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Transient Thermal Effect of FRC Incorporated PECC under High Temperature

J.Jeyanthi, P.Vincent

***Abstract:** In this paper thermal behavior of Partially Encased Composite column (PECC) made of Fiber Reinforced Concrete (FRC) has been carried out. Steel wool (SW) and carbon fiber (CF) were used to make fiber reinforced concrete (FRC) specimens. The fiber proportion was varied from 0 to 1%. From the Compressive strength test it was observed that FRC with 0.5%CF-0.5%SW has more strength, to be the best proportion among the tested specimens. Transient thermal analysis of PECC made of FRC was carried out by ANSYS 17.2 The temperature range was considered from 400ºC to 800ºC with a time frame of 30 to 120 minutes, for the time interval of 30 minutes as per ISO 834.From the analysis it was observed that temperature at the core of fibre incorporated PECC was found to be very less i.e. 11ºC to 26 ºC compared to surface temperature of 400 ºC to 800 ºC and slows down the heat transfer from surface to core, made the column for high temperature application.*

***Index Terms:** Fibres, PECC, ANSYS R17.2, Heat transfer.*

I. INTRODUCTION

The performance of Fiber reinforced concrete structure in excessive fire is dependent on the composition and properties of aggregates used, the mix design, moisture condition, and fiber volume fraction. Even though Concrete is non inflammable material, at critical temperature it will undergo deformation. Steel fiber volume fraction is significantly added value to the compressive strength of steel fiber reinforced high strength concrete [1].The randomly distributed carbon fibers can reduce the damage of the pore of concrete structure by the thermal decomposition processes [2].High-strength concrete (HSC) and Hybrid Fiber Reinforced HSC are tends to spall at 400 °C, 800 °C respectively [3].At elevated temperatures strength and stiffness of the concrete are considerably reduced. Moreover steel fibers enhance the ductility and the cracking behavior of concrete [4].The use of hybrid fibers in concrete can result in the development of higher residual tensile strength and improved toughness at elevated temperatures [5].

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Three dimensional (3D) finite element (FE) model for the accurate prediction of both the thermal and the mechanical behavior of RC exposed exposed to fire was developed [6]. The incorporation of polypropylene and carbonate aggregate enhances the heat resistance of the concrete.

The addition of fibers greatly improves the thermal andmechanical behavior of concrete [7].The decrease in residual strength and thermal expansion of High Strength concrete noticed at higher temperature [8].Finite element analysis of SFRC beams subjected to bending shows a good agreement with the experimental failure study [9].FRC with incorporation of PPF or SF is good substitute to plain concrete since its strength, performance in high temperatures are better and setback the concrete spalling[10].The addition of steel fibers to plain concrete increases the flexural strength up to 1.5%, decreases in case of 2% [12].Fibres in concrete prevent the crack propagation so that formation of voids can be eliminated [13].

From the literatures it was concluded that the addition of fibers greatly improves the thermal and mechanical behavior of concrete.

II. EXPERIMENTAL PROCEDURE

A. Preparation of Test Specimens:

Fig A. Experimental Specimens

The standard size cube and cylindrical specimens in figure A were cast as per standard mix proportions with and without fiber combination to determine the compressive strength of the concrete specimens. Five different fiber volume fractions of Carbon and steel wool fiber shown in Table1 were chosen to prepare Fiber Reinforced Concrete specimens (FRC) for testing.

Table 1. Fiber Volume Fraction (V_f)

S.No	Carbon fibre (%)	Steel Wool fibre (%)
1	0	1.0

2	0.25	0.75
3	0.50	0.50
4	0.75	0.25
5	1.0	0

For each Fiber proportion, 3 numbers of cubes were cast for each trial. Totally 132 cubes were cast .

The specimens were de-molded after 24 hours and cured in submerged conditions. The Young's modulus of elasticity & Poisson's ratio was calculated using a stress strain plot of the cylindrical specimens.

B. Compressive Strength Test before thermal degradation:

The cured cube specimens were tested in 1000 kN capacity Universal Testing Machine (UTM) as in Figure B.

Fig B. Specimen tested in the UTM

The specimens were compressed up to the ultimate to determine the peak load at room temperature to determine the suitable hybrid fiber proportion in the strength aspect. The Figure C shows the compressive strength of specimens for various FRC mix proportions of the concrete.The Figure C clearly shows that the compressive strength increases with increase in fiber content compared to normal concrete (M30) but begins to decrease after certain fiber proportions. The maximum compressive strength was found in the FRC mix having an equal percentage of fiber proportions (0.5%CF-0.5%SW) for both 7days and 28 days cured specimens. The best fiber proportion of FRC according to compressive strength values was found to be 0.5%CF-0.5%SW and the same was considered for numerical analysis.

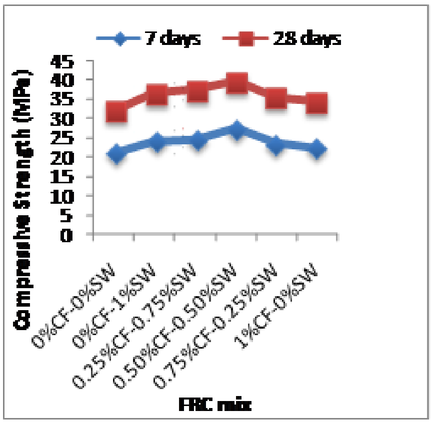

Fig C. Compressive strength before thermal degradation

C. Mass reduction of FRC specimens:

When exposed to elevated temperature voids will be formed in the specimens by the evaporation of water in the pores, which reduces the mass of the specimens by some percentage as shown in Figure D.

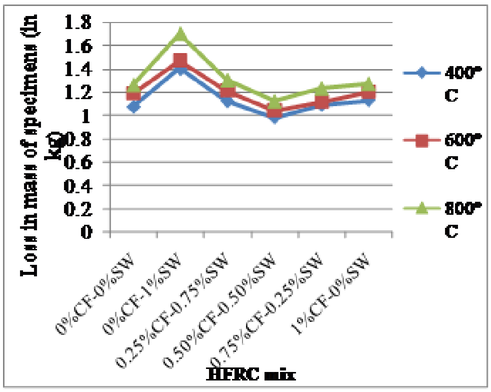

Fig D. Reduction in mass of specimens

The specimens were kept at elevated temperature in muffle furnace for the time period of 120 minutes. The minimum and maximum reduction in mass of 1.12 and 1.7 kg was found for FRC having 0%CF-1%SW , 0.5%CF-0.5%SW proportion respectively at 800ºC compared to other mix proportions for all temperature levels. The best fiber proportion of FRC according to mass reduction test was found to be 0.5%CF-0.5%SW and the same was considered for numerical analysis.

D. Compressive Strength Test after thermal degradation:

The cured cube specimen subjected to thermal load using a muffle furnace as in Figure E. From the standard fire curve as per ISO 834[11], the average temperature of a building during a fire is around 600ºC. Hence the cube and cylindrical specimens were subjected to the temperature range between 400 to 800 ºC. The holding time for all the specimens within the furnace was up to 120 minutes.

Fig E. Specimen in muffle furnace

After being exposed to elevated temperature, the specimens were again tested in the UTM to find out the compressive strength after thermal degradation. The Figure F illustrates the residual compressive strength for various mixes of FRC specimens after being exposed to different elevated temperatures.

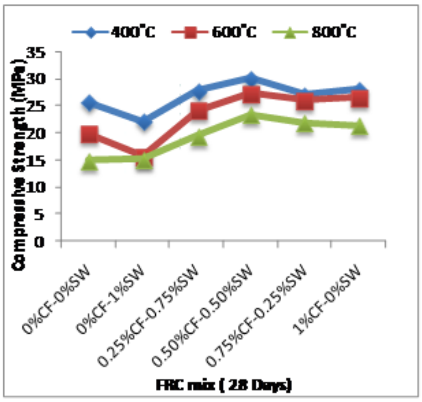

Fig F. Compressive strength after thermal degradation

The result indicates that the considerable reduction in compressive strength of the FRC on exposure to elevated temperatures compared to room temperature condition. It was noticed that the increase in temperature reduces the strength of concrete, even though the fiber proportions are same. Moreover, increase in the carbon fiber percentage from 0 to 0.5 with FRC increases the strength of the concrete and then started to reduce slightly. Carbon fibers act as a thermal barrier in concrete that enhances the strength of the concrete. It was also noticed that FRC having 0% CF – 1% SW shows less strength compared to plain concrete. The increase in the steel fiber percentage from 0 to 0.5 in FRC increases the strength of the concrete and then reduced slightly. On the whole, from the above results, 0.50% CF – 0.50% SW combination can be adopted as a best fiber proportion for FRC used in PECC under elevated temperature because it exhibits the maximum residual strength for all temperature levels.

III. TRANSIENT THERMAL ANALYSIS OF PECC:

A. Introduction:

In order to improve the fire resistance of PECC, FRC was placed in between the flanges of the I section. The Finite Element Modeling and Analysis of steel column and PECC were performed using ANSYS 17.2 (ANSYS heat workbench). Steady state, transient thermal analysis had been carried out to determine deformation, thermal stress, and the temperature distribution from surface to core of PECC. The various steps involved in the analysis are pre-processing, solution and post-processing. The two major components of PECC are Steel column and FRC.

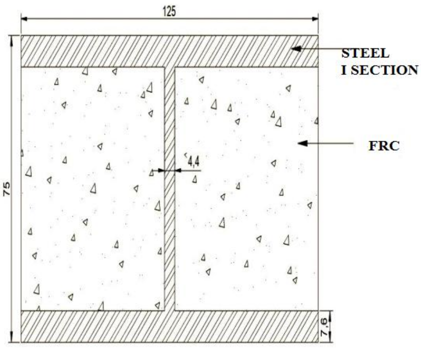

Fig G. Cross section of PECC

The steel I section consideration of the PECC model was ISMB 125 X 75. The dimension of the steel section with flange thickness 7.6 mm, web thickness.4 mm and the Length as 800 mm. The actual dimension with geometry is in Figure G.

B. Development of Finite element model:

The material properties for bare steel I section were taken from SP 6-1 (1964). The material properties found from the compression strength test were given as input for FRC. The material properties of steel I section and FRC are presented in Table.2.

Table 2. Material property

S.No	Property	Unit	Structural steel (Fe 415)	FRC (0.50% CF – 0.50% SW)
1	Density	Kg/m^3	7850	2300
2	Young's modulus	MPa	2 x 10^5	66240
3	Poisson's ratio	–	0.3	0.27

Steel column was modeled using an element called Solid185. An eight-node solid element, Solid 65, was used to model Fiber Reinforced Concrete (FRC).

C. Result and Discussion:

The FE model with boundary conditions is shown in Figure H.

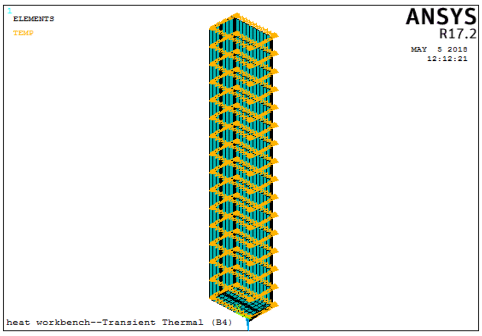

Fig H. FE model of PECC with thermal load

The Figures I to T shows the temperature distribution in PECC with the best fiber proportion of the FRC for the temperature ranges from 400°C to 800 °C with a time frame of 30 to 120 minutes.

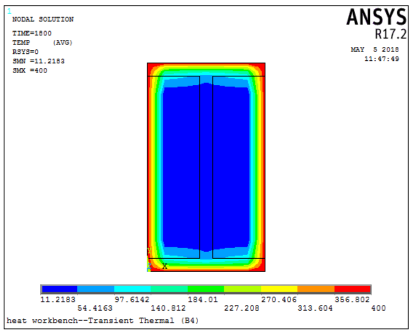

Fig I. Temperature distribution in PECC-0.50CF.0.50SW (400°C)At 30 minutes

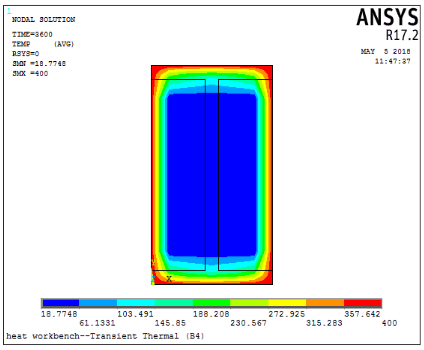

Fig J. Temperature distribution in PECC-0.50CF.0.50SW (400°C) At 60 minutes

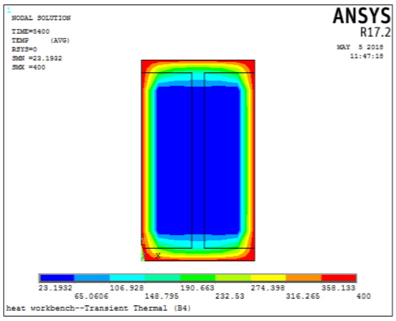

Fig K. Temperature distribution in PECC-0.50CF.0.50SW (400°C) At 90 minutes

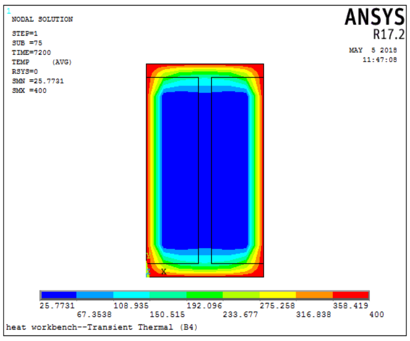

Fig L. Temperature distribution in PECC-0.50CF.0.50SW (400°C) At 120 minutes

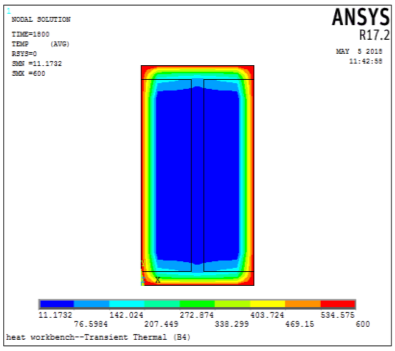

Fig M. Temperature distribution in PECC-0.50CF.0.50SW (600°C) At 30 minutes

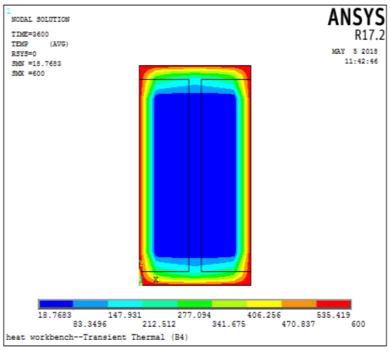

Fig N. Temperature distribution in PECC-0.50CF.0.50SW (600°C) At 60 minutes

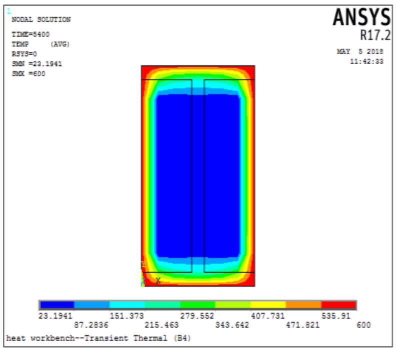

Fig O. Temperature distribution in PECC-0.50CF.0.50SW (600°C) At 90 minutes

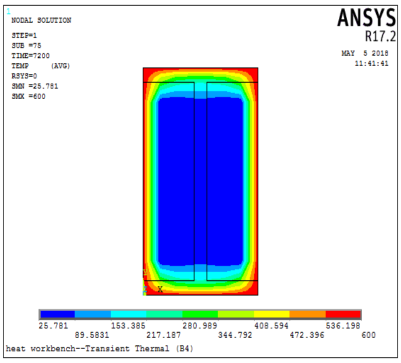

Fig P. Temperature distribution in PECC-0.50CF.0.50SW (600°C) At 120 minutes

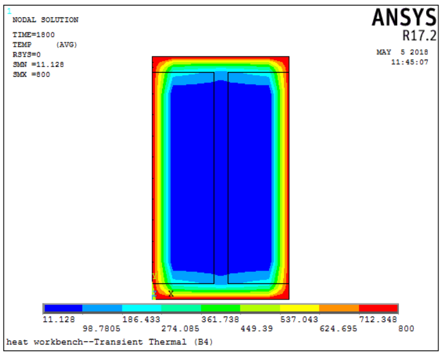

Fig Q. Temperature distribution in PECC-0.50CF.0.50SW (800°C) At 30 minutes

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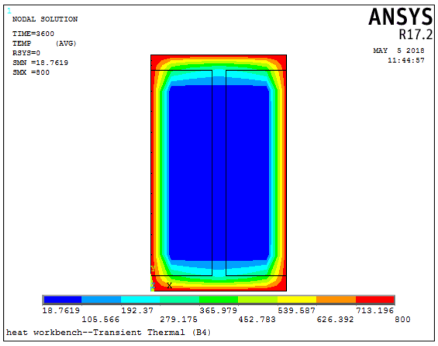

Fig R. Temperature distribution in PECC-0.50CF.0.50SW (800°C) At 60 minutes

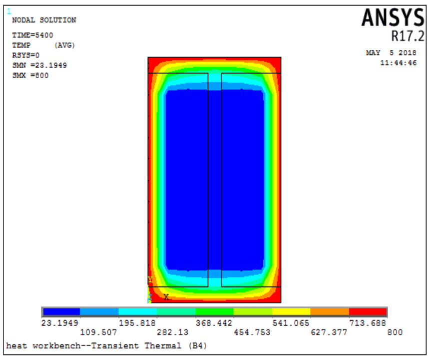

Fig S. Temperature distribution in PECC-0.50CF.0.50SW (800°C) At 90 minutes

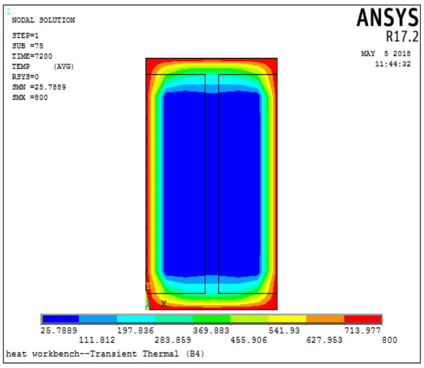

Fig T. Temperature distribution in PECC-0.50CF.0.50SW (800°C) At 120 minutes

From the above figures it was identified that the transfer of heat from the surface to the core in PECC was reduced by the addition of steel and carbon fiber in the concrete. When the surface temperature is at 400 °C, the temperature at the core of the column was found to be 11 °C, 18 °C, 23 °C and 25 °C for the exposed time period of 30, 60, 90 and 120 minutes respectively. Even though the surface temperature increases from 400°C to 800 °C, the core temperature of the PECC with FRC during the time period of i.e. 30, 60, 90 and 120 minutes were found to be almost same.

Table 3. Summary of results.

S.No	Applied Temperature (°C)	Surface Temperature of PECC (°C)	Minimum Core Temperature of PECC at			
			30 minutes	60 minutes	90 minutes	120 minutes
1	400	400	11.1	18.19	23.01	25.26
2	600	600	11.17	18.56	23.10	25.46
3	800	800	11.57	18.76	23.13	25.76

Hence, it is significant that the addition of fibers play an important role in lowering the heat transfer rate through the concrete, thereby delaying the time for the elevated temperature to reach the core I section and increase of the fire resistance of the PEC column. The summary of results is given in the Table. 3.

IV. CONCLUSION

From the analysis of the PECC reinforced with FRC, followings were found.

- The best fiber combination for the FRC as per the compression test and mass reduction analysis is 0.5%CF-0.5%SW.
- The compressive strength of the 0.5%CF-0.5%SW FRC was sustained by 76%, 68.96% and 59.24%, even after the thermal load of 400°C, 600°C and 800°C.
- The core temperature of the PECC with FRC was between 11°C to 26 °C compared to surface temperature of 400 °C to 800 °C.
- The temperature distribution plot depicts the maximum thermal stress at the surface and minimum thermal stress in the core of the PECC.

Hence, the fiber in the concrete reduces the heat transfer rate from the surface to the core in PECC, thereby delaying the temperature to reach the core and increase the thermal resistance of the PEC column for high temperature applications.

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Mrs.J.Jeyanthi, is pursuing her Ph.d in the area of Structural Engineering. As on date she has around 14 years of teaching experience. She has organized around 10 national level programme and published papers in reputed journals. Also she has presented paper at national level conference in reputed institutions. She is Life member in ISTE. She is guiding projects for students at UG and PG level.

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