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Experimental Investigation on the Cold – Formed Steel – Concrete Composite Beam Under Flexure

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ABSTRACT

Steel – concrete composite members are widely used in the construction of multistorey buildings and bridges. Composite construction takes the advantages of steel and concrete, in turn reduces the cost of construction. This paper discuss the use of galvanised steel with concrete as composite beam under flexural loading. Six specimens were tested to failure with varying number of headed stud connectors from 0 to 5. Load carrying capacity of the composite beam specimen improved by 62 % as compared to beam without shear connectors. The mode of failure of the composite beam is mainly due to failure of the shear connectors at tension zone, which leads to formation of multiple cracks on concrete portion. The analytical model was developed using finite element software ANSYS and found to obtain similar result as compared to the experimental results with minimal variation in the central deflection.

1 Introduction

Cold – formed steel sections have been recognized as an important contribution to sustainable and light weight structure in the developed countries. The new solutions was proposed to solve the analytical model of the composite beam with the effect of slippage, shear – lag and time – dependent and concluded that shrinkage of concrete and creep caused the significant influence on the structural response of the composite beams [1]. The steel – concrete composite beam of span 6 m were loaded at their thirds was studied to calculate the deflection of the beam, their composite action and modelled the same to analysis using finite element method [2]. The flexural behavior of concrete in – filled hollow sections was studied experimentally and showed that confinement effect got reduced for rectangular and square section [3]. The test conducted by Angeline Prabhavathy et. al [4] concrete in-filled steel frames, and concluded that composite beams give additional stiffness, which delays the failure of the columns. Adil Dar M et.al [5], presented a novel method to

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improve the strength and stiffness of cold-formed steel-composite beams. Sangeetha et. al [6-9], studied the composite behavior of the beam and space truss under maximum loading condition and concluded that composite action in the member were achieved by providing proper and enough shear connectors. This study tried to study the flexural behavior of the cold-formed galvanized steel – concrete composite beam with or without headed stud connectors.

2 Material and methods

The Galvanized steel channel section of size 150 × 50 × 3 *mm* with lip 20 *mm* were used to make the composite beam of length 1000 *mm*. The stud connectors of head 30 *mm* and height 40 *mm* were used as shear connectors to resist the shear force between GI and concrete. Fig.1 shows the dimensions of the composite beam with five numbers of stud connectors. The parameter varied in the study was the number of shear connectors to achieve the composite action. The concrete of grade M20 mix was used to cast the composite beam. The composite beam with one, two, three, four and five numbers of shear connectors were tested to failure under flexural loading. The results of the same were compared with the control specimen without shear connectors. The notation for the specimens CB – GI – 0SC that were used in which CB - Composite Beam, GI - Galvanized Iron, SC - Stud Connector and 0 represents number of stud connectors. Fig. 2 shows the GI beam with stud connectors for all the specimens. The composite beam before test with strain gauge were shown in Fig. 3.

Fig.1 – Dimensions of the specimen.

Fig. 2 - Galvanized Iron Channel section with stud connector.

Fig. 3 – Composite beam before test

The test set up of the GI composite beam was shown in Fig.4. The single point load is applied at the center of the beam using Universal Testing Machine (UTM) of capacity 600kN.All the composite beam was tested to failure. The position of the dial gauges was shown in Fig. 4. The dial gauge 1 and 2 were used to measure the lateral deflection between steel and concrete. The difference in the lateral deflection between GI and concrete measured as slip and dial gauge 3 was employed to measure the maximum central deflection. All the specimens were fixed with one strain gauge of 20 *mm* gauge length to measure the strain and the same were recorded using five channel strain indicators. Fig. 5 shows the testing of composite beam.

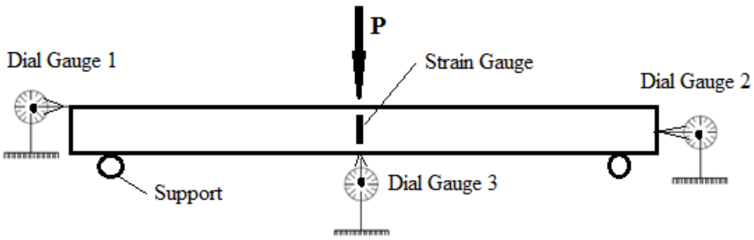

Fig. 4 – Test set up for beam under flexural loading.

Fig. 5 – Specimen under loading.

3 Results and Discussion

3.1 Load – Deflection Behavior

The detailed incremental load – central deflection curve is plotted against the varying number of stud connectors in the composite beam which is shown in Fig.6. From the graph, flexural behavior of the specimen CB – GI – 5SC is good and able to resist the maximum central deflection of 4.22 *mm*. The percentage increase in flexural load carrying capacity of the composite beam is 62 % for the specimen with increase of connector from 0 to 5. Thus, the specimen with five numbers of stud connectors (CB – GI – 5SC) gives full composite action between the galvanized iron and concrete and flexural capacity of the same is two-third of the composite beam without stud connectors (CB – GI – 0SC). The stiffness of the composite beam is obtained from the load- deflection curves and found that specimens with shear connectors are stiffer than the beam without shear connectors.

Table 1 – Stiffness, Energy absorption & Ductility factor of the composite beam.

Sl.No	Specimen Number	Stiffness *kN/mm*	Energy absorption *kN-mm*	Ductility Factor
1	CB – GI- 0SC	375	7	1.30
2	CB – GI- 1SC	1067	12	1.60
3	CB – GI- 2SC	1700	27	1.69
4	CB – GI- 3SC	3000	58	2.42
5	CB – GI- 4SC	4000	79	2.65
6	CB – GI- 5SC	7333	96	2.81

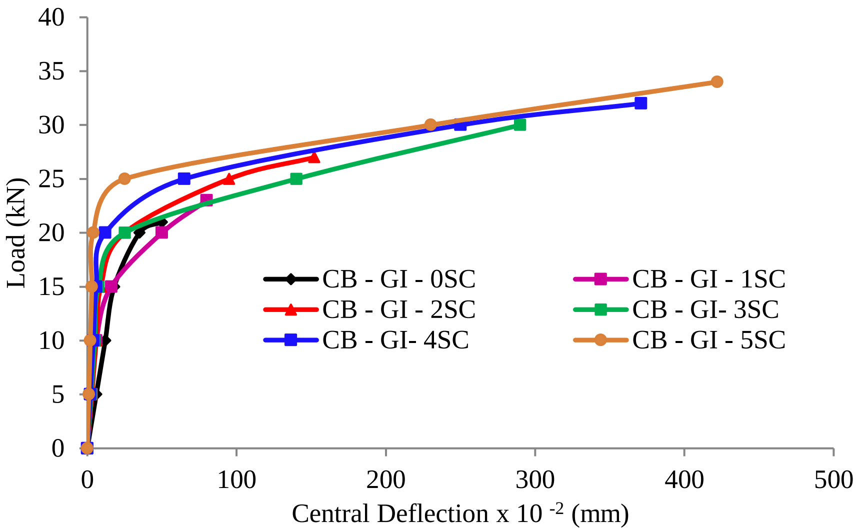

Fig. 6 – Load-central deflection curve of the cold - formed galvanised steel concrete composite beam.

3.2 Load – Strain Behavior

The load- strain plot was drawn to study the behavior of the composite beams with varying number of connector and it is shown in Fig. 7.

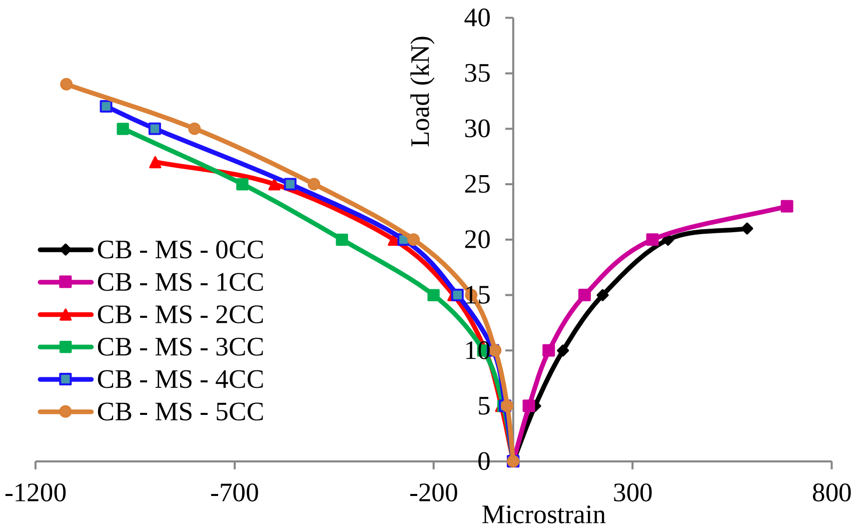

Fig. 7 – Load-strain curve of the cold - formed galvanized steel - concrete composite beam.

The specimen CB – GI – 0SC and CB – GI -1SC behaves in the similar manner and it was the positive strain with the maximum value of 0.007. The observed strain was negative because as it was considered as zero strain at the initial condition in order to recover residual strain. Whereas for all other four specimens shows the negative strain under flexural loading with the maximum strain of 0.012.

3.2 Load – Slip Behavior

The slip is the horizontal displacement or slippage between the steel and concrete in any composite structure. For full composite action, the slip value should be zero that can be achieved by providing proper and enough shear connectors. The shear transfer mechanism between GI and concrete was performed by providing stud type shear connector and it is also observed that increase in the number of connectors reduces the slip and achieved composite action. Fig. 8 shows the load – slip behaviour of the composite beam made using galvanised iron and concrete. From the Fig. 8 it is observed that the specimen CB – GI – 5SC developed the slip of 5.8 mm for the ultimate load of 34 kN and it is 43 % less than the composite beam without shear connector. The zero slip can be achieved by increasing the number of stud connectors in the composite beam.

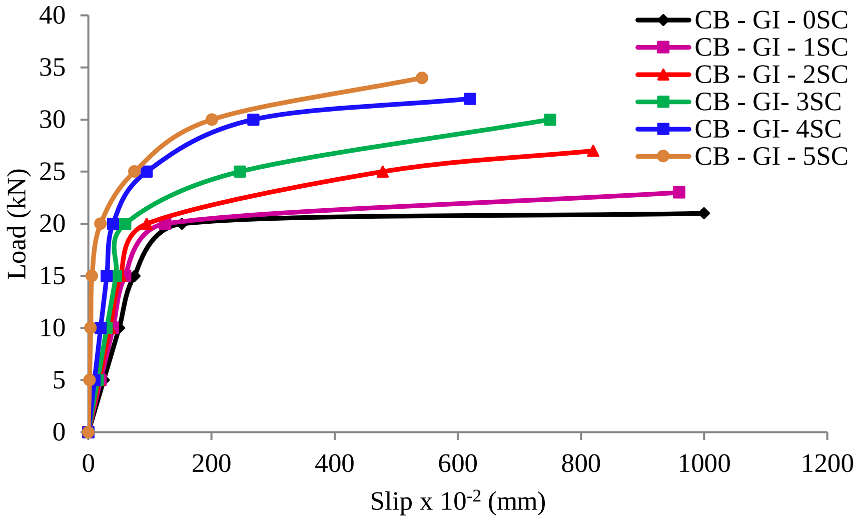

Fig. 8 – Load-slip curve of the cold - formed galvanised steel - concrete composite beam.

3.4 Failure Mode

All the specimens were tested to failure under flexural loading. The specimens after testing were shown in Fig. 9. The first crack in the specimens were able to observe only after the application of 70 % of the ultimate load. All the cracks start from the point of shear connectors, due to the failure of shear connectors. The multiple cracks were observed under the loading point. The width of the cracks is less for the specimen CB – GI – 5SC when compared to other specimens and Fig. 9(b) shows the ductile behavior of the composite beam after loading.

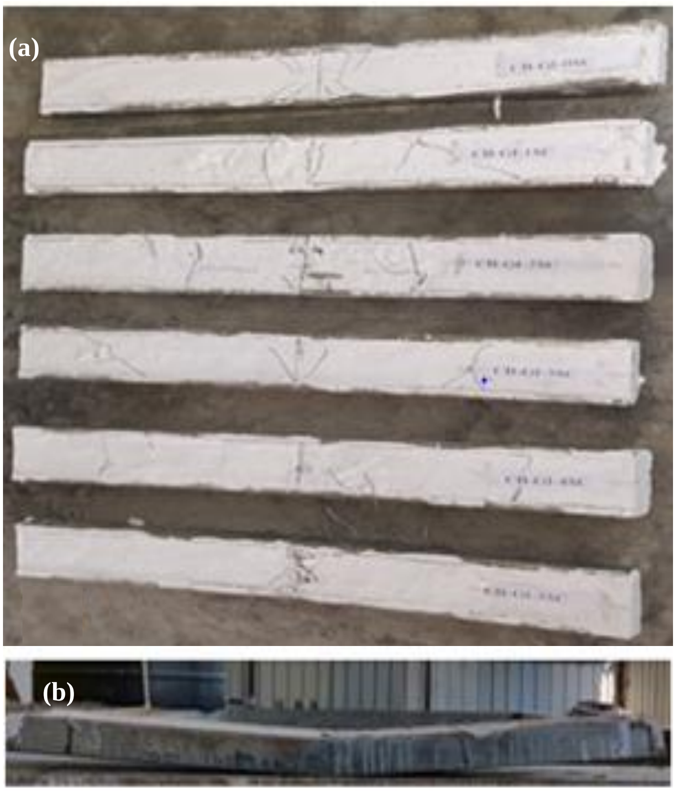

Fig. 9 – Composite beam after testing.

The cold - formed steel – concrete composite beam CB – GI – 2SC was captured using Infrared thermography(IRT) Camera before and after subjected to load. The real beam and IR image before and after testing was shown in Fig. 10 and Fig. 11 respectively.

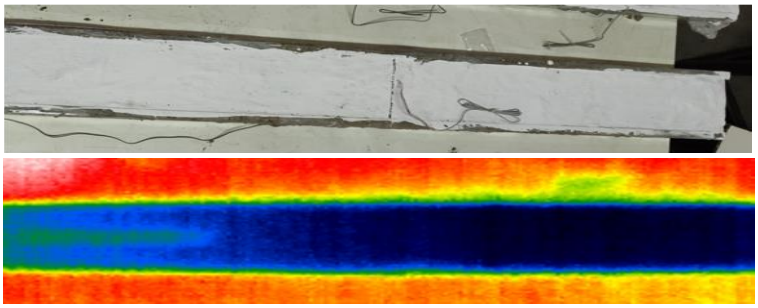

Fig. 10 – Specimen CB – GI – 2SC before testing (Mobile IR Camera).

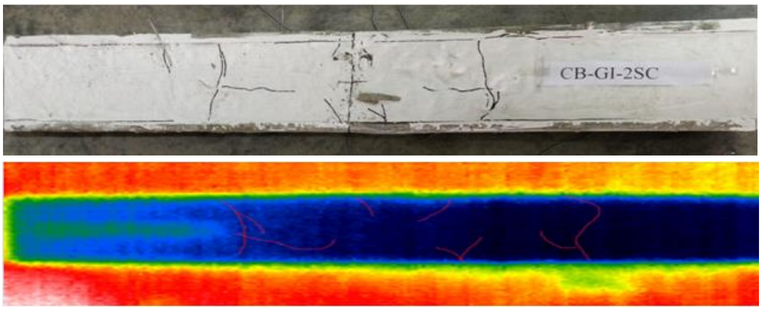

Fig. 11 – Specimen CB – GI – 2SC after testing (Mobile IR Camera).

From the images obtained from the IR camera, the inference obtained are, red colour shows the surrounding and blue colour represents the composite beam. After subjected to load, cracks developed in the specimens were clearly seen as red line on the specimen. The pattern of crack observed form the IR image is similar to that of real composite beam.

3.5 Analytical Results

The entire composite beam was also analysed using the finite element software ANSYS 19.0. The elements in the ANSYS library SOLID 186 and SOLID 65 were used to model the steel and concrete portion of the composite beam respectively. Fig. 12 shows the stress plots of the composite beam. The stress plot implies that stress is more (red colour) under the load for the specimen without connectors and it is shown in Fig. 12 (a).

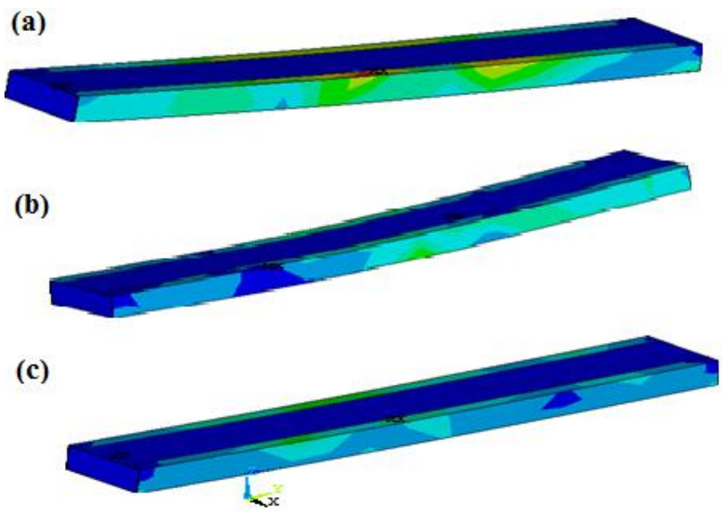

Fig.12 – Stress plot of the composite beam (a) CB - GI- 0SC (b) CB- GI - 1SC (c) CB - GI - 5SC.

The maximum central deflection of all specimens was obtained using ANSYS and compared the same with the experimental results. Fig. 13 shows the comparison of the experimental and analytical results. From the graph the analytical deflection is lesser than the experimental due to connections between the steel, concrete and connectors are rigid in the analytical model. The average percentage difference in the maximum central deflection between the experimental and analytical is 4.77 % which is tabulated in the Table 2.

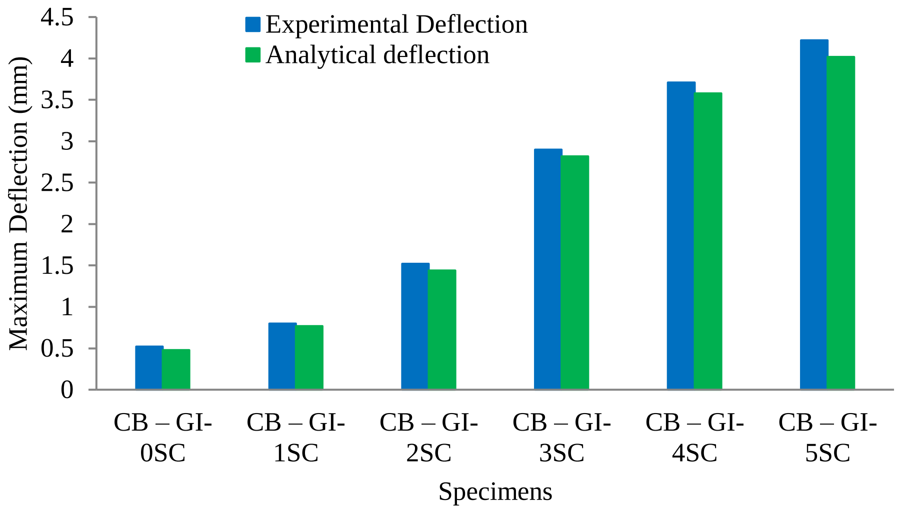

Fig.13 – Comparison between the maximum deflection between the experimental and analytical.

Table 2 – Comparison between experimental and analytical results.

Sl.No	Specimen Number	Ultimate Load [*kN*]	Experimental Deflection [*mm*]	Analytical Deflection [*mm*]	% Difference in Deflection
1	CB – GI- 0SC	21	0.52	0.48	7.69
2	CB – GI- 1SC	23	0.80	0.77	4.69
3	CB – GI- 2SC	27	1.52	1.44	5.26
4	CB – GI- 3SC	30	2.90	2.82	2.76
5	CB – GI- 4SC	32	3.71	3.58	3.50
6	CB – GI- 5SC	34	4.22	4.02	4.74

4 Conclusions

From the experimental investigation on cold formed steel (galvanised iron) concrete composite beam under flexural loading the following conclusions were arrived.

- The flexural load carrying capacity of the composite beam gets improved by 62% for increasing the number of stud connectors from 0 to 5.
- The composite action was achieved using headed stud connectors in the steel concrete composite beam with a minimum slip of 5.8 *mm*.
- Increase in the number of connectors in the composite beam increases the ductility and energy absorption capacity.
- The failure of the composite beam is mainly due to the formation of crack near the shear connectors. The specimen with five numbers of shear connectors failed by formation of multiple minor cracks and able to resists the more flexural load.
- Infrared thermography(IRT) Camera can be employed to examine the failure and its crack pattern of the composite beam precisely.

– The analysis of the composite beam using ANSYS gives lesser deflection when compared to the experimental result, this is due to rigid connection between the steel and concrete in the composite beam.

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