Investigation on Failure Modes of Precast Foamed Sandwich Panels under Punching

Praveen Anand, H Thiagu

Abstract*: This study focuses to develop the strength of foam concrete by trying different mixes of cement and fly ash. If strength obtained is not enough to convert the specimen into a structural element, cementitious materials like GGBS are imparted into the mix. The various mix ratio of fly ash and cement is investigated here. Analysis of precast foamed sandwich panel(PFSP) and RCC panels are done. And they tend to possess same cracking pattern. The ultimate load of PFSP is quite comparable to that of RCC panel. Also two panels, square and rectangular ones, and their cracking patterns and the load at which the panels fail and their stress patterns are observed. Shear connectors are provided so as to improve the shear resistance of the panels. This technique is highly desirable as sandwich panels are highly efficient. The effect on compressive strength at 7^{th} and 14^{th} days have been discussed. Thus PFSP can be used as a replacement for RCC slabs as they tend to possess less density and high thermal resistivity properties.

Index Terms*: Precast foamed sandwich panel(PFSP), cracking pattern, ultimate load, stress patterns, Shear connectors, Foamed concrete

I. INTRODUCTION

Concrete is one of the vast building materials widely used around the world. When stable voids are tend to be introduced in concrete, the density of the concrete automatically reduces to a greater extent[1], which paves way for the formation of foamed concrete. These voids are thus created by the means of foaming agent that makes way for the formation of foam concrete. Foam concrete is generally made of cementitious materials such as cement, flyash, GGBS, Silica fume and at times sand can also be used thus completely eliminating the use of coarse aggregates. This versatile concrete having densities varying from 400 kg/m^3 to 1900 kg/m^3 is very much lower as compared to conventional concrete [2]. Foam concrete is said to have lightweight and highly resistant to heat, fire and seismic [3]. Replacing large amount of cement with fly ash does not significantly affect the compressive strength of foam concrete [4].

Hence compressive strength plays a vital role in converting a material into structural one. Cement, fly ash and the latter foam added cannot convert a material into structural one. Hence cementitious material such as GGBS can be imparted into the mix to convert this one as an structural material.

Compressive Strength in MPa	Density in kg/m^3	Application
<15	<1600	Non structural material
>15	1600 to 2000	Structural material

Table 1 Varying density and its application

Precast Concrete Sandwich Panels (PCSP) consists of concrete layers, Insulation layer and Shear connector(SC). However most commonly used insulation layers are Expanded Polystyrene (EPS) and Extruded Polystyrene (XPS). Variety of application comes under sandwich panel. These concrete layers are connected by the means of Shear connector. These panels can be classified into three types i.e., fully composite panels, partially composite panel and non-composite panels [5]. The strength of the panels mainly depends on the material and capacity of the shear connector, Shear connectors also impact the degree of composite action [6]. These panels tends to reduce the density by 10 to 15 percent as compared to the conventional concrete and hence these are less prone to seismic forces [7].

Puput Risdanareni et al [8] attained the compressive strength of 25.2 MPa at the density of 1822 kg/m^3. These experiment indicate that the strength to weight ratio of foam concrete tends to be higher than the normal concrete and hence it can be used as structural material. Junsuk Kang [9] investigated that there were great difference between composite and non composite panels, the main effect was due to the arrangement of shear connector and the resistance provided by those shear connector. Mugahed Amran et al [10] studied that the increase in aspect ratio significantly reduces the flexural strength and the cracking pattern was along one direction only as in RCC panels, these panels can also be used as an alternative for RCC panels. Qian Huang et al [11] developed a finite element model of a sandwich panel having diagonal FRP bar connectors and their structural behaviour is investigated, their cracking, material and geometric non linearities are observed. Hamid Kazam et al [12] evaluated the shear strength by exposing it to the effect of sustained loading and EPS panels are affected by age more than XPS panels. Sani Mohammed Bida [13] showed that the thermal performance increased by using staggered shear connectors and also increasing the gap shows subsequent increase in thermal performance. Yun Hyun-Do et al [14] investigated the shear strength of sandwich panel with Glass fibre Reinforced Polymer(GFRP) as shear connector by pullout test and showed that the XPS panels tends to perform better than the EPS panels.

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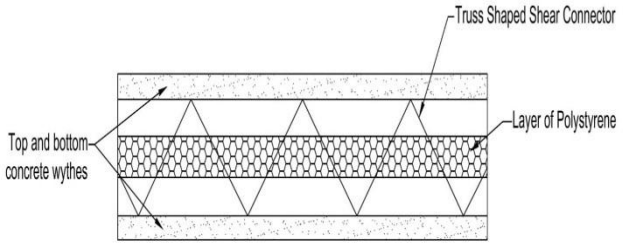


Figure 1- A typical sandwich panel along with shear connector

II.RESEARCH SIGNIFICANCE

Investigation are done on square and rectangular PCSP under punching load condition. And these PCSP are compared with RCC slabs. This study investigates on the cracking pattern of both RCC and PCSP. Since deflection will be maximum at the bottom portion of the slab, the deflection at the mid portion in the bottom side of the panel is obtained. The panel is also studied using Finite Element Analysis (FEA) and the key output parameters such as load-deflection, load-stress and stress-strain are obtained. Truss shaped shear connector are used as its being effective rather than other. Validating analytical and experimental test results can be useful in helping the guidelines of Precast Foam Concrete Sandwich Panel is the importance of this study.

III.PANEL DESCRIPTION AND MATERIAL

Two types namely square and rectangular panels are casted and tested in this present study. The dimension of the square panel is 600*600*100mm (length*breadth*thickness) and the dimension of the rectangular panel is 840*540*100mm (length*breadth*thickness) respectively. Schematic diagram of the sandwich panel is shown in fig 3.

Figure 2-Shear connector welded with mesh

Mesh is kept at the top and bottom wyth of the concrete at a distance of 60mm and this 60mm depth is well connected by the means of shear connector. Welded Galvanised Iron(GI) Mesh 30mm by 30mm opening is used and 6mm steel rods are used as shear connector. These Shear connector are welded at the top and bottom mesh . And a layer of Expanded Polystyrene(EPS) is kept at inbetween the mesh while casting of concrete. Shear connector are kept at an angle of 45 degrees. Spacing of the shear connectors are 150 mm and 3 nos of shear connectors are used. here. The mix proportion is 1:1:0.75 (Cement:Flyash:GGBS). Protein based foaming agent of 80 L/m^3 density is used here. Average cube compressive strength is 15.3 N/mm^2 and the tensile strength is 1.64 N/mm^2. The compressive strength is found out using 100 mm cubes while tensile strength is found out using diameter 100mm and height 200mm.

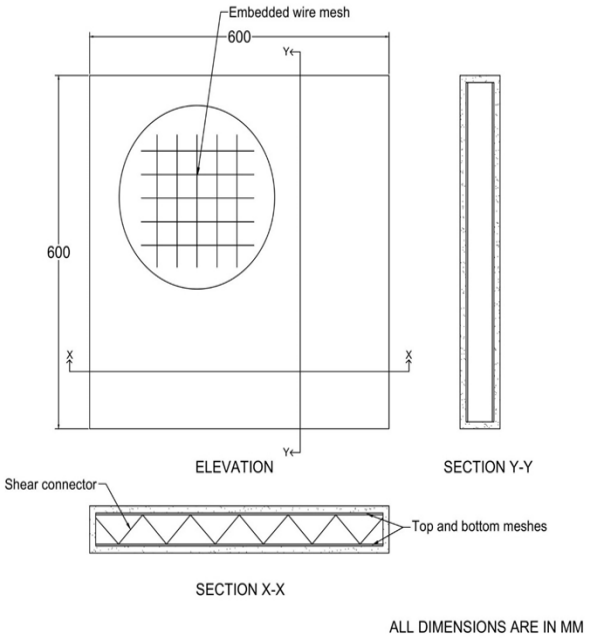


Figure 3- Sketch of sandwich panel

IV.CASTING OF PANELS

Firstly, the shear connectors are welded along the top and bottom meshes. And the layer of polystyrene is kept at the centre by providing adequate cover at the top and the bottom of the meshes and then foam concrete is poured inside and then the panel is vibrated at regular intervals. Finally after adequate compaction, finishing of concrete is done. Whereas in RCC, 6 mm HYSD steed bars are used as reinforcement and grade of concrete were said to be M25. Cover of 20 mm is given at the top and bottom for placing the mesh in place and for RCC 20mm cover is given for reinforcement details.

(i)

(ii)

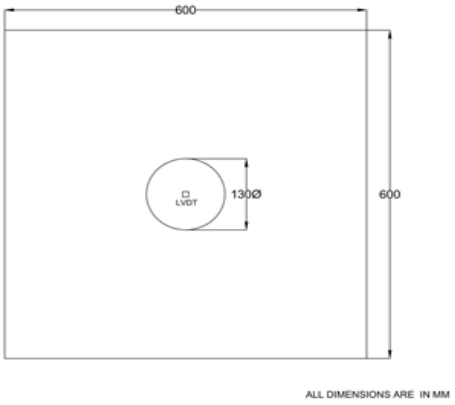
(iii)

(iv)

Figure 4- Casting sequence of PFSP

V.TEST SETUP AND INSTRUMENTATION

The panel is being tested under static loading. Maximum of 100 kN load can be applied by means of hydraulic jack. Transverse deflection are measured using dial gauge whose maximum deflection is 50mm. A support is made using steel cage and the panels are kept in, making the panel fixed. And cubes are kept at the four edges of the panel at the bottom. The panels are painted in white for better visibility of cracks. Initial crack was along the bottom of the panel



(i)

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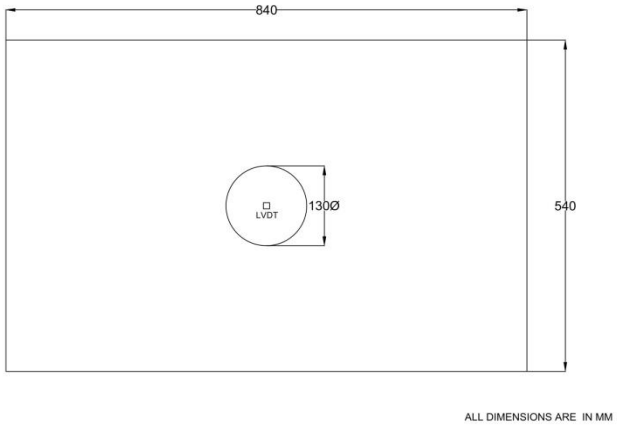

(iii)

Figure 5- Test setup and details of both square and rectangular panels

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VI. EXPERIMENTAL RESULTS AND DISCUSSIONS

Initial crack load, Cracking pattern and deflection are calculated using principles. However the initial crack tends to occur at the bottom wythe of the panel. There were many minor cracks observed in the panel at the sides and major cracks were at the bottom of the panel. Load deflection curves were obtained using this experiment. An load of 2 kN is applied by the means of hydraulic jack in every intervals.

Results and discussion of punching load test is presented here. At 12 kN initial crack were observed in the RCC slab, in other hand at 10 kN initial crack was observed in foamed sandwich panel. However, both the slab tends to fail at the ultimate load of 36 kN. At the ultimate load there tends to appear immense flexural cracks at the bottom part in both the panels. And some minor fissure cracks were appeared at the sides of the panel. Both micro and major cracks tend to appear in the panel as a whole.

When reinforcement in the flexural side is increased, ultimate load is also increased, but displacement at the final stage is decreased also reducing the ductility properties [15]. Also there is no impact on the punching shear strength on removing the tensile strength of concrete in the cross sectional directions [16].

While the initial load is applied, deflection is said to be around 0.56 mm in RCC square panel, Whereas in PFSP (Square) the deflection was only 0.27 mm. Also at the ultimate load of 36 kN, the deflection in the RCC slab(Square) was 5.41mm and in the PFSP 5.2 mm, Also the cracking pattern of both these slabs are quite similar, the yields line are along the same direction. Coming to the case of rectangular panels, the ultimate load of RCC and PFSP is said to be 30 kN and 26 kN respectively, whereas the initial cracking load was 8 kN and 6 kN respectively. And flexural cracks were observed at the bottom side of both the panels, and fissure like cracks were observed at the sides of both the panels.

Also the shear connector gives shear resistance and load bearing capacity to the panel. And only if the shear connector acts in an semi composite or composite manner, the panel tends to bear quite equivalent load to that of RCC. Hence the composite action of the panel decides whether it makes this panel equivalent to RCC.

Table 2 Summary of results

Type of panel	Initial cracking load (kN)	Ultimate load (kN)	Remarks
Square RCC panel	12	36	
Square foamed sandwich panel	10	36	
Rectangular RCC panel	8	30	
Rectangular foamed sandwich panel	6	26	

(ii)

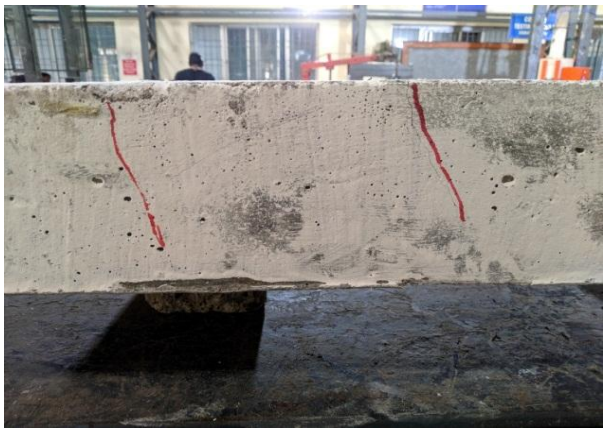
(i)

(iii)

Figure 6-Testing of square panels

(i)

(ii)



(iii)

Figure 7- Testing of Rectangular panels

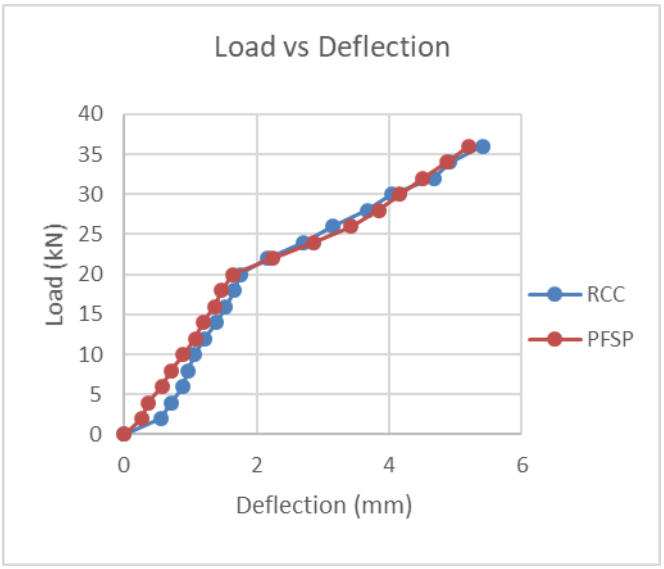


Figure 8- Load vs Deflection curve of Square panels (Experimental)

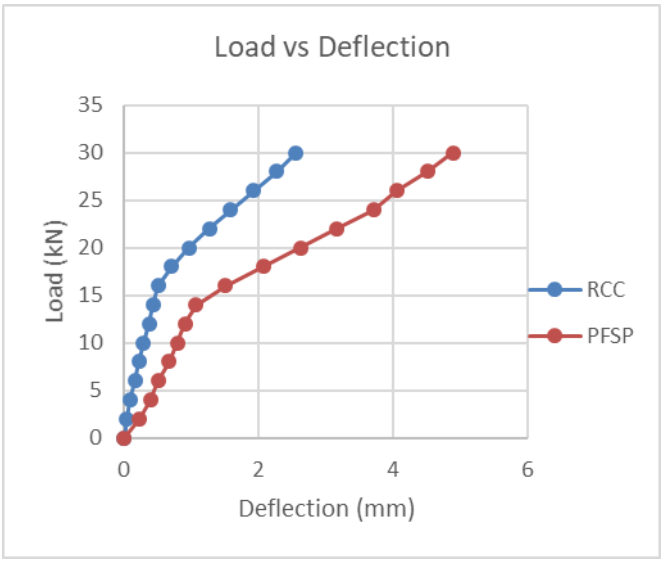


Figure 9-Load vs Deflection curve of Rectangular panels (Experimental)

VII. ANALYTICAL STUDY

Finite element analysis is done by using Abaqus v6.14 Quasi static is the type of analysis being used here and it is the most appropriate one for shear punching of the panels. The panel is given fixed support (U1=U2=U3=UR1=UR2=UR3=0).Uniform meshing of 20mm is done along all the sides of the panel. After the properties, being feeded load of 50 kN is applied at the top of the panel. Bending is assumed to be resisted by the means of wythes whereas shear is resisted by the means of Shear connector [7]. An uniform load of 50 kN is applied to the slab and the deflection is obtained in all the panel.

Figure 10- Schematic view of RCC panel

Figure 11- Schematic view of Foamed sandwich panel

For the two surfaces of the slab, the maximum principle tensile stresses is shown and these tensile stresses are used to show to cracking pattern [17]. After the application of the load yielding of concrete starts at the edges and the bottom. At the load of 50 kN the panels tends to crack greatly at the bottom, at the point of loading and at the four corners of the panel, both the foam sandwich panel and RCC tends to fail in the same manner, hence they tend to have the same cracking pattern. Cracking pattern is obtained using Maximum principle stress.

Table 3 Properties of Concrete

Type of Concrete	Density (kg/m^3)	Young's Modulus (MPa)
RCC	2400	25000
Foam Concrete	1600	18126

Table 4 Properties of Steel and Mesh

Material	Density (kg/m^3)	Yield Stress (MPa)
GI Mesh	8050	500
Steel	7850	415

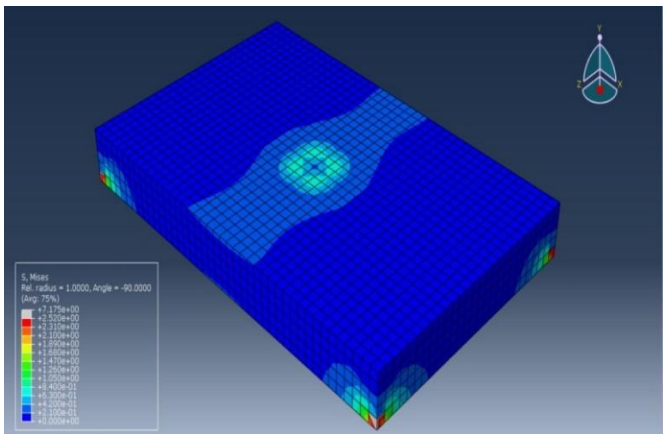


Figure 12-Initial crack of the panel

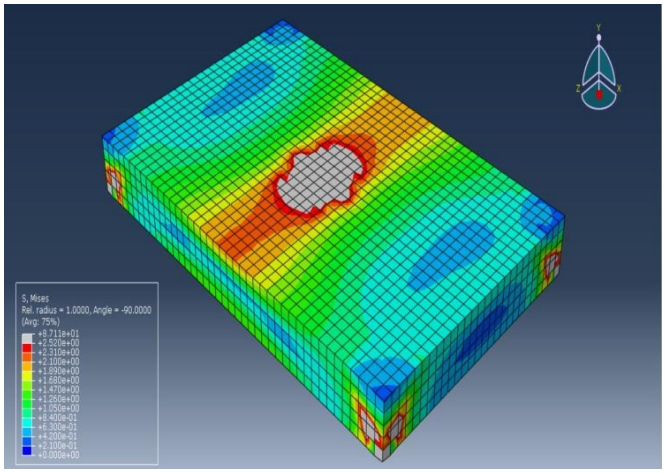


Figure 13- Final crack of the panel

The load vs deflection and load vs strain curves are as follows:

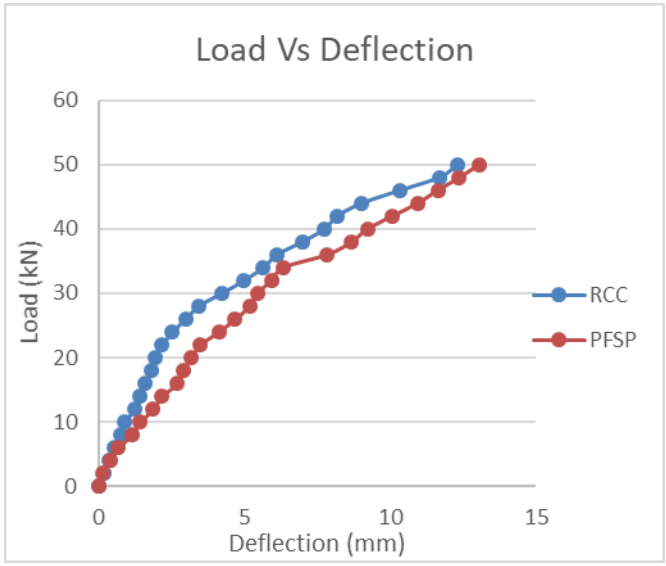


Figure 14- Load vs deflection curve of Square panel (Analytical)

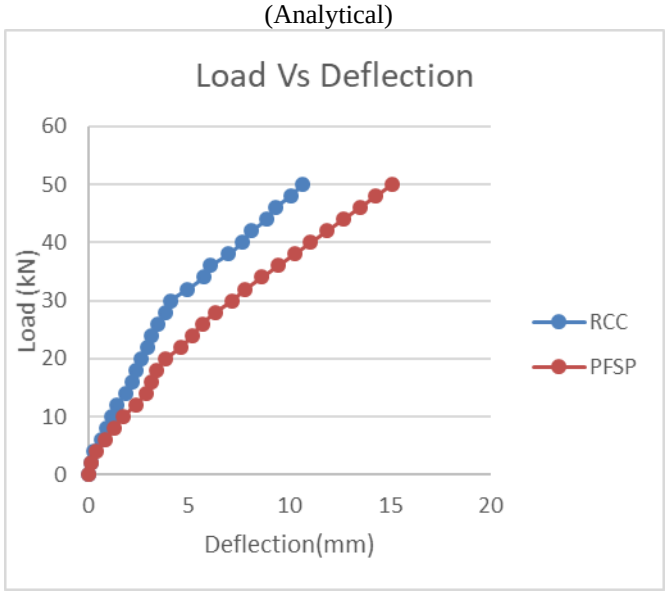


Figure 15- Load vs deflection curve of Rectangular panel (Analytical)

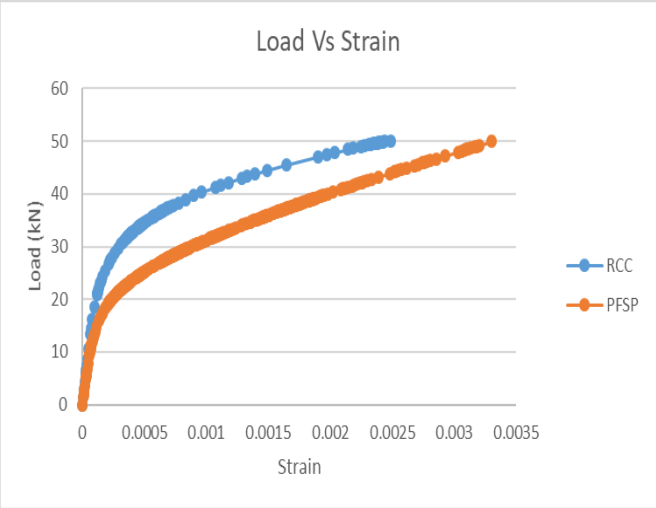


Figure 16- Load vs Strain of Square panels

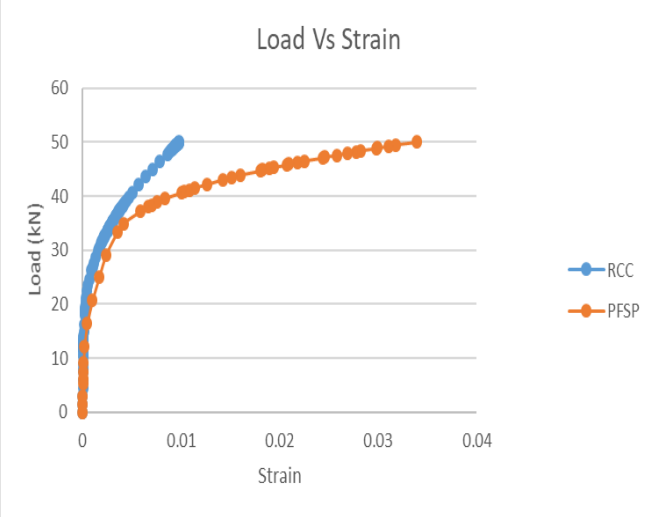


Figure 17- Load vs Strain of Rectangular panels

RCC square panel tends to fail at 37.68 kN whereas its final deflection at the load of 50 kN is said to be 12.6 mm , On other hand PFSP (Square) fails at ultimate load of 31.67 kN whereas its final deflection comes around as 13.1 mm at the end load. Similarly RCC rectangular panel tends to fail at 34.19 kN and its deflection at end load is around 10.1 mm, Similarly in PFSP (Rectangular) fails at an ultimate load of 24.31 kN and its end deflection is said to be 15.37 mm. The use of shear connector clearly provides adequate strength which makes it an equivalent thing for RCC panel. And the strain in the rectangular PFSP tends to be more than in RCC panels whereas in the case of square PCSP its strain values are quite negligible compared to RCC. The maximum strain in PCSP rectangular is around 0.035.

VII. CONCLUSION

Results of both the analytical and experimental studies are discussed below. The flexural behaviour of PFSP is similar to that of RCC panel. Even though the initial cracks tends to occur at lower phases for PFSP, the ultimate load of both square and rectangular panels are equivalent to that of RCC panel. After the initial crack, it takes more time for the PFSP, and at the final stage, the panel gets enormously cracked at the bottom and at some point on the edges. This experiment indicates that different loading conditions like punching can cause significant damage to the panel. The square PFSP panel tends to perform well than the Rectangular PFSP, due to its closely spaced shear connector, and its adequacy to carry the whole structure and when the space of shear connector is reduced in rectangular PFSP it can significantly bear equivalent load. Foamed Sandwich Panel tends to serve as an alternate source of panels for RCC, as they are highly efficient, low in density and having good thermal insulation properties. Finally, more experiments and different types of loading must be done on PFSP for developing guidelines for practical use.

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