Numerical Study on Thermal Performance and Flexural Behaviour of Slim Floor Beam with Hollow Core Slabs using Carbon Fiber Reinforced Polymer

Agnes Manoj[1,*], Deepa Joseph[1]

[1]Department of Civil Engineering, St. Joseph's College of Engineering and Technology, Palai -686579, India
* agnesmanoj2108@gmail.com, Tel. : 6282456203

ABSTRACT

Slim Floor Beams are steel sections inserted in a concrete slab that provide the benefits of a steel-concrete composite structure with a shallower floor depth, resulting lighter in weight. Composite slim-floor beams can be utilized in conjunction with a variety of floor components, such as profiled steel deck or precast concrete slabs. One of the most intriguing typologies is created by combining the slim-floor beam with precast hollow core slabs. Steel-concrete composite beams are used in buildings and industrial structures, which are much stronger and stiffer. It is a well-known and effective solution that enables both simple installation of technical equipment and a significant reduction in floor thickness. it is mostly used in the expanding market for open-plan workplaces and multi-story parking structures. This study focuses on using Carbon Fiber Reinforced Polymer as an I-Beam instead of a steel beam, along with a bottom steel plate welded to the lower flange of the I-beam. The thermal performance and structural behaviour of Slim Floor Beam with Hollow Core Slabs are investigated using a finite element model created with ANSYS. The modal parts consist of CFRP I - beam, bottom steel plate, precast concrete slab, concrete encasement, reinforcing bars, and concrete topping. Here, two hollow core slabs were supported on the bottom plate, and between them a reinforcing bar and concrete encasement, along with concrete topping provided. The analysis strategy chosen is thermal and structural analysis, which is done to find thermal performance during a fire and structural behaviour in load-bearing capacity. Based on this study CFRP I – beam increases load carrying capacity and enhancing fire resistance.

Keywords - Slim Floor Beam, Hollow Core Slabs, Thermal Performance, Flexural Behaviour, ANSYS

1. INTRODUCTION

Steel-concrete composite structural systems are being used more frequently in the construction sector due to their cost-effective material consumption, and are actively being researched by the best universities and businesses in the globe. The slim-floor beam is one of the types of steel-concrete composite beams that are most frequently employed in real-world applications. A steel section inserted in a concrete slab to create the shallow flooring system, also known as the Composite Slim-Floor Beam (CoSFB), which offers the advantages of a steel-concrete composite structure while being lighter in weight than a pure concrete slab. In addition to improving the fire resistance of the floor, reducing the overall height of a building for a given number of floors, and achieving a flat soffit with complete freedom in service distribution below the floor. CoSFB systems provide a variety of other benefits that can be used in open-plan offices and multi-story parking systems.

This paper is focused on the development of a Finite Element Model (FEM) for the evaluation of slim-floor beams with precast hollow core slab floors were bottom steel plate welded to the lower flange of the CFRP I -beam. When precast hollow core slabs are combined with slim-floor beams, one of the most intriguing typologies is created. As it offers other advantages like quick construction and structural effectiveness for longer spans. The major goal is to identify the thermal and structural analysis, which is done to find thermal performance during a fire and structural behaviour in load-bearing capacity.

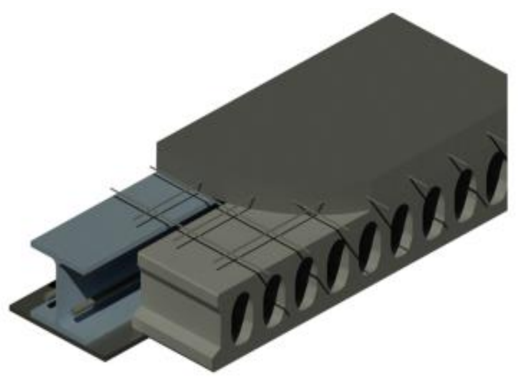


Fig. 1. Slim Floor Beam with Hollow Core Slabs

In particular, an appropriate fire behaviour in the case of a fire is anticipated since, unlike other composite beams that are not completely immersed in the floor, this type of beam is only exposed to fire from its lower flange. For composite beams with concrete encasement, EN 1994-1-2 offers model to assess temperature in the event of a standard ISO-834 fire exposure (EN 1994-1-2 Annex F). Also, instead of using steel I-beams, the emphasis of this work is to focuses on using Carbon Fiber Reinforced Polymer I – beam and its thermal performance and flexural behaviour of slim-floor beams with hollow core slabs.

Advantages of using CFRP I – beam are:

- Light weight and corrosion resistance
- Five times lighter than steel
- High strength
- Five times stronger than steel and twice as stiff

2. FEM OF SLIM FLOOR BEAM WITH HOLLOW CORE SLABS

2.1 GEOMETRY

The creation of a finite element model for evaluating slim-floor composite beams—primarily those of the SFB typology—in combination with precast hollow core slab floors supported by the bottom steel plate and welded to the lower flange of the beam is the major goal of this research. Using the aid of ANSYS, a finite element thermal model for simulating nonlinear heat transfer analysis was created, and transient thermal analysis was used to examine the thermal performance of the CFRP I-beam. The structural behaviour of the following model was also investigated by structural analysis.

There is a thermal model specifically for the examination of the slim-floor in a fire and a mechanical model for load bearing capacity. The mechanical model was used to conduct the static structural analysis to determine their structural performance, while the thermal model was used to conduct the transient thermal analysis to determine their thermal performance. All model components were mesh-assembled. For meshing, a finite element size of 5 mm was used. The geometry of the hollow core slab holes in the finite element model was simplified, as can be seen. They had a square hole design.

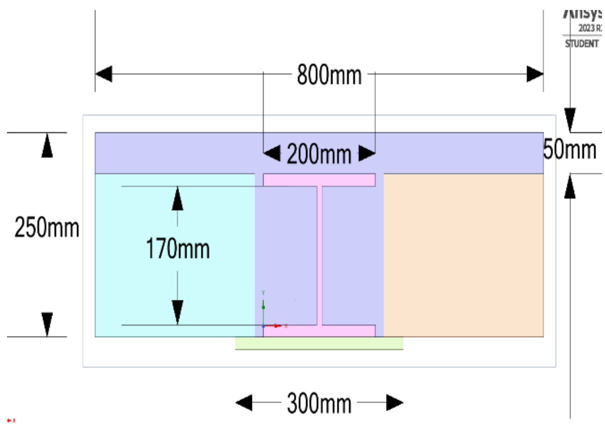


Fig. 2. Dimensions of Slim Floor Beam with Hollow Core Slabs

Table 1. Sizes of Validated Beam

PARAMETERS	**SIZES**
Length	6200mm
I Section	HEB 200
Base Plate	300X15mm
Rebars	2Ø20mmbar
Concrete Topping	50mm
Hollow Core Slab	200mm
Width of Web	42mm
Width of Hole	115mm
Height of Hole	130mm

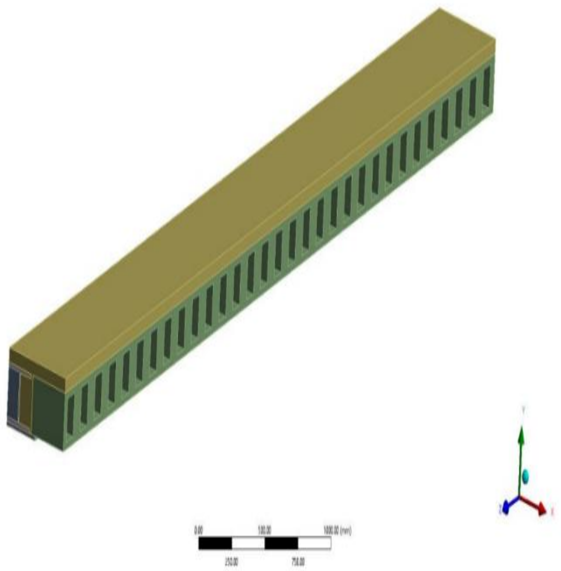


Fig. 3. Geometry

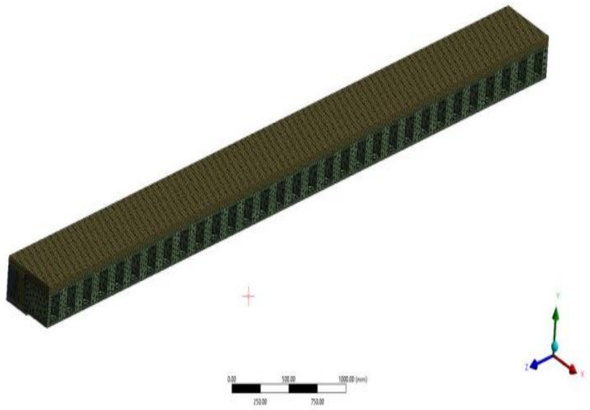


Fig. 4. Mesh

2.2 MATERIAL SPECIFICATION AND ENGINEERING PROPERTIES

The EN 1994-1-2 recommended temperature dependence of the thermal and mechanical properties of concrete, steel, and CFRP was considered during the numerical simulations.

Table 2. Materials

PARAMETERS	**DIFFERENT MATERIAL CASES**
I Beam Material Type	CFRP
Base Plate	Structural Steel

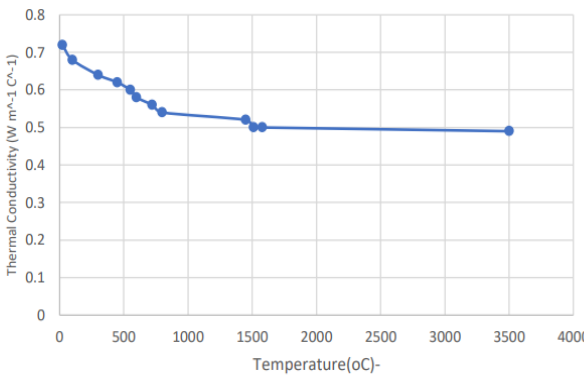


Fig. 5. Thermal Conductivity of Concrete as Per EN 1994 Table 1-2

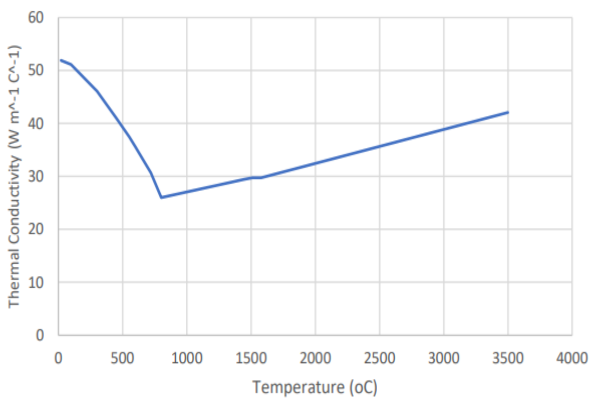


Fig. 6. Thermal Conductivity of Steel as Per EN 1994 Table 1-2

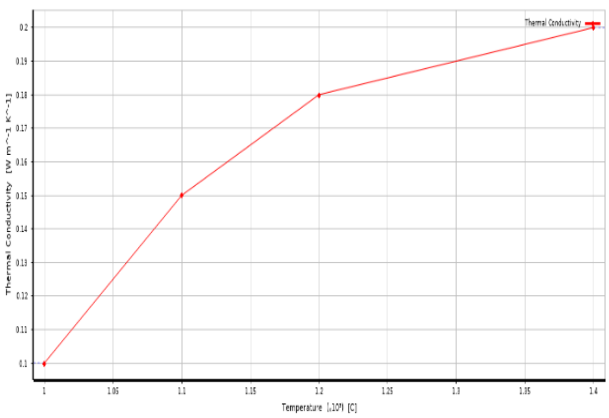


Fig. 7. Thermal conductivity of Carbon fiber as per EN 1994-1-2

- The temperature dependent material behaviour property changes, due to this reason thermal conductivity of concrete, steel, and CFRP taken from EN 1994 Table 1-2.
- When Comparing steel and CFRP, where steel is having higher thermal conductivity (42.1 $Wm^{-1}K^{-1}$) and CFRP is having low thermal conductivity (0.24 $Wm^{-1}K^{-1}$).
- For steel, when temperature increases thermal conductivity increases and the thermal resistivity decreases. But for CFRP, the temperature increases slowly due to low thermal conductivity and the thermal resistivity increases.

2.3 ANALYSIS

The numerical simulation was carried out using a thermal and structural analysis, therefore two distinct models - a mechanical model and a heat transfer model were required. The analysis was carried out by first computing the temperature field using a transient thermal analysis, and then computing the structural response using a static structural analysis. The slim-floor cross-section was only exposed to fire from its lower surface. The values recommended in EN 1991-1-2 were adopted for the governing parameters of the heat transfer problem.

Standard fire curve as per ISO 834 equation:

$$T = 20 + 345 \log (8t + 1)$$

Where, T -: Temperature

t -: Time

3. MODELLING OF CFRP I – BEAM

- Study is limited to the thermal performance of SFB configuration by using advanced materials like Carbon Fibre Reinforced Polymer.

- Study is limited to the use of Carbon Fiber Reinforced Polymer for enhancing the load-bearing capacity in SFB with HCS.

3.1 THERMAL ANALYSIS

- Boundary conditions :- Fire load, symmetry, convective coefficient bottom, convective coefficient top, emissivity, cavity radiation, adiabatic.
- Fire load :- Fire is given at the bottom portion, for that fire curve as per ISO 834 value taken from equation and enter into Ansys and obtain curve and maximum temperature is 1110^{o}c in 10800 second.

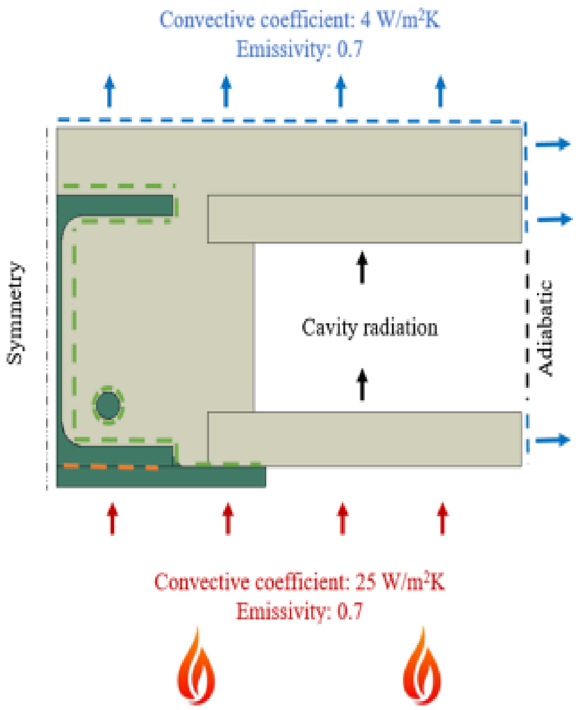


Fig. 8. Boundary Condition of SFB Thermal Model

- Symmetry :- Here, only the half portion is drawn and given symmetry in left side face and it form mirror plane.
- Convective coefficient bottom :- Due to fire there will be heat transfer and the bottom portion the convective coefficient is 25 W/m^2K.
- Convective coefficient top :- Due to fire there will be heat transfer and the top portion the convective coefficient is 4 W/m^2K.
- Radiation :- Due to fire there will be radiation throughout all portion around top, bottom, and cavity region.
- Cavity radiation :- In this region the emissivity is 0.7.
- Adiabatic :- There is no heat transfer excluding cavity region the right side face is given as perfectly insulated as magnitude zero.

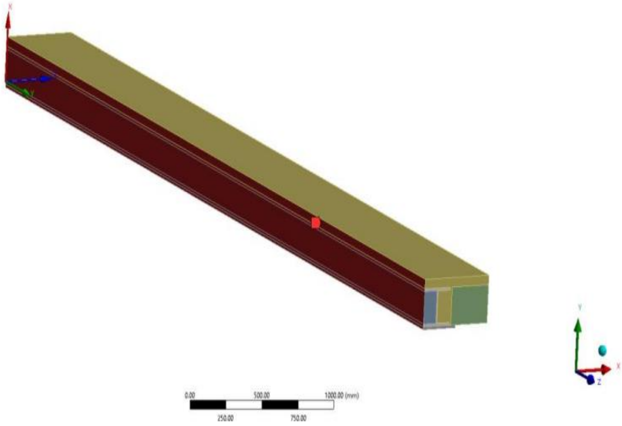


Fig. 9. Symmetry Region

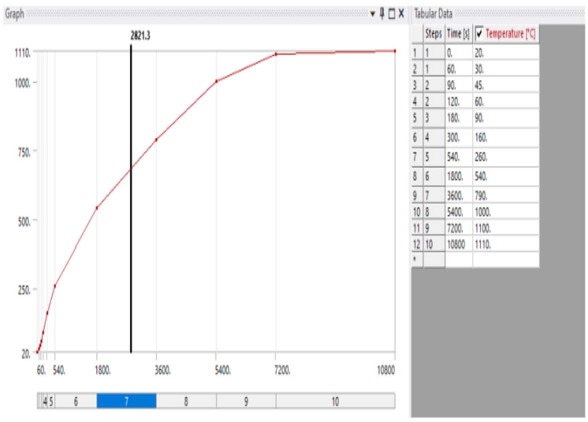


Fig. 10. Fire Curve

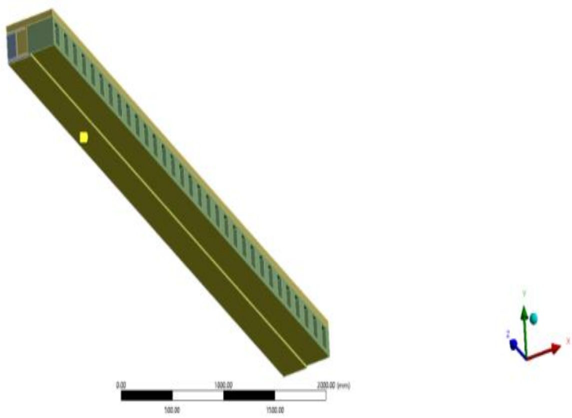


Fig. 11. Bottom side convection

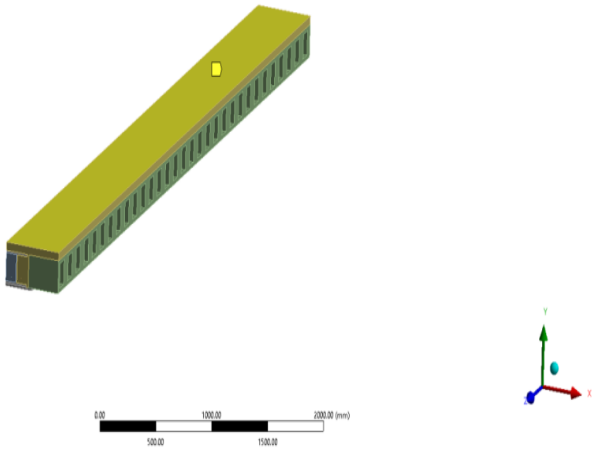


Fig. 12. Top side convection

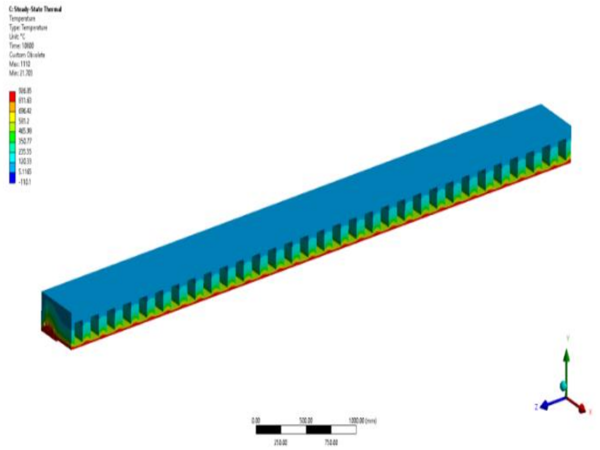


Fig. 15. Temperature distribution

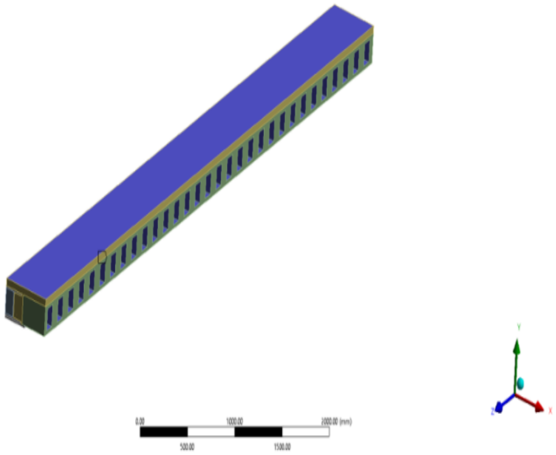


Fig. 13. Radiation top, bottom, and cavity

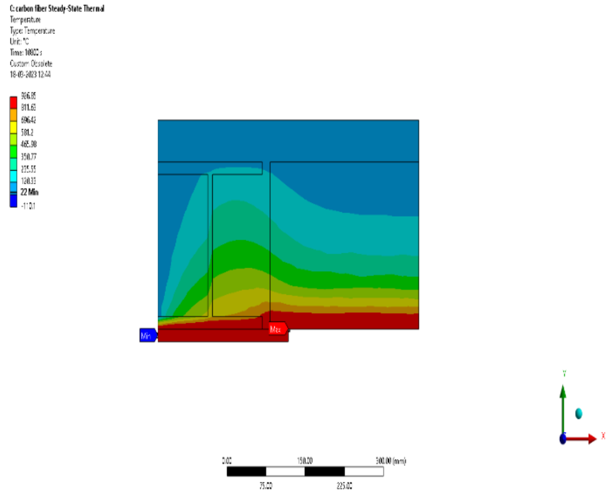


Fig. 16. Temperature profile

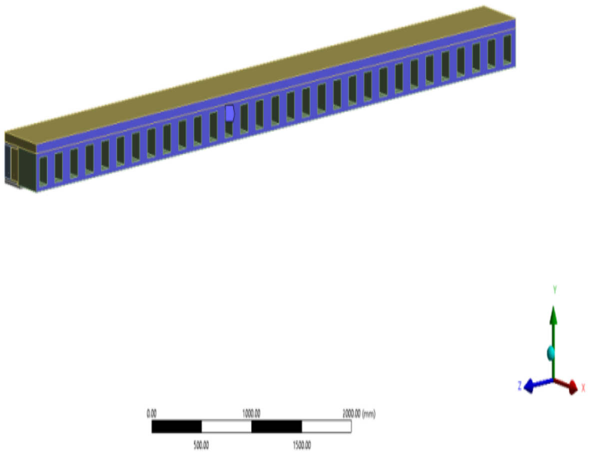


Fig. 14. Insulation

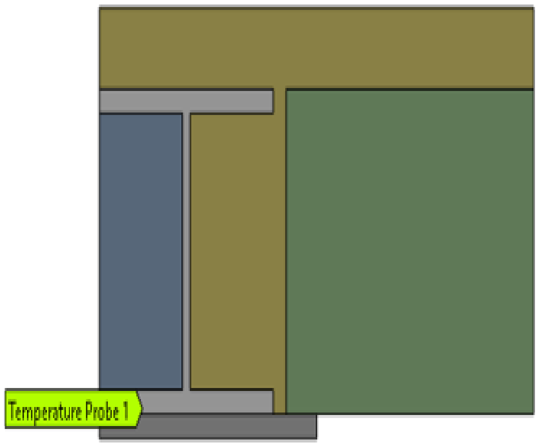


Fig. 17. Temperature probe 1

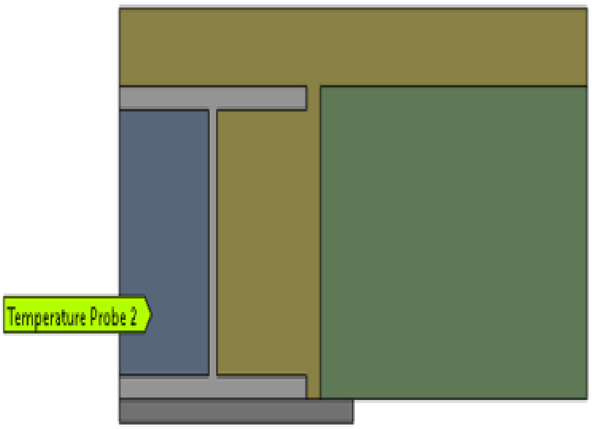


Fig. 18. Temperature probe 2

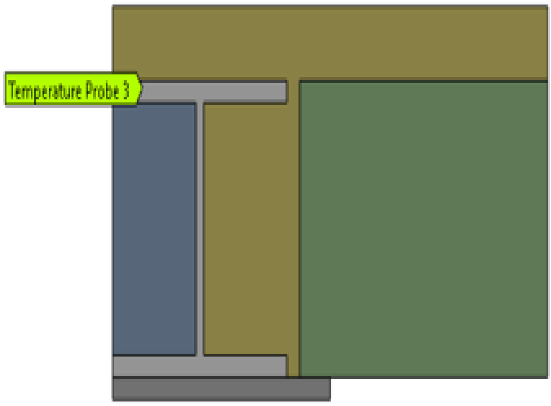


Fig. 19. Temperature probe 3

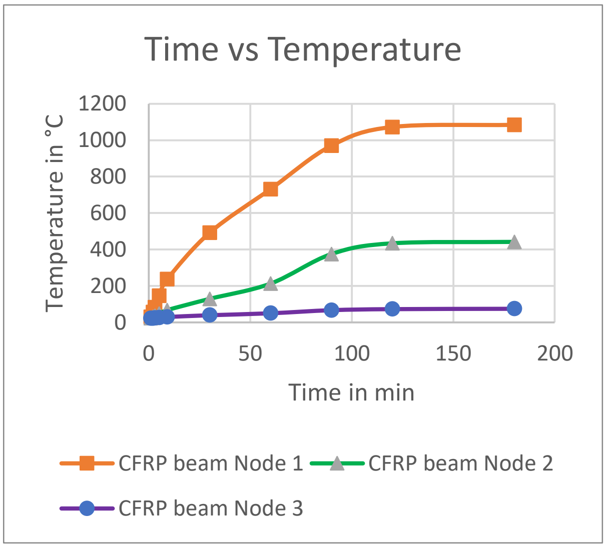


Fig. 20. Time vs Temperature of CFRP Graph

3.2 STRUCTURAL ANALYSIS

- Symmetric boundary conditions :- two symmetric boundary conditions are A-X symmetry and B-Z symmetry shown in red . Where a plane is selected and given name A in X direction symmetry and also a plane B selected in Z direction symmetry.
- Boundary condition and loading :- here six degree of freedom and four point load where RX is free and is pin supported on edge. Similarly, due to symmetry the other side edge is also pin supported. Then prescribed displacement as 31mm downward direction. From that we can obtain the ultimate load the beam can carry.
- Results and graph obtain related to total deformation, equivalent stress contour and load displacement of CFRP I – beam.

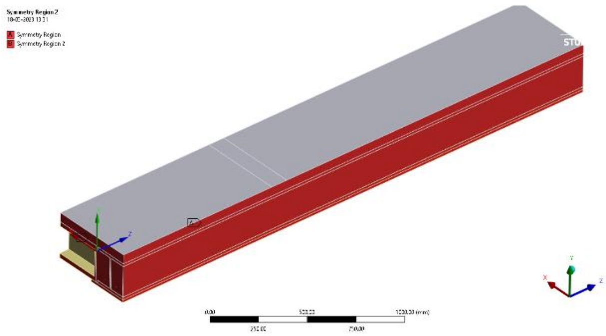


Fig. 21. Symmetric boundary conditions

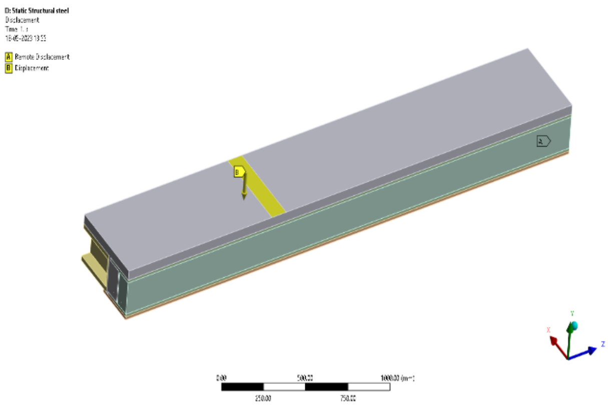


Fig. 22. Boundary conditions and loading

Table 3. Boundary Conditions and Loading

Degrees of freedom	X	Y	Z	RX	RY	RZ
A-Pin joint	0	0	0	free	0	0
Prescribed displacement	0	-31mm	0	0	0	0

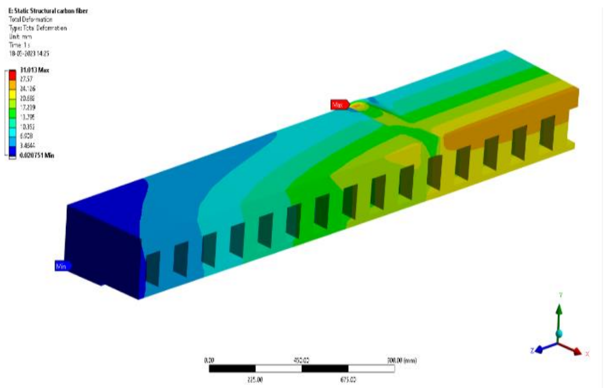


Fig. 23. Total deformation

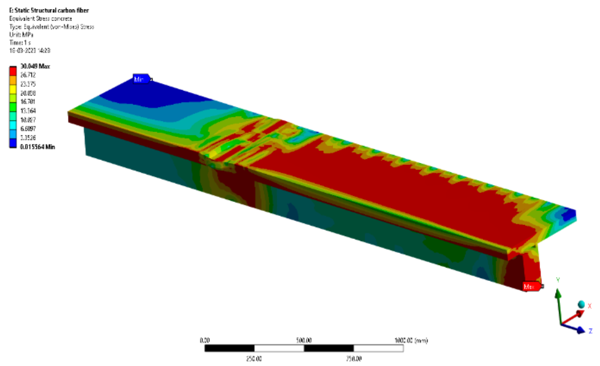


Fig. 24. Equivalent stress concrete

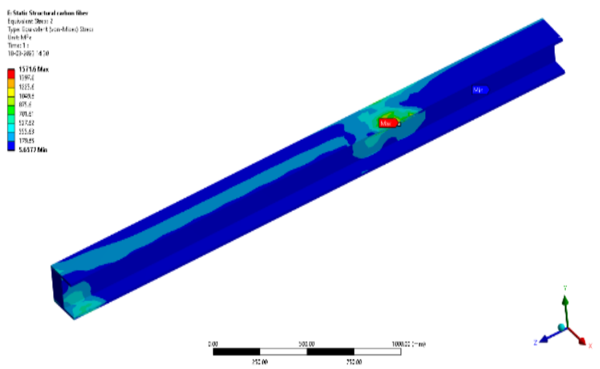


Fig. 25. Equivalent stress CFRP beam

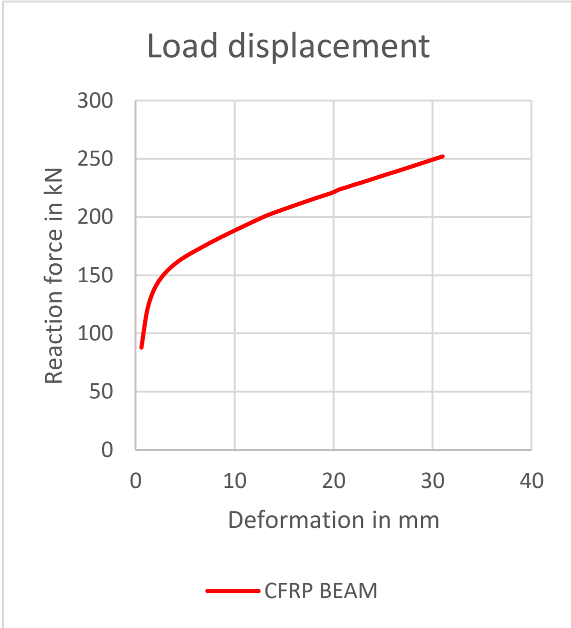
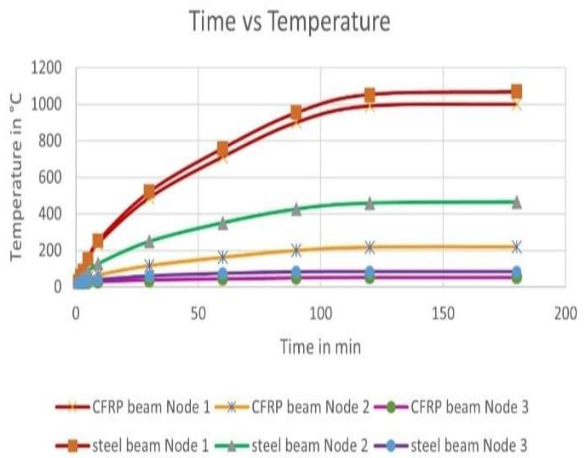


Fig. 26. Load displacement of CFRP graph

4. RESULTS

- In this thermal analysis involved replacing the structural steel part with a CFRP section to analyse the SFB with HCS. The temperature curve for a slim floor beam with a hollow core slabs made of CFRP is shown after thermal analysis. The maximum temperature recorded in SFB using CFRP in embedded I beam is 1000.5 °C at Temperature probe 1, 218.8 °C at Temperature probe 2 and 52.653 °C at Temperature probe 3. This decrease in temperature in SFB with HCS is due to the change in the thermal properties of CFRP. This demonstrates that the thermal performance of the CFRP material section is better than the structural steel material.
- Following a structural analysis, the maximum load the CFRP that can carry is 252.5kN an increase in ultimate load. Compared to



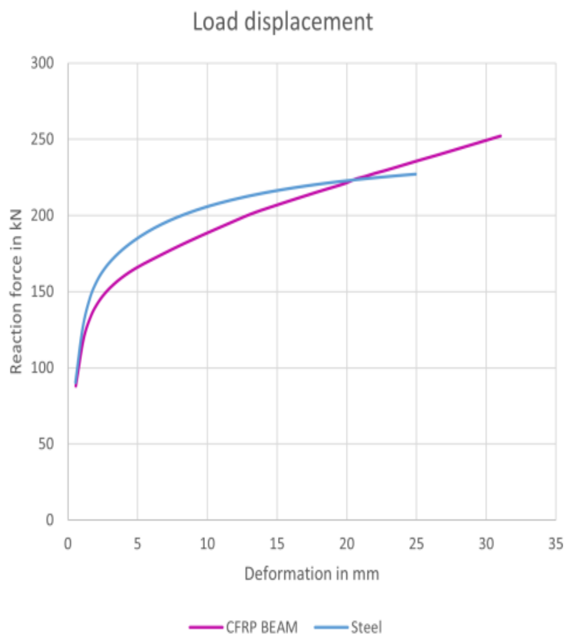
structural steel material sections, it has better thermal and structural performance..

Fig. 27. Comparison graph of Time vs Temperature between Steel and CFRP beam

Table 4. Comparison between steel and CFRP beam of thermal analysis

MATERIAL	T1 (^{o}C)	T2 (^{o}C)	T3 (^{o}C)
Steel I – beam	1100.8	452.1	81.5
CFRP I -beam	1000.5	218.8	52.653

- From this transient thermal analysis, the comparison conducted between steel and CFRP beam. Its very clear that CFRP beam, increase the temperature slowly due to low thermal conductivity by this thermal resistivity increases.



- Due to decrease in temperature, the CFRP I – beam shows better fire resistance than steel beam and validated.

Fig. 28. Comparison graph of Load displacement graph between steel and CFRP beam

Table 5. Comparison between steel and CFRP beam of structural analysis

SPECIMEN	ULTIMATE LOAD IN KN
Steel I - beam	227KN
CFRP I - beam	252.5KN

- From this structural analysis, the comparison conducted between steel and CFRP beam. Its clear that CFRP beam, has five times stronger than steel and twice as stiff and having high strength.

- Due to increase in ultimate load, CFRP I – beam shows better load bearing capacity than steel beam and validated.

5. CONCLUSION

Based on numerical studies conducted, the following conclusion can be drawn:

- From the Time versus Temperature graph, shows the use of material like CFRP I – beam can perform good fire resistance than structural steel.
- From the Load-Displacement graph, shows the use of CFRP beam the load carrying capacity is higher compared to the structural steel beam model. Hence a better structural performance.
- Also, the use of reinforcing bars combined with concrete and the use of the bottom plate may contribute enhancing the fire resistance of slim-floor beams.
- The maximum temperature recorded in SFB using structural steel in embedded I beam is 951 °C at Temperature probe 1, 418.33 °C at Temperature probe 2, and 81.24 °C at Temperature probe 3. Where, the maximum temperature recorded in SFB using CFRP in embedded I beam is 1000.5 °C at Temperature probe 1, 218.8 °C at Temperature probe 2, and 52.653 °C at Temperature probe 3. This decrease in temperature in SFB with HCS is due to the change in the thermal properties of CFRP. From the result of thermal analysis, CFRP is better than a steel beam.
- The load carrying capacity for structural steel is 227KN and for CFRP beam is 252.5KN. So from this result, it's easy to identify the structural performance of the CFRP beam has five times stronger than steel and twice as stiff, light weight and corrosion resistance, five times lighter than steel, high strength is better than a steel beam.
- A well-validated numerical model revealed that the slim-floor beam configuration had the most influence. It was determined that this configuration increases load carrying capacity and enhancing fire resistance.

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