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Experimental Study on the Structural Performance of Composite Beam with J-hook Connectors

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Abstract: This paper focuses on an experimental study in order to predict the structural performance of a composite beam. The composite beam was referred to a structural member in which concrete core was sandwiched between two steel plates. The two steel plates were connected by a J-hook shear connector in order to develop a composite action between the plates and core concrete. The concrete core consists of fibre reinforced and foam concrete representing normal and light weight concrete. The concrete was reinforced with various percentages of discrete fibres. The composite beams were loaded and tested under four-point bending system. The experimental results in NWC revealed that the proposed composite beam with higher content of steel fibres enhanced the load carrying capacity of the composite beam. In case of LWC the beam with 1.5% of steel fibres has a higher load carrying capacity. The stiffness of NWC beams with a higher content of steel fibres showed a significant improvement when compared to control beams. For LWC beam in which 1.5% of steel fibres were added shows maximum stiffness when compared to beams in which no fibres were added. The failure of all the beams initiated with yielding of steel plates and formation of cracks in the concrete core. The concrete core failure was observed to be ductile and not brittle due to the presence of fibres which prevents the formation of cracks and delays the failure of the beams.

Keywords: *Composite beam, J-hook, bending, HYFRC, Fibre reinforced foam concrete*

1. Introduction

In recent years, Steel-Concrete-Steel (SCS) sandwiched system has become inevitable in the construction industry. [1] Sandwiched construction is also known as double-skinned composite construction and it combines the advantage of both steel and reinforced concrete systems. Sandwiched system allows prefabrication of large panels in factory and enables quicker erection thus reducing construction time and cost. The two steel plates act as a permanent formwork during construction and thus providing an impermeable skin. Nowadays, the civil infrastructure has a great demand to increase the impact and blast loads. This type of SCS construction provides better resistant against impact and blast loads which enables better structural integrity and helps in achieving better composite action. In sandwich structures, mechanical connectors are required to provide effective bond between the steel face plates and the concrete core. A welded stud, spiral bar, short length of channel or another similar connector that resists horizontal shear between components of a composite beam. Every shear connector is designed in accordance with two fundamental principles, i.e. to resist the horizontal shear forces developed at the interface between two mediums and they should not allow to the pull up the forces to separate the two mediums by resisting the tension forces. Due to its higher stiffness and strength, this form of construction is emerging more popular in offshore structures, nuclear structures, and bridge decks, high rise buildings, floating breakwaters, ship hulls, protective structures and many other civil engineering applications.

There is a large variety of mechanical shear connectors, varying in shape, size and methods of attachment such as headed studs, bi-steel connectors and novel connectors. Studs are generally placed in rows, the spacing (and thus the number per unit length) being dependent on the design shear force between girder and slab. The shear transfer between steel face plates and concrete core depends on the overlapped headed shear studs. The overlap length and close spacing of studs could lead to difficulty in concreting or grouting.

Bi-Steel connectors have an advantage of high strength and speed of construction. [1] However, the thickness of the prefabricated panel is limited by the welding machine in which the panel depth should be between 200 mm and 700 mm with face plate thickness between 5 mm and 20 mm. The bar diameter is fixed at 25 mm with minimum spacing of 200 mm. Thus the Bi-Steel SCS panel cannot be used for slim deck with thickness less than 200 mm. The novel connectors should be designed to satisfy three basic requirements for providing interface slipping resistance, preventing complete ‘pullout’ from the concrete core and enhancing the cross section shear resistance to resist vertical load. Several new type of connectors are proposed for the SCS composite structures. They are angle-steel bar-angle, angle-T channel, angle steel hoop-angle. Some researchers [1, 3, 4, 10] proposed new types of shear connectors together with the J-hook connectors developed earlier. J-hook connectors provide direct connection to the two face plates and their main functions are to resist both longitudinal and transverse shear, and to prevent plate buckling.

Some researchers investigated [1, 3, 4, 5] to evaluate the impact, flexural behaviour of composite beam. Jia-Bao Yan et al [8] proposed an analytical model and verified against the results from a series of experimental work which include bi-steel sandwich beams, double skin beams, sandwich beams with J-hook connectors, angle connectors, and cable connectors. Various failure modes of the sandwiched beam were studied. The new methods to predict the ultimate strength of SCS sandwich composite beams were recommended for design purposes. Noridah Mohamad et al [11] conducted an experimental study on Structural Behaviour of Precast Lightweight Foam Concrete Sandwich Panel with Double Shear Truss Connectors under Flexural Load But the concrete utilized in this type of construction is a major concern. Based on the application area the concrete core may vary. For offshore and lightweight structures the concrete may be of lightweight materials and in case of structures that need higher stiffness and strength different type of concrete cores shall be used.

Relatively limited literature exists on the normal weight concrete or light weight concrete of SCS sandwiched composite beams. The newly developed hybrid fibre reinforced concrete (HFRC) and fibre reinforced foamed concrete (FRFC) was chosen as the core material. The structural performances of SCS composite beam with HFRC and FRFC have not been studied. Therefore, this study investigated on the structural behavior of SCS composite beam with HFRC and FRFC through a series of four-point bending testing system.

2. Experimental Study

The properties of various materials, casting and testing of SCS composite beams are described in this section.

2.1 Materials

The properties of the materials that were used in this study are discussed here.

Cement: OPC of 53 grade of cement was used in this investigation. The properties of cement were conducted experimentally as per IS codes [4031-part 11 1988, 4031-part 4 1998, 4031-part 5 1988]. The specific gravity, consistency, initial setting time and final setting time for cement was found to be 3.15, 36%, 32 minutes, and 540 minutes respectively.

Fine aggregate and Coarse aggregate: The maximum size of coarse aggregate adopted for the study was 20 mm. The basic properties of fine and coarse aggregates was done as per IS codes. The fineness modulus of fine aggregate (IS 2720-4) was found to be 2.74. The specific gravity of fine aggregate and coarse aggregate (IS 2386-3) was found to be 2.60 and 2.64 respectively. The water absorption test for fine and coarse aggregate was conducted as per IS 2386-3 and it was found to be 8% and 1.2% respectively.

Steel plates with j-hooks: Mild steel plates of 6mm thickness were used at both tension face and compression face of the beam. Fig.1 shows the dimension of J-hooks and was welded to the steel plates with a spacing of 100mm. The yield strength of steel plates was found to be 265 N/mm^2.

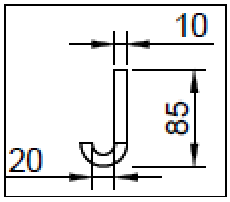

Fig.1: *J-hook specification*

Steel fibres: Steel fibres with hooked ends which provide tensile strength to the concrete were used in this study. The aspect ratio of the fibre used was 20 with a length of the steel fibre was 60mm. The diameter and the tensile strength of the fibre were 0.75mm and 1050-1225MPa respectively.

Polypropylene fibre: In this study, the polypropylene fibre was used to enhance the performance of the concrete. The thickness and length of the fibre was 6mm and 20mm respectively. The elongation property of polypropylene fibres was 15%.

Fly Ash: Class F fly ash according to ASTM C 618 was used in the experiment for the preparation of foam concrete.

Foaming agent: The foaming agent used in the study has a combination of potassium permanganate and calcium carbonate which was used as an accelerator stabiliser as well as viscosity controller. Egg powder was also used in the production of foam with alpha olefin sulfonate which acts as a pH controller.

2.2 Concrete

In this investigation, two different types of concrete namely normal and light weight concrete used as a core in between the steel plates to assess the performance of SCS composite beam.

2.2.1 Normal weight Concrete (NWC)

When discrete fibres are added to concrete said as fibre reinforced concrete and if it is reinforced with more than one type of fibres called as hybrid fibre reinforced concrete. The fibres were added in percentage to the volume of concrete. The concrete mix design of concrete was done in accordance with IS 10262:2009. After the trial mix, the final design was proposed for NWC as 1:1.67:2.96:0.45. The fibres were added in concrete at different volume fractions of 1% with a combination of steel – polypropylene at 75%-25%; 50%-50%.

2.2.2 Light weight Concrete (LWC)

Foam concrete was produced by mixed foaming method. In mixed foaming, the surface active agent was mixed along with the base mix ingredients. During the process of mixing, foam was produced resulting in cellular structure in concrete. Fig.2 shows the photographical view of foam used during casting.

Fig.2: *Photographical view of foam during casting*

The mix ratio for making the foamed concrete is originally investigated based on the experience of the engineers in the foam generating plant. For the foamed concrete, 1 part of cement with 2 parts of fly ash was added. Fig.3 shows the density of 1400 kg/m^3 for the light weight foamed concrete.

Fig.3: *Weighing of foam concrete*

2.3 Details of the Specimens

The properties of concrete core and the details of composite beam are shown in Table1. In Hybrid fibre reinforced concrete steel and polypropylene fibres were added in concrete at different volume fractions of 1%. Foam concrete core was reinforced with steel fibres of 1% and 1.5%. The composite beams of size 200 mm width, 162 mm depth and 1.2 m length were constructed. The steel plates of 6 mm thickness were welded with J-hooks of 10 mm diameter. The longitudinal and cross section of composite beam are presented in fig.4 (a) and (b). A total of six beams were investigated.

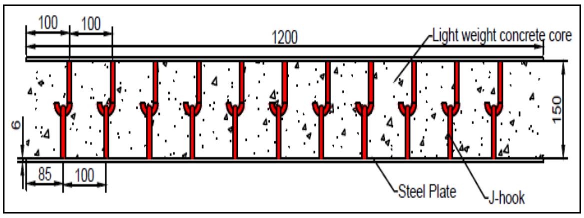

Fig.4 (a): *Longitudinal section of beam*

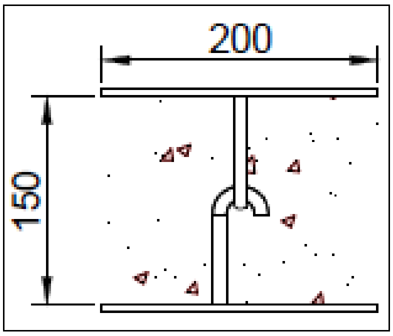

Fig.4 (b): *Cross section of beam*

Table1: *Details of the composite beam*

Specimen ID	Concrete core	f_{ck} (MPa)	Density of concrete (kg/m^3)
B1	NWC	26.3	2370
B2	HYFRC1	33.6	2412
B3	HYFRC2	31.2	2391
B4	LWC	11.52	1400
B5	FRFC1	12.6	1420
B6	FRFC2	13.8	1430

B1- normal weight concrete, B2- hybrid fibre reinforced concrete with 0.75% of steel fibre and 0.25% polypropylene fibre, B3- hybrid fibre reinforced concrete with 0.5% of steel fibre and 0.5% polypropylene fibre, B4- lightweight concrete, B5- fibre reinforced foam concrete with 1% steel fibre, B6- fibre reinforced foam concrete with 1.5% steel fibre.

2.4 Casting of Specimens

The beam specimens were cast by connecting the two steel plates to which the j-hooks are welded as shown in fig4. The steel plates are connected properly such that it maintains a depth of 150mm. The ends of the steel plates were covered by using cover plates to prevent the flow of concrete as shown in fig.5. In between the steel plates, concrete was poured as shown in fig.6 and compacted.

Fig.5: *Arrangement of steel plates*

Fig.6: *Pouring of concrete*

After casting the beams, curing was done for a period of 28days before they were tested. Care should be taken while curing period to avoid the corrosion of steel plates.

2.5 Testing of Specimens

The composite beams were simply supported over an effective span of 1000mm and tested under four-point loading system. Loading was applied by using a hydraulic jack of capacity 50tons. The load applied on the beam was measured using a load cell. The deflection at the mid-span was measured by using Linear Variable Differential Transformers (LVDT). Static load was applied incrementally at a rate of 5kn/min. To visually observe the cracks in the concrete core it was painted with limewater mixture. The load cell and LVDT were connected to computer via data logger that records all data such as load, deflection while testing. The first crack and the first yielding of concrete and steel were closely observed. After testing the concrete core was removed to observe the deformation of the shear connectors. The experimental setup for testing the beam is shown in fig.7.

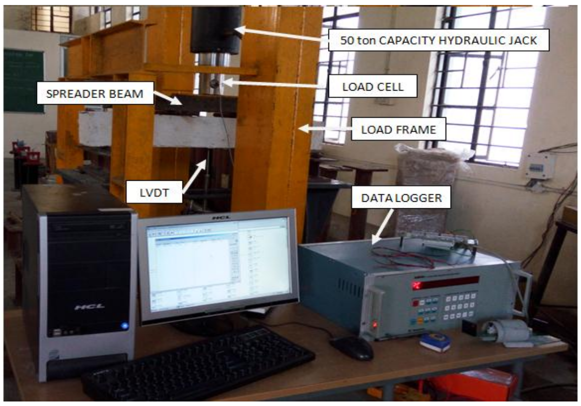

Fig.7: *Arrangement of the specimens for testing*

3. Results and Discussion

The composite beams were tested under two point loading and the results were discussed. The ultimate load carrying capacity and deflection of the specimens for different concrete cores was in Table2.

Table2: *Experimental test results*

Beam ID	Ultimate Load (kN)	Deflection (mm)
B1	211	9.3
B2	278	14.2
B3	252	11.2
B4	82	10.4
B5	110	12.5
B6	189.65	17

3.1 Ultimate Load Capacity

The ultimate load carrying capacity of NWC and LWC beams is shown in fig.8.

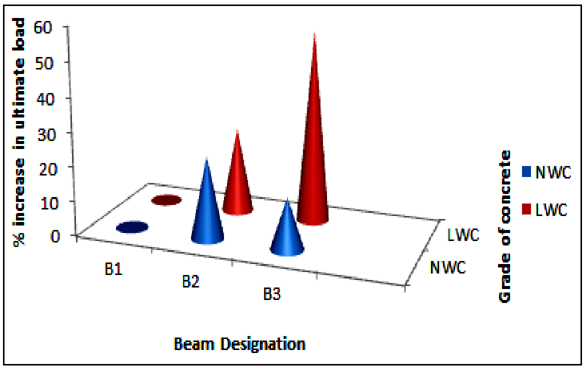

Fig8: *Ultimate load capacity of beams*

From the chart it can be seen that the ultimate load carrying capacity of NWC is higher than the LWC beams. This is due to the strength of the concrete core. The strength of light weight concrete core was lower than that of the normal concrete. The ultimate load carrying capacity of NWC and LWC beams were found to be 211kN and 82kN respectively, i.e. the NWC (B1) beam has 2.57times more load carrying capacity when compared to the LWC (B4) beam.

On comparing the ultimate load of the beams B1, B2, B3 the beam B2 with 0.75% steel fibre and 0.25% polypropylene fibre has a higher load of 278kN which is 24% and 9.3% more than B1 and B3.

Similarly on comparing the ultimate load of the beams B4, B5, B6 the beam B6 with 1.5% steel fibre has a higher load of 186kN which is 56% and 40% more than B4 and B5.

3.2 Effect of Concrete Core Strength

The strength of the concrete core has a direct effect on the ultimate load carrying capacity of the composite beam. It was observed that the strength of the concrete core increased from 11.5 to 26.3 MPa. It was found that there was 61% increase in the ultimate load carrying capacity of composite beam. In NWC the increase in strength of the concrete was due to the higher modulus of concrete and lower deformation when compared to LWC.

3.3 Effect of Fibre Content

Increase in the fibre content in concrete core increases the stiffness of the beam because of the better crack arresting mechanism. In NWC beams the load carrying capacity increases because of the higher percentage of steel fibres than the specimen with no fibre content. The beam B2 has a load carrying capacity of 278kN which is 19.7% higher than that of control specimen. But in case of foam concrete, beam with 1.5% of steel fibres shows higher load carrying capacity. The presence of steel fibre increases the stiffness of the beams. The beam B6 has a load carrying capacity of 189.56kN which is 55.4% more than the control specimen. Thus the addition of fibre to the concrete core delays the propagation of cracks and increases its tensile strength.

3.4 Load Deflection Behaviour

The load deflection graph for NWC and LWC beams are shown in fig.9 and fig.10.

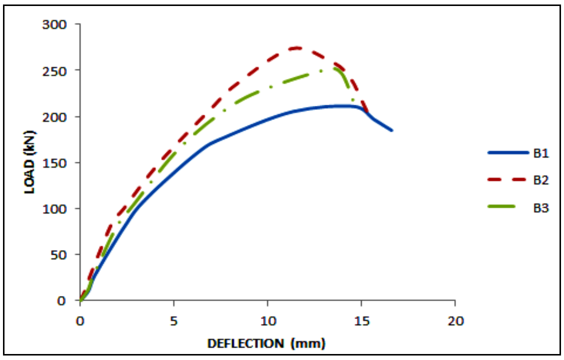

Fig.9: *Load vs Deflection for NWC*

From the fig9, it was observed that the beam B2 has higher load carrying capacity when compared to other beams. The stiffness of the beams B1 and B3 were found to be lower than that of the beam B2. This shows that the beam B2 has more stiffness for the same load of 40kN at which the beams B1 and B3 shows relatively lower stiffness. The increase in stiffness of beam B2 was due to the presence of higher percentage of steel fibres which holds the concrete matrix together and delays the formation of cracks.

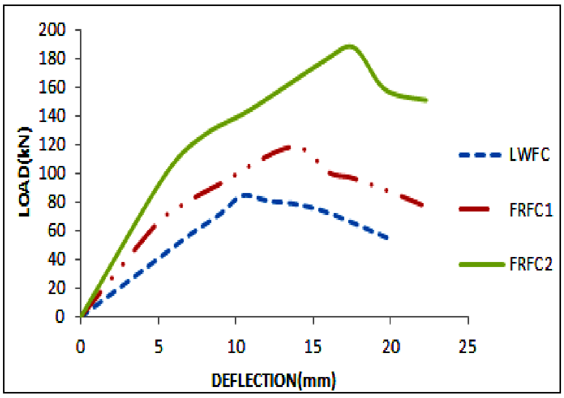

Fig.10: *Load vs Deflection for LWC*

From fig9 it can be seen that the initial crack load for the beam B2 is higher when compared to the other two beams. The beams to which steel fibres were added shows significant stiffness than the LWC beam. The deflection of the beam at a particular load was less for the beam B2 indicating the stiffness of the beam. Beam B2 has higher load carrying capacity with lesser cracks in the concrete core which indicates the effectiveness of the presence of steel fibres.

3.5 Failure Modes and Crack Pattern

The failure of all the beams initiated with yielding of steel plates and formation of cracks in the concrete core at initial loading. At ultimate state the beams were failed by formation of more cracks in the concrete core and bending of shear connectors. The failure modes and crack pattern of NWC beams and LWC beams are shown in fig 11 to 13.

Fig.11: *Failure of the NWC composite beam*

Fig.12: *Failure of LWC composite beams*

Fig.13: *Shear Failure of the beam at ultimate stage*

From fig11 and fig12, it was observed that there was lesser number of cracks formed in the concrete core. This was due to the presence of fibres in the concrete which delayed the formation and propagation of cracks as a result of which the beam has higher load carrying capacity when compared to other beams to which fibres were not added. The concrete core failure was observed to be ductile and not brittle due to the presence of fibres which prevents the formation of cracks and delays the failure of the beams.

Conclusions

The following conclusions were drawn from the present work:

1) The strength and stiffness for the beam B2 and B3 were found to be maximum when compared to control beam for NWC. For LWC the strength of the beam B6 to which 1.5% of steel fibres where added shows higher strength and stiffness than beams B4 and B5.
2) The experimental study shows that the load carrying capacity of the light weight foam concrete beam was 62% lower than the normal weight concrete beam.
3) The ultimate load carrying capacity of the beam B2 was found to be 24% and 9.3% more than that of the beams B2 and B3. This is due to the presence of higher percentage steel fibres in the concrete core.
4) For LWC beams, the ultimate load carrying capacity of the beam B6 was found to be 56% and 40% higher than the beams B4 and B5.
5) The composite beam with 0.75% and 0.25% steel fibre and polypropylene fibre bears more loads (B2) with minimum deflection when compared to B1 and B3 due of the presence of higher % of steel fibre.
6) The shear resistance of the light weight concrete core increased because of the presence of j-hook connectors.
7) The concrete core failure was observed to be ductile and not brittle due to the presence of fibres which prevents the formation of cracks.

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