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Original Research Article

COMPRESSION BEHAVIOUR OF POLYPROPYLENE FIBRE REINFORCED CELLULAR LIGHT WEIGHT CONCRETE MASONRY PRISM

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Abstract

Sustainable development of the built environment in developing countries is a major challenge in the 21st century. The use of local materials in the construction of buildings is one of the potential ways to support sustainable development in both urban and rural areas where burnt clay bricks are used predominantly. This work focuses mainly on the use of polypropylene micro fibers in ordinary Cellular Lightweight Concrete blocks. The main objective is to develop a high-performance fibre reinforced cellular concrete to provide a better alternative than clay bricks for structural applications of masonry. This paper presents the stress-strain behaviour of polypropylene fibre reinforced Cellular Lightweight Concrete stack bonded prisms under axial compression. Masonry compressive strength is typically obtained by testing stack bonded prisms under compression normal to its bed joint. Use of micro-fibres enhances the pre-cracking behaviour of masonry by arresting cracks at micro-scale in the post-peak region. These efforts are necessary to ensure that CLC blocks become more accepted in the world of building materials and considered as a reliable option for providing low-cost housing.

Keywords: cellular light weight concrete, polypropylene fibers, masonry prism

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1. INTRODUCTION

Global warming and Environmental pollution are now a global concern. The CO_2 emission in the bricks manufacturing process is considered as a significant factor to global warming [1]. Usage of lightweight concrete blocks has seen rapid growth in recent years and is slowly replacing the conventional clay bricks in masonry construction. Building with Cellular Lightweight Concrete (CLC) blocks is becoming more popular due to their low cost, sustainability, density, low thermal conductivity and use of fewer mortar joints[2],[3].The energy consumed in the production of CLC blocks is only a fraction compared to the production of red bricks and emits no pollutants and creates no toxic products or by-products[4]. CLC blocks are produced by making a slurry of Cement, Fly Ash and Water, which is further mixed with a foaming agent in ordinary concrete mixer under ambient conditions. To improve the performance of CLC in seismic region,fibres can be added to the slurry to produce Fiber Reinforced Cellular Lightweight Concrete (FRCLC). A large percentage of the building stocks in India and around the world comprises mainly of unreinforced masonry (URM). The performance of these buildings in the past has shown that these masonry buildings are highly vulnerable to failure under seismic loads. In particular URM exhibits brittle failure modes under seismic loads and are prone to collapse leading to loss of property and lives. It is essential to develop a low-cost brick masonry system with improved tensile and shear strength to minimise the loss of life and property during earthquake events. Therefore, the purpose of this study is to explore the development of sustainable low cost fiber reinforced blocks for structural application of masonry that van result in better seismic performance. The strength and the seismic performance of CLC structures can be improved by the addition of fibre reinforcement into the CLC masonry system[5],[6]. Addition of fibres improvesthe ductile behaviour of CLC under shear, tensile and compression loadings making it suitable for seismic applications [7]. This improvement can be attributed to arresting of micro cracks in FRCLC whereas the unreinforced specimen is observed to have crack localization in the major crack plane [8],[9]. Further, the addition of fibres in CLC masonry can increase the structural integrity by reducing permeability and leading to better durability and increased life. Researchersin the past have studied the load-deflection behaviour of fibre reinforced cellular concrete subjected to different modes of loading[10], [11]. Use of micro fibres arrest the crack at micro scale and enhance the pre-cracking behaviour of masonry prisms, while macro fibres induce ductile behaviour in the post-peak region by arresting the structural cracks. Post-peak residual strength and ductile behaviour of CLC masonry can be attained by the addition of fibres[12], [13]. Review of previous literature indicate that there is very limited information on the mechanical properties of CLC blocks of density range 800-900 Kg/m^3.However, a thorough knowledge about the behaviour and the failure modes of engineered fibre reinforced CLC masonry is necessary to formulate the design guidelines. The objective of this study is (i) To understand the stress-strain behaviour of stack bonded masonry prisms made of sustainable, affordable and cost-effective synthetic fiber reinforced CLC blocks under compression. (ii) To prove that the developed FRCLC has better performance compared to that of conventional clay brick masonry in particular under the post-peak region.

2. MATERIALS AND METHODOLOGY

The scope of the experimental investigation is to characterize the mechanical properties including stress-strain curves for CLC blocks and CLC prisms under compression. Secondly to study the effectiveness of synthetic fibre reinforcement on energy dissipationcapacity and failure modes on the stress-strain behaviour of fibre reinforced CLC prisms under compression. CLC blocks with varying fibre dosages were cast and tested to get stress-strain curves under compression. Mortar cylinders with cement and sand (1:6 by weight) were cast and tested under compression to obtain the stress-strain curve characteristics of the bed joint. Thereafter, CLC prisms with fibre reinforced CLC blocks and normal cement mortar were cast and the influence of varying fibredosage on the composite action of masonry CLC prisms under axial compression behaviour is studied. Fibresadded to the CLC blocks provide necessary tensile and shear resistance under the action of lateral loads. The developed CLC masonry can be used as a load-bearing masonry construction, which would be largely subjected to compressive stresses. The objective of adding synthetic fibres was not to increase the compressive strength but more importantly to improve the post-peakbehaviour under tension, flexure, compression and their combinations.

2.1. Materials

Four basic materials were used for control CLC mixture viz., 53 grade Ordinary Portland Cement, siliceous type class F fly ash,potable water and foaming agent. Lime content in class F flyash is typically less than 15%. The foaming agent consisted of hydrolyzed proteins. The foaming agent was diluted with water in a ratio of 1:40 (by volume), and then aerated to a density of 75 kg/m^3. The mix proportion of fly ash: cement: water: foam was 835:280:280:1.4 kg/m^3. Water-binder ratio is kept constant at 0.4, considering the fact that fly-ash also acts as a binder. The addition of fibres in the mix by volume proportion is not greater than 0.55% in case of the highest dosage of fibre i.e., 5 kg/m^3. The volume fraction of fibre is determined by equation 2.1:

$$\frac{V_{Fiber}}{V_{fiber}+V_{mix}} \tag{2.1}$$

Fibres used in this study are microfiber and shown in Figure. 1. The physical properties of fibres are mentioned in Table 1. A batch of specimen with different volume fraction of micro-fibers such as 0%, 0.22%, 0.33%, 0.44%, 0.55% were cast.

Fig. 1. Polypropylene Micro fibers used in CLC

Table 1. Properties of polypropylene Micro fibers

Physical property	Range
Raw material	100 % polypropylene
Type	monofilament
Length	4-5 mm
Diameter	30-40µm
Melting point	105±10°C
Softening point	95±10°C
Acid and alkaline resistance	Strong
Density	0.91 g/cm3
Colour	white
Water absorption	No
Specific Gravity	0.9
Youngs modulus	3.45 ×103Mpa
Tensile Strength	551 Mpa

2.2. Details of specimen

Experimental program includes testing of CLC blocks with fibres, without fibre, mortar cylinders and CLC stack bonded prisms constructed with CLC blocks and mortar. Details of the specimen andfibre dosage are givenin Table 2. Dimension of Stack bonded CLC prism with cement mortar as joints and CLC blocks with fibre reinforcement are shown schematically in Figure. 2

Table 2. Details of the specimen and fiber dosage

Type of specimen	Series	Specimen name	Number of specimens	Fiber dosage (%)
CLC Cylinder	I	Control	5	0
	II	0.22% VF	5	0.22
		0.33% VF	5	0.33
		0.44% VF	5	0.44
		0.55% VF	5	0.55
Cement Mortar	Cement: Sand (1:6)	Mortar cylinder (1:6)	3	0
CLC stack bonded Prism	I	Control	2	0
	II	Pl-mi-0.22	2	0.22
		Pl-mi-0.33	2	0.33
		Pl-mi-0.44	2	0.44
		Pl-mi-0.55	2	0.55

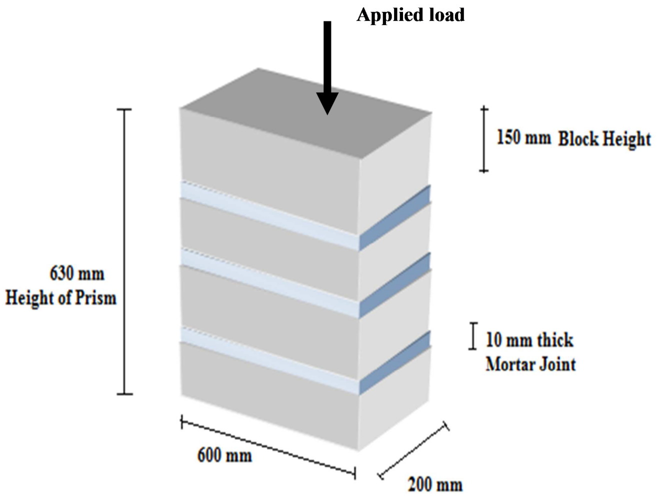

Fig. 2. Dimension of stack bonded prism with CLC blocks for compression test

2.3. Mixing, placingand curing

The dry raw materials, cement and fly ash were first introduced into the mixer and mixed thorough enough to ensure even distribution of the contents. Potable -water was then added to the mixer until all the dry raw materials are converted to wet mix. The preformed foam was introduced at a rate of 35 gm/sec for 40 seconds to the mixer. Additional 5 minutes of mixing was done along with the fibres to get uniform consistency and to form a slurry of CLC. Thereafter, this slurry was poured into cuboidal moulds of 200 mm x 150 mm x 600mm. After 24 hours Specimens were remoulded and curing was done as per IS-456 2000 (Plain and Reinforced Concrete - Code of Practice).The process of manufacture of CLC blocks are shown in Figure. 3.

a. CLC manufacturing plant b. Mixing of foaming agent

c. CLC mixture d. placing in mould

e. CLC blocks ready for curing f. CLC cylinder

Fig.3. Process of manufacture of CLC blocks

The quantities of various materials were arrived based on trial mixes. The density of CLC was not much affected by the addition of fibres. CLC used in this study does not have coarse and fine aggregates as typical in other lightweight concretes. CLC consist of only cement, flyash and foaming agents. Studies in the past have revealed that optimum air content at which maximum strength to weightratio for foam concrete is around 40% [14]. At this air content, the density of foam concrete tends to be close to 750 kg/m^3. However, for this study, a total void ratio of about 0.35 is used in order to achieve 900±50 kg/m^3 density. Water absorption tests carried out on CLC blocks showed that the water absorption was found to be 15 to 20%, which is comparable to that of existing clay brick masonry. Prisms were cast using blocks of 200 x 150 x 600 mm. Four CLC blocks were used for constructing each prism. Cement mortar with cement: sand weight ratio of 1:6 and 10 mm thickness was used for joints. The constructed CLC prism with and without fibers are shown in Figure. 4. Compression test on CLCblocks was carried out in displacement control mode,after curing for 28 days.

Fig.4. casting of CLC block stack bonded masonry prism

2.4. Test method

The quality of masonry structure is usually defined by its compressive strength. The American Society for Testing and Materials (ASTM) provides standardized test methods for compression testingof masonry specimen. It is always desirable to ensure that the specified properties of masonry assemblages are satisfied using simple and economical tests, in order to save time and money during the design and construction [15]. Testing of masonry prisms is more economical than full-scale testing of masonry assemblages. The loading surfaces of the prisms were scraped and levelled to ensure a smooth contact area before testing. The load-displacement data were recorded through the Data Acquisition (DAQ) System. The prisms were tested using the servo-controlled compression testing machine. Even though there exist no standards for testing fibre reinforced CLC prisms under compression, ASTM C1314 – 16 (Standard test method for compressive strength of masonry prisms, 2012), IS 1905-1987 (Structural use of unreinforced masonry), and IS 3495-1992 (Parts 1-4: Methods of tests of burnt clay building brick were used as a guideline to establish stress-strain curves of CLC prisms under compression [16]. To provide a flat bearing surface and to distribute the load uniformly to the specimen, fiber board were used on the top of the specimen. Testing of prism specimen in compression was done in a servo-controlled compression testing machine by applying the load at a rate of 0.1 kN/sec upto70% of the peak load. Thereafter, the loading was applied in displacement control mode at a rate of 0.001mm/sec. The applied load was measured through a load cell and displacements were measured in the direction of loading using Linear Variable Displacement Transducers (LVDTs) as shown in Figure 5.

Fig.5. Testing of CLC prism

3. RESULTS AND DISCUSSION

A total of 10 CLC prisms was cast with different fibre dosages and tested in two series. Series I was the control one with no micro fibre reinforcement. Series II had microreinforcement in the blocks with four different fiber dosages (0.22%,0.33%,0.44%,0.55%). A minimum of three specimens was tested for each series to ensure the consistency of results. Test results of CLC stack bonded prisms in compression for the two series of specimens are presented in Table 3. The average results are reported for comparison of the behaviour of CLC prisms with and without fibers.

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

Type of specimen	Series	Specimen ID	Peak Compressive Strength (Mpa)			Mean Strength (Mpa)
			1	2	3	
CLC cylinder	I	Control	4.63	4.52	4.91	4.71
	II	0.22%VF	7.51	7.43	7.81	7.64
		0.33%VF	8.21	7.91	7.54	7.89
		0.44%VF	8.64	8.56	8.48	8.56
		0.55%VF	9.1	8.91	8.75	8.82
CLC Stack bonded prism	I	Control	3.42	3.52	3.32	3.52
	II	Pl-mi-0.22	3.76	3.87	3.54	3.66
		Pl-mi-0.33	3.71	3.92	3.63	3.81
		Pl-mi-0.44	3.87	3.84	4.1	3.94
		Pl-mi-0.55	4.21	4.23	4.01	4.13

3.1. Compression behaviour of CLC cylinders with and without fibres

The compression behaviour of CLC cylinder is briefly explained here for comparison with the compression behaviour of prism. Strength of fibrereinforced CLC blocks was obtained by testing of cylinders under compression. The peak compressive strength of CLC was found to be varying with a coefficient of variation of 12 to 15% with respect to fibre dosage. The average stress-strain response of CLC cylinders is shown in Figure 6. Unreinforced CLC cylinders (CLC cylinders without fibers) subjected to compression showed a linear stress-strain behaviour (Fig. 6) upto 30% of the peak stress. Subsequently, it became nonlinear and continued up to the peak stress due to adjustment of air-voids at higher loads. Resistance to the applied strain was observed to be less after attaining the peak load, resulting in a sudden collapse of the prism.

The pre-cracking behaviour of CLC cylinders with and without micro fibres were similar. However, a slight increase in the elastic stiffness was observed with the addition of fibers (Fig. 6). The peak strength increased with the increase in fibre dosage. As the displacement entered the post-peak region, load drop was not observed rather the post-peak load followed almost a constant value close to peak load indicating relatively less degradation in post-peak stiffness. The peak load in fiber reinforced CLC cylinder increased upto about 20% with respect to that of cylinders without fibres. Compressive strength of CLC cylinders was found to be in the range of 4 to 8 MPa.

3.2. CLC prism with no fibres

The stress strain curve for CLC prism in comparison with CLC block and Mortar cylinder is shown in Figure 7. Stress-strain curve for the Control CLC prism exhibited a linear behaviour up to 33% of the peak load under axial compression. After the peak load was attained, Control CLC prism showed almost negligible resistance to the applied strain loading and the failure was quite sudden as the specimen collapsed. Figure 7 shows that the strength of the unreinforced prism (3.7 MPa) was closer to that of block strength. The elastic modulus of the mortar (12200 MPa) was about three times greater than that of the block (4100 MPa). However, the elastic modulus of the Control CLC prism assemblies is lesser than that of both mortar cylinder and CLC block. The elastic modulus of the prism was 2100 MPa which is less than 50% of the modulus of CLC block (4100 MPa). The failure in prism is due the effect of tri-axial compression in blocks and bi-axial tension and uniaxial compression in mortar. The failure was initiated by tension cracking in the mortar followed by its propagation as splitting cracks into the CLC blocks leading to the overall failure of the prism.

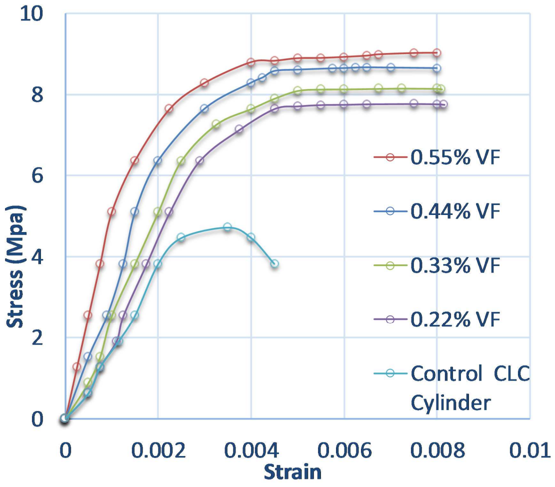

Fig.6. Stress strain plot of mortar cylinder with and without fibers

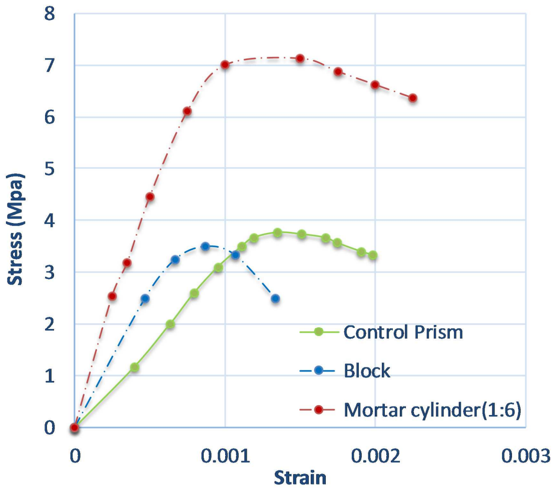

Fig.7. Stress Strain plot of Control Prism with mortar cylinder and CLC Block

3.3. CLC prism with different fibre dosage

The stress-strain curves for prisms reinforced with different dosage of fibres are compared in Figure 8. Micro fiber reinforced CLC prisms showed a significant increase in the elastic modulus. While the softening behaviour was more pronounced in the post-peak region. The degradation in stiffness was lesser in the post peak region. The peak strength of Micro fibre reinforced CLC prisms was higher than the blocks and its elastic modulus was lying between the blocks and mortar.

The peak compressive load in fibre reinforced prisms increased when compared to control CLC blocks and control CLC prisms. This increase in peak load can be explained by the better arresting of micro cracks by the fibers which led to the increase in peak compressive strength and better post-peak behaviour. Post-peak behaviour is improved in terms of residual load carrying capacity and compressive toughness index. Peak compressive strength of 3 to 5 MPa was attained in this study. Therefore, it can be concluded that the fibre reinforced CLC prism is a good alternative to the existing clay brick with superior mechanical properties for structural applications.

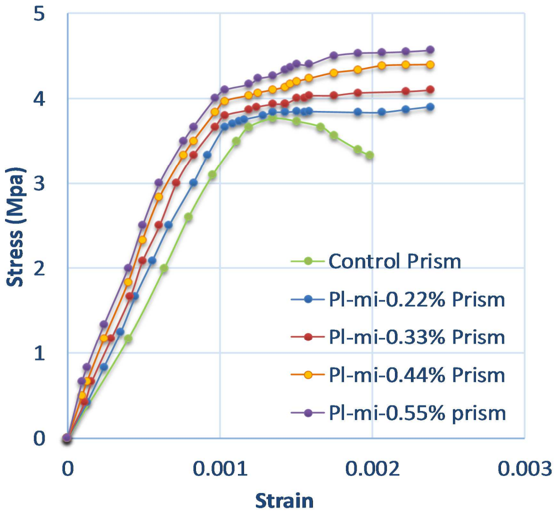

Fig.8. Stress Strain plot of FRCLC Prism with different fiber dosage

3.4.Failure mode

Addition of fibers in Autoclave Aerated Block (AAB) may result in melting of fibers due to application of high temperature. Therefore, it is essential to develop a high performance fiber reinforced cellular concrete without high pressure steam curing process. Fiber reinforced CLC blocks can be used as a replacement for AAB. The failure mode exhibited by controls prism specimen is predominantly a single explicit crack as shown in Figure 9. Stress concentrations in particular region can be attributed to the inability of distributing the stress across the cross-section of the prism. The load transfer takes place largely around the crack region, leading to faster propagation of crack. On contrary to this, compression prisms with fibre reinforced cellular lightweight concrete blocks, showed a large number of micro cracks (Figure 10). Once the matrix in CLC block is cracked, polypropylene micro fibres get engaged in the crack arresting process, as a result, large number of micro cracks emerges in the material as shown in Figure 11. The formation of major cracks is arrested by the fibres in the CLC blocks which forms a closed network. Elastic modulus of fibre reinforced blocks was lesser than that of the mortar. This resulted in uniaxial compression and bi-axial tension in the mortar joint and tri-axial compression in CLC blocks. Failure progression of control CLC prisms was due to crack initiation in mortar joint leading to further crack propagation in CLC blocks leading to overall failure. Presence of fibres in the CLC blocks led to better crack resistance leading to improved post-peak behaviour. With the increase in load, a greater number of micro cracks are developed along the direction of loading. The propagation of cracks in the block is prevented by the Fibres which bridged the cracks and leading to lesser degradation of strength with higher strains at failure.

Addition of synthetic polypropylene fibers increases the tensile and unconfined compressive strength up to ten-millimetre length of fiber. It was further stated that beyond this length, the strength is still increasing but at a slower rate. Addition of fibers can improve the ductile behaviour of CLC under shear, tensile and compression loadings making it suitablefor seismic applications. This improvement can be attributed to arresting of micro cracks in FRCLC whereas the unreinforced specimen is observed to have crack localization in the major crack plane.

Study on fiber reinforced CLC indicates that the cost is only 20% higher than the normal CLC. Overall life-cycle analysis indicates the beneficial effects of adding fibers overweigh the additional cost incurred due to fiber addition. Compression tests on CLC prisms constructed with mortar of low strength and modulus than CLC blocks would be interesting. This combination would induce tri-axial compression in mortar and bi-axial tension and uniaxial compression on the CLC blocks and therefore the failure modes would be very different to what is reported in this study. A study on the effect of addition of fibrillated fibers on mortar and its influence on compression behaviour of CLC prisms would also be interesting and is scope for further work.

Fig.9. Failure of unreinforced CLC prism

Fig.10. failure of stack bonded fiber reinforced CLC prism

Fig.11. failure of mortar joint and micro cracks formation in fiber reinforced CLC prism

4. CONCLUSION

The performance of CLC which are sustainable, and light in weight can be enhanced by the addition of fibres and improving its post-peak strength degradation and higher strains at failure. The effect of adding synthetic polypropylene fibres to CLC was studied by testing CLC stack bonded prisms with various fibre dosages under compression. Based on the results present in this study, the following conclusions can be drawn:

1. The compression behaviour of control CLC prisms was similar to that of individual CLC cylinders under axial compression.

2. Compressive strength of CLC prisms increases progressively with the increase in fibre dosage. when compared to that of control prisms, the compressive strength increased up to 17 % for 0.55% volume fraction of micro fibre.
3. Elastic modulus of fibre reinforced CLC blocks was lesser than that of the mortar cylinder. Lesser elastic properties resulted in tri-axial compression in CLC blocks and uniaxial compression and bi-axial tension in the mortar joint. Failure progression of control CLC prisms was due to crack formation in mortar joint leading to further propagation in CLC blocks leading to sudden failure. Presence of fibres in the blocks led to better crack resistance and led to lesser degradation of strength and stiffness degradation when compared to control prisms.
4. Fibre reinforced CLC stack bonded prisms showed a good composite behaviour under compression. This is due to the fact that the increase in fibre dosagereduces the difference in strength and stiffness between mortar and fibre reinforced CLC blocks.
5. Addition of fibers can improve the ductile behaviour of CLC under shear, tensile and compression loadings making it suitablefor seismic applications. This improvement can be attributed to arresting of micro cracks in FRCLC whereas the unreinforced specimen is observed to have crack localization in the major crack plane.

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