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Performance of expanded polystyrene light weight self compacting concrete in composite slab

Revathy Jayaseelan*, Gajalakshmi Pandulu, Srinivasan Mahendran

Department of Civil Engineering, B. S. Abdur Rahman Crescent Institute of Science & Technology, India

ABSTRACT

Composite constructions have gained importance due to faster and economical construction. Composite sections are generally made with cold formed corrugated profile sheet, which also act as a permanent formwork. To promote the use of composite sections in construction industry, it is necessitate to target to minimize the self-weight. It also facilitates to save the construction cost. In composite slabs, shear connectors are provided for composite action. It would be difficult to pour the conventional concrete; hence self compacting concrete would be ideally suited for such places. To reach the above objective, an effort has been made to investigate the expanded polystyrene light weight self compacting concrete in composite slab. To achieve the light weight concrete, expanded polystyrene beads were added in different proportions to the coarse aggregate. The composite slab was performed for four-point bending test under flexure and push out test. The test result concluded that the light weight expanded polystyrene self compacting concrete composite slab exhibit a higher performance with reduction in the thickness of the slab. The minimum spacing of shear connector was well performed. It could able to control the shear crack and de-bonding effect between the profiled steel sheet and concrete.

Keywords: Composite slab, Light weight, Profiled steel sheet, SCC, Shear connectors.

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Corresponding Author:
Revathy Jayaseelan
revathyj@crescent.education

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1. INTRODUCTION

Composite section such as composite slab, composite beam and composite column has gaining importance all over the world. In modern construction concept especially in multi-storey buildings, composite constructions are predominantly preferred unlike the conventional reinforced concrete construction. Composite sections are generally made with cold formed corrugated profile sheet, which also act as a permanent formwork. To improve the composite action between the profile sheet and concrete, shear connectors are used. A significant number of research works were done in the area of composite construction. Structural behaviour of composite beams (Nie et al., 2008) was studied under four-point bending test. The study indicated that partial shear connectors provide better performance in the maximum bending moment regions of the continuous composite beam. An experimental study on composite slabs (Abbas et al., 2015; Baskar and Jeyasehar, 2012; Chen et al., 2011) were performed by many investigators. The test results of the study revealed that the composite slab has high ductility and could able resist the shear capacity. An experimental and analytical investigation was also demonstrated on the shear studs through push-out test (Bouchair et al., 2012; Spremic et al., 2013; Prakash et al., 2012). Through the advancement of construction materials, performance of composite constructions were prepared with fibre reinforced concrete (Gholamhoseini et al., 2017; Revathy and Kumar, 2017), self compacting concrete (SCC) (Lawan et al., 2016). To promote the use of composite sections in construction industry, it is necessitate to target to minimize the self-weight. It also facilitates to save the construction cost. In composite slabs, shear connectors are provided for composite action.

It would be difficult to pour the conventional concrete; hence self compacting concrete would be ideally suited for such places. To reach the above objective, an effort has been made to investigate the expanded polystyrene light weight self compacting concrete (EPLW SCC) in composite slab. This study investigates on the expanded polystyrene light weight self compacting concrete (EPLW SCC) in composite slab under four-point bending test under flexure and push out test.

2. MATERIALS AND METHODS

The experimental investigations consist of two parts. The first part is to study the performance of composite slab under the action of four-point bending test. The second part is to study the behaviour of composite slab under push-out test and it is described in the subsequent sections.

2.1 Description of Composite Slab for Flexure Test

The composite slab of length 1200 mm and width 680 mm was used for the flexure test. The slab has two different thicknesses of 120 mm and 150 mm. The design and selection of shear connector was carried out in accordance with American Institute of Steel Construction (AISC) & Steel Construction Manual (SCM). The diameter and thickness of the head of shear connectors was designed respectively as 32 mm and 8 mm. The diameter and height of the shaft of shear connector was kept as 16 mm and 97 mm respectively. Fig. 1 presents the schematic sketch of composite slab with 250 mm spacing of shear connector. Fig. 2 depicts the cross-sectional view of composite slab. Table 1 shows the details of composite slab under flexure test.

The labelling of the specimen in this article were depends on the type of test (flexure), concrete type (SCC & EPLW SCC), slab thickness (150 mm or 120 mm) and spacing of shear connectors (200 mm and 250 mm). For instance, FST2SS2 represents the specimen was tested under flexure for conventional self compacting concrete composite slab. T2 denotes the thickness of slab of 120 mm and SS2 refers the spacing of shear connectors of 250 mm.

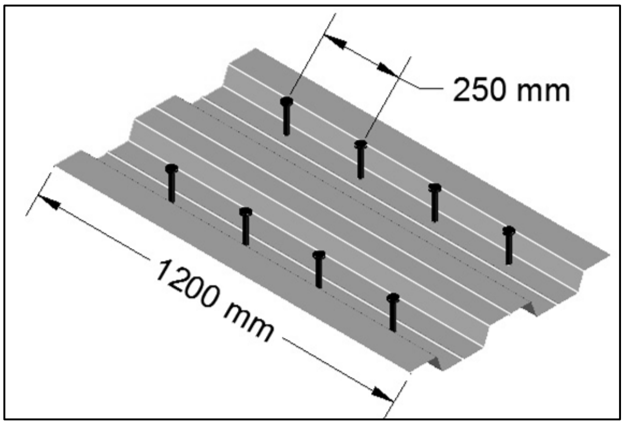


Fig. 1. Schematic sketch for 250 mm spacing of shear connector

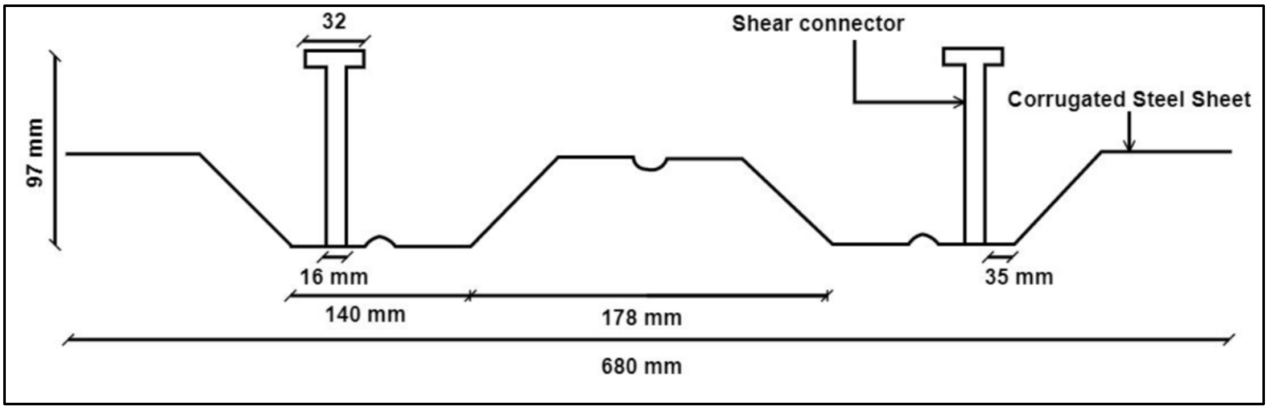


Fig. 2. Cross-sectional view of composite slab

Table 1. Details of composite slab under flexure test

Slab designation	Type of concrete	Thickness of slab (mm)	Spacing of shear connectors (mm)
FST1SS1	SCC	150	200
FST1SS2			250
FST2SS1		120	200
FST2SS2			250
FET1SS1	EPLW SCC	150	200
FET1SS2			250
FET2SS1		120	200
FET2SS2			250

2.2 Details of Composite Slab for Push Out Test

The specimen of size 550 mm width and 300 mm length with variation in the depth of the slab as 150 mm and 120 mm was used. In this work, ISMB 200 @ 254 N/m with an area of 32.30 mm^2 was selected. The depth and width of the beam was 200 mm and 100 mm respectively. The thickness of flange and web of ISMB 200 was 10.8 mm and 5.7 mm. The edge distance between the centre of the shear connector and edge of the beam flange was kept as 32 mm. Fig. 3 shows the schematic sketch for push out test specimen. Table 2 presents the details of specimen for push-out test. The slab designation in Table 2, refers to the type of test (push-out test), type of concrete (SCC and EPLW SCC) and thickness of slab (150 mm and 120 mm). For example, PET2 indicates the push-out test conducted for an expanded polystyrene light weight self compacting concrete for a thickness of 120 mm.

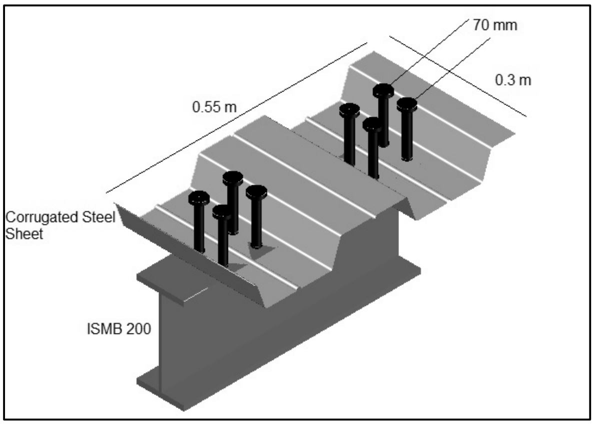


Fig. 3. Schematic sketch for push out test specimen

Table 2. Details of specimens for push-out test

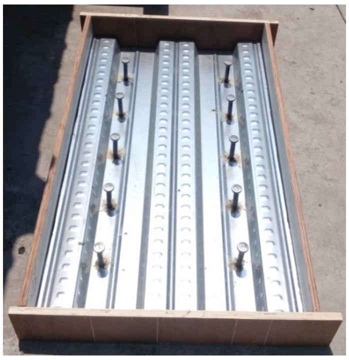
Slab designation	Type of concrete	Thickness of slab (mm)
PST1	SCC	150
PST2		120
PET1	EPLW SCC	150
PET2		120

2.3 Fabrication of Composite Slab

Open trough corrugated trapezoidal steel sheet with oval shaped embossment was used for mechanical interlocking of steel-concrete. The decking sheet was certified in accordance with BS 5950(4)-1994 (Structural use of steelwork in building-design of composite slab with profile sheeting). The thickness, tensile strength and yield strength of the galvanized cold rolled corrugated steel sheet were 1 mm, 350 MPa and 240 MPa respectively. The height and width of embossment were 45 mm and 25 mm respectively. The distance between the two embossments was provided as 60 mm. Based on the design carried out, shear connectors were welded to beam flange along with profiled sheet. Gun welding was employed in fabrication work. Welding work was carried out in accordance with ASW (American Society of Welding). Fig. 4(a) and Fig. 4(b) respectively shows the fabricated specimen for the flexure test with a spacing of shear connectors of 200 mm and 250 mm. Fig. 5 and Fig. 6 shows the gun welding in progress and fabricated specimen for push-out test.

2.4 Preparation of SCC

Ordinary Portland Cement of 53 grade was used. Class F fly ash, obtained from Ennore power plant, India with a specific gravity of 2.56 was used in the investigation. River sand was utilized as fine aggregate, which conforms to Zone II. Coarse aggregate of size less than 10 mm was preferred in this work for better performance due to the flow properties as well as in terms of light weight aspect. Master Glenium SKY 8233, a high range water reducing admixture with a specific gravity of 1.08 was used as chemical admixture. From the marsh cone test, 0.8% of chemical admixture was added to the weight of binder. A spherical shape expanded polystyrene beads of diameter ranging 3 mm - 7 mm with a specific gravity of 0.011 was used in the work. Table 3 presents the test results of various materials used for SCC. The results of the fresh properties of SCC are presented in Table 4. The composition of conventional SCC mixture without the inclusion of expanded polystyrene beads is presented in Table 5.



(a)

(b)

Fig. 4. Fabricated specimen for flexure test (a) spacing of shear connectors of 200 mm (b) spacing of shear connectors of 250 mm

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Fig. 5. Gun welding in progress

Fig. 6. Push-out test specimen

Table 3. Properties of materials for SCC

Properties	Standards	Result
Fineness of cement	IS 4031-1988 (Part-1)	6%
Standard consistency	IS 4031-1988 (Part-4)	28%
Specific gravity of cement	IS 4031-1988 (Part-11)	3.11
Initial setting time	IS 4031-1988 (Part-5)	162 mins
Final Setting time	IS 4031-1988 (Part-5)	230 mins
Specific gravity of fine aggregate	IS 2386 (3)-1963 (Part-3)	2.59
Fineness modulus		2.43
% water absorption		2.00
Compacted Bulk Density		1610 kg/m^3
Loose Bulk Density		1410 kg/m^3
Grading zone	IS 383-1970	Zone II
Specific gravity of coarse aggregate	IS 2386 (3)-1963 (Part-3)	2.62
% water absorption		1.02
Compacted Bulk Density		1544 kg/m^3
Loose Bulk Density		1483 kg/m^3

Table 4. Fresh properties of SCC

Fresh Properties	Standards	SCC	EPLW SCC
Spread flow test	EN 12350 (8)-2010	650 mm	620 mm
T_{500} Slump test		4 seconds	5 seconds
V-funnel test	EN 12350 (9)-2010	10 seconds	12 seconds
L-Box test	EN 12350 (10)-2010	0.92	0.83

Table 5. Composition of conventional SCC mixture

Materials	Weight (kg/m^3)
Cement	357
Fly ash	152
Water	200
Fine aggregate	834
Coarse aggregate	772
Superplasticizer	0.8 %
w/c ratio	0.37

To achieve the light weight SCC, expanded polystyrene beads were added in different proportions to the coarse aggregate. Based on the preliminary investigation, the proportions of expanded polystyrene beads were chosen. The proportions of expanded polystyrene beads to coarse aggregate were 0 – 100 %, 40 – 60 %, 50 – 50 %, 60 – 40 % and 70 – 30%. Lightweight aspect was checked from density test and classified the type of concrete based on the density range provided. From the test performed (average of three cube specimens), the density and compressive strength of concrete specimens is shown in Table 6. It was observed that 70 – 30% had a density of 1783 kg/m^3. Based on the achieved flowability properties and desired strength, the composite slabs were cast for flexure test and push out test. The composite slabs were tested at the age of 28 days.

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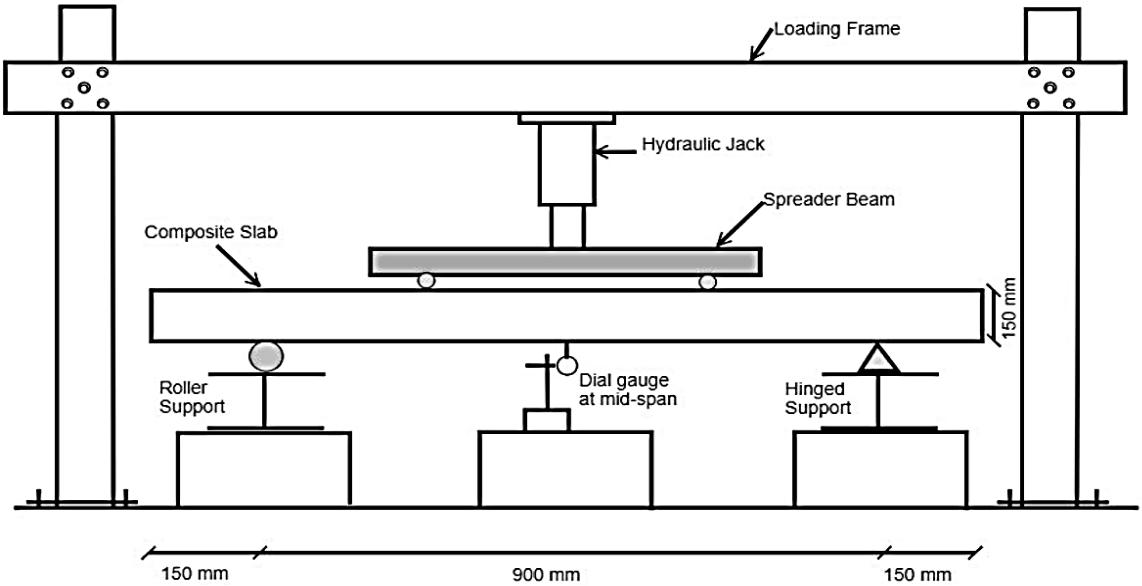
Table 6. Density and compressive strength of concrete specimens

Expanded polystyrene beads (%)	Coarse aggregate (%)	Density (kg/m^3)	Compressive strength at 28 days (MPa)
0	100	2545	36.18
40	60	2237	18.31
50	50	2015	15.69
60	40	1905	14.20
70	30	1783	13.08



(a) Schematic sketch of a flexure load test of acomposite slab

(b) Photo of a flexure load test of a composite slab

Fig. 7. Four-point load test under flexure for composite slab

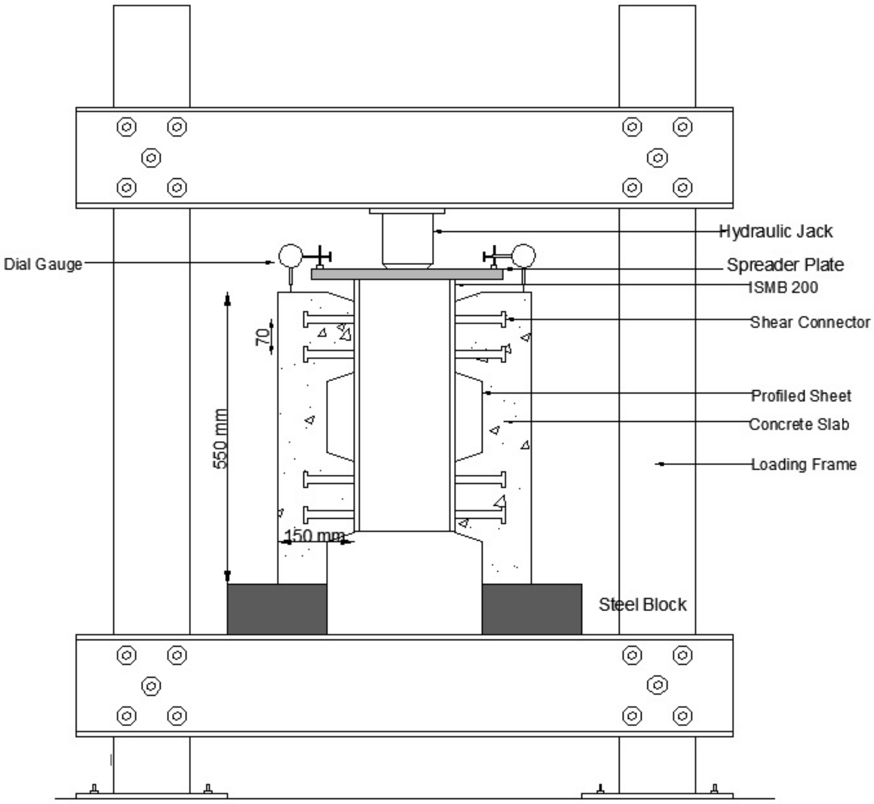
2.5 Testing of Composite Slab Under Flexure

Four-point loading test under flexure was conducted for both conventional SCC and EPLW SCC. End support distance of 150 mm was left on both sides of slab. Roller and hinged supports were provided respectively for left and right end supports. Mid-span deflection was measured using dial gauge. Load was applied at one-third of its span with a rate of 16 kN/min. Ultimate load, deflection and crack pattern were observed. Fig. 7 shows the schematic sketch and experimental setup for composite slab under flexure test.

2.6 Push-Out Test on Composite Slab

Static push-out test of steel-concrete specimens using high strength shear (HSS) connectors was conducted to study the shear resistance of the composite slab and end-slip. Push out test was conducted for both conventional SCC and

EPLW SCC concrete. Load was applied monotonically over steel beam at a rate of 16kN/min. The load gets transferred from beam flanges to composite slab (via., shear connectors) whereas the reaction forces from concrete opposes the load from shear connector in opposite direction thereby causing shear movement. The ultimate shear resistance of shear connector to transfer this shear load was conducted experimentally. The concrete opposing the load from shear connector's results in slippage and de-bonding are measured. End slips are measured using dial gauges placed at the top of concrete slabs. Ultimate load, slip and crack pattern were observed. Fig. 8 shows the push out test of the composite slab.



(a) Schematic view of a push-out test of composite slab

(b) Photo of a push-out test of composite slab in progress

Fig. 8. Push-out test of composite slab

3. RESULTS AND DISCUSSION

Table 7 furnished the results of all the composite slabs tested under four-point bending test.

Table 7. Results of all the composite slabs tested under four-point bending test

Slab designation	First crack load (kN)	Ultimate load (kN)	Deflection at mid-span (mm)
FST1SS1	42.46	77.76	18.37
FST1SS2	40.42	64.79	14.8
FST2SS1	41.68	56.7	18.08
FST2SS2	38.9	52.64	23.6
FET1SS1	32	45	14.04
FET1SS2	31.5	40.50	8.86
FET2SS1	31.5	40.49	10.13
FET2SS2	27.9	36.49	22.36

3.1 Load-Deflection Curve on Composite Slab under Flexure Test

Load-deflection curves was plotted to study the behaviour of conventional SCC and EPLW SCC composite slab. Fig. 9 to Fig. 12 depicts the load-deflection at mid-span. In general, the conventional SCC composite slabs experienced more deflection compared to EPLW SCC composite slab. Typically, the failure mode depends on the ratio of shear span to effective depth of slab. In this study, shear span of 300 mm is kept as constant throughout the test and the thickness of slab was varied as 150 mm and 120 mm. The flexural failure occurs at a higher ratio of shear span to effective depth while at the lower value; it indicates the vertical shear failure. In this work, the specimens exhibited a ductile mode of failure. In all the composite slabs, variation in slope was noticed with the initiation of cracks. All the tested composite slabs indicated the similar fashion in the linear elastic phase. With the initiation and development of cracking, it was affirmed there was a loss in the linear elastic phase. On reaching the maximum load, the deflection of all the composite slabs was increased with a reduction in load carrying capacity. It was observed that the composite action was enhanced due to presence of shear connectors, which acts as anchor that transfer the forces from concrete to profiled steel deck sheet. The EPLW SCC specimens had demonstrated less slippage between concrete and profiled steel sheet when compared to the conventional SCC slabs. Almost in all the lightweight composite slabs, the initial load was developed at 32 kN with a deflection of 1.73 mm. The failure load generally increased with the decrease of spacing of shear connector for all composite slabs.

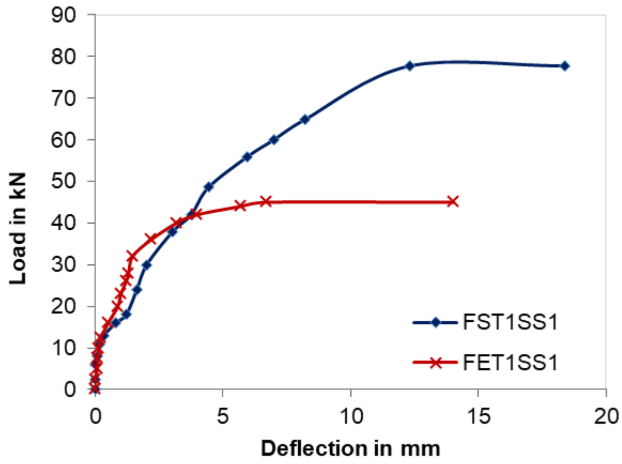


Fig. 9. Load-deflection curve for slabs FST1SS1 and FET1SS1

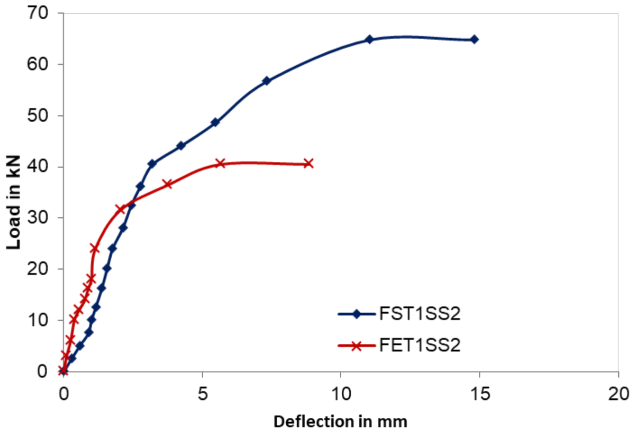


Fig. 10. Load-deflection curve for slabs FST1SS2 and FET1SS2

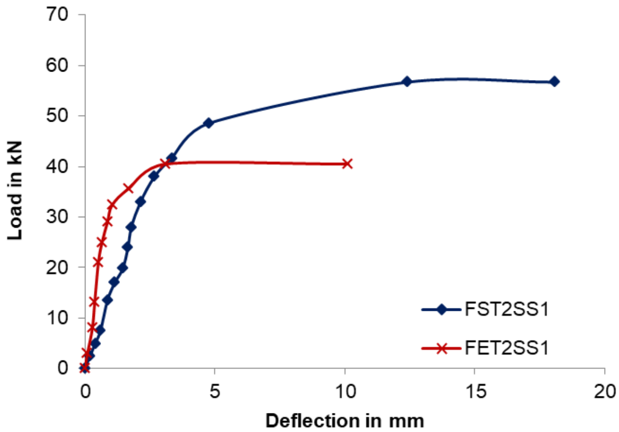


Fig. 11. Load-deflection curve for slabs FST2SS1 and FET2SS1

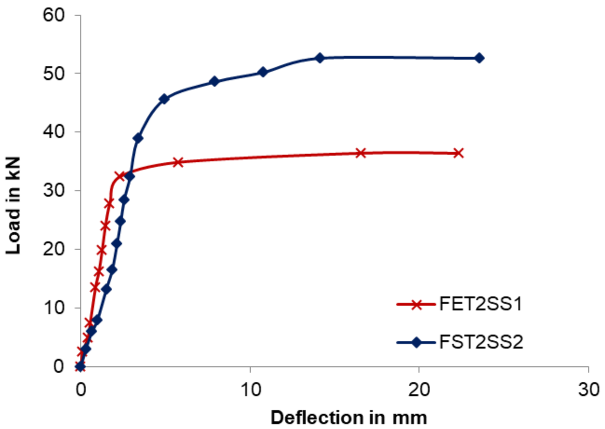


Fig. 12. Load-deflection curve for slabs FST2SS2 and FET2SS2

3.2 Effect of Thickness of Composite Slab

The effect of slab thickness was studied with respect to the corresponding type of concrete and spacing of shear connector. It was observed that the specimen with 150 mm thickness (FST1SS1) has increased the load carrying capacity by 37.14% than that of the specimen with thickness of 120 mm (FST2SS1). The EPLW SCC specimen, FET1SS1 exhibits a higher performance of 11% in the load carrying capacity when compared to FET2SS1. Fig. 13 and 14 shows the effect of thickness of composite slab for SCC and EPLW SCC respectively.

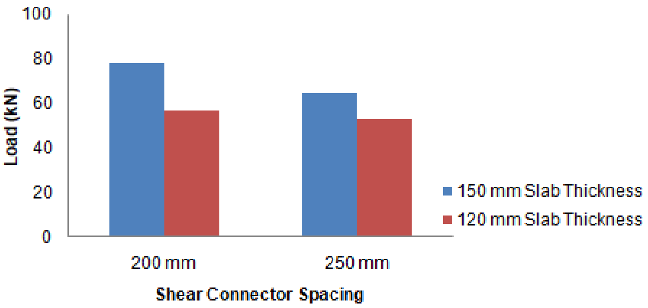


Fig. 13. Effect of thickness of composite slab for SCC

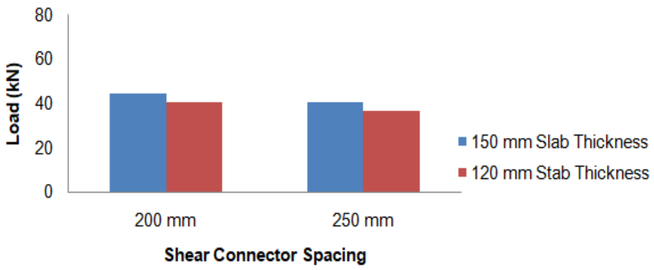


Fig. 14. Effect of thickness of composite slab for EPLW SCC

3.3 Effect of Spacing of Shear Connector

The shear crack would be controlled by the spacing of shear connector, and de-bonding of steel from concrete. It was observed that about 14% and 10% increase in shear resistance was found for conventional SCC and EPLW SCC respectively. Fig. 15 and 16 presents the effect of spacing of shear connector in composite slab for SCC and EPLW SCC respectively.

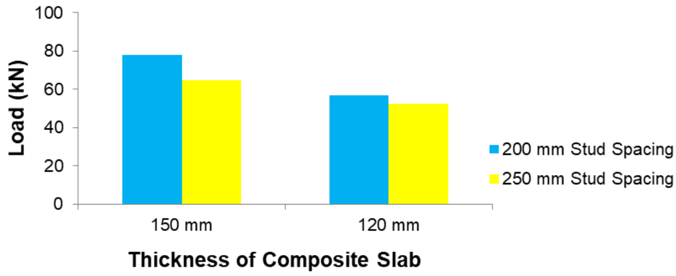


Fig. 15. Effect of spacing of shear connector for SCC

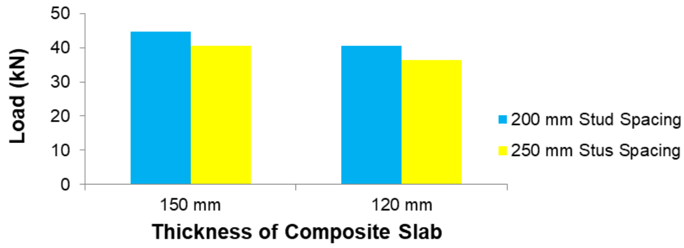


Fig. 16. Effect of spacing of shear connector for EPLW SCC

3.4 Failure of Composite Slabs

In all the composite slabs, cracks were formed in the top horizontal surface and as the load increased, it was propagated to the depth of the slab. Vertical cracks were observed at the bottom of the slab after the formation of horizontal cracks. Vertical shear cracks were also noticed under the loading points. The vertical crack causes the debonding effect of trapezoidal profiled steel sheet and concrete. Fig. 17 depicts a transverse crack in self compacting concrete of slab thickness 200 mm with a spacing of shear connector of 200 mm (FST2SS1). A debonding of steel sheet from concrete slab was observed in FST2SS2 and is shown in Fig. 18. A crack at mid-span was observed in expanded polystyrene light weight self compacting concrete for a thickness of 120 mm with a spacing of shear connector of 200 mm (Fig. 19). A slip of profiled steel sheet was noticed in the composite slab, FET2SS2 and is presented in Fig. 20.

Fig. 17. Transverse crack in FST2SS1 composite slab

Fig. 18. De-bonding of FST2SS2 composite slab

Fig. 19. Crack at mid-span of FET2SS1 composite slab

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Fig. 20. Slip of steel sheet in FET2SS2 composite slab

3.5 Results of the Push-Out Test

3.5.1 Effect on the Type of Concrete

The test results showed that SCC performed well in shear resistance due to high strength concrete when compared to EPLW SCC composite slab. Fig. 21 and Fig. 22 demonstrate the behaviour of load carried by each shear connector and slip for SCC and EPLW SCC respectively. The EPLW SCC slab attained early failure due to low strength aspect. It was also observed that the failure was due to crushing of concrete near steel blocks and shear cracks along the slab. It was clear from curve that average of only 40% of total strength of SCC was attained in EPLW SCC slab.

3.5.2 Effect of Thickness of Composite Slab

The thickness of slab was greatly influenced by the load carrying capacity of composite slab, subjected to shear load. Fig. 23 shows the effect of thickness of slab. It was observed that the strength was decreased as that of the reduction in thickness of slab of about 17% and 33% respectively for SCC and EPLW SCC slab.

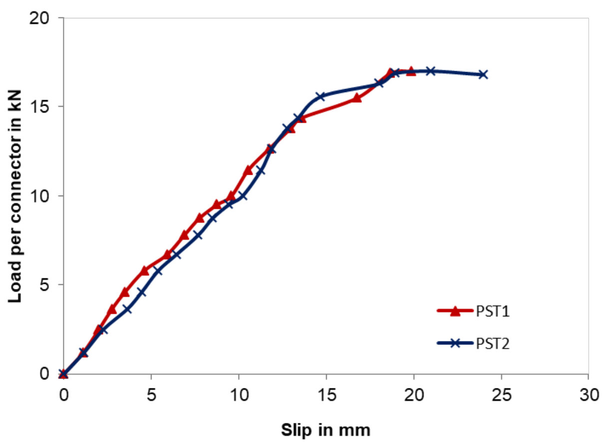

Fig. 21. Load per connector vs slip behaviour for SCC

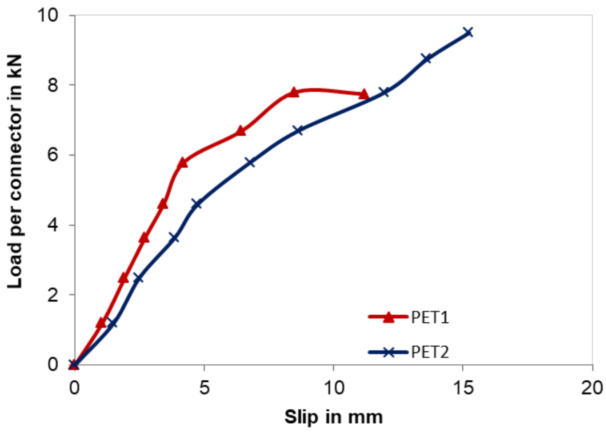

Fig. 22. Load per connector vs slip behaviour for EPLW SCC

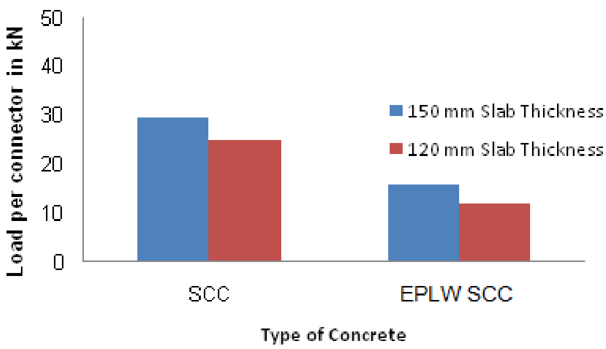

Fig. 23. Effect of thickness of slab subjected to push-out test

3.5.3 Failure Modes

The crushing of concrete was noticed in SCC slabs. Early shear cracks were appeared in EPLW SCC slabs. It was found that after the failure of shear connector, slip was found. The crack propagates and tends to separate the profile sheet and concrete. Fig. 24 to Fig. 26 depicts the failure pattern of slabs conducted through push out test.

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Fig. 24. Crack pattern on the sides of 'PET1'

Fig. 25. Crack pattern in slab 'PET1'

Fig. 26. Crack pattern in slab 'PET2'

4. CONCLUSIONS

An experimental study on the performance of expanded polystyrene light weight self compacting concrete under flexure test and push out test were conducted. Based on the experimental study, the following conclusions are drawn.

- The light weight expanded polystyrene self compacting concrete composite slab of thickness 150 mm attained 78% strength of conventional self compacting concrete composite slab of 120 mm thickness.
- The thickness of composite slab affected the ultimate load of the composite slabs.
- The minimum spacing of shear connector of 200 mm was well-performed. The light weight self compacting concrete composite slab could able to resist the shear capacity.
- Push out test of SCC composite slab shows high shear performance of reduced strength of 17% and 33% in composite slabs of lower thickness in SCC and EPLW SCC slab.
- Vertical shear cracks were observed under the loading points. Thus, it causes the debonding effect of trapezoidal profiled steel sheet and concrete.

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