Characteristics of Fiber reinforced light weight concrete wall panel

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Abstract - The heavy dead weights of concrete structures are posing a head ache for the structural engineers to design the various members much complicated to take its own weight. The present investigations are carried out to develop a simple, lightweight and cost effective technology for replacing the existing wall systems. Aerated concrete is defined as a light cellular concrete which can be classified as a lightweight concrete (density of 400–1850 kg/m^3) with random air-voids created from the mixture of air entraining agents in mortar. Aerated concrete is recognized for its high flowability, low cement content, low aggregate usage, and excellent thermal insulation. This paper deals with the characteristics of aerated concrete reinforced with steel fibres for use as structural walls. Here aluminium powder is used as the air entraining agent. The study mainly tends to evaluate the structural properties of aerated concrete and then six panels were cast of which three from each fiber reinforced concrete panels and non fiber reinforced concrete panels incorporating additional reinforcement in forms of welded mesh and reinforcement bars. Concrete panels of size 600mm×600mm×100mm were prepared and tested to get load-bearing capacity, load–deflection profiles, load–strain relationships, failure and collapse modes and cracking patterns.

Key Words: **light weight concrete, aeration, wall panels, mesh reinforcement, steel fibers**

1. INTRODUCTION

Aerated concrete is a lightweight concrete in which aeration can be done with the help of air entraining agents like aluminium powder in which air is entrapped in the mortar matrix. Light weight concrete is an important and versatile material in modern construction. It has many and varied applications including multi storey building frames and floors, bridges, offshore oil platforms, and prestressed or precast elements of all types [1]. Many architects, engineers, and contractors recognize the inherent economies and advantages offered by this material, as evidenced by the many impressive lightweight concrete structures found today throughout the world. Structural light weight concrete solves weight and durability problems in buildings and exposed structures. Structural lightweight concrete offers design flexibility and substantial cost savings by providing: less dead load, improved seismic structural response, longer spans, better fire ratings, thinner sections, decreased storey height, smaller size structural members, less reinforcing steel, and lower foundation costs. Lightweight concrete precast elements offer reduced transportation and placement costs. Light weight concrete has density less than conventional concrete that is less than 1800 kg/m^3 [14].

Evolution of the development in construction activities around the world, the demand for Construction materials is increasing exponentially. Continued extraction of natural aggregate is accompanied by serious environmental problems. [8] Furthermore, the wall constructed with conventional masonry system contributes higher dead weight to the structure. The reduction in the weight of wall will significantly reduce the dead weight of structure which results in overall reduction in sizes of structural components. Furthermore, the improved technologies are necessary to manage the shortfall in the availability of natural aggregate materials. With these reasons, there is a need for the alternative system to fulfil the construction demand without compromising strength, affordability and environmental friendly. The fiber reinforced light weight concrete wall panels are such system, which is more suitable for wall construction.

The study mainly tends to evaluate the structural properties of aerated concrete and then six numbers of panels were cast of which three from each fiber reinforced concrete panels and non fiber reinforced concrete panels incorporating additional reinforcement in forms of reinforcing bars and wire meshes. The primary independent variables were the types and volume fraction of fibers, and the amount of air in the concrete. Steel fibers were investigated at 0, 0.25%, 0.5%, 0.75% and 1% volume ratios. Aluminium powder is also added to introduce air into the concrete. This work provides basic information regarding the mechanical properties of fiber reinforced light weight concrete.

1.1. .Aerated Concrete and sustainability

The worldwide cement production results in approximately 5% of global manmade carbon dioxide emissions. From a life-cycle perspective, however, the energy consumption and the resulting CO2 emission from the operation of buildings are much larger than the energy consumed during production of the building materials. This indicates that developing efficient construction products can be a cost effective way to reduce our overall energy consumption. Aerated concrete is a class of construction materials which can serve the purpose of manufacturing and construction efficiency and thermally attractive products. The air-pores in aerated concrete are usually in the range of 0.1–1 mm in diameter and typically formed by the addition of aluminium powder (or paste) at 0.2– 0.5% (by weight of cement).The chemical reaction of calcium hydroxide and aluminium generates hydrogen gas shown in Eq. (1) is associated with large volume changes, resulting in the expansion of the fresh mixture to about twice of its original volume [3].

$$2Al + 3Ca(OH)_2 + 6H_2O \rightarrow 3CaO.Al_2O_3.6H_2O + 3H_2\uparrow \quad (1)$$

1.1.2. Fiber-Reinforced Aerated Concrete

A novel class of aerated concrete is Fiber-Reinforced Aerated Concrete (FRAC) or Flex Crete which includes internal reinforcement with short polymeric fibers such as polypropylene steel fibers etc. In order to avoid potential damage to the polymeric fibers, autoclaving is eliminated from the production of FRAC and curing is performed at room temperature. Elimination of autoclaving process may create lower strength values and higher inhomogeneity when com- pared with autoclaved aerated concrete. The structures of FRAC and AAC are therefore of different natures. Short fibers however have a positive effect in bridging the cracks formed during the plastic stage or later on due to the mechanical forces, drying shrinkage, or heating–cooling cycles. It has been reported by Perez-Pena and Mobasher that the addition of short polypropylene fibers to lightweight cementitious panels can largely improve the mechanical properties. In their study, modulus of rupture in- creased from 3.2 to 4.0 MPa and toughness increased from 0.6 to 1.2 N m when fiber content was raised from 0.4% to 1.4%. Additionally, adding short fibers reduces the shrinkage cracking in the plastic phase or later in the elastic phase while drying. Aerated concrete products can exhibit a considerable amount of residual compressive strength after reaching the peak strength.

2. LITERATURE REVIEW

Fiber reinforced aerated lightweight concrete (FALC) was developed to reduce concrete's density and to improve its fire resistance, thermal conductivity, and energy absorption. Fiber aerated lightweight concrete (FALC) has a promising future for precast concrete panels that can be used in both small and tall building structures because it combines the comfort of AALC, the adaptability of lightweight aggregate concrete, and the reliability of FRC Polypropylene fibers are sensitive to fire, sunlight and oxygen, they have low modulus of elasticity, and they bond poorly with the concrete mix whereas steel fibers can be used as it has better bonding with matrix and also are less sensitive to fire, sunlight[14].Foamed concrete with a density of 800–1500 kg/m3 and compressive strength of 10–50 MPa can be made by using silica fume and PP fiber. Fine silica fume and PP fiber greatly improved the compressive strength of foamed concrete. In addition, adding PP fiber significantly improved the splitting tensile strength and drying shrinkage resistance. Steel fibers are used in foamed concrete as they yield better compressive strength and splitting tensile strength than PP fibers[4].Fiber-Reinforced Aerated Concrete (FRAC) block had higher porosity and less density than the bottom portion due to the non-uniform distribution of air-pores, the residual compressive strength values are more consistent due to the role of fibers in integrating the material after failure. FRAC is a ductile material and absorbs high amounts of energy as a result of crack bridging action of fibers. In comparison, while FRAC had as much as 50% less compressive strength than the Auto cleaved Aerated Concrete [AAC] its flexural toughness was more than 100 times more than AAC due to the role of fibers in bridging the micro and macro cracks. With very low thermal conductivity values, FRAC can be a used as a sustainable construction material for residential applications [3].The addition various air entraining agents causes the concrete to rise like cake but it reduces the strength of concrete due to the formation of air voids. Oleic acid results in maximum reduction of density as compared to other air entraining agents like hydrogen peroxide and olive oil. The dry density and compressive strength of the mix reduces slowly when the admixture proportion is increased from 0% to 0.5% and then to 1%.The dry density and compressive strength of the mix reduces gradually when the admixture proportion is increased from 1% to 1.5%.[10]Precast concrete sandwich panels are commonly used to construct the outer shells of numerous typical buildings such as residential, commercial and warehouses; and as they are vertically spanned between foundation and floors or roofs that mostly resist the axial/compression loads.[12] The dosage of aluminum powder required to achieve a desired density reduces with an increase in its fineness. Al powder with fineness C50 provides higher strength to density ratio and lower water absorption [5]. The externally bonded textiles layers significantly improved the mechanical properties of lightweight low-strength aerated concrete core. Dynamic flexural strength was greater than the static flexural strength by as much as 4 times. For specimens with larger cross-sections, unreinforced-autoclaved AAC core had a 15% higher apparent flexural capacity. With 0.5% volume of polypropylene fibers in the core, the flexural toughness however increased by 25%[11].Thermal conductivity of fiber substituted autoclaved aerated concrete changes linearly with thermal conductivity of the substituted fibers and basalt fiber reinforced autoclaved aerated concrete gives the highest thermal conductivity. But, it has been seen that the best compression and flexural strength was given by the carbon fiber reinforced samples. Fibers create a physical bond in the materials and remain independent greatly affected the result. Polypropylene and glass fibers increased the compressive and flexural strength of the samples but on the other hand, it also increased their thermal conductivity [6].

3. EXPERIMENTAL STUDY

3.1 Material

Ordinary Portland cement of 53 grade being used in the present investigation. Manufactured sand (M-sand) has been used for the present investigation. Aggregate which is passing through 1.7mm sieve were used as they are much fine otherwise bubbles of foam will get break up making the concrete more stiffer and denser. Aluminium powder used for the study has an atomic weight of 26.98 and particle size 200 mesh. It is of fine, uniform, smooth metallic powder free from aggregates. Chemical composition been tabulated in Table 1. The steel fiber reinforcement offers a solution to the problem of cracking by making concrete tougher and more ductile. The Master Glenium SKY 8233 used as superplasticizer.

Table- 1: Chemical Composition of Aluminium Powder

Compounds	Composition (%)
Assay	99.50
Arsenic (As)	0.0005
Lead (Pb)	0.03
Iron (Fe)	0.5

3.2. Casting of specimen

One of the main constituents of aerated concrete is cement mortar. The ratio of cement to fine aggregate was 1:2 and the water cement ratio was taken as 0.45.The first stage deals with the determination of optimum percentage of foaming agent by weight to be added to mortar with cement sand ratio of 1:2. Light weight concrete (LC) mixes were prepared with 0%, 0.25%, 0.5%, 0.75%, 1%, 1.25%, 1.5%, 1.75%, 2%, of foaming agent by weight of cement. The optimum percentage of aluminum powder is determined with the density and compressive strength of LC with different percentages of foaming agent.

The second stage deals with the effect of adding steel fibers with different percentages to optimized LC. Fibered Light weight Concrete (FLC) specimens were prepared with 0%, 0.25%, 0.5%, 0.75% and 1% of steel fibers by volume of concrete specimen and optimized and finally Fiber reinforced Light weight Concrete wall panels(FLP) were prepared. Figure.1 shows casting of aerated cubes.

Figure1: Casting of specimen

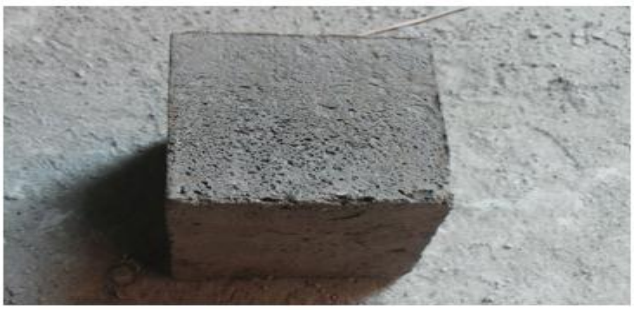

Figure 2: Lightweight concrete cubes

3.3 Details of Wall panel

The size of the light weight wall panel is taken as 600mm×600mm with thickness 100mm.6 panels where casted with first 3 set of panels with light weight concrete and reinforcement are single layer 8mm dia bars[RLP], single layer wire mesh of 12mm opening[MLP] and 2 layer wire mesh[2MLP] respectively. The other 3 sets of panels are made with Steel fiber reinforced concrete, with light weight concrete and reinforcement are single layer 8mm dia bars[RFLP], single layer wire mesh of 12mm opening[MFLP] and 2 layer wire mesh[2MFLP] respectively. Two specimens of each category were cast for studying the structural behavior of wall panel.

3.3 Casting of Wall panel

The 600mm x 600 mm x 100mm mould was prepared and water was sprinkled on the base in order to reduce the water absorption. For casting of wall panels three different reinforcement cases are studied, with single layer of reinforcement, single layer mesh and two layer mesh reinforcement. The first two panels are casted as shown in figure.3, a first layer of mortar was placed up to half the thickness required. Then the reinforcement was placed over the first layer. The last layer of mortar was placed over the reinforcement so that the reinforcement was sandwiched in between the mortar layers. In two layer mesh reinforced panels wire meshes are provided at one third and two third of its height.

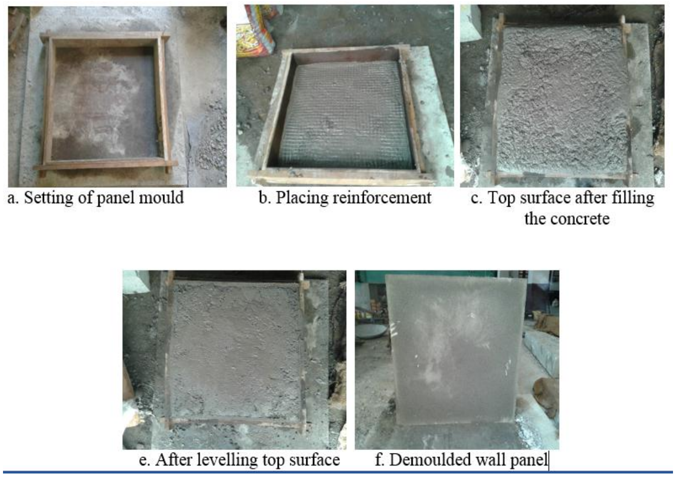

Figure 3: Typical views of sequences in casting of lightweight concrete wall panel

3.4 Test setup

The specimens casted were tested for their failure load. The specimens were placed on the loading fame with two ends fixed. The load was applied at a constant rate without shocks and increased continuously. For testing of wall panels, hydraulic jack of 500T capacity was used. The wall panel was supported at both ends by a 30cm steel plate such that the strut formed due to failure will not move outwards the panel. Load was applied till the wall panel fails. Load applied was measured using a dial gauge. Figure.4.4 shows the test set up as per ACI 318 – 08.The loading area will be 15cm towards both sides from center. Figure.4 shows the wall panel placed on loading frame for testing.

a. Grid line marking

b. Testing of Panel

c. Strain gauge and dial gauge attachment

Figure 4: Typical view of testing arrangements for testing wall panel

4. Results and Discussion

4.1 Density of Aerated Concrete with Various Percentages of Aluminium powder

The wet and dry densities of Light weight concrete (LC) with different percentages of aluminium powder is calculated at 7 and 28 days. The aluminium powder percentages taken were 0%, 0.25%, 0.5%, 0.75%, 1%, 1.25%,1.5%,1.75%,2% by weight of cement which is weighed using vessel. Wet and dry densities of specimens at 7 and 28 days are graphically represented in Figure 5.

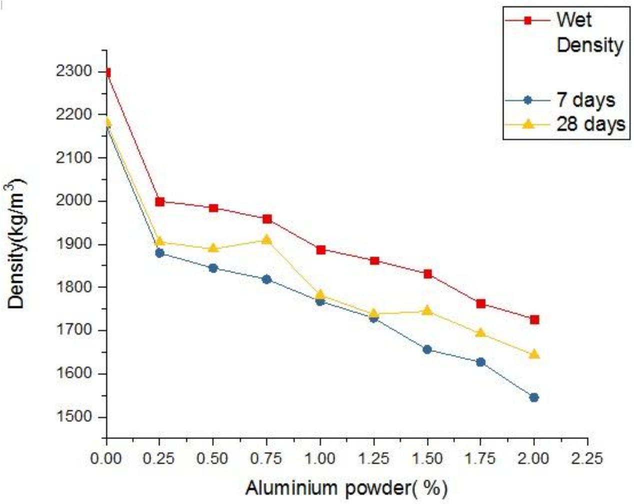

Figure 5: Densities at different percentage of aluminium powder for 1:2 mix

4.2 Compressive Strength with Various Percentages of Aluminium powder

The compressive strength of specimens with cement sand proportion 1:2 with different proportion of aluminium powder were calculated at 7, and 28 days of curing and the results are graphically represented in Figure 6.

Lower sand cement ratio results in aerated concrete of higher compressive strength and from the experimental study comparing the values of density and compressive strength the mix proportion was fixed as 1:2 and the aluminium dosage was fixed as 1%.

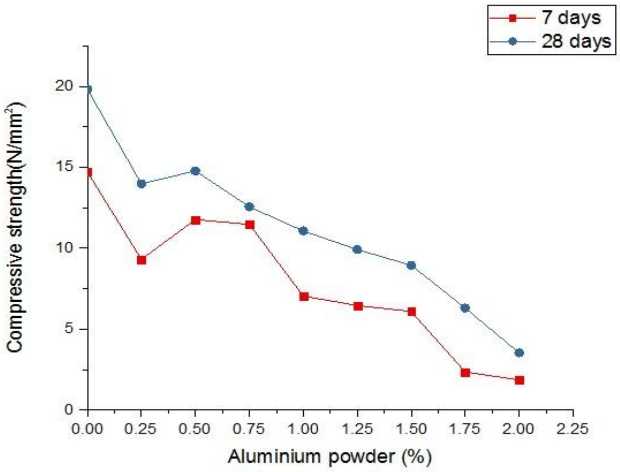

Figure 6: Compressive strength at different percentage of aluminium powder for 1:2 mix

4.3 Density of Aerated Concrete with Varying Percentages of Steel Fiber

The wet and dry densities of optimized aerated concrete with different percentages of steel fibers were calculated at 7 and 28 days. The variation have been depicted in Figure. 7.

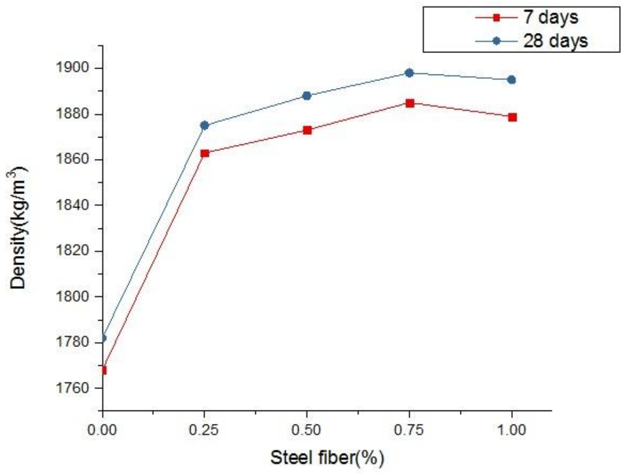

Figure7: Densities at different percentage of Steel fibers

4.4 Compressive strength of foamed concrete with varying percentages of steel fiber

The fiber is added at various percentages which are 0%, 0.25%, 0.5%, 0.75% and 1% by volume of specimen. Compressive strength of aerated concrete with addition of steel fibre is calculated at 7, and 28 days and the results are shown in figure 8. The density of the fibrous concrete increases as the percentage of steel fiber increases. Initially it shows a 100 kg/m³ increment in dry density for an addition of 0.25% steel fiber. On further addition of steel fibrous the dry density increment is around 5-10 kg/m³. Addition of steel fiber to the mix has increased the compressive strength. It was observed that compressive strength goes on increasing by an amount of 6% up to 0.5% addition of steel fiber beyond which it decreased. Analysing the results 0.5% of steel fibour is chosen as optimum steel fiber percentage.

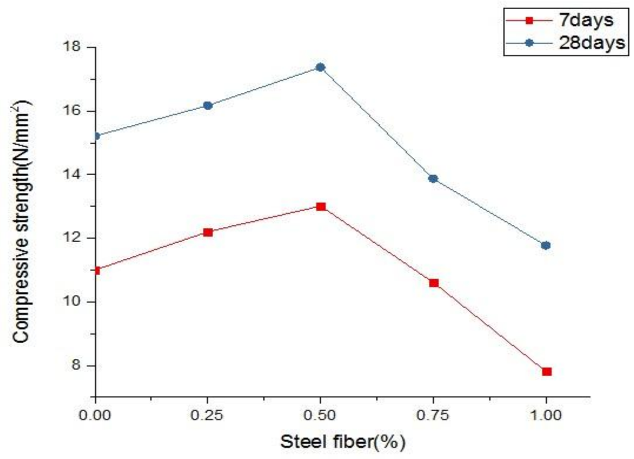

Figure 8: Compressive strength at different percentage of steel fibers

4.5 Failure loads and cracking patterns of wall panels

The wall panel specimens of size 600mm×600mm×100mm with single layer of reinforcement, single layer mesh and two layer mesh reinforced panels were tested after 28 days of curing. The specimens were tested in loading frame and in plane loading was given. The failure load of wall panels obtained after testing is as given in Table 2. The sandwich concrete wall panel is experimentally tested under in-plane compression loading. The load is gradually applied and the corresponding deflection and strain readings are recorded. The load drops when the first crack is observed. The load is increased further and the panel carries the load steadily and the second load drop is noticed. The cracks were formed at the edge of the panel and several micro cracks were formed on the surface. The load is increased and found that the cracks were enlarged further. The cracks on the vertical side surface are extended and the ultimate failure load is measured. The maximum compressive strength of is found about 11.33 N/mm² in RFLP where 2MFLP shows 9.56 N/mm². The load is dropped with crushing and spalling of concrete. The cracking pattern of lightweight concrete infilled wall panel is shown in figure 10. The compressive strength of concrete wall panels with different reinforcement are compared and presented in figure.9. The failure of the sandwich wall panel with lightweight concrete infill is gradual and several micro and macro cracks are formed before the ultimate failure. No bursting or easing out of lightweight concrete is seen from the experiment .The maximum load carrying capacity of the lightweight concrete wall panel of bar reinforced and 2 mesh reinforced are reasonably comparable.

The first cracks appeared at loads of 197kN, 108kN, 123kN, 275kN, 154kN, and 192 kN for panels RLP, MLP, 2MLP, RFLP, MFLP, and 2MFLP respectively. The cracking patterns occurred approximately symmetric in both concrete panels with and without fiber reinforcement. When the panel reached its ultimate load, a significant failure occurred because of concrete crushing at either one or both top and bottom ends of the panels in bar reinforced and two mesh reinforced panel. The first cracks were initially recorded at a load of 33–82% of the ultimate load of failure. Mostly small crack patterns are vertical, and the cracking patterns widths were initially small in fiber reinforced panels because of the lightweight and ductile concrete material used for casting concrete.

Table-2: Cracking and failure loads for panel tests

Specimen	Cracking Load [kN]	Failure Load [kN]	Stress [N/mm²]
RLP	197.37	259.7	8.65
MLP	108.12	204	6.8
2MLP	123.69	217	7.23
RFLP	275.4	340	11.33
MFLP	154.132	248.6	8.28
2MFLP	192.29	287	9.56

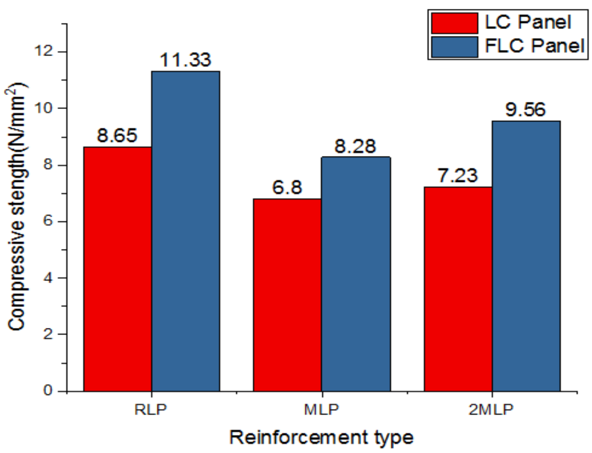

Figure 9: Compressive strength of panels at different reinforcement cases

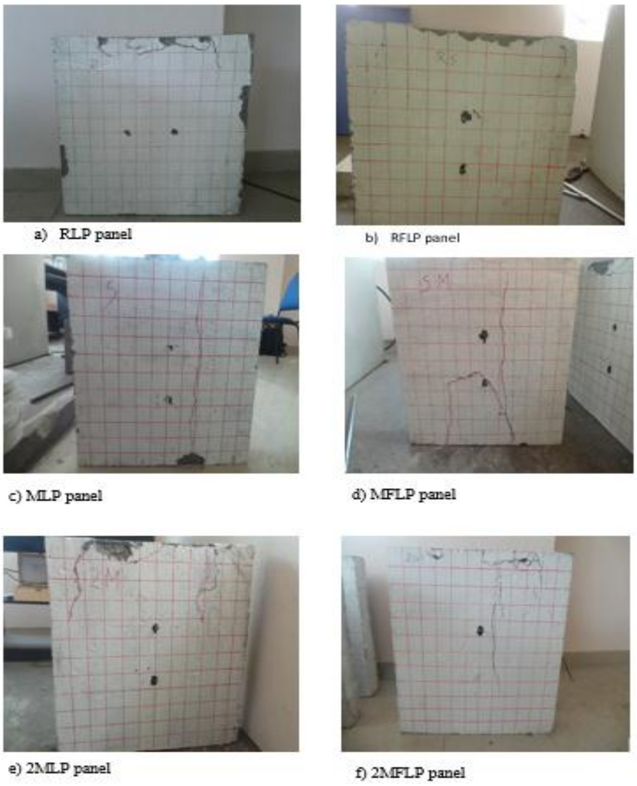

Figure 10: Failure pattern of lightweight concrete wall panels

4.6 Strain characteristics of light weight panels

Fig.11 and 12 illustrates a typical strain variation across the mid-height of LC and FLC panels at different axial loading stages. Experimentally, all panels revealed nearly similar strain variations at the early time of axial loading stages, and only a very small dis- continuity of the strain across the insulation layer under axial load increments was noticed. However, all the panels still revealed similar full-composite behavior in most axial loads when significant cracks occurred. The developed strains were too small and maximum strain in RLC panel is 0.00552 and 0.018, 0.0112 in the MLC and 2MLC panel. The maximum strain obtained in fiber reinforced panels are 0.00112, 0.003786, and 0.00173 for RFLC, MFLC, and 2MFLC respectively. In RLC and FRLC panel the strain variations recorded behaved almost elastically in the early time of increasing loads before the first crack in concrete occurred. Later, the behavior developed became proportional with the load increments and nonlinear. The behavior of the steel reinforcements were almost similar to that of the shear connector. It transfers forces between two layers efficiently until failure point, so as to make a composite action. Furthermore, the increase in concrete strains was almost proportional to the axial load increase, even after the occurrence of concrete cracking. The maximum compressive strain recorded in LC panels will reduces due to the incorporation of fibers which will show in fig.12. All the panels failed because of concrete crushing either at the top or bottom ends or, in some cases, at both ends of the tested panel.

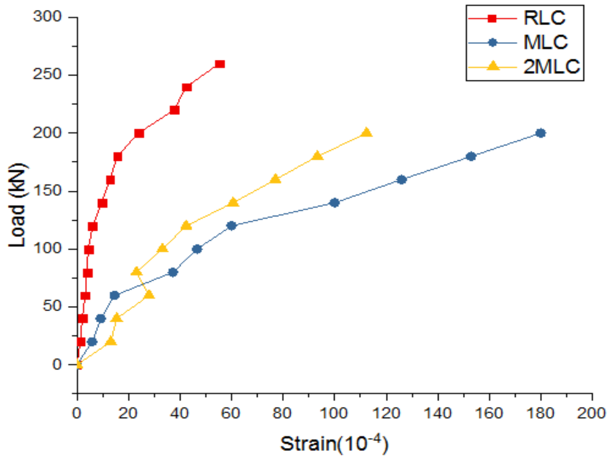

Figure 11: Strain variation across the mid-height of LC panels at different load stages.

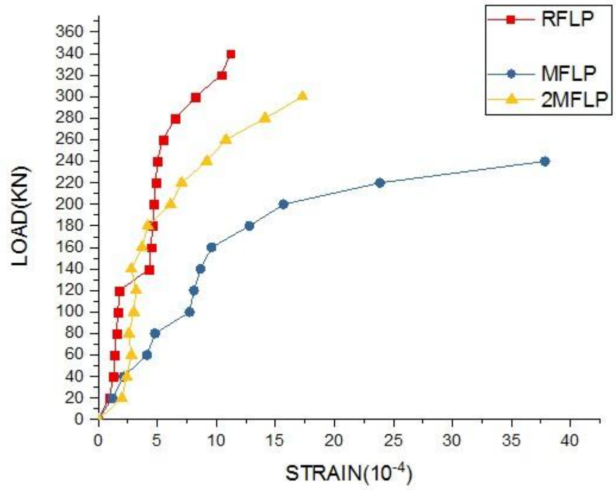

Figure 12: Strain variation across the mid-height FLC of panels at different load stages.

5. CONCLUSIONS

Based on the limited study made on light weight concrete wall panels, the following conclusions are drawn:

- For all mixes a lower cement sand ratio 1:2 results in aerated concrete of lower density leading to reduction in self weight which made it light weight.
- Density and compressive strength of aerated concrete decreased with the increase in aluminium content. The optimum dosage of aluminium powder to be added so as to produce foamed concrete with desirable strength is found to be 1%.
- Since the conventional foam concrete is brittle, addition of steel fibers serves to mitigate the brittle nature of the material by imparting post cracking strength and toughness to the composite and improves strength of panels by about 30%.

- The wire mesh sufficiently confined the panel skins and effectively reduced the concrete spalling out of outer skin layer.
- As per IS 2185-1 the minimum compressive strength for individual concrete masonry block of class A is 3.5 to 15 N/mm^2 and as based on the results the strength obtained is in the range of 10 N/mm^2.
- The ultimate compressive strength of RFLP panel and 2MFLP panel is found about 11.33 N/mm^2 and 9.56N/mm^2, which is much comparable. The result confirms the suitability of fiber reinforced lightweight concrete infilled panels for the load bearing and non-load bearing walls.

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