Performance of Fiber-reinforced Concrete Sandwiched in Double Skinned Plated Composite Beams

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ABSTRACT

The present experimental study examines the structural performance of fiber-reinforced concrete sandwiched in double skinned plated beams. In this study, J-hook was used as a shear connector. Discrete hooked end steel and polypropylene fibers were used in the study at a volume fraction of 1 %. Ultimate load and deflection were studied. The experimental results revealed that ultimate load carrying capacity was considerably enhanced in fiber-reinforced concrete composite beam specimen. Ultimate deflection was decreased due to the incorporation of hybrid fibers into the concrete when compared to the reference composite beam. Failure was observed by yielding of bottom face steel plate in the double skinned plated composite beam and cracks formed in core concrete at the initial load. A ductile mode of failure was noticed in hybrid fiber-reinfored concrete sandwiched in double skinned plated composite beams.

KEYWORDS: Composite beams, Double skin plate, Hybrid fiber-reinforced concrete, J-hook, Sandwiched construction, SCS.

INTRODUCTION

In recent years, the steel-concrete-steel (SCS) sandwiched system has become widely accepted in construction industry. Sandwiched construction is also recognized as double-skinned composite construction. These types of construction could resist impact and blast loads and enable better structural integrity that helps in achieving better composite action. This type of construction is attractive in offshore structures, nuclear structures, bridge decks, high-rise buildings and other civil engineering applications due to higher stiffness and strength. In the SCS system, the top and bottom steel plates act as a permanent formwork during construction, thus providing an impervious skin (Liew and Sohel, 2009). Shear connectors are provided in between these top and bottom plates for an improved composite action. These plates will ensure a prefect bond between the plates and the concrete core. These shear connectors generally resist horizontal forces developed at the interface between two plates and should not allow to pull up the forces to separate the two plates by resisting tension forces. Based on shape, size and connecting method, a large variety of mechanical shear connectors is offered. Bi-steel connectors have gained importance due to their increase in strength and speed of construction (Xie et al., 2007). Static and fatigue behaviours on the performance of bi-steel beams were studied with varying depth and thickness. The study reported that a deck of less than 200 mm could not be adopted.

A new type of shear connectors has been addressed by various researchers (Anandavalli et al., 2013; Foundoukos and Chapman, 2008; Sohel et al., 2012;

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Chu et al., 2013). Some researchers conducted investigations to evaluate the impact behaviour of composite beams (Liew and Wang, 2011; Liew et al., 2008). Test was carried out by drop weights on the sandwich composite beams. It was proposed that J-hook connectors could effectively be interconnected with the top and bottom steel plates. The study indicated that after the impact test, the flexural strength was greatly reduced to 30%. An investigation was conducted on the static and fatigue strength behaviours of composite sandwich beams connected with J hook connectors and less density concrete made up of fibers (Sohel et al., 2003; Dai and Liew, 2010; Sohel and Liew, 2011; Yan et al., 2015). The results showed that J-hook connectors were effectively bonded and no slip was observed at the concrete and steel interface. An analytical model was also proposed and verified against the results from a series of experimental work which included bi-steel sandwich beams, double skin beams, sandwich composite beams with J-hook connectors, angle connectors and cable connectors (Liew and Sohel, 2009). Various failure modes of the sandwiched beams were studied. The new methods were recommended to predict the ultimate design strength of SCS beams.

Little or so far no experimental investigations were found on the flexural performance of concrete sandwiched in double skinned plated composite beams. Relatively limited studies exist on normal weight concrete or light-weight concrete of SCS sandwiched composite beams. These research studies focussed on the newly developed hybrid fiber-reinforced concrete (HYFRC), which was utilized as the core material and investigated for its flexural performance in double skinned plated composite beams.

MATERIALS AND METHODS

Materials Used in Composite Beams

In the present investigation, grade 53 ordinary Portland cement was used. Fineness and specific gravity of cement were obtained as 7% and 3.15, respectively. Test results for initial and final setting time was observed as 32 minutes and 540 minutes, respectively. The compressive strength for cement at the age of 28 days was found to be 53.25 MPa. The fine aggregate was locally available river sand belonging to zone II conforming to IS 383-1970. The fineness modulus and specific gravity of fine aggregate was obtained as 2.74 and 2.60 respectively. The absorption of water in fine aggregate was found to be 8%. The specific gravity of coarse aggregate was found to be 2.68 and water absorption of coarse aggregate was obtained as 1.2%. Mild steel plates of 6 mm thickness were used for the investigation. 10 mm diameter steel bars were used to fabricate J-hooks. The characteristic yield strength of steel plates and steel bars was found to be 265 N/mm^2. Short steel fibers with hooked ends and polypropylene fibers were used in this investigation. The length and diameter of steel fibers were 60 mm and 0.75 mm, respectively, with an aspect ratio of 80. The tensile strength of steel fibers was in the range of (1050-1225) MPa. The corresponding thickness and length of polypropylene fibers were 6 mm and 20 mm with a maximum elongation of 15%. Based on IS 10262-2009, the mix ratio was performed as 1: 1.97: 2.96 with a water cement ratio of 0.45.

Properties of Concrete

The hybrid fiber-reinforced concrete was used at a volume fraction of 1% with steel-polypropylene as 0.75%-0.25% and 0.5%-0.5%, respectively. Herein, CS referred to a control specimen without the addition of fibers. HYFRC1 and HYFRC2 represented a combination of steel-polypropylene at 0.75% - 0.25% and 0.5%-0.5%, respectively. The workability and consistency of concrete were investigated by slump test in accordance with IS 1199-1959. Slump was obtained for normal concrete as 55 mm and for hybrid fiber-reinforced concrete as 40 mm. To assess the strength properties of concrete with and without fibers, compression test, splitting tensile test and flexural strength test were conducted.

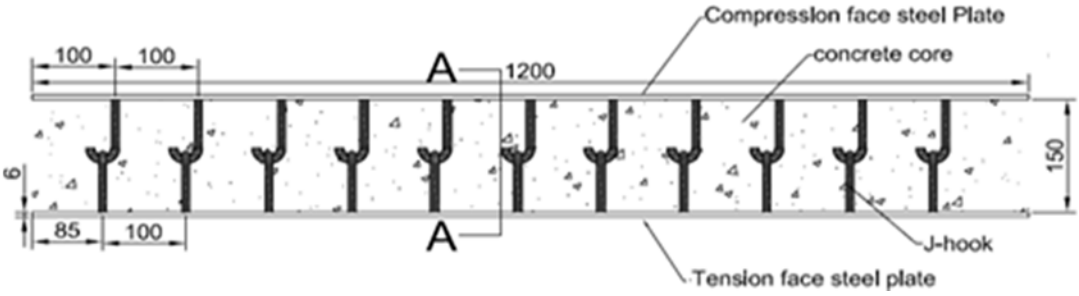
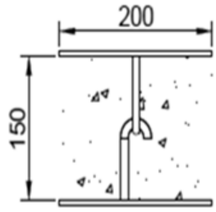


Figure (1a): Longitudinal section of composite beam



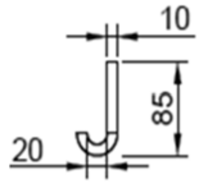


Figure (1b): Cross-section of composite beam **Figure (1c): J-hook**

All dimensions are in mm.

Details of Composite Beam

A rectangular beam with a width of 200 mm, a depth of 150 mm and a length of 1200 mm was constructed. Two steel plates of 6 mm thickness were used as double skinned plate on tension and compression face of the composite beam. Longitudinal and cross-sectional details of double skinned plated composite beam are depicted in Figures 1 (a) and 1 (b). J-hooks were fabricated with a mild steel bar of 10 mm diameter and depicted in Figure 1 (c). J-hooks were fixed by welded connections to top and bottom steel plates and placed with a spacing of 100 mm. The hybrid fiber-reinforced concrete was considered as a core, sandwiched between the double skinned plated composite beams. In the present investigation, three composite beams were fabricated. One composite beam with normal concrete served as the reference specimen (B1). Composite beam (B2) was sandwiched with HYFRC, which is a combination of 0.75%-0.25%. The third type of composite beam (B3) sandwiched with HYFRC is a combination of 0.5%-0.5%. Three composite beam specimens were prepared for each category.

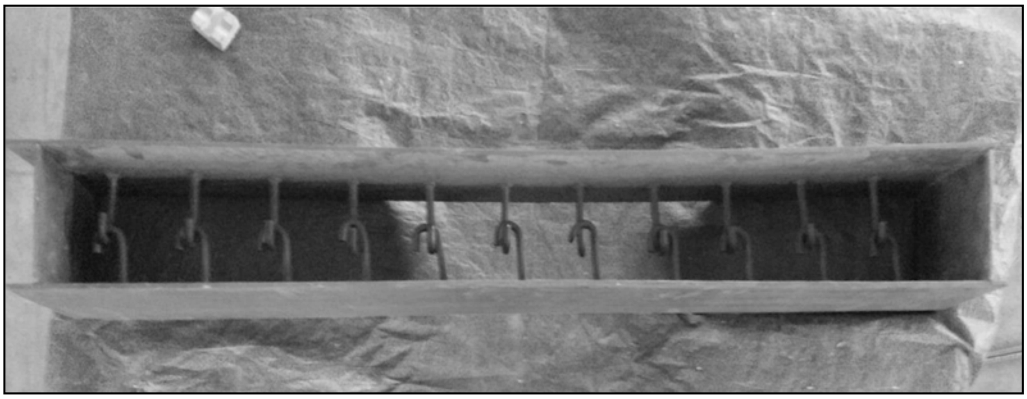


Figure (2): Double skinned steel plates connected by J-hooks

Casting and Testing of Composite Beams

Double skinned steel plates with J-hooks were interconnected in such a way that tension face plate with J-hooks perpendicular to width was connected to compression face steel plate with hooks parallel to width. The arrangement of double skinned steel plates connected with hooks is presented in Figure 2. Concrete was prepared by using a rotating drum mixer and poured between the plates in layers and good compaction was attained by using a compaction rod. Curing of the specimens was carried out for 28 days.

Figure 3 depicts the test setup of composite beam tested under static loading. The composite beams were tested under two-point loading with a simply supported span of 1000 mm. Loading was applied by using a hydraulic jack with a capacity of 50 t. The load was applied on the beam using a load cell which was positioned below the hydraulic jack. The deflection at the mid-span of the beam was measured by using a linear variable displacement transducer (LVDT). Data, such as load and displacement, were all obtained through a computer interfaced 20-channel data acquisition system.

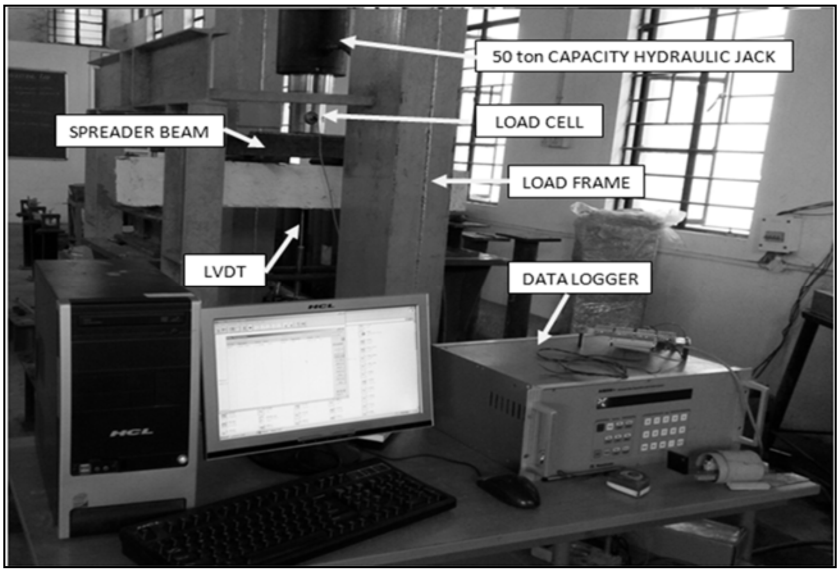


Figure (3): Test setup of SCS composite beam

RESULTS AND DISCUSSION

Table 1. Results on mechanical properties of concrete

Type of test	Specimen ID	Test results (N/mm^2)
Compressive strength test	CS	32.6
	HYFRC1	39.4
	HYFRC2	35.4
Splitting tensile strength test	CS	3.4
	HYFRC1	4.2
	HYFRC2	3.9
Flexural strength test	CS	3.9
	HYFRC1	4.4
	HYFRC2	4.2

Results on Mechanical Properties of Concrete

Table 1 summarizes the results on mechanical properties of concrete with and without addition of fibers.

Effect on Concrete Strength

It was observed that there was an increase in compressive strength of about 20.85% and 11.29% for HYFRC1 and HYFRC2 specimens, respectively. This was due to that the addition of fibers in concrete specimens reduced the formation of cracks that occurred in the microstructure of concrete and delayed their propagation. From the results, it is clear that there was a significant enhancement in splitting tensile strength of concrete by 23.5% for HYFRC1 and by 14.7% for HYFRC2 specimens, respectively. This was due to the randomly distributed fibers in concrete which were bridging diametrical splitting cracks. It can also be registered that longer and thicker steel fibers have more effectiveness on delaying crack formation. For specimen HYFRC1, it was observed that there was an increase in flexural strength of concrete of about 12.8%. This was because of the addition of fibers into the concrete. It was also worthy to note that 0.75% of steel fibers were added in this specimen, preventing the cracks in concrete and thus enhancing the flexural strength. Due to the addition of polypropylene fibers, the bending stiffness of concrete has increased.

Results of Composite Beams

Table 2 summarizes the test results of concrete sandwiched double skinned plated composite beam.

Table 2. Test results of double skinned plated composite beam

Beam ID	Initial crack load (kN)	Initial deflection (mm)	Ultimate load (kN)	Ultimate deflection (mm)
B1	145	3.3	211	14.58
B2	213	2.9	278	11.62
B3	197	3.1	252	13.44

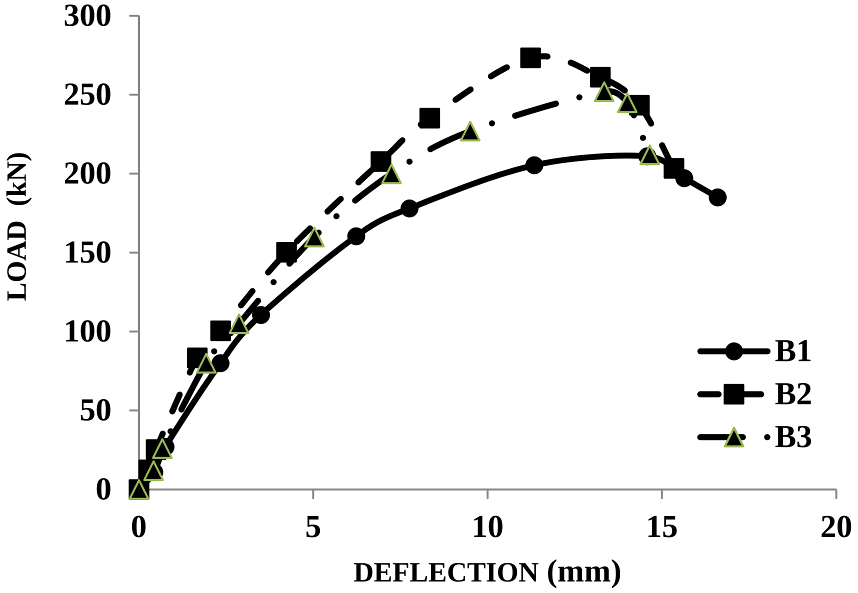


Figure (4): Load *vs.* deflection for composite beams

Load-Deflection Behaviour

Figure 4 illustrates the load-deflection behaviour of all tested beams. The strength of the concrete core has a direct consequence on the ultimate load carrying capacity of double skinned plated composite beams. It was observed that the strength of the concrete core has improved with the addition of fibers. All the beams experienced a linear behaviour till the formation of initial cracks. The initial cracks were observed in the concrete core at an initial load of 145 kN in the reference beam B1. In HYFRC beam, the initial cracks were delayed and formed at 46.8 % and 35.8% for beams B2 and B3, respectively. This is due to the addition of discrete fibers in B2 and B3. It was also observed that B2 has a higher content of steel fibers, which delayed the formation of cracks when compared to other composite beams. When compared to control beam B1, the HYFRC composite beams B2 and B3 showed lower stiffness in the load-deflection curves. This is due to the addition of fibers into the concrete. It was revealed that under flexural load, tensile stresses occurred in the microstructure of concrete and fibers withstood this tensile stress, hence the bending strength of concrete core in SCS beam increased. After this load level, the bottom steel plate started to yield. At this stage, the load-deflection curve exhibited a non-linear behaviour. The beams showed a ductile behaviour with an increase in ultimate load carrying capacity, but with a large deformation of the beam.

Crack Pattern and Failure Modes

The crack pattern and failure modes were observed in concrete sandwiched double skin steel plated composite beams during the test as presented in Figures 6 and 7. The bottom steel plate was yielded in all the composite beams. The vertical flexural cracks were observed in the concrete and found in between the application of loads. A ductile mode of failure was noticed in the composite beam B2. This was due to the presence of fibers which prevented the formation and growth of cracks in the concrete. As around 80% of ultimate load was reached, composite beams failed in shear, which was distinguished by inclined shear cracks that formed in the core from the bottom plate to the location of the load. The concrete in between the two face steel plates was cleared off to study any deformation of J – hook, as presented in Figure 8.

Figure (5): Yielding of bottom steel plate in composite beam B1

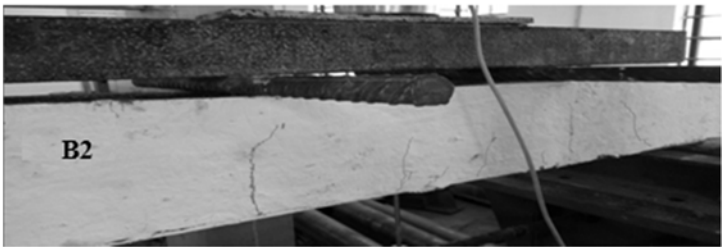


Figure (6): Ductile mode of failure in composite beam B2

Figure (7): Flexural cracks in composite beam B3


Figure (8): Deformation of shear connectors

Effect of Fiber Content on Composite Beam

The HYFRC sandwiched in double skinned plated composite beam was assessed with the control beam. Specimens B2 and B3 showed an increase in the ultimate load of the beams of 31.75% and 19.43%, respectively. From the results, it is obvious that the concrete reinforced with discrete fibers provided an effective strength to composite beams. The ultimate deflection was decreased due to the incorporation of fibers into the concrete. The ultimate deflections of SCS composite beams B2 and B3 were reduced by 20.3% and 7.8%, respectively, when compared to the control SCS composite beam. A notable behaviour was found in fiber-reinforced SCS composite beam. The fibers were randomly oriented in the concrete, effectively improving the bending resistance of SCS beam.

Effect of Sandwiched Core Strength in Composite Beam

From the results, it can be noticed that increasing the strength of core material enhanced the load carrying capacity of the composite beam. It also improved the ductility of HYFRC composite beams. This phenomenon is due to that the higher strength core material leads to higher tensile strength and compressive strength. These higher strengths increase longitudinal shear and tensile strength by J-hook connectors. It can also be noticed that higher strength concrete provided higher compressive force of concrete, leading to a larger moment of beam section. As expected, these increased strengths caused the beam to fail in flexure mode.

CONCLUSIONS

The following conclusions were drawn from the experimental study:

1. With the increase in steel fiber content, the strength characteristics of hybrid fiber-reinforced concrete have improved. Thus, this helps prevent the propagation of tensile cracks in concrete.
2. With the addition of polypropylene fibers in hybrid fiber-reinforced concrete, the bending stiffness of concrete has increased.
3. The strength of the concrete core has a direct effect

on the ultimate load carrying capacity of the SCS composite beam. The strength of the concrete core has increased with the addition of fibers.

4. The fiber-reinforced concrete sandwiched in double skinned plated composite beam showed a maximum load carrying capacity and a lower deflection. Thus, it can be advantageously adopted for dynamic resistant structures.
5. A ductile mode of failure was noticed in SCS composite beam with hybrid fiber-reinforced concrete, which helps increase the structural integrity.

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