FLEXURAL BEHAVIOUR OF STEEL FIBRE REINFORCED AERATED CONCRETE BEAM

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Abstract

Lighweight concrete can be made used either using foamed concrete or aertaed concrete. Aerated concrete is gaining importance due to lot of advantages like reduced dead weight, economy in construction, good thermal and acoustaical insulation. Aerated concrete can be made using aluminium powder or hydrogen peroxide to introduce air bubbles in concrete which forms isolated air voids resulting in lightweight. Commercialy aerated concrete is used as building blocks for infill walls of framed structure. Research focus is now towards expanding the use of this material for use in precast structural members. Aerated concrete using aluminium powder as aerating agent and reinfored with steel fibres was used in this project . Aluminium powder reacts with lime and liberates hydrogen gas which is the reason for the air voids in the concrete . The aerated concrete was cured in steam curing chamber at 100℃ for 24 hours. This paper deals with the optimization of steel fibre reinforced aerated concrete to be used as beam members in the place of conventioanl concrete. The density of the aerated concrete that was achieved in this work was 967 kg/m3. The compressive strength of the concrete was 22.12 MPa and the flexural strength was 3.12 MPa. Durability tests like sorptivity test, carbonation test and sorptivity test were carried out to study the durability characteristics. The experiments were designed using central composite design of Response surface methodology. Trials were carried out based on the designed combimnations. Finally an optimized mix proportion was obtained for maximum strength and minium sorptivity. Beam members were casted for the optimized mix ratio and tested for flexural strength and deflection. The results show that the stell fibre reinforced beam can be used as a structural member. The precast industries can use this product advantageously to manufacture other structural members also after carrying out appropriate tests.

KeyWords: *aeration, pores, strength, durability*

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1. INTRODUCTION

Lightweight concrete (LWC) is widely used in building construction due to its low density, low thermal conductivity, low shrinkage and high heat resistance. There are many advantages in low density, for example reduction of dead load, faster building rate and lower haulage cost. Aerated concrete (AC) is the LWC produced by creating gas bubbles in a cement slurry and cured in high-pressure steam curing (autoclaved). Aerated concrete is described and identified by the presence of large voids deliberately included in it to reduce the density [1-3]. Aerated concrete is made from quartz-rich sand, lime, cement and an aerating agent. Generally aluminium powder is the aerating agent used. The aluminium powder reacts with calcium hydroxide to form hydrogen gas in the making of aerated concrete, as follows,

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

The properties of aerated concrete depend on its microstructure (void-paste system) and composition, which are influenced by the type of binder used, methods of pore-formation and curing [4,5]. High-pressure steam curing was used to improve compressive strength of aerated concrete. The most important improvement is, the product is ready for use within 24 hours (the strength is generally equivalent to 28 days under ambient curing), less shrinkage and lower moisture content after curing. Aerated concrete can be non-autoclaved or autoclaved based on the method of curing. The compressive strength and density of aerated concrete are largely influenced by the composition and method of curing. Conventionally, strength is related to density alone, with little attention paid to the composition [6,7]. The compressive strength, drying shrinkage, absorption properties etc. directly depend on the method and duration of curing. Autoclaving initiates reaction between lime and silica/alumina bearing ingredients.

Researchers have improved the strength of aerated concrete by introducing fibres, polymer laminates and industrial by-products. Fibre reinforced aerated concrete (FRAC) is a concrete with reduced weight due to aeration process and fibrous material are included to increase its structural integrity. It contains short discrete fibres that are uniformly distributed and randomly oriented. Hybrid fibre-reinforced polymer laminates was used in autoclaved aerated concrete for wall panels for producing a very high stiff panel [8]. The effect of zeolite on the properties of autoclaved aerated concrete was also investigated [9]. Zeolite was used as a quartzite replacement in conventional AAC mixtures. The zeolite containing aerated concrete specimens were prepared at bulk densities of 270–500 kg/m^3. The effect of chemically and thermally resistant carbon fibre additives of various mechanical treatment on structure formation and properties of autoclaved aerated concrete (AAC) was studied [10]. By-products like fly ash and bottom ash from thermal power plants have found extensive use in lightweight concrete due to their porous particle structure and pozzolanic properties. Fly ash has been used as replacement for cement [11,12] and bottom ash has been used as replacement for sand [13-15].Bottom ash was used as Portland cement replacement to produce lightweight concrete (LWC) by autoclave aerated concrete method [16]. Other materials like Copper tailings and blast furnace slag were used as a substitute of calcium compounds in autoclaved aerated concrete blocks [17]. It was reported that copper had taken part in the hydration reaction and the chemical elements were present in the hydration products which were examined during the micro structural investigation. The density of the blocks was 610 kg/m^3 and compressive strength was 4 MPa. Non-autoclaved aerated concrete was prepared using phosphogypsum, ground granulated blast furnace slag (GGBFS), quick lime and Na_2SO_4 [18]. The samples were cured at 90°C. Compressive strength, frost resistance and thermal conductivity were investigated and it was found to be comparable with Chinese autoclaved aerated concrete block standards. Phosphogypsum was not only the filler component it activated the chemical reaction. Steel fibres were used to enhance the properties of the concrete. The character of fibre-reinforced concrete changes with varying concretes, fibre materials, geometries, distribution, orientation, densities , tensile strength of fibres and aspect ratio. The focus of this paper is to study the properties of aerated concrete with steel fibres and the use of this concrete as wall panels which can be used in precast industries.

2. MATERIALS & METHODOLOGY

The materials used for the production of fibre reinforced aerated concrete are Portland cement of 53 grade, aluminium powder of grade Conc-95, sand, fly ash and bottom ash having the properties as given in Table-1 obtained from Neyveli Lignite Corporation. Steel fibres of Diameter 0.75 mm, Length 35 mm, Aspect ratio L/D- 47 and Tensile strength 1200 MPa was used.

There are several components involved in the making of fibre reinforced aerated concrete like fly ash, bottom ash, aluminium powder, steel fibres and W/C ratio. The traditional methods of experimentation consider only one factor at a time and a series of experiments are conducted, sequentially varying the parameters. Thus, this method deprives the opportunity to understand the influence of each factor and combination of factors on the response. Statistically based experimental design techniques are much useful when there are a number of controllable variables. The use of designed experiments helps to identify those variables that have the greater influence on response. In addition, running designed experiments helps in deriving meaningful conclusions from the experimental series. In order to find the optimal combination of the various components Statistical analysis is done using Response Surface methodology of Central composite design.

Table-1 Properties of Class- C fly ash and bottom ash

Physical properties		
	Fly ash	Bottom ash
Specific gravity	2.64	1.84
Fineness, (m^2/kg)	414	212
Chemical properties (% by mass)		
Silicon dioxide (SiO_2), %	31.52	30.25
Calcium Oxide (CaO), %	19.2	18.23
Alumina (Al_2O_3), %	29.2	31.16
Ferric Oxide (Fe_2O_3), %	8.54	7.81
Magnesia (MgO), %	3.21	2.31
Sodium Oxide (Na_2O), %	0.84	1.02
Potassium Oxide (K_2O), %	0.13	0.15
Sulphuric anhydride (SO_3), %	4.32	3.52
Manganese Oxide (MnO), %	0.02	0.03
Loss on Ignition, %	3.02	5.52

Table 2 Factors used for the Experimental Design

Factors	Lower limit	Upper limit
Aluminium powder (%) (A)	0.25	0.35
W/C (ratio) (B)	0.45	0.55
Steel fibre (%) (C)	0	10
Fly ash (%) (D)	0	20
Bottom ash (%) (E)	0	20

The limits of each component were decided based on preliminary trials and these limits given in Table-2 were used to design the experimental runs. Each combination was carried out for two trials and the mean value was adopted. The mortar mix was prepared using Portland cement of grade 53, fine aggregate passing 2.36 mm sieve, fly ash, lime, bottom ash and steel fibres are dry mixed in a mortar mixer for 3 minutes. Fly ash and bottom ash were used as partial replacement of cement and sand respectively. Aluminium powder was mixed with the mixing water and added to the dry mix and mixed for 2 minutes. To improve the workability of the mortar mix superplasticiser (ECMAPLAST) was used as 0.7% by weight of the binding material. The moulds were then greased and filled with the mortar. After few minutes the mix started to aerate resulting in increase in volume as shown in Fig-1. The aeration process continued for some time. After a stage when the mix stopped increase in volume the top portion was leveled using a sharp knife and the mix was allowed to set. The next day the specimens were demoulded and subjected to steam curing at 100°C for 24 hours. Cubes were casted for determining the compressive strength and beams were casted for flexural strength.

Fig-1 Aeration of fresh mortar mix

3. PROPERIES OF AERATED CONCRETE

The density of concrete varied from 1000 to 1265 kg/m^3. Compared to conventional concrete which has a density of 2500 kg/m^3, the density of aerated concrete was less.

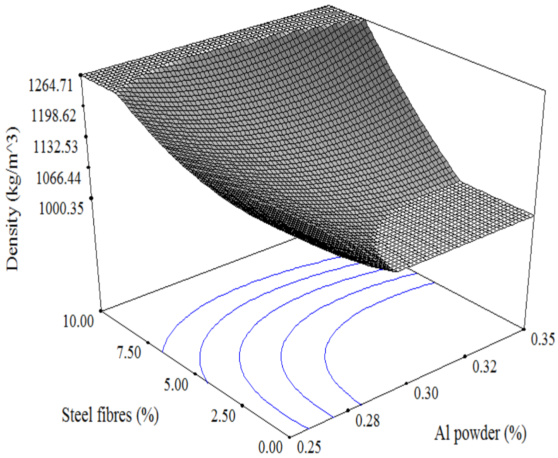

Fig-2 Response surface for Density with Al powder and steel fibres

As shown in fig-2 with increase in steel fibres ratio from 0 to 10% the density increased from 1000 to 1264 kg/m^3. For 0% steel fibres the density decreased with increase in aluminium powder. The density reduced from 1100 to 1066 kg/m^3 for increase in aluminium powder from 0.25 to 0.35. At a constant aluminium powder content the density increased with increase in steel fibre content. This is due to the increased bulk density of steel compared to the other components used in the concrete.

3.1 Compressive Strength

The compressive strength was tested in a compression testing machine at the end of 28 days. The crack was found to propogate in the central portion and the fibres were embedded in the concrete. The response surface graph in fig-3 shows that for a constant aluminium powder %, increase in steel fibres has increased the compressive strength from 1.95 to 19.93 MPa. But for 0.35% aluminium powder there was the compressive strength reduced to 15.43 MPa from 19.93 MPa which may be attributed to more air voids due to higher aeration.

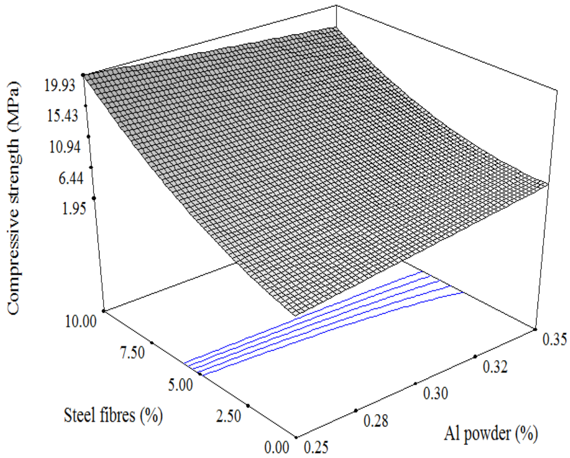

Fig-3 Response surface for compressive strength with Al powder and steel fibres

3.2 Flexural Strength

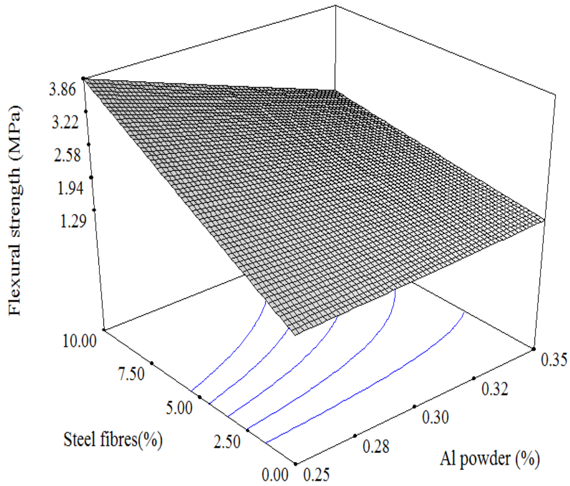

Fig-4 Response surface for flexural strength with Al powder and steel fibres

The flexural strength was tested at 28 days with a two point load system. The graph shown in fig-4 explains the increase in flexural strength from 1.29 MPa to 3.86 MPa as the steel fibre content increases from 0 to 10%.At 10% steel fibre content there was reduction in flexural strength from 3.86 MPa to 2.33 MPa due to voids formed of excessive aeration.

3.4 Sorptivity

Sorptivity tests have been conducted on steam cured cube samples conditioned in oven at 105 $\pm$ 5ºC for 24 hours and then cooled in desiccators. The weight of the oven-dried cube was measured to the nearest 0.01 g. The surface of concrete cubes, which was parallel to the direction of casting, was placed in a tray containing water and rested on 5 mm glass rods to permit the free access of water to the inflow surface. The lower areas on the sides of the specimens adjoining the inflow face were sealed with epoxy coating to achieve unidirectional flow. The water level was maintained at 10 mm above the base of the cube. The absorption of water was measured at intervals of 4, 9, 16, 25, 36, 49, 64, 81, 100, 121, 144 and 169 minutes after the start of placing the specimen in water on wiping out the surplus water. Sorptivity *S* of each sample was determined from the slope of the regression line represented by the experimental data *i* against $\sqrt{t}$. For each mix, Sorptivity was determined for 3 samples.

The graph in fig-5 shows that the maximum Sorptivity value was 0.182 mm/√min with steel fibres. Even at higher aluminum powder ratio the Sorptivity was 0.15 mm/√min. This may be attributed to the increase in strength and compact microstructure as the fibre content was increased.

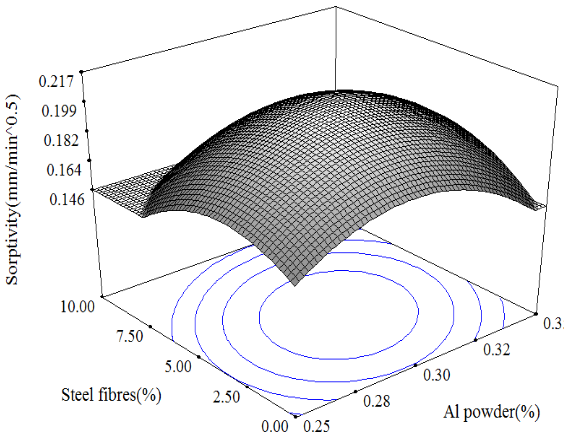

Fig-5 Response surface for sorptivity with Al powder and steel fibres

3.5 Micro Structural Investigation

Microstructure of aerated concrete was investigated using X-ray Diffraction (XRD) pattern and Scanning Electron Micrograph (SEM) analysis. Powder diffractometer using Cu Kα radiation at 40kV and 30mA was used for recording the data with a range of measurement (2θ) 5° to 60°. XRD pattern for aerated concrete was recorded on powdered samples, of size finer than 75 micron. SEM micrographs were taken on a fractured surface of 1 cm^3 samples.

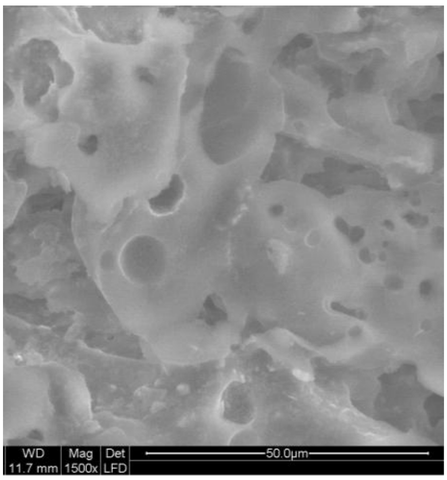

Fig-6 SEM image of aerated concrete showing voids and reaction products

q - quartz (SiO_2), h- hematite (Fe_2O_3), m-magnetite (Fe_3O_4), c_2s- di calcium silicate (Ca_2SiO_4), csh - calcium silicate hydrate $Ca_3(OH)_2Si_{16}.4H_2O$, a- anhydrate $CaSO_4$, e - ettringite ($Ca_6Al_2(SO_4,SiO_4,CO_3)_3$ (OH) $_{12}.26H_2O$) and g - gypsum ($CaSO_4.2H_2O$)

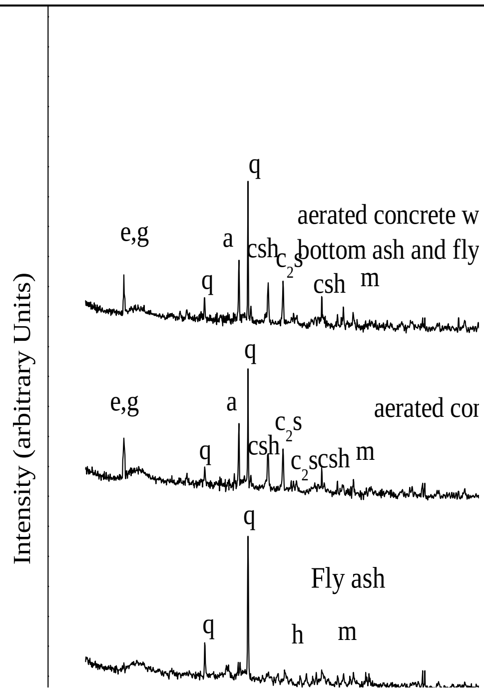

Fig-7 XRD of fly ash, conventional aerated concrete and aerated concrete with bottom ash and fly ash

The samples were mounted and subjected to the electron beam from a Quanta FEG 200 High Resolution Scanning Electron Microscope. Aeration process causes isolated air voids as shown in SEM image fig-6. Though the concrete was porous there were no interconnected pores and hence there is very little chance of permeability in concrete which will lead to durability issues. The reaction products formed in aerated concrete is shown in the XRD pattern fig-7.

3.6 Multiple Optimizations

As the production of fibre reinforced aerated concrete is a multivariable process, optimization was done keeping for the range of factors used in the experimental investigation. The criteria adopted for the multiple optimizations were maximum strength with minimum density and sorptivity. The optimized values are summarized in Table-3. For each combination of the optimized level, aerated concrete was casted and the tests were carried out. The results of the predicted and observed values are presented in Table-4.

Table-3 Optimized Values

Al powder	W/C	Steel fibres	Fly ash	Bottom ash
0.26	0.50	8.52	18.47	15.2

Table-4 Predicted and Observed Results

	Compressive Strength (MPa)	Flexural Strength (MPa)	Sorptivity	Density (kg/m^3)
P	21.43	3.83	0.10	925.80
O	22.1	3.12	0.16	1018.9

P-predicted, O-Observed

4. FLEXURAL BEHAVIOUR OF BEAM

Using the optimized values beams were cast for a size of 230 mm x 230 mm x 1200 mm. Two bars of 12 mm diameter were provided in the compression face and 2 bars of 10mm diameter were provided in the tension. Two legged stirrups of 6mm diameter were provided at a spacing of 150 mm c/c. The beams were cast and subjected to steam curing for 24 hours after demoulding the specimen. All beams were simply supported over a span of 1200 mm and tested in a Universal testing machine with a capacity of 400kN. Two concentrated loads placed symmetrically over the span loaded the beams. The distance between the loads was 300 mm and deflectometer was used to determine the maximum deflection that occurred in the beam. Two equal point loads of 75KN each are applied at a distance of 1/3rd of beam span from both the supports. Flexural strength of the beam was 8.19 MPa, the maximum mid span deflection was 4.95 mm and the slope was 0.93 radians.

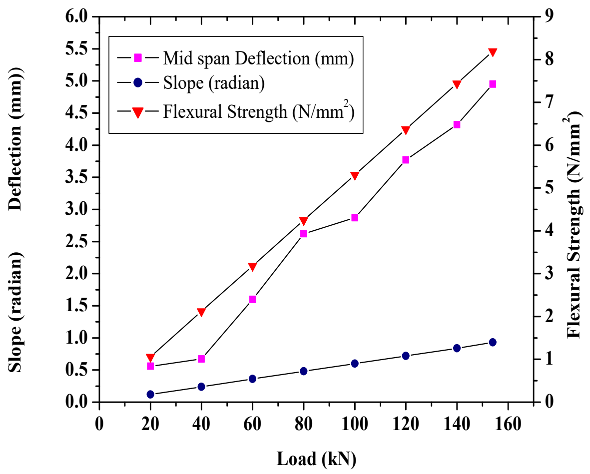

Fig-8 Behaviour of Beam

5. CONCLUSION

The properties of fibre reinforced aerated concrete were found to be superior to the conventional autoclaved aerated concrete blocks that are being used for infill walls. Moreover the steam curing process enables the product to be available in 24 hours after demoulding. The properties show that these fibre reinforced aerated concrete blocks can also be used for structural load bearing walls.

[1]. The addition of fly ash and bottom ash as replacement for cement and sand enhanced the aeration process and reduced the density of aerated concrete.
[2]. The addition of steel fibres enhanced the compressive strength and flexural strength of the aerated concrete blocks.
[3]. Though the concrete is porous isolated air voids were formed and there were not many interconnected voids as per the microstructure investigation which may not affect the durability of concrete.
[4]. This product can be used in fabrication of precast concrete walls which can be used as a load bearing member.

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