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Analytical Study of FRCM under Elevated Temperature

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Abstract: ***The term strengthening means to increase the capacity of an existing structure and probability that it will survive for a long-period of time. This can be accomplished through strengthening by externally bonded FRP. Externally bonded FRP have advantages like light-weight, high tensile strength and resistance to corrosion which makes it an alternative to conventional methods. But it has certain limitations like poor behaviour of epoxy resin at temperatures above the glass transition temperature and relative high cost of epoxies [1]. The epoxy resin can be substituted with a cementitious matrix to improve the overall performance of strengthening system. This new system is known as Fiber Reinforced Cementitious Matrix (FRCM). FRCM has long-term durability, inherent heat resistance and compatibility with the substrate. In this paper, the mechanical properties of beam strengthened with FRCM at elevated temperature are studied analytically using ANSYS software. The reduction in load carrying capacity of FRCM strengthened beam at 300ºC after 1.5hrs, 2hrs, 3hrs and 6hrs were 2.1%, 2.8%, 5.6% and 12.5% respectively.***

Keywords: Strengthening, FRP, FRCM, Elevated temperature

1. Introduction

Repairing of a structure means to return the strength of the building or part of building. A building may get damaged through many ways like corrosion, overloading or by exposure to severe weather. If these damages are not repaired properly, the building may fail to continue its function. Externally bonded reinforcement is a good option as retrofitting system. Example for externally bonded reinforcement is fiber reinforced polymer (FRP). FRP consists of a polymer matrix and fibers (e.g. carbon, glass fibers). The advantages of FRP are light weight, high tensile strength and corrosion resistant. But it has several disadvantages due to the epoxy resin like debonding of FRP from the concrete structure, unstable nature of the epoxy at higher temperatures, and expensive.

A new composite material called fiber reinforced cementitious matrix (FRCM) can be used as an alternative to FRP. FRCM consists of a fiber mesh (e.g. carbon, PBO) and a cementitious matrix. The epoxy resin in the FRP is replaced by a cement mortar in FRCM, thus reducing the drawbacks offered by epoxy. FRCM has the following advantages [2].

(i) Compatibility with concrete
(ii) Corrosion resistant and long term durability
(iii) Inherent heat resistance

The application of FRCM for strengthening and change in the properties at higher temperatures should be further studied.

Bisby L.A experimented on FRCM systems for flexural strengthening on concrete under high temperature exposure. The type of FRCM used for the study was polybenzoxozole (PBO) FRCM and the experimental program included twelve RC beams – four were strengthened with FRP, six were strengthened with PBO FRCM and remaining two control beams. The beams were tested up to temperature of 120ºC and proved to be effective in bending [3]. As an extension they conducted an experiment on FRP versus FRCM at temperatures 50ºC and 80ºC i.e. glass transition temperature of epoxy resin. Beams were strengthened with CFRP and PBO FRCM. The reduction of strength in FRP strengthened beam was from 52% to 74% compared with 6% to 28% reduction in FRCM strengthened beam [4].

Rizwan Azam et al. investigated the effectiveness of different types of FRCM systems to strengthen shear critical reinforced concrete beams [5]. The results showed increase of load carrying capacity ranged from 19% to 105%. U-wrapped and side bonded strengthening schemes were also adopted and both exhibited similar behaviour.

2. Objectives

1. To investigate flexural behavior of FRCM strengthened beam using ANSYS software
2. To investigate the mechanical properties of FRCM beam at elevated temperatures.

3. Beam Specimen

For the study, a rectangular beam of size 600mm x 300mm is adopted (Figure 1). The beam is simply supported with an effective span of 6m. Grade of concrete adopted is M25 and grade of steel is Fe415.

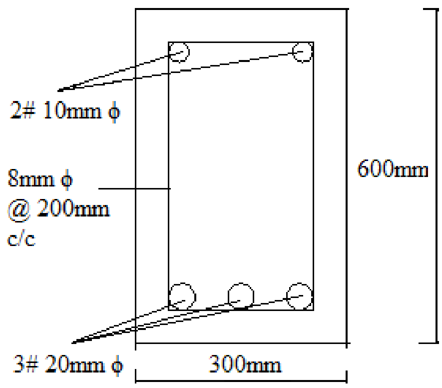

Figure 1: Details of beam specimen

The fiber for FRP is carbon. FRP is provided as three layers each of 1mm. The material for fiber mesh in FRCM is polybenzoxozole (PBO) and two layers of cement mortar (2mm each) is used Table 1 shows the properties of carbon FRP and FRCM.

Table 1: Material properties

Material		*Modulus of Elasticity (GPa)*	*Poisson's ratio*
Concrete		25	0.2
Steel		200	0.3
FRCM	PBO	270	0.33
	Cement Mortar	6	0.2
FRP		E_x = 62 E_y = 4.8 E_z = 4.8	v_{xy} = 0.22 v_{xz} = 0.22 v_{yz} = 0.3

4. Finite Element Analysis

4.1 Elements used

Solid65 was used for concrete beam. It has 8 nodes with 3 degree of freedom at each nodes, translations in nodal, x, y & z directions. Beam188 was used for steel reinforcement. It is a 2-node linear beam element in 3-D with six degrees of freedom at each node. For FRP, solid185 layered element was used, which has eight nodes having three degree of freedom. In the case of FRCM, for PBO fiber Link180 3D spar and for cement mortar SOLID185 with layered solid option is adopted. For the support and loading plate, SOLID185 was used.

4.2 Real Constants and Beam Section

Real constant for concrete is defined as 1. Real constant for PBO fiber is defined as 2 and its area of cross-section given is 3 mm^2. Shell section is defined for FRP and cementitious mortar and it includes thickness of layer and its orientation with respect to the axis. The beam section is defined for the steel reinforcement. The radius of the bar is given and shape of section is given as circular.

4.3 Material Properties

Linear properties such as modulus of elasticity and Poisson's ratio and non-linear properties like stress-strain curve, yield stress of steel reinforcement etc. are added.

4.5 Modelling and meshing

One-fourth of Concrete beam of size 600x300x6800 mm was modelled by creating volumes. Meshing was done by giving each specified element edge length size. Steel reinforcement is created by joining each nodes formed by meshing by specifying the section number, thus separate meshing is not required for steel reinforcement. After meshing, the areas between the supporting and loading plates, FRP layer, cementitious layer and beam should be bonded properly by contact pair.

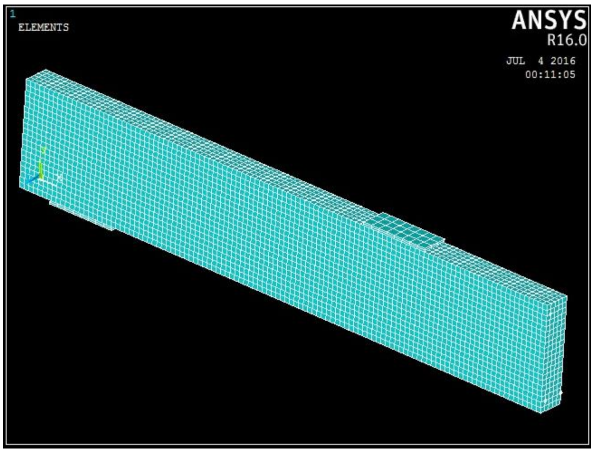

Figure 2: One-fourth beam model

4.5 Analysis

The beam is subjected to four-point bending. The appropriate boundary and support conditions were applied. Static structural analysis is done. Each load step is defined and during the analysis load step is divided into substeps. The time at end load step in solution and control option is total load at the load step. The load step file is solved.

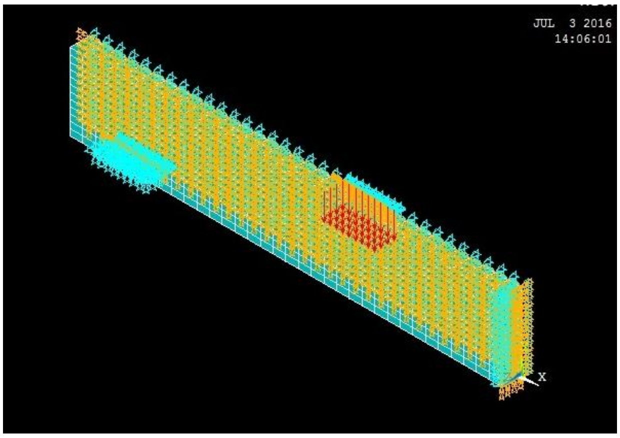

Figure 3: Beam model with support and boundary conditions

4.6 Results

The ultimate load for control beam obtained from static analysis is 86.5 kN. The maximum loads obtained for FRP and FRCM strengthened beams are shown in Table 2. The nodal displacement contours and the load versus deflection graph for control beam, FRP and FRCM strengthened beams are shown in Figure 4 to Figure 9.

Table 2: Ultimate loads obtained

Specimen	*Ultimate load obtained (kN)*	*Deflection (mm)*
Control beam	86.5	4.42
FRP strengthened beam	99.7	5.73
FRCM strengthened beam	107.6	6.13

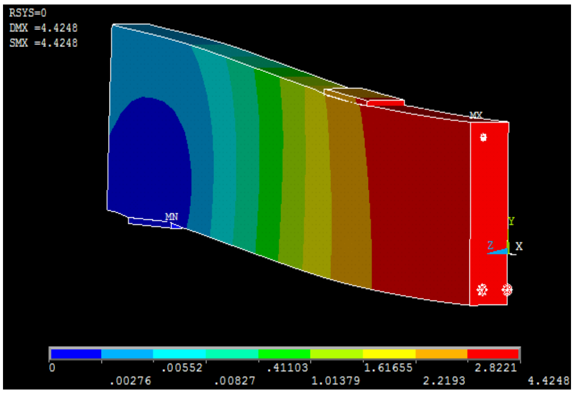

Figure 4: Deflection of control beam

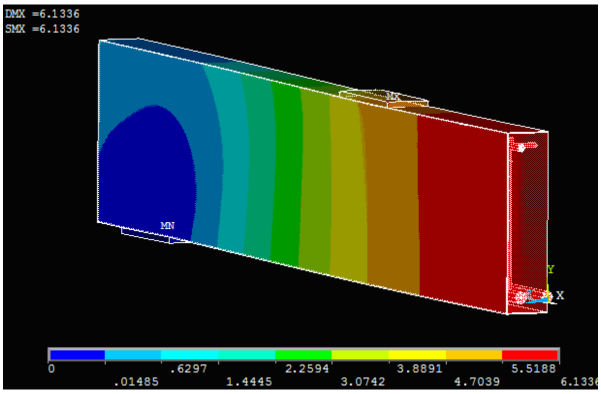

Figure 8: Deflection of FRCM strengthened beam

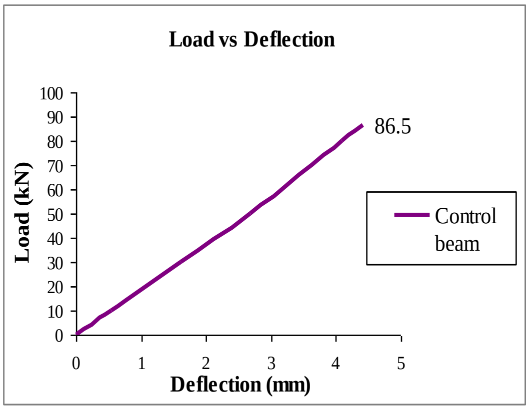

Figure 5: Load vs. Deflection at mid-span of control beam

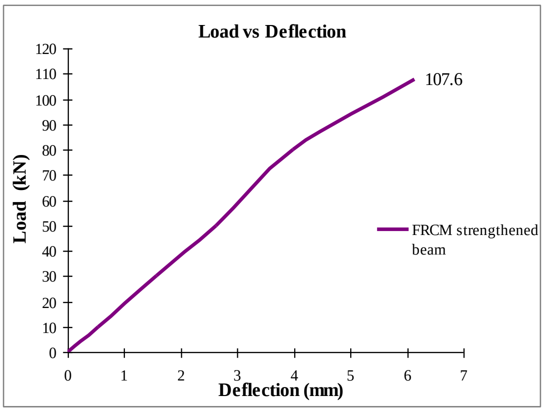

Figure 9: Load vs Deflection of FRCM strengthened beam

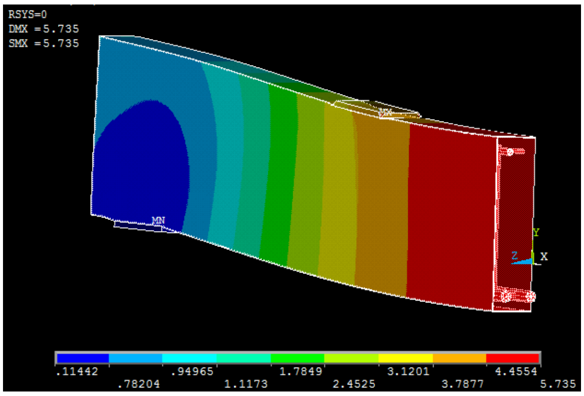

Figure 6: Deflection of FRP strengthened beam

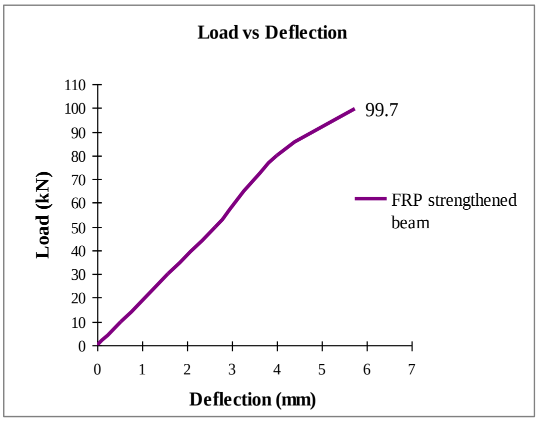

Figure 7: Load vs. Deflection of FRP strengthened beam

5. Coupled Thermal and Structural Analysis

5.1 Preprocessor

The element used for PBO fiber is LINK33 and rest is SOLID70. Thermal conductivity, specific heat and Thermal expansion coefficient are defined as the thermal properties. The beam is modeled. The thermal load is applied on the beam on the areas of the volume. The duration of heating is defined as time at the end of load step for the thermal analysis.

Along with thermal analysis, structural analysis is also done in order to know the flexural behaviour of the strengthened beam at higher temperature. After the analysis the results were plotted. The combined thermal and structural analysis was done at 300ºC up to duration of 6hrs. The thermal properties of the materials used are given Table 3.

Table 3: Thermal properties

Materials	*Density (kg/m3)*	*Specific heat (J/kg°C)*	*Thermal Conductivity (W/m°C)*
Concrete	2400	1000	1.2
Steel	7875	500	60
FRCM- PBO fiber	1560	1600	20
FRCM – cement mortar	1800	900	0.72

5.2 Results

The ultimate loads obtained for FRCM strengthened beam after 1.5hrs, 2hrs 3hrs and 6hrs at 300ºC are 105.4kN, 104.6 kN, 101.55 kN and 94.12 kN respectively which is higher than the maximum load carrying capacity of control beam. Their corresponding deflections are 6.29mm, 6.4mm,

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6.49mm and 6.6 mm. The percentage reduction in load carrying capacity at 300ºC for various durations is shown in Table 4. A gradual decrease in the load carried by FRCM strengthened beam is observed up to 6hrs. The nodal displacement plots at 300 ºC after 1.5hrs, 2hrs, 3hrs and 6hrs are shown in Figure 10 to Figure13.

Table 4: Percentage reduction in load carrying capacity of FRCM strengthened beam

Temperature	*Duration (hrs)*	*Percentage reduction in load carrying capacity (%)*
300ºC	1.5	2.1
	2	2.8
	3	5.6
	6	12.5

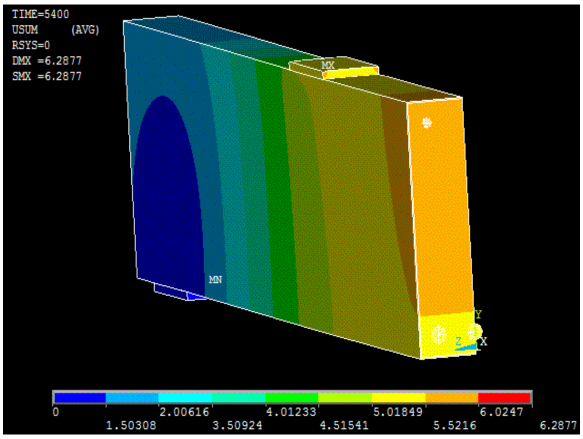

Figure 10: Deflection at mid-span after 1.5hrs

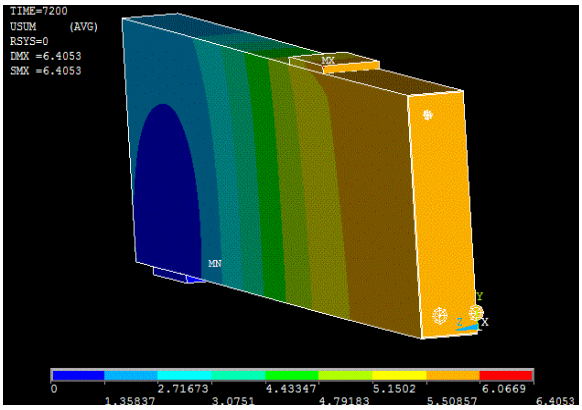

Figure 11: Deflection at mid-span after 2hrs

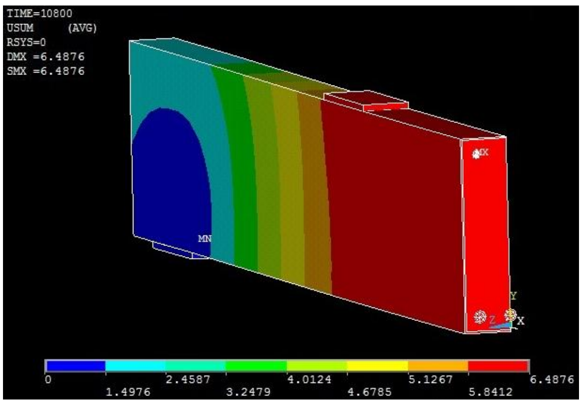

Figure 12: Deflection at mid-span after 3hrs

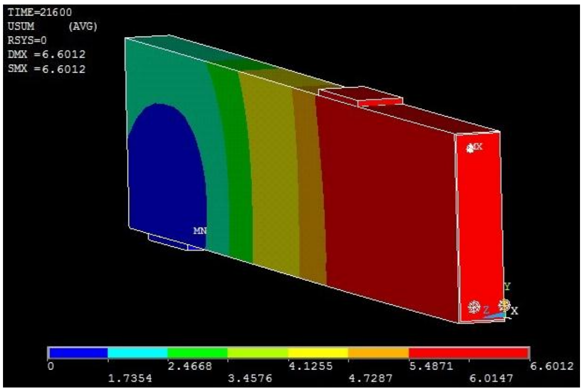

Figure 13: Deflection at mid-span after 6hrs

6. Conclusions

The structural analysis of control beam, FRP strengthened beam and FRCM strengthened beam was done by using ANSYS. The following conclusions were made from the coupled field thermal and structural analysis:

- FRCM strengthened beam were more efficient in flexural behavior.
- The percentage increases in load carrying capacity of the beam were 15% and 25% for FRP strengthened beams and FRCM strengthened beams respectively.
- The percentage reduction in load carrying capacity of FRCM strengthened beam at 300C after 1.5hrs, 2hrs, 3hrs and 6hrs were 2.1%, 2.8%, 5.6% and 12.5% respectively.
- FRCM strengthened beams retained the load carrying capacity of the control beam when subjected to 300 ºC up to duration of 6hrs.
- Further studies are needed to know the upper limit of the temperature up to which the FRCM can be effective without any failure.

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