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Hollow Beams Strengthened with Steel Fibres and FRP Wrapping

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Abstract- In the field of construction hollow sections have found wide application due to its advantageous properties. Many research works have been conducted to study the flexural and tensional behaviour of hollow reinforced concrete beams. But its behaviour using High-Performance Concrete (HPC) has been poorly noticed. In this study an attempt made to evaluate Hollow reinforced beams made with HPC and reinforced with hybrid steel fibres. The flexural behaviour of hollow beams based on the effect of Carbon fibre reinforced polymer (CFRP) has also been explored. A comparison is made between the results obtained from analysis using ANSYS software with the experimental test result. It is noticeable that the flexural strength, its ductility, and stiffness is not affected but the self-weight of the structure is reduced due to hollow beams.

Index Terms*: *HPC (High Performance Concrete), Hollow beams, CFRP (Carbon Fibre Reinforced Polymer)

I. INTRODUCTION

High Performance Concrete (HPC) is a unique type of concrete which is used to construct complex structures. It is recently used in the construction of new structures, because of its vast advantages [1]. Compared to normal concrete, the production cost of HSC is high. Many civil engineers are preferring HPC in construction field because of its excellent strength and durability properties. The current concrete manufacturing knowledge and technology are executed in the HPC production and application [2]. With the addition of hybrid steel fibres HPC beam's structural performance was studied by [3]. Researches reveal that steel fibres impart certain properties which result in enhanced crack response, stiffness and load carrying capacity (LCC) against a decrease in the ductility. LCC of beams showed signs of improvement from 26%–55% due to the 1.75% addition of steel fibres and ductility was observed to be lowered by 12%–72%. The post-peak response and ductility are increased with the inclusion of twisted steel fibres and by increasing the length of smooth steel fibres. The fibre length and type play a major role with respect to cracking response. No visible difference was noted in the LCC and post-cracking stiffness [3]. The hollow sections have poor tensional loads and reveal desirable strength against bending moments. HSC and HPC sections are used in hollow beam sections due to its high-strength characteristics. In the existent building structures, torsion plays a vital role in the reinforced concrete beams resulting from the external loads or due to the or deformations resulting from the beams being continuous. Torsion was not directly taken in to account in the design. It was considered as a secondary effect, but it has a great impact on the overall factor of safety [4]. In concrete beams insufficient reinforcement results brittle fractures, corner cracking appeared due to fragile fracture, crisp failure and ductile failure occurred due to the insufficient strength of concrete. These failures appeared in high-strength concrete structures under torsion. With the increase in the concrete strength of the beam, the failure becomes more explored. Plastic analysis of high-strength concrete hollow beams was conducted under pure torsion and evaluated with the twist capacity [5]. The results indicated that the increase in compressive strength results reduce the small amount of twist capacity of beams. Again, in the year 2014, hollow beams constructed with HSC was investigated under torsion and the cracking modes were studied. The result specified that compared to NSC, HSC produced less ductility [6]. Numerical and experimental results are obtained with respect to torsional strengthening of solid and hollow RC beams, and the ultimate strength, cracking obtained was 77% and 41% with CFRP [7]. A study was carried out by [9] without special reinforcement on the opening zone the effects of reinforced concrete beams was studied. There was no effect on the ultimate load capacity when the depth of beam (D) was less than 44% with circular openings in the reinforced rectangular beams. The ultimate load capacity is reduced to 34.29% when the circular opening diameter is more than 44%. They also suggested that structural opening reveals more strength than that of square opening and has a difference of 9.58%. FRP has been used in the construction industry for a few years. The structure constructed with FRP shows good strength, stiffness, resistance to corrosion, easy to be used and provides better ductility when compared to normal concrete [10]. They were initially used as reinforcement bars in Russia in 1975. [11] found that FRP consists of synthetic or natural fibres to strengthen the concrete and was identified as Fibre Reinforced Plastic. [12]

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stated that FRP is eight times vigorous than normal steel reinforcement bars. Hence this FRP is considered the main material in the field of construction (ACI 440 part 6-8 2008). FRP laminates such as glass fibre reinforced polymers (GFRP), carbon fibre reinforced polymer (CFRP) and aramid fibre reinforced polymer (AFRP) are frequently used in the construction sector.

The main advantages of CFRP was studied by Al-Sunna in 2012. He reported that CFRP have high corrosion resistance, strength to weight ratio and easily installed over the concrete beam. The applications of FRP with hollow beams are also studied.

II. MATERIAL PROPERTIES

A. *Concrete Properties*

For the design of M40 grade of concrete, 0.4 water/cement ratio was used according to IS 10262:2009. In accordance with IS-383: (1970), the aggregates used were crushed stones of two proportions ranging from 12.5 mm to 2.36 mm and 20 mm to 4.75 mm. The results are listed in Table II. In accordance with IS 383:1970 the fine aggregates passing through 4.75mm sieve were taken for the experiment. The final test results are in table 2.3. As per the codal provision IS: 456 (2000) the physical properties of binder are tested and listed in Table IV. This study uses ordinary Portland cement of grade 40. For curing and mixing process portable water was used, in order to maintain water quality and to be free from harmful materials. In this study Class C fly ash is used as a partial replacement of cementitious material with 30% of admixtures.

Table I Mix Proportion

Description	Cement	Fine Aggregate	Coarse Aggregate	Water
Material Quantity	463.5 kg	530.27 kg	1153.13kg	185.4
Mix Proportion	1	1.14	2.49	0.40

Table II Coarse Aggregate Properties

SI.No	Properties	Values
1	Specific Gravity	2.64
2	Fineness Modulus	4.08
3	Water Absorption (% dry weight)	0.81
4	Bulk Density	

Table III Fine Aggregate Properties

Sl. No	Properties	Values
1	Specific Gravity	2.63
2	Fineness Modulus	4.762
3	Water Absorption (24 hours)	0.26
4	Bulk Density	17.75

Table IV Cement Properties

Sl. No	Properties	Values
1	Fineness of Cement	350 kg/mm^2
2	Standard Consistency	31%
3	Initial Setting Time (minutes)	40
4	Final Setting Time (minutes)	240
5	Specific gravity	3.12
6	Soundness Test(mm)	0.3

III. EXPERIMENTAL PROCEDURE

A. *Test on Beams*

Universal Testing Machine of 1000KN was used to test the beam specimens. A dial gauge placed at the mid span of the beam was used to record the vertical deflection of the beam. From the beginning to failure the operation was acutely noted by recording starting point of the crack until its propagation. The first crack load was recorded, a further increase in loads results in the development and propagation of cracks along the beam structure. The loading was continued until the beam collapsed. Pure bending tests conducted using four point loading setup so the three point loading set up was altered to make four point flexural setup using iron block having the loading span of 266mm and the load is applied through the hydraulic cylinder. The applied load with the corresponding deflections were noted, and further, the plot of load vs. deflection was drawn. The applied load increased until it reaches the final failure mode of the beam.

IV. RESULT AND DISCUSSION

A. *Load Carrying Capacity*

The test specimens were subjected to four-point flexural test. The maximum load recorded from the load dial. The ultimate strength of the beam and the cracking load is noted at the time in which the first crack developed on the concrete beam. A slight variation was observed in the load carrying capacity of hollow beams with carbon fibres reinforcement and without carbon fibre reinforcement. Hollow beams reinforced with CFRP laminates exhibited the highest value of load carrying capacity compared with normal hollow beams. Comparison chart of load carrying capacity of hollow beams with CFRP laminates and without CFRP laminates is shown in fig.1 and the values are recorded in table V.

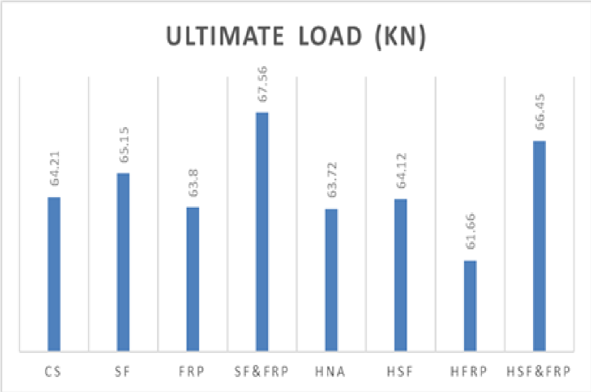

Fig.1. Ultimate load of test specimens

B. Load Vs Deflection Graph

The deflection of beams started when the applied load was increased at a uniform rate. Deflection values corresponding to each load is noted in the table. From the table deflection graph was plotted and this graph represents linear relation between load and deflection up to certain load. Further increase in load causes deformation of beams due to the loss of elasticity of the materials in the beams. Hence, the strength of the materials can be easily estimated by the load vs deflection graph.

C. Failure Mode

The failure mode noticed from the beams test represents shear tension failure. Shear stresses in concrete beams gives rise to inclined cracks which appear over the concrete beam structure and sliding type failure occurred over the well-defined surface of the concrete beam structure. When the load continues the shear cracks also propagates but it doesn't result in the failure of the beam. Flexural cracks lead to the development of secondary cracks which propagates along the longitudinal direction of the concrete beams and results in bond loss between concrete and reinforcement leading to anchorage failure. This research adopts a 3D finite element approach for the development of a FE model simulating the loading of a Hollow reinforced concrete beam subjected to static loading. A model depicting the actual test specimen was subjected to FEA using software and a comparison of the test results have been given in fig 3,4,5,6,7.

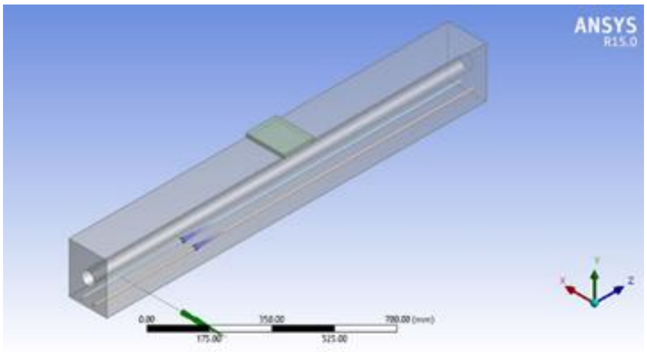

Fig .2. Geometry of hollow beam

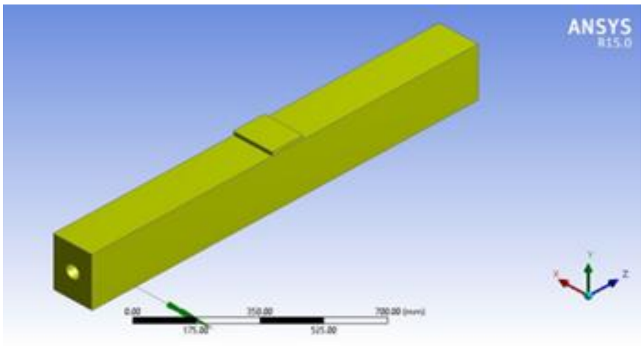

Fig.3. Solid of hollow beam

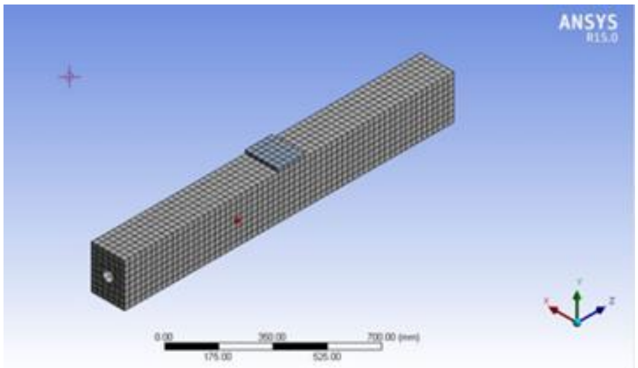

Fig.4.Mesh of hollow beam

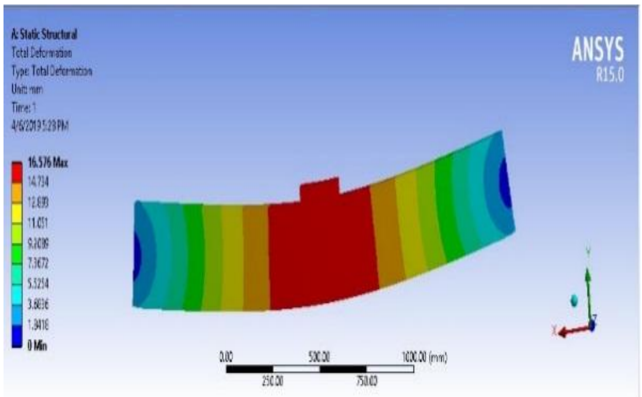

Fig .5. Solid beam under load

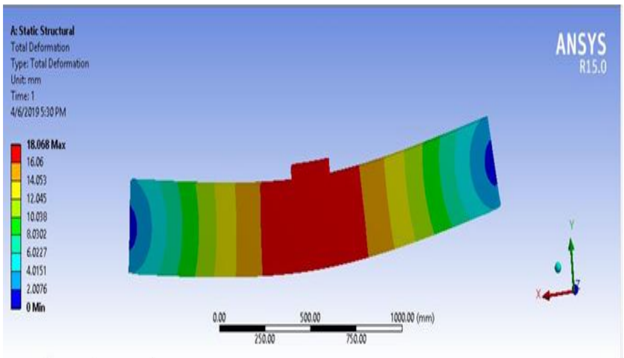

Fig.6. Beam with SF subjected to load

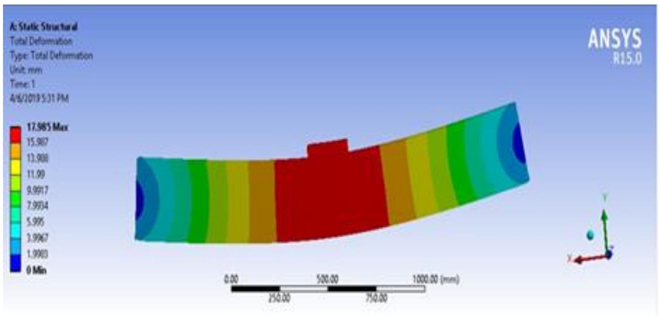

Fig.7. Beam with FRP subjected to load

Table V Experimental Test Results

Sl.No	Specimen Designation	First Crack Load (kN)	Ultimate Load (kN)	Deflection at first Crack (mm)	Ultimate Deflection (mm)	ANSYS Results (mm)
1	CS	28.56	64.21	1.21	16.43	16.57
2	SF	33. 34	65.15	1.40	18.07	18.06
3	FRP	29.68	63.8	1.37	18.01	17.98
4	SF&FRP	38.5	67.56	1.87	19.44	19.64
5	HNA	28.90	63.72	1.47	17.27	17.97
6	HSF	32.34	64.12	1.54	18.70	18.56
7	HFRP	28.98	61.66	1.40	17.91	17.97
8	HSF&FRP	37.54	66.45	1.75	18.79	18.73

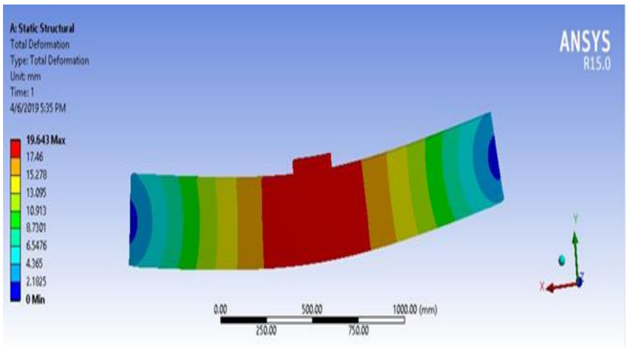

Fig.8. Beam with SF & FRP subjected to load

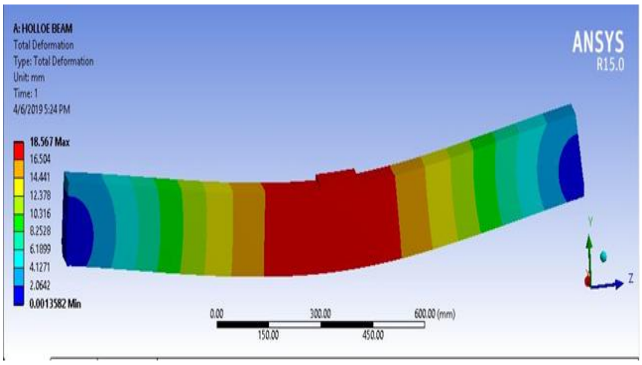

Fig.10. Hollow Beam with SF subjected to load

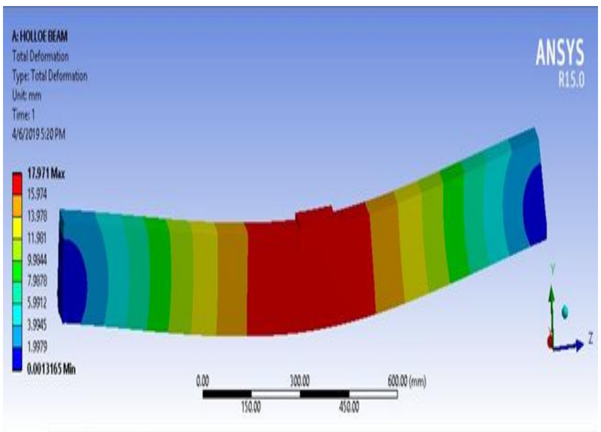

Fig.9. Hollow Beam subjected to load

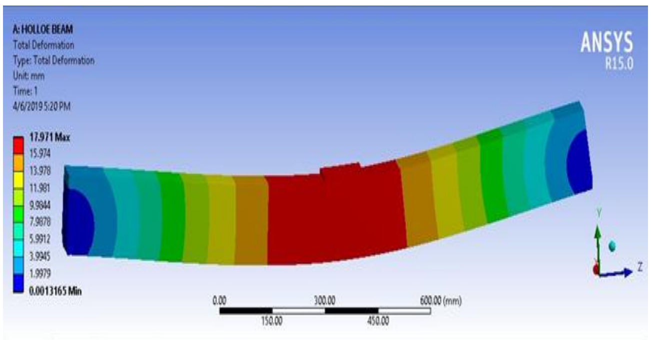

Fig.11. Hollow Beam with FRP subjected to load

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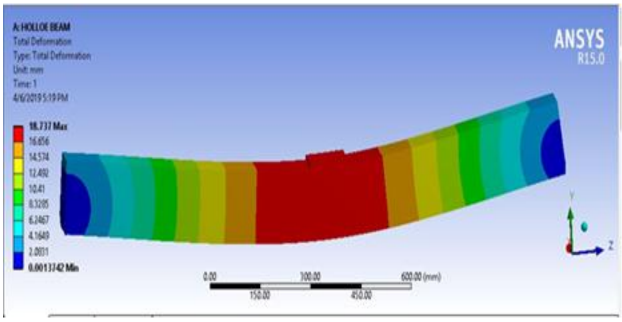

Fig.12. Hollow Beam with SF & FRP subjected to load

V. CONCLUSION

Eight pairs of concrete beams in which each pair having one hollow beam and the other one is solid beam with steel fibre and FRP wrapping combination were tested. Normal concrete beam is compared with the hollow beams with and without Steel fibre and FRP wrapping. Solid beams with Steel fibre show better loading capacity at the same time solid beam with FRP wrapping alone does not give satisfactory results in terms of loading capacity. Combination of SF and FRP provides much better results than that of solid beams. The variation of loads between solid and hollow beam is less and also the strengthening of hollow by steel fibre and FRP satisfactorily enhanced its loading properties due to its tensile strengths of the SF and FRP. The results indicated that the hollow beams with SF and FRP gained strength properties so it can be used in the place of solid beams. From this work it could be concluded that hollow beams help in saving concrete thereby leading to economic gain without compromising on the strength properties.

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