

EXPERIMENTAL STUDY ON FLEXURAL BEHAVIOUR OF STEEL-FOAM CONCRETE COMPOSITE PANELS

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Abstract— Steel–concrete–steel sandwich (SCSS) construction is a relatively new and innovative form of construction consisting of a plain concrete core, sandwiched between two layers of relatively thin steel plate, connected to the concrete by shear connectors. SFCC floor panel consists of thin cold-formed profiled steel sheet of thickness 0.8 mm as the outer skins and aerated foam concrete (FC) of density 850 kg/m³ as the infill. The use of low density FC reduces the self-weight of panel. Shear connectors in the form of through- through mild steel studs are used to transfer shear between steel sheet and FC core. The mesh comprises of 8-node brick element (C3D8R) for FC core and 4- node shell elements (S4R) for the steel sheet.

FE model is incorporated with contact surface to simulate the interfaces between profiled steel sheets and concrete core. The penalty friction contact option for tangential contact behaviour and hard contact for normal behaviour is utilized. The failure of studs is not observed in the experiment and hence to simplify the analysis, studs are not modelled. At the locations of studs, node tie constraint is used to simulate the connectivity between sheet and FC.

The plastic behaviour of FC is modeled by using concrete damage plasticity (CDP) model which assumes two failure mechanisms: tensile cracking and compressive crushing of the material. The current study is based on FE analysis of SFCC panel using ABAQUS and comparison with the experimental result. And also parametric study on SFCC floor panel is done. Nonlinear FE analysis has shown that these SFCC floor panels have displayed a high degree of flexural characteristics, ultimate strength and ductility. Close agreement has been observed between the FE and experimental results for ultimate loads and load–deflection responses. The FE model is thus found to be capable of predicting the behaviour of SFCC floor panels accurately throughout the entire range.

Index Terms - steel-concrete composite panels, ductility, infilled concrete, sandwich panel, profiled sheets, Connectors, Foam concrete, load-deflection, strain gauges, Load-deflection response

I INTRODUCTION

Development of light weight sandwich panels for housing is growing trend in construction industry. The conventional materials are replaced by materials having good improved properties such as energy efficient, light in weight, easy in handling and erection. The use of steel-concrete composite panels has gained popularity due to its ability to well combine the advantages of both concrete and steel. Composite members exhibits enhanced strength, ductility, fire behaviour and stiffness when compared to the contribution of their components acting separately and represent a competitive solution to civil engineering applications. Composite structures have been created for economic reasons such as it reduces cost of shuttering and scaffold and to build faster.

The usage of light weight material in industry is also being increased due to its high strength to weight ratio. The steel-concrete composite panel construction provides high performance than the conventional constructing method.

Cold formed steel sections are made by rolling or pressing steel into semi-finished or finished products at room temperature. The strength of elements used for design is governed by buckling. The construction practices are similar to timber frames using screws to assemble stud frames.

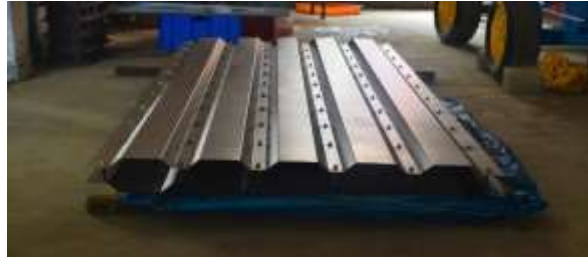
The double skin composite panel is based on steel-concrete-steel arrangement. The system consists of steel plates as outer skin and concrete as infilled material. The profiled steel sheets act as a bracing for the steel frame system and also act as a permanent formwork to the infilled concrete. The shear studs are used for the composite action between steel sheets and concrete. The structure shows greater flexibility as they are made up of individual parts and arranged together, this allows for a greater amount of flexibility. Light weight cellular concrete, foamed concrete, reduced density concrete, cellular lightweight concrete are the terms refers to foam concrete. use of foam concrete will reduce self weight and also provides high strength-weight ratio.

Experimental study on the flexural behaviour of precast sandwich panel of cold formed steel sheeting , foam concrete infill

and analytical studies for simulating the behaviour of SFCC panels under flexural loading condition also carried out using Abaqus software.

II MATERIALS USED

The floor panel of dimension 3m length, 1m wide and overall thickness is 130mm is assembled. The cold formed steel is provided as outer skin and infill material used is light weight foam concrete. The number of specimen casted is two. 28 days curing has been done. Four point loading test is done and results are obtained.



In the corrugated cross section, a pair of 0.8 mm thick cold formed steel sheets is used and the composite action is provided by using 8 mm diameter through through mild steel studs. A total number of 66 studs are provided.

For analysis ABAQUS software is used. Before modeling and analysing in the FEA software the validation should be done in order to know the procedure for analysing. In this a steel-foam concrete composite floor panel is analysed. The properties are assigned to steel and foam concrete. By assembling the model, the interaction between the steel and concrete is provided. Then boundary conditions are provided and analysis is carried out. The four-point bending test is made and the results are plotted.

The parametric study is done considering the parameters i.e number of studs, spacing of studs, density of foam concrete, plain sheet compared to profiled sheet behaviour, thickness of sheet. By doing this study, the comparison is made and the behaviour of the panel is discussed. The steel-foam concrete floor panel (SFCC) is tested under four point bending condition. The test results are compared to the analytical results. The behaviour of the panel is discussed and documented for further investigation in case if there is any necessary for improvement in results.

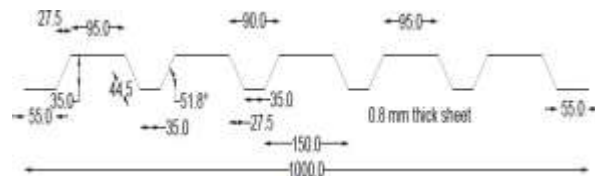


Fig 1 Profiled cold form section

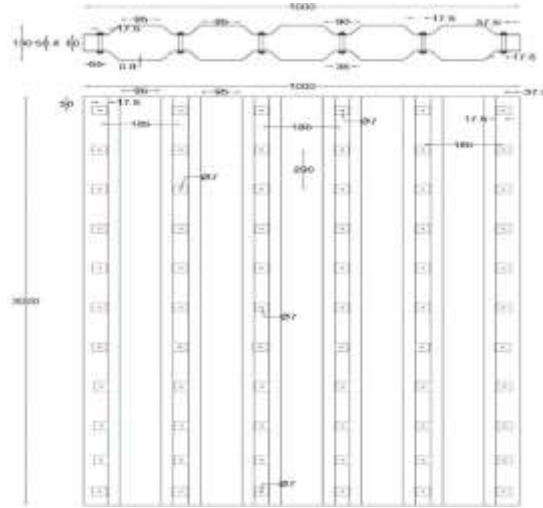


Fig 2 SFCC Floor Panel

The profiled sheets are connected using through mild steel studs. Spreader plates of size 30mm x 30mm x 1mm are provided in the outer faces of the sheet before placing nuts and bolts.

Fig 3 Assembled SFCC floor panel

Coupon specimens are done from the same cold form sheets used for the floor panels are tested to obtain the properties of the steel sheet. Tension coupons have been fabricated and tested according to IS: 1608 (2005) specifications. The coupons used are having a length of 236mm, 40mm width and 0.8mm thickness. Since the thickness is too low, extra plates are welded at both ends of the specimen to ensure proper holding in the grips of the testing machine.

Fig 4 Testing of coupons Fig 5 Failure of Coupons

Methodology

Strain gauges are connected to the coupon both in horizontal and vertical directions to obtain the elongations in transverse and longitudinal directions respectively. Automatic data acquisition system is used to get the extension of the specimen under loading. Failure of all the specimens is identical with an inclined crack near to the bottom of the specimen.

Fig 6 Stress Strain behaviour of sheet

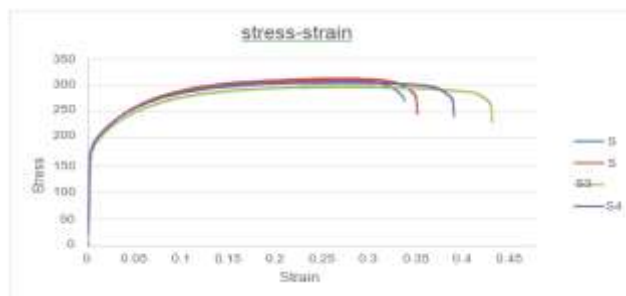


Table1 Properties of Cold Form Steel Sheet

Specimen no.	Thickness in mm	Young's Modulus E MPa	Yield strength F_y MPa	Ultimate strength F_u
Specimen 1	0.8	198000	182.01	300.17
Specimen 2	0.8	199000	182.13	299.32
Specimen 3	0.8	200000	183.42	302.25
Specimen 4	0.8	200000	181.51	301.21



The Foam concrete infilled between the steel sheets is the important component of SFCC panel. Foam concrete is free flowing self levelling created by uniform distributions of air bubbles of size 0.1 to 1mm. It serves the purpose of preventing inward buckling of the cold formed sheets to a certain extent. The current study deals with foam concrete with a density of 850 kg/m³ as infill material.

Fly ash is also added as supplementary cementitious material. The size of fine aggregate is limited to ensure good flow characteristics and to avoid foam breakage. The mix ratio to achieve the desired density of 850 kg/m³ is 1:0.8:0.87:0.7:0.041 (cement: fly ash: fine aggregate: water: foam). The foam density is kept around 70- 80gm/litre by adjusting the pressure. Natural protein based foaming agent FC lite is used as the foaming agent. The foaming agent is diluted with water in the ratio 100:3.5 (water in litres: foaming agent in litres).

Fig 7 Preparation of foam concrete



Fig 8 Foam forming agent



Fig 9 Testing of cubes and cylinder

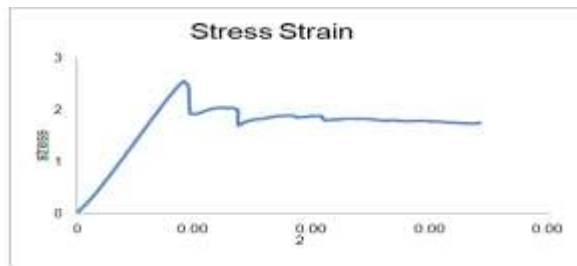


Fig 10 Stress versus strain behaviour of cube

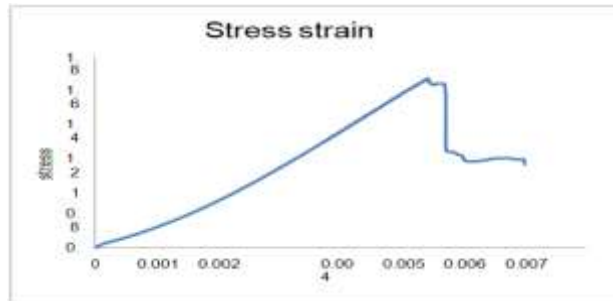
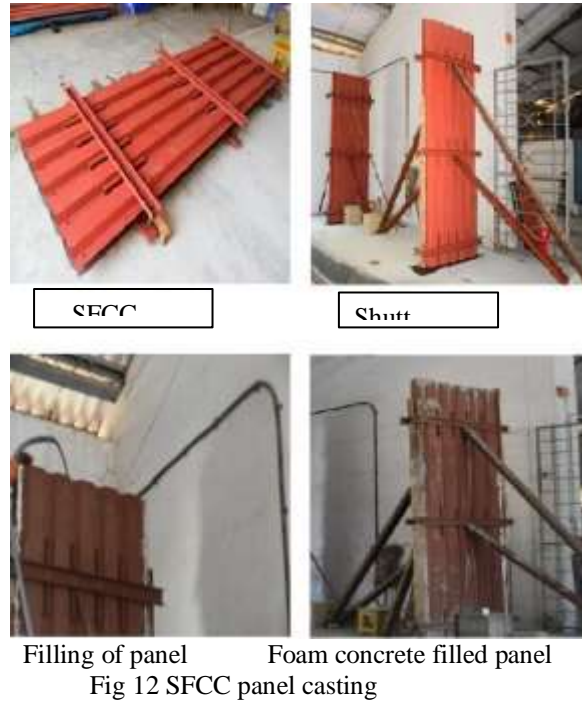


Fig 11 Stress versus strain behaviour of cylinder

Table 2 Properties of foam concrete

Specimen	f_{ck} MPa (28 days)	f_t MPa (28days)
cube	2.796	1.17
cylinder	2.624	1.13

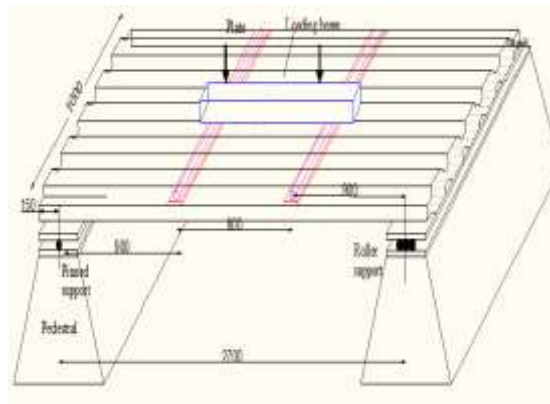
The facing of the SFCC panels, which also acts as a foam work is erected vertically on the floor as shown in figure 12.



Filling of panel Foam concrete filled panel
 Fig 12 SFCC panel casting

III EXPERIMENTAL PROGRAMME

Four-point bending tests have been conducted by using hydraulic actuator 500kN capacity under monotonic loading with



simply supported boundary conditions. The schematic diagram for the experimental setup is shown in fig 13.

Fig 13 Schematic diagram for the
 Experimental setup

The total span is 3000mm. Two loaders are used to distribute the load to the panel at one third span locations. The distance between loader to centre of support and in between two loaders is 900mm. The distributor box beam size 1400x300x125mm is placed above the loaders for uniform load transfer to the specimen. Cement mortar 1:3 is placed below the loading points and above the supports to fill the profile for the uniform distribution of load. The distributor plate of 1000mm length 10mm depth and 100mm wide is placed. The specimens are instrumented using 14 strain gauges at steel faces at either side of the sheet. Out of 14 numbers of strain gauges 7 are placed at top face and 5 are placed at bottom face of the sheet. And 2 are placed at the concrete. Three LVDT's are placed. For SFCC panel-1 one at middle, one at loading point and another at the middle end. SFCC panel-2, one at the middle and other two below the loading points to measure the vertical deflections. The three dial gauges are placed to measure the relative slip between sheet and core. The LVDT placed position are shown in fig14

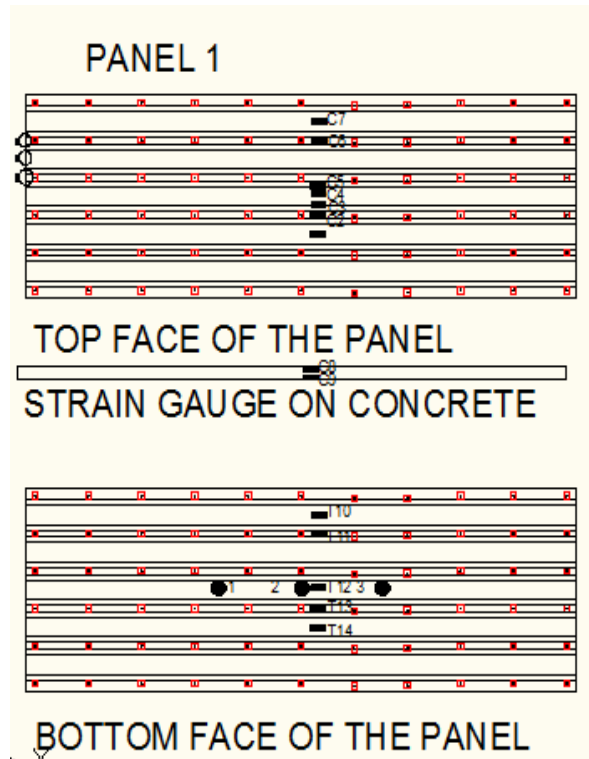


Fig 14 LVDT position in SFCC panel 1

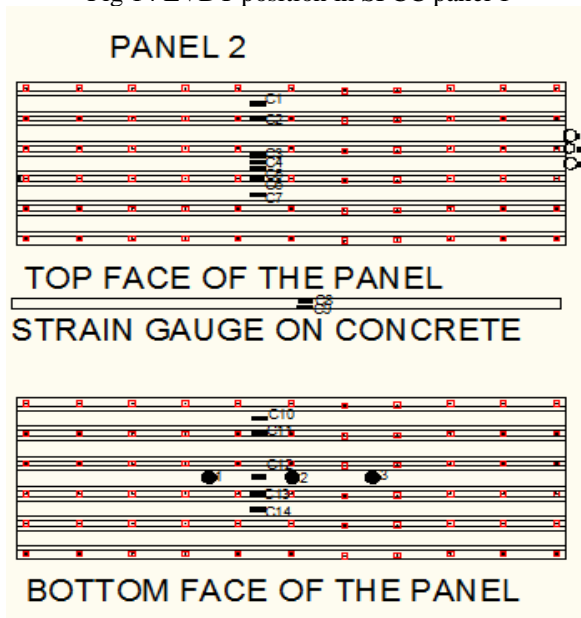


Fig 15 LVDT position SFCC panel 2



Fig 16 Strain gauge fixed at top face of the panel



Fig 17 Strain gauge fixed at bottom face of the panel



Fig 18 Dial Gauges position



Fig 19 LVDT position



Fig 20 Deflection of SFCC panel 1



Fig 21 Deflection of SFCC panel 2

Table 3 Experimental first crack, deflection, load capacity

Specimen ID	First crack load (kN)	Mid-span deflection (mm)	Load capacity at mid-span displacement(kN)
SFCC-1	19.84	89.62	23.24
SFCC-2	10.32	59.75	18.03

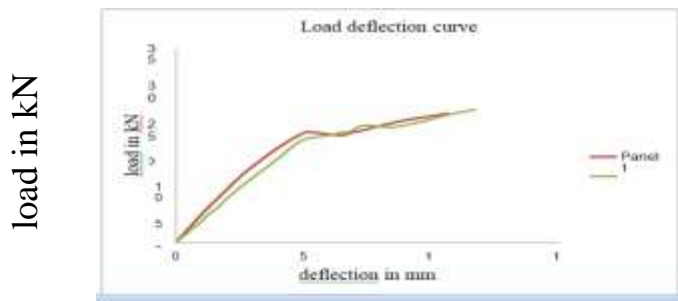


Fig 22 Load deflection response

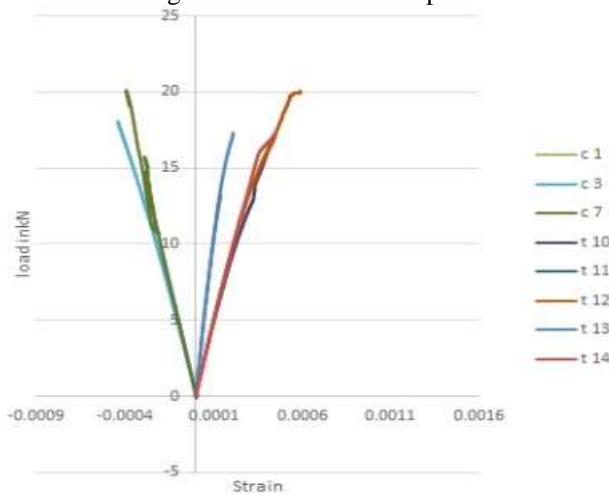


Fig 23 Load deflection response

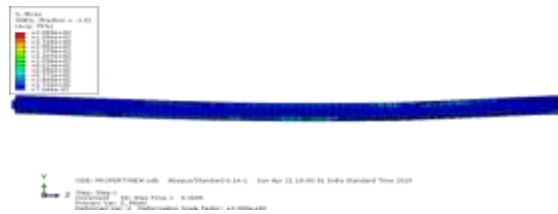
IV RESULT AND DISCUSSION

The behaviour of SFCC-Floor Panel is compared with respect to the load-deflection response and failure mode. The first crack load, load capacity and mid-span deflection obtained from the experiment are presented in table 3. The lateral load versus overall hydraulic actuator deflection responses of SFCC panel 1 and panel 2. Initial linear elastic regime is observed until the first slip for panel 1 of load 19.84 kN for panel 2 of load 10.32 kN occurred resulting in a slight decreases of load due to the release of mechanical bond between sheet and concrete core.

The first crack of the specimens for SFCC panel 1 and SFCC panel 2 are 19.84kN and 10.32kN respectively. The SFCC panel 1 and SFCC panel 2 carried the maximum load of 23.24kN and 18.03kN at the corresponding mid-span displacement of 89.62mm and 59.75 mm respectively. The above observed load is not the ultimate load due to the reasons that the experiment is terminated prior to failure due to the restrictions in stroke to the actuator. The span to deflection average ratio for SFCC panels is 1 in 35. The relative slip between sheet and concrete is found to be 15mm. Due to the flexural load, the top and bottom face of the sheet underwent compression and tension respectively as expected which is evident from the strain gauges readings.

A finite element (FE) model is developed to simulate the behaviour of SFCC panel under flexural loading. A Finite Element software Abaqus is used for modelling and analysis. FE model is validated using previous experimental data available.

For the simulation of the interface between the profiled sheets and concrete core in SFCC panel surface to surface contact is used. While providing interaction the steel sheet is considered as master and the surface of concrete core is the slave. Tangential contact behaviour is given as friction where friction coefficient is 0.52. Separation of the surfaces is allowed after contact. Tie constraints are provided at the place of providing studs in order to restrain the movement between steel sheet and FC core. The boundary condition provided is one end pinned and another end roller support. Meshing has been done in order to get accuracy results.



A floor panel of length 3000mm width 1000mm is analysed. 3D nonlinear Finite element analysis (FEA) is performed using ABAQUS software to simulate the behaviour of steel-foam concrete composite floor panel. The thickness of the steel sheet is 0.8mm. The friction co-efficient is given as 0.52. The specimen was subjected to bending only. SFCC panel consists of thin cold-formed profiled steel sheet of thickness 0.8 mm as the outer skins and aerated foam concrete (FC) of density 850 kg/m³ as the infill. The debonding and buckling behaviour of steel sheets near observed in FE model is similar to experimental investigations. The numerical model was able to predict the failure load. The load deflection curve and buckling behaviour shows close comparison. The sudden drop in load-displacement graph in experiment is due to the unexpected loading difficulties. The ultimate load carrying capacity of panel analysed in FEA closely matches with experiment.

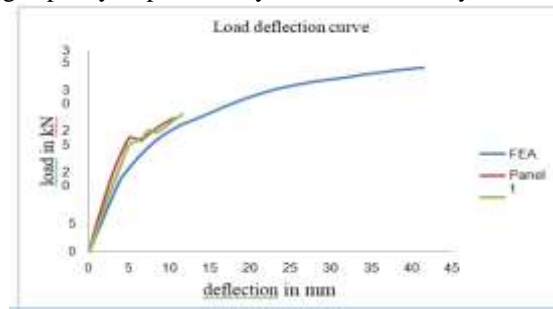


Fig 24 Comparison of Load-deflection response

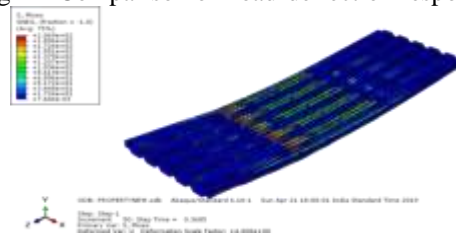


Fig 25 Failure of panel predicted by FEA

The FE model SFCC floor panels are developed by varying the number of studs to study their influence in the load-deflection behaviour and the failure load. The panel dimensions are kept constant and only the number of studs is varied as 18, 36 and 66 numbers.

The load capacity of the panel increased with the increase of number of studs. On comparing the load deflection curves, it shows that when the number of studs is decreased the deflection of panel is increased with decreasing load carrying capacity. The required studs must be provided in order to restrain the movement of sheet and core.

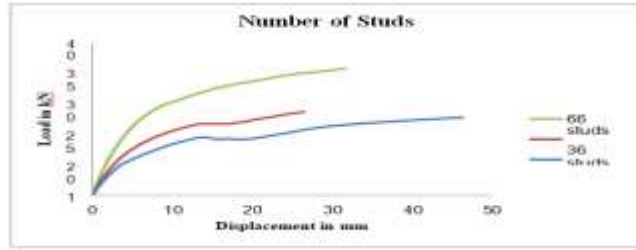


Fig 26 Load deflection graph for number of studs

The density of foam concrete is important parameter that affects the load carrying capacity of SFCC panel. The effect is studied by changing the density to 1250 kg/m³ and 450kg/m³. The results are compared with the original specimen having a density of 850 kg/m³. The change in behaviour of SFCC panel with different densities are plotted in figure 5.2. The ultimate load carrying capacity of panel with density 1250kg/m³ is 42.5kN. Where as for density 850kg/m³ the capacity is 33.15kN. From the graph it is well known that, by increasing the density of foam concrete the load carrying capacity of the panel will be increased.

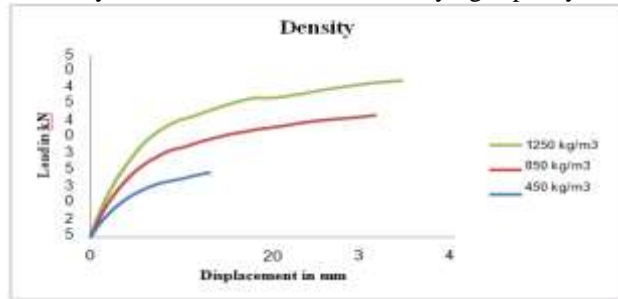


Fig 27 Load deflection graph for different densities

One of the main factors to be considered in flexure study of SFCC panel is the sheet profiles. Here the comparison is done between profiled sheet and plain sheet. The load carrying capacity is higher in the profiled panel than the plain panel. As the plain panel has less stiffness and can be bending easily. Thus it cannot carry higher load and plain panel will undergo large deflection at lesser load. The profiled sheet has greater stiffness and can withstand comparatively higher load and deflection in this panel is comparatively less.

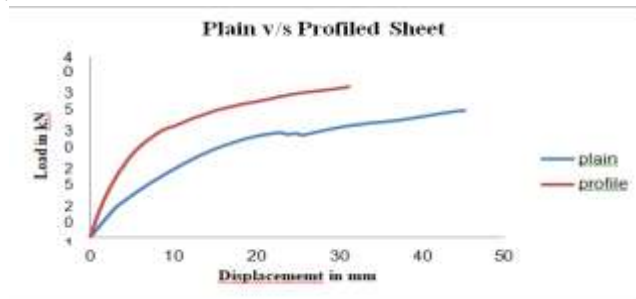


Fig 28 Load deflection graph for sheet profiles

The combined effect in the panel which includes panel subjected to compression with bending and bending alone. The load carrying capacity of the panel with combined effect is 30kN and the load carrying capacity of panel subjected to bending is 34kN.

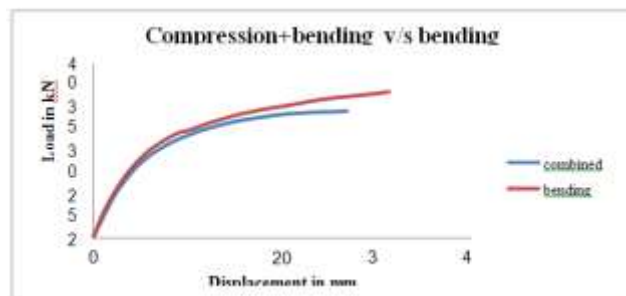


Fig 29 Load deflection graph for combined effect

The dimensions of SFCC panel are kept constant and using 66 number of shear studs, sheet thickness is varied. The thickness of the sheets chosen for the study is 0.8, 1.2 and 1.6 mm. The behaviour of SFCC panels with different sheet thickness is almost similar up to the proportionality limit and they are having same stiffness. Beyond this point stiffness is found to increase with increase in sheet thickness. At higher sheet thickness the degree of confinement on the foam core will be higher. This may be attributed to the increase in ultimate load carrying capacity.

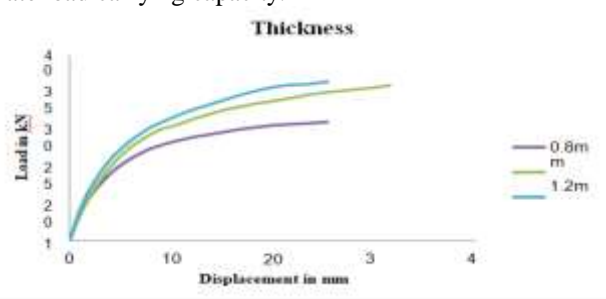


Fig 30 Load deflection graph for Thickness

The panel properties are kept same and the variation is done by changing size of panel. The size of panel taken for comparison is 3x1m and 3x3m. The load carrying capacity of panel 3x1m is about 25kN and for 3x3m is about 89kN. Here the load carrying capacity is thrice on comparing with small scale panel.

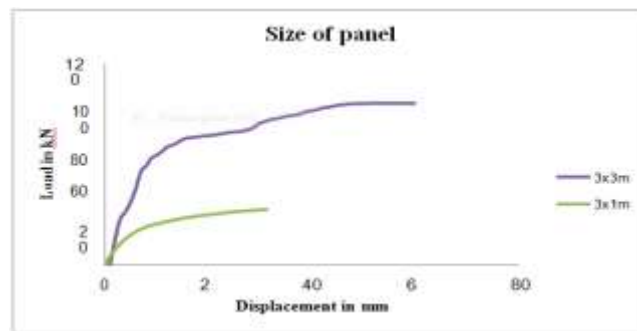


Fig 31 Load deflection graph for Size of panel

CONCLUSION

This chapter presents the details of the parametric study conducted in a full-scale SFCC floor panel of size (3000mmx1000mmx130mm) under four point bending. Numerical analysis is carried out by using ABAQUS software. Steel foam concrete composite floor panels showed the load deflection behaviour of each effect. From the result of parametric studies it is observed that the number of studs placing has influence on the load carrying capacity of the panel. By increasing the number of studs the panel capacity can be increased. The density of foam concrete has effect on the load carrying capacity of the panel. As the panel capacity is increased by increasing the density of foam concrete. Profiled sheets are better than plain sheets in terms of deflection and load capacity.

Numerical studies have been conducted by using ABAQUS, FEA software to simulate the behaviour of panels under flexural condition. The numerical model was able to predict the failure load. The load deflection curve and buckling behaviour shows close comparison. Parametric studies have been done with thickness variation, number of studs, density. Four point bending test have been conducted to study the flexural response of panels. In the parametric study, observed that the increasing in number of studs, increasing sheet thickness has influence on the load carrying capacity of the panel.

The increase in density has effect on load carrying capacity of panel. Experimental results include the failure modes, load capacity, load-deflection and load-strain curves. The two panels having the load carrying capacity ranging about 25 – 30kN. The failure mode is by the formation of tensile cracks in foam concrete and the sheet is still taking the load without any sudden drop in the capacity. The load- deflection behaviour of the panel shows gradual increase in the load carrying capacity. The sheet and concrete are connected with mild studs which enable the panel to carry more loads after the failure of foam concrete.

The FE model is capable of predicting the behaviour of SFCC panel under flexural loading. It is concluded that the SFCC panel has flexural capacity and can be used in low rise building.

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VI .BIOGRAPHIES



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