flexural stress, toughness, ductility, and toughness index, compared to plain mortar. Merta and Tschegg [7] carried out work on natural fiber reinforced composites and concluded that the fracture energy was enhanced by the addition of natural fibers. Wang et al [8] studied the tensile property of concrete composites reinforced with acrylic, nylon, and aramid fibers and concluded that the tensile properties of concrete composites were enhanced due to the addition of synthetic fibers. Joshi et al. [9] compared the performance of natural fiber reinforced composites with glass fiber reinforced composites and concluded that natural fiber are much better than synthetic fiber. Fang et al [10] used synthetic fiber to improve the mechanical strength of fiber reinforced concrete and reduced the crack formation in canal lining. Jute fibers when added to concrete, arrest cracks, shares major amount of tensile load and absorbs large amount of fracture energy in concrete composites. [11-14]. Ramaswamy et al. [15] studied the tensile property and breaking strength of jute fiber which was around 2260 kg/cm². It had been concluded from many researches that adding jute fibers contributes in the increase of toughness, tensile and flexural strengths of concrete composites ([16,7,14]). The author conducted research work using polypropylene and banana fiber in light weight concrete prism [17 &18] and reported positive response in the crack resistance mechanism of CLC prism.

Chandar and Balaji [19] reported that there was around 44% and 12% increase in flexural strength and tensile strength of concrete due to the addition of jute fibers. Rasheed and Prakash [20&21] used poly olefin micro and macro fibers as reinforcement for cellular lightweight concrete. Lightweight concrete prism with different dosages of macro fibers and combination of micro and macro fibers were tested. The density of concrete specimen was around 800-900 Kg/m³. The micro fibers increases the ductile nature of masonry in the post peak region while the micro fibers arrest the crack at micro level and improves the pre cracking behaviour. Addition of fibers increases the performance of concrete by reducing the permeability, increasing the structural integrity and thereby increasing the durability and service life of concrete structure. Therefore, synthetic and natural fibers increases the ductility and post peak residual strength of composite specimens. From the literature it can be concluded that only limited information is available on the mechanical property of jute fiber reinforced concrete specimen of density around 800-900 Kg/m³. Therefore, a thorough knowledge is required to study the failure pattern and compression behaviour of Jute Fibre Reinforced Cellular Light Weight Concrete (JFRCLC) masonry prism. The detailed objective of this study is to plot the stress strain behaviour, and finally develop a high strength, low cost fiber reinforced lightweight concrete masonry unit.

3. Test programme

Experimental investigation was first carried out in light weight foam concrete block, cylinders and prism without any fibers, those specimens were treated as control specimen. In the next phase of study, jute fibers were added to light weight foam concrete in four different dosages. Those fiber reinforced CLC blocks and prism were subjected to compression load and the stress strain plot was obtained. The effectiveness of jute fiber as reinforcement in CLC blocks and the energy dissipation capacity of the same was studied. In order to study the property of mortars used in bed joints, mortar cylinder was cast in the proportion of 1:6 and the stress strain plot were obtained. Thereafter, reinforced CLC prisms were cast using jute fiber and the influence of different jute fibre (JF) dosage on the CLC prism were studied. The added jute fiber increases the tensile strength and shear resistance
capacity of the CLC prism. The added jute fiber does not play a major role in the compressive strength but it helps to improve the performance of the prism in the post peak region.

### 3.1 Material properties

Ordinary Portland cement, class F-fly ash, water and foaming agent were mixed in appropriate proportion to prepare the fresh foam concrete mix. The mix proportion of cement: Fly ash: water is 1:3:1. The amount of foaming agent was 1.4 kg/m³. Water binder ratio is 0.4. Class F fly ash with less lime content was used to prepare CLC. Synthetic foaming agent was diluted in the ratio of 1:40 and then the mixture was fed into the foam generator to produce an aerated mix of density 75 kg/m³. The maximum dosage of fibers in the mix is around 5 Kg/m³ of CLC mix, which corresponds to 0.55 % of volume fraction. The different fiber dosages is calculated based on the ratio of volume of jute fiber to the total volume of CLC mix and jute fiber. The jute fiber were cut to a length of 6 - 8 mm (Figure 1) and mixed with CLC. The properties of the fiber are listed in Table 1. Specimens with fiber dosages of 0% (control), 0.22%, 0.33%, 0.44%, 0.55% of jute micro-fibers were cast in different t batch and cured.

![Jute fibers used in lightweight foam concrete](image)

#### Table 1. Properties of Jute Fibers

| Property          | Raw material | Type          | Length of fiber | Width | Water adsorption | Tensile strength | Stiffness |
|-------------------|--------------|---------------|-----------------|-------|-----------------|------------------|----------|
| Range             | Jute fiber   | Single filament | 9 mm           | 0.08 mm | 84 %            | 400-800 Mpa      | 10-30 KN/mm² |

### 3.2 Specimen details

Test specimen includes, plain CLC block without fibers, CLC blocks with fibers of different volume fraction, CLC cylinder with and without fibers, CLC prism without fibers, CLC prism with fibers and finally mortar cylinders. Figure 2 shows the dimension details of CLC block prism. The dimension of each block is 600 x 200 X 150. Test specimen details, specimen ID and volume fraction of fiber are listed in Table 2. Series I specimen consist of control Specimen without fiber dosage. Control specimens are CLC block, CLC cylinder, Mortar Cylinder (1:6) and CLC prism. Series II consist of CLC cylinders with different volume fraction of jute fibers. Series III consist of CLC prism built using different volume fraction of jute fiber reinforced CLC blocks. Specimen name JF-mi-0.22% stands for CLC prism built with Jute micro-fiber-with 0.22 % volume fraction CLC blocks.

### 3.3 Preparation of specimen

Dry raw materials, were added to the mixer and thoroughly mixed for 5 minutes. After thorough mixing, water was added to the mixture and a wet mix was obtained. Then the diluted and aerated synthetic foaming agent was added to the wet mix. The foaming agent was then introduced into the mixture, in increments at the rate of 35 g/s for a duration of 40 sec. For fiber reinforced lightweight mix, jute fibers of length approximately 9 mm were added to the wet mix and mixed for another five
minutes. After thorough mixing, the CLC slurry was poured into the assembled mould of required dimension and curing was done. The specimens were demoulded after 24 hours and cured for 28 days. The detailed procedure of manufacturing of lightweight foam concrete blocks in CLC plant is shown in Figure 3. Light weight fiber does not affect the density of CLC blocks. Wee et al [22] has stated that at an optimum air content of around 40%, the strength to weight ratio for foam concrete is achieved. A total void ratio of 0.35 is adopted in this study to arrive at a concrete density of 900 kg/m$^3$. The water absorption tests revealed that CLC block masonry absorbs more or less same amount of water as clay brick masonry. Four CLC block were joined using 10 mm thick cement mortar to form the prism. The finished CLC prism with and without fibers are shown in Figure 4.

3.4 Test methods

According to ASTM, testing of masonry prism assembly is sufficient to predict the strength of masonry and It is also more economical than full-scale testing. The top surface of the specimen was levelled and uniform smooth surface was formed before applying load. The stress-strain plot was obtained using the reading recorded in Data Acquisition (DAQ) System. Testing of specimen was done in compression testing machine of capacity 2000KN. Fiber board were used on the top of the specimen to ensure uniform distribution of load. Initially Testing of the specimens were done by applying the load at very small increment, after reaching about 75% of the peak load the rate of loading was 0.001mm/sec. The axial deformation was measured using LVDTs along the direction of loading. The test setup is shown in Figure 5.

Table 2 Details of test specimen and fiber dosage

| Specimen type                  | Serie s | Specimen ID | Quantity | Volume Fraction (%) |
|-------------------------------|---------|-------------|----------|---------------------|
| Mortar cylinder               | I       | Control     | 3        | 0                   |
| CLC Cylinder                  |         | Control     | 3        | 0                   |
| CLC Blocks                    |         | Control     | 3        | 0                   |
| CLC Prism                     |         | Control     | 3        | 0                   |
| CLC cylinder with jute fibers | II      | CI-0.22%    | 3        | 0.22                |
|                              |         | CI-0.33%    | 3        | 0.33                |

Figure 2. Dimension of CLC blocks prism subjected to compression
| CLC Prism with jute fibers | III | Cl-0.44% | 3 | 0.44 |
|---------------------------|-----|----------|---|-----|
|                           |     | Cl-0.55% | 3 | 0.55 |
|                           |     | JF-mi-0.22 | 3 | 0.22 |
|                           |     | JF-mi-0.33 | 3 | 0.33 |
|                           |     | JF-mi-0.44 | 3 | 0.44 |
|                           |     | JF-mi-0.55 | 3 | 0.55 |

(a. synthetic foaming agent; b. adding foam to cement and fly ash; c. CLC mixture; d. CLC mould preparation; e. placing of mixture in mould; f. CLC blocks ready for curing; g. cured CLC blocks; h. CLC cylinders)

Figure 3. Process of manufacture of CLC blocks

Figure 4. Fabricated jute fiber reinforced CLC prism

Figure 5. Testing of CLC prism
4. Result and Discussion
Lightweight foam concrete specimen was casted and tested in three series. Series I consist of control specimens without any fibers. CLC cylinder with four different fiber dosages form the series II specimens. Series III had jute fiber reinforcement CLC Prism with four different fiber dosages (0.22%,0.33%,0.44%,0.55%). Three specimens were tested for each case and the average reading was taken. Test results of control specimen, CLC block, CLC cylinder and CLC prisms in compression are presented in Table 3.

4.1 Compression behaviour of Control CLC block and prism
The stress-strain curve for control specimens is shown in Figure 6. Stress-strain plot of Mortar cylinder, CLC block and CLC prism were compared. The elastic modulus of mortar cylinder was much higher when compared to CLC prism, on reaching the maximum load CLC prism showed minimum resistance to the applied compression load and a sudden failure occurred. The stress strain plot of CLC prism showed linear behaviour till it reaches 30% of peak load. After which the crack formation takes place and failure of specimen occurred. The strength of CLC prism (3.7 MPa) is much closer to that of CLC block. The elastic modulus of mortar cylinder was around 12200Mpa while that of CLC block and CLC prism was around 4100 Mpa and 2100 Mpa respectively. From the elastic modulus values, it is clear that mortar cylinders are much stiffer than CLC block and CLC prism. In CLC prism, the blocks are subjected to tri-axial compression and mortar joints are subjected to uniaxial compression and bi-axial tension. The failure started from the mortar joint followed by crack formation which is transmitted to the CLC blocks and results in the failure of prism.

Table 3 Compressive strength of CLC cylinder and CLC prism with and without fibers

| Specimen type            | Serie s | Specimen ID        | Compressive Strength (Peak) (Mpa) | Average Strength (Mpa) |
|--------------------------|---------|--------------------|----------------------------------|------------------------|
| Mortar cylinder          | I       | Control            | 4.63 4.52 4.91                  | 4.71                   |
| CLC Cylinder             |         | Control            | 7.3 7.2 6.8                     | 7.1                    |
| CLC Prism                |         | Control            | 3.42 3.52 3.32                  | 3.52                   |
| CLC Blocks               |         | Control            | 3.5 3.8 3.2                     | 3.5                    |
| Jute Fiber Reinforced CLC Cylinder | II  | Cl-0.22%           | 7.51 7.43 7.81                  | 7.54                   |
|                          |         | Cl-0.33%           | 8.01 7.91 7.54                  | 7.79                   |
|                          |         | Cl-0.44%           | 8.40 8.50 8.48                  | 8.46                   |
|                          |         | Cl-0.55%           | 8.9 8.91 8.75                   | 8.62                   |
| Jute Fiber Reinforced Prism | III | JF-mi-0.22%        | 3.56 3.77 3.54                  | 3.46                   |
|                          |         | JF-mi-0.33%        | 3.61 3.52 3.63                  | 3.61                   |
|                          |         | JF-mi-0.44%        | 3.87 3.54 4.1                   | 3.74                   |
|                          |         | JF-mi-0.55%        | 4.02 4.03 4.01                  | 4.03                   |
4.2 Compression behaviour of CLC cylinders

On comparing the compression behaviour of JFRCLC cylinder with control cylinder, the peak strength of jute fiber reinforced cylinder is increased by 12-15% with the addition of fibers. The stress-strain plot of CLC cylinders is shown in Figure 7. In unreinforced CLC cylinders (CLC cylinders without fibers) when subjected to compression load, the stress strain behaviour was linear up to 30 % of the peak load after that the curve become nonlinear due to lack of fiber reinforcement. Resistance offered by the prism to the applied load decreases with the increasing axial load particularly after the peak load, and collapsed suddenly. The pre-cracking behaviour was same for both control CLC cylinders and JFRCLC cylinder. A mild increase in peak load carrying capacity and increase in elastic stiffness was observed with the increase in fibre dosage. As the load increases, after reaching the peak value, the load remains constant which indicates a less amount of degradation or increased stiffness after post peak region (Vijayalakshmi and Ramanagopal 2020 (a)). The peak load in JFRCLC cylinder increased up to about 20% with respect to that of cylinders without fibres. The CLC cylinder reached up to a maximum of 4-8Mpa strength.

4.3 CLC prism with different jute fibre dosage

The stress-strain curves for prisms reinforced with different dosage of jute fibres are compared in Figure 8. Jute fiber reinforcement, increase the elastic modulus of CLC prism and reduces the stiffness degradation in the post peak region and provides a softening behaviour to the constructed prism. The values of elastic modulus of fiber reinforced CLC prism lies between CLC block and mortar cylinder. As the fiber dosage increases, the peak strength of CLC prism also increases, this increase in peak strength is mainly due arresting of cracks at the micro level and results in the increased performance after post peak region. The residual load carrying capacity and toughness is increases due to the addition of fibers in lightweight foam concrete. Therefore, fiber reinforced light weight foam concrete can be used as a better alternative for clay bricks.
4.4 Crack formation and failure pattern

Autoclaved Aerated Blocks (AAB) are subjected to high temperatures during the manufacturing process, so addition of fibers is not feasible in AAB. The fiber added to AAB will melt at such high temperature, therefore light weight foam concrete block with fibers is a better alternative. In the control prism the crack formation was a single explicit crack (Figure 9). Stress concentrations in particular region led to the formation of wider cracks which cannot be distributed to the entire section of the prism due to the absence of fibers. In control prism the mortar joints form the weak section and crack formation starts from the joint. The crack are then transmitted to the CLC blocks and sudden failure of prism occurs. In case of fiber reinforced CLC, the jute fibers involves in the crack arresting mechanism and distributes the cracks at micro level (Figure 10). once cracked formed in the matric of CLC, jute micro fibres get engaged in the crack arresting process, as a result, large number of micro cracks emerges. The formation of major cracks is arrested by the fibres in the CLC blocks which forms a closed network. Fiber reinforcement also improves the post peak strength of CLC. Therefore, it can be concluded that fiber helps to improve the strength and ductility of CLC matrix under compression load, shear and tension load. From this study it can be suggested that fiber reinforced CLC can be used as reinforced masonry unit in seismic zone.

5. Conclusion

The effect of adding natural jute fibres to lightweight foam concrete was tested by adding different volume fraction of fiber to CLC block and testing the CLC prism under compression load. The following conclusion was derived from the study:
• The behaviour of CLC prism was more or less same as that of the CLC cylinder when tested under compression load.

• The peak strength of CLC prism with different fiber dosage increase with the increase in the volume fraction of fibers. A maximum of 15% increase in peak strength was observed for 0.55% VF when compared to control prism.

• Failure in CLC prism without fiber was sudden and a single explicit crack was formed across the section of prism. But in case of jute fiber reinforced CLC prism a large number of micro cracks was formed and formation of major weak plane was prevented. Jute fibers embedded in the matrix of CLC, distributes the crack and increases the peak strength of prism. It also increases the stiffness of prism in the post peak region.

• Jute fiber reinforcement converts the CLC block to exhibit a composite behaviour. Addition of fibers improves the stiffness and strength of CLC block which is more or less similar to mortar cylinder.

• Addition of fibers increases only 10% of the total manufacturing cost, which in turn helps to improve the overall life and durability of the structure.

REFERENCES

1. Yang KH and Lee KH (2015) Tests on high-performance aerated concrete with a lower density. Constr. Build. Mater. 57(4): 109–117.
2. Ali M (2016) Use of coconut fibre reinforced concrete and coconut-fibre ropes for seismic-resistant construction. Mater. Constr 66(32): e073.
3. Cook DJ, Pama RP and Weerasingle HL (1978) Coir fiber reinforced cement as a low-cost roofing material. Build. Environ.13(3):193–198.
4. Ramakrishna G, and Sundararajan T (2005) Impact strength of a few natural fiber reinforced cement mortar slabs: a comparative study. Cem. Concr. Compos 27(5): 547–553.
5. Ali M (2014) Seismic performance of coconut-fibre-reinforced-concrete columns with different reinforcement configurations of coconut-fibre ropes. Constr. Build. Mater. 70: 226–230.
6. Oraimi SK, Seibi AC (1995) Mechanical characterisation and impact behaviour of concrete reinforced with natural fibers. Compos. Struct. 32 (4):165–171.
7. Merta EK and Tschegg (2013) Fracture energy of natural fiber reinforced concrete. Constr. Build. Mater 40: 991–997.
8. Wang Y,Backer S and Li VC (1987) An experimental study of synthetic fiber reinforced cementitious composites. J. Mater. Sci. 22(12): 4281–4291.
9. Joshi SV, Drzal LT, Mohanty Ak and Arora S (2004) Are natural fiber composites environmentally superior to glass fiber reinforced composites. Composites Part A. 35(3): 371–376.
10. Fang HG, Liu, PH, and Zhang T (2011) Experimental investigation on the polypropylene fiber concrete performance of yellow river canal lining in the middle line of south-to-north water transfer project. Appl. Mech. Mater 52:1987–1991.
11. Gupta ND, Paramasivam P and Lee SL (1978). Mechanical properties of coir reinforced cement paste composites. Hous. Sci. 2(6): 391–406.
12. Mansur MA, and Aziz MA (1982) A study of jute fiber reinforced cement composites. Int. J. Cem. Compos. Lightweight Concrete. 4(2): 75–82.
13. Zhou X, Ghaifar SH, Dong W, Oladiran O and Fan M (2013) Fracture and impact properties of short discrete jute fiber-reinforced cementitious composites. Mater. Des. 49: 35–47.
14. Zakaria M, Ahmed M, Hoque MM and Islam S (2017) Scope of using jute fiber for the reinforcement of concrete material. Text. Clothing Sustain. 2 (11).
15. Ramaswamy HS, Ahuja BM and Krishnamoorthy S (1983) Behaviour of concrete reinforced with jute, coir and bamboo fibers. Int. J. Cem. Compos. Lightweight Concrete 5(1): 3–13.
16. Liu B, Zhang LZ, Liu QX and Ji T (2013) Study on behaviors of jute fiber reinforced cement-based materials. Appl. Mech. Mater. 25(3): 508–511.
17. Vijayalakshmi R and Ramanagopal S (a) (2020) Compression behaviour of polypropylene fibre reinforced cellular light weight concrete masonry prism. Civil and Environmental Engineering Reports 30(1): 145-160.
18. Vijayalakshmi R and Ramanagopal S (b) (2020). Experimental Investigation on Banana fiber reinforced lightweight Concrete Masonry Prism sandwiched with GFRP sheet. Civil and Environmental Engineering Reports 30(2): 15-31.
19. Chandar SP and Balaji CJ (2015) Experimental study on the mechanical properties of concrete mixed with jute fiber and steel fiber. Int. Res. J. Eng. Technol. 1(2):77–82.
20. Rasheed MA and Prakash SS (2015) Mechanical behaviour of sustainable hybrid- synthetic fiber reinforced cellular light weight concrete for structural applications of masonry. Construction & Building Materials 98: 631–640.
21. Rasheed MA and Prakash SS (2018) Behavior of Hybrid-Synthetic Fiber Reinforced Cellular Lightweight Concrete under Uni-axial Tension - Experimental and Analytical Studies. Construction and Building Materials 162: 857-870.
22. Wee TH, Babu DS and Tamilselvan TLH (2006) Air-void systems of foamed concrete and its effect on mechanical properties. ACI Materials Journal 103(1): 245–52.