Endurance of Insulated CFRP Strengthened Concrete Slab Subjected To Fire

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ABSTRACT

Carbon Fiber reinforced polymer (CFRP) composites are recently becoming an efficacious solution in rehabilitation and strengthening work for deteriorated reinforced concrete structures, because of their superior properties. It is important to maintain a sound interaction between CFRP and concrete for transferring stresses between concrete substrate and the CFRP sheet or plate. However, the epoxy adhesive used to create the bond is very sensitive to the temperature and mechanical properties deteriorate rapidly with exposure to the elevated temperature. The CFRP sheet or plate itself cannot provide sufficient insulation to the composite system. Therefore, application of a suitable insulation onto the CFRP sheet is important especially in the application of buildings.

Initially, a numerical model was developed to determine the behaviour of an insulated CFRP strengthened concrete block. The model predicted results were well agreed with the test results. Then the model was further developed to understand the behaviour of a CFRP strengthened concrete slab subjected to fire. Parametric studies were carried out to determine the fire resistance levels of the composite slab with the conductivity and the thickness of insulation.

Keywords: CFRP, Concrete, Insulation, Fire, Finite element modeling

1. INTRODUCTION

All structural materials such as concrete, steel etc; show some degradation in material properties at high temperatures. Hence Carbon Fiber Reinforced Polymer strengthen concrete members are also susceptible for deterioration. Carbon fibers have very good thermal stability and are relatively unaffected by temperatures in excess of 1000°C. But the epoxy adhesive is very sensitive for higher temperatures. Therefore temperature resistance of CFRP strengthened concrete member depends on the resin matrix. The load carrying capacity of the CFRP concrete composite system under fire is determined by the adhesive which has a lower glass transition point around 65°C – 150°C (ACI 2001). It has been shown by Gamage et al. (2005) that rapid strength loss appears when the epoxy reaches the temperature around 73.6°C. Although most of the advanced resin systems that are cured at high temperatures produce high quality and high performance even under elevated temperatures, the construction adhesives (epoxy) show poor characteristics at elevated temperatures. Therefore, the need arises to provide a passive fire resistance system. A few specified passive fire protection systems for FRP are available in the industry. The material called Vermitex-DX, a mixture of vermiculite cement blend with trace element, was applied passive fire protection for CFRP strengthened concrete members in this project. However, the thickness required to maintain suitable fire endurance is large and requires additional support for installation (e.g. mechanical reinforcement). This is not convenient in practice and that affects the aesthetic appearance of the structure. Full-scale fire tests are relatively difficult and very expensive to perform. Therefore the development of an accurate numerical model is necessary for further exploration of the composites in a wide variety of fire scenarios.

2. FINITE ELEMENT MODELING

ANSYS finite Element analysis program (release 12.1), was used for heat transfer analysis. The program employs the finite element method, and its theory is based on Fourier's law. The model consists of mainly three materials including concrete block, epoxy and CFRP sheet. For modeling purposes, Plane 55 elements was used which is a plane element with a 2-D thermal conduction capability. The element has four nodes with a single degree of freedom, temperature, at each node and is applicable to a 2-D, steady-state or transient thermal analysis. The mechanical material properties of CFRP and Epoxy were found from literature. Isotropic material properties were taken into account. The model assumed that there is no thermal property variation with temperature. For the epoxy and CFRP, element size of 0.176 mm was assigned whereas for the Concrete, 5mm of element size was assigned. A dense mesh was obtained at the interface of CFRP and Epoxy. There were no structural loads applied on the model. It was assumed that heat conducted to the model surfaces are convected away by surrounding air. So the model outer surfaces were exposed to the fluid having a convection coefficient of 0.04NS/mm/°C.

3. HEAT TRANSFER WITHOUT INSULATION

CFRP/concrete with no insulation was analyzed under experimental temperature conditions simulating the fire tests performed by Gamage et al. (2005). The experimental temperature in the oven was not uniform. For this model, the thermo-couple measured temperatures were applied onto the relevant surfaces as illustrated in Figure 1.

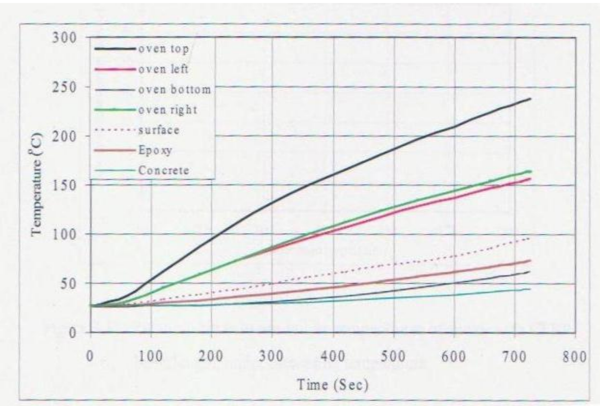


Figure 1: Ambient temperature curves based on the experiment (Gamage et al. 2005)

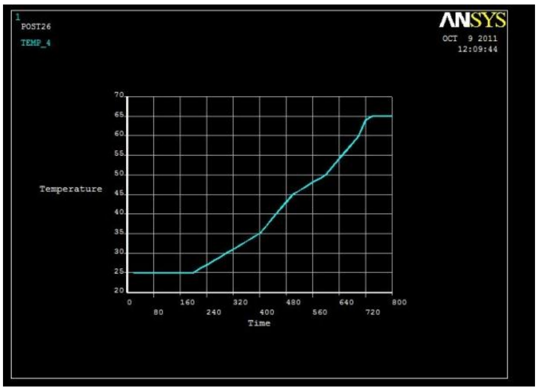


Figure 2: Numerical temperature variation between CFRP/Epoxy interfaces

Analysis was carried out using non-linear transient heat solver with small time steps of 20 seconds. The temperature variation at CFRP/Epoxy interface is shown in Figure 2. Experimentally measured temperatures in the specimen were compared with the temperatures predicted by the model. The temperature distributions agree well with those measured experimentally, with a difference of approximately 1% for concrete-epoxy interface and 5% on CFRP surface as illustrated in Figure 3. Since it can be expected higher accuracy.

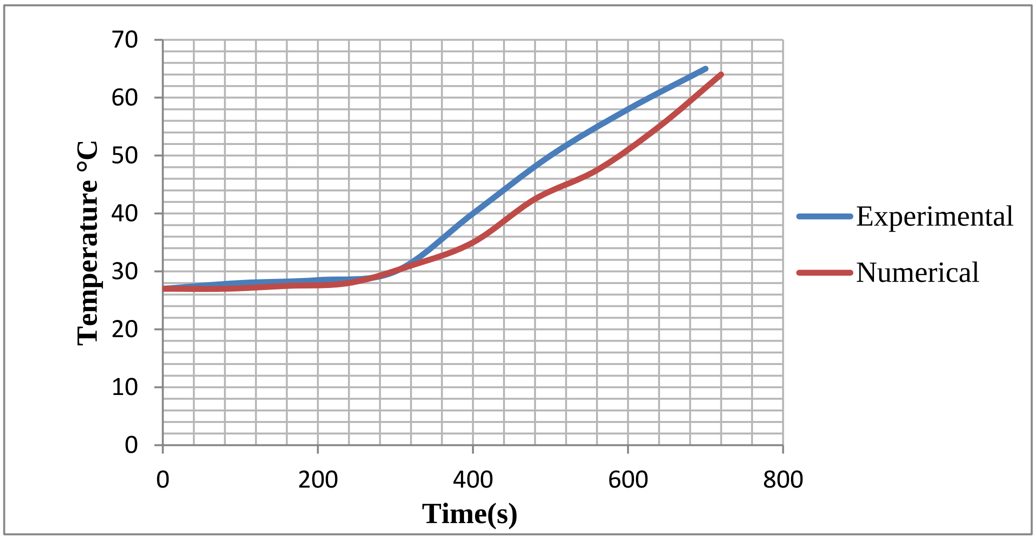
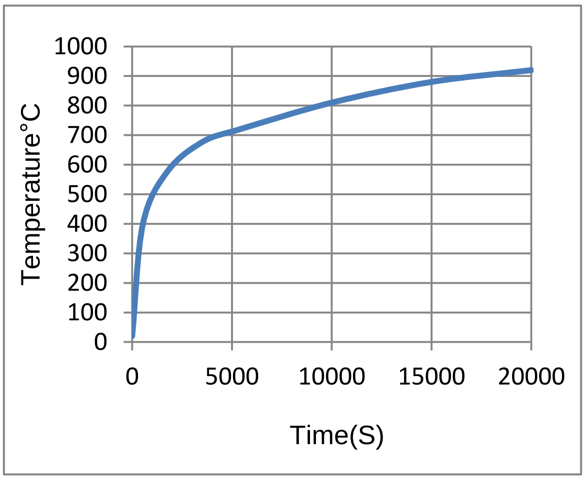
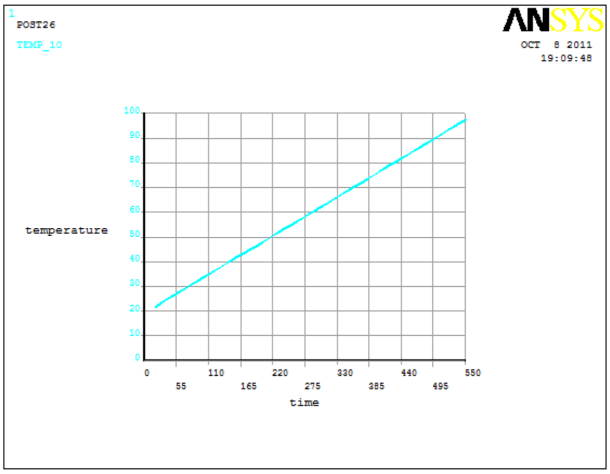


Figure 1: Comparison In between Experimental and Numerical results

Based on the finite element model developed as above, simulation of a heat transfer processes for the same CFRP strengthened concrete member under standard fire curve was carried out. The model was assumed to be subject to the standard fire curve in accordance with ACI, 2001, as in Figure 4. When analyzed the model, the specimen reached the failure temperature of about 73°C after a little more than 355 seconds of exposure to the fire. The model predicted temperature distributions at CFRP/Epoxy interface is shown in Figure 5.



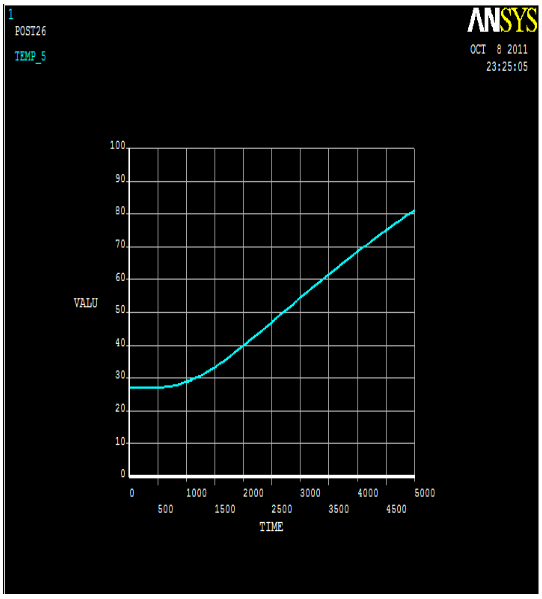


4. HEAT TRANSFER WITH INSULATION

For the current series of analysis, the material called “Vermitex” (vermiculite cement blend + trace elements) was used as the insulation. Model was analyzed for a series of different thicknesses of insulation layer. The insulation thickness of the CFRP layer was varied from 40 mm to 80mm. For this model, standard fire curve was applied only onto the top surface (CFRP plated side) of the specimen. The resultant temperature variation within the most sensitive interface, CFRP/epoxy, having 50 mm insulation thickness is illustrated in Figure 6.

Figure 2: Standard Fire curve (ACI, 2001)

Figure 3: Temperature variation between CFRP/Epoxy



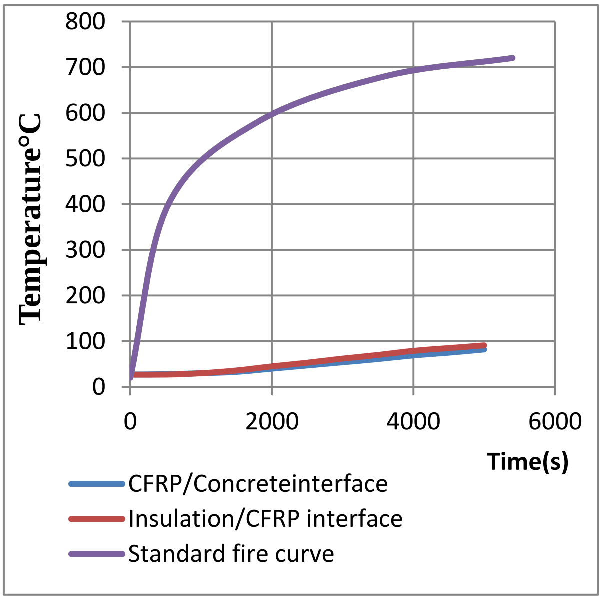


Figure 5: Temperature variation in between CFRP/Epoxy interface

Figure 4: Comparison between temperature variance at different interfaces & standard fire curve

With the insulation thickness variation, the fire resistance level varied accordingly. Fire ratings, based on the epoxy failure temperature of 73°C (Gamage et al 2005), for different insulation thicknesses are illustrated in Table 1 and Figure 8.

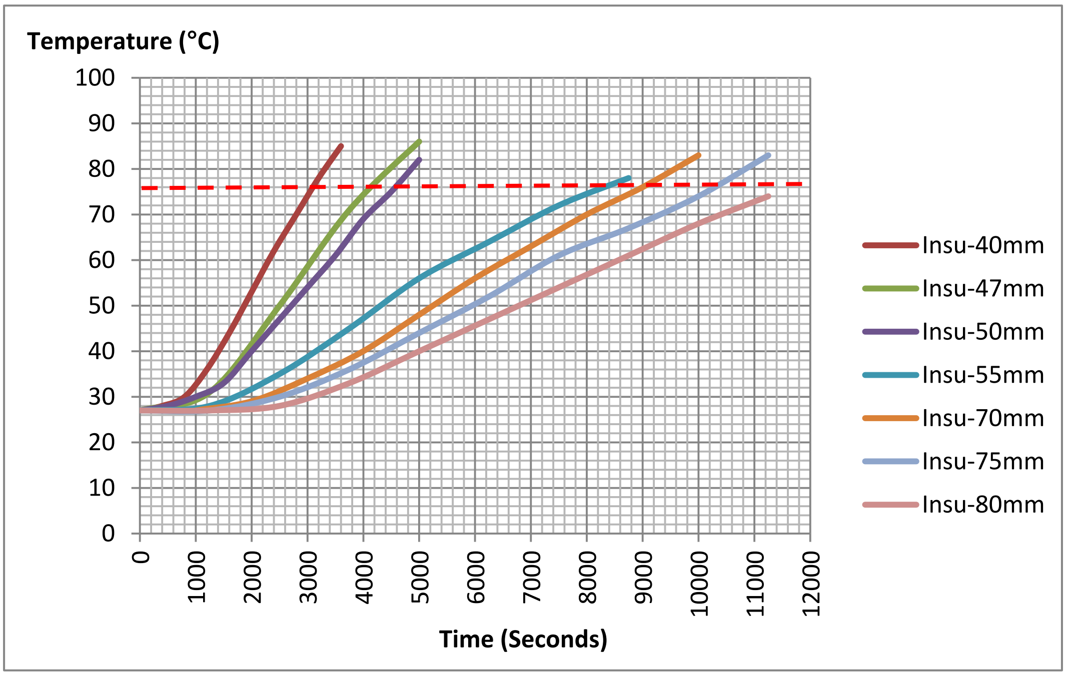


Figure 6: Temperature variation for different insulation thicknesses

Table 1: fire resistant level for different thicknesses of insulation

Specimen Number	Insulation thickness (mm)	Fire resistance level
1	40	47 minutes
2	47	1 hour
3	50	1 hour 11 minutes
4	55	2 hours
5	70	2 hours 22 minutes
6	75	2 hours 37 minutes
7	80	3hours

The model results were compared with the manufacturer's values. Table 2 illustrates the comparison between the model predicted fire resistance levels and the values given by the manufacturer.

Table 2: Comparison for insulation thickness

FRL (Hours)	Manufacturer's recommended insulation thickness (mm)	Numerical model predicted Thickness (mm)
1	45	47
2	60	55
3	75	80

5. PARAMETRIC STUDY

According to the manufacturer data thermal conductivity of insulation is 0.114 Nmm/s/mm/c. In order to improve the FRL, the thermal conductivity of the insulation was reduced stepwise while maintaining insulation layer thickness constant of 50 mm. The Figure 9 shows the FRL variation with the variation of thermal conductivity of the insulation layer. Hence, it was found that FRL would be 2 hours for the same 50 mm thickness insulation, if the thermal conductivity of the insulation layer was reduced to 0.08 Nmm/s/mm/c.

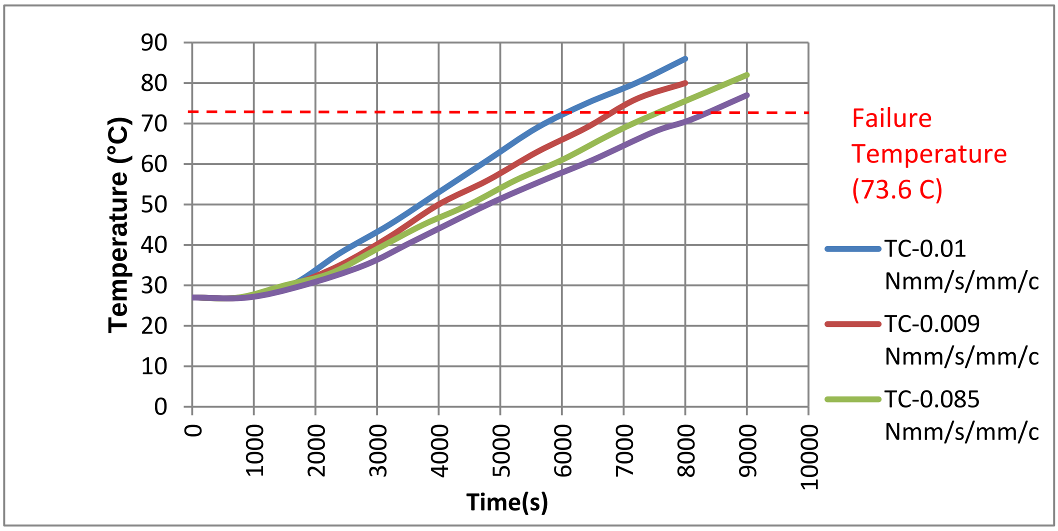


Figure 7: Variation of FRL for different thermal conductivity of insulation layer

CONCLUSIONS

Based on the heat transfer analysis conducted on the insulated CFRP strengthened concrete members, the following conclusions can be presented:

- Developed numerical model is very accurate (deviation from the experimental results is between 1% and 5%). It can be used to predict heat transfer within non insulted and insulated CFRP strengthened members under exposure to a standard fire.

- The non insulated model show nearly 5 minute fire resistance level under exposure to the standard fire. Therefore a suitable insulation material is required to provide adequate passive fire protection for the strengthened member.

- The numerical analysis results shows insulation Vermitex layer thickness of 47mm, (45mm –manufacturer data) can provide 1 hour resistance level; a 55mm (60mm-manufacturer data) thick insulation layer can provide 2 hour fire resistance level and an 80mm (75mm- manufacturer data) thick insulation layer can provide 3 hour fire resistance level.

- Parametric studies conducted using the numerical model indicates that the conductivity of the insulation, applied on the CFRP surface, is important factor affecting the fire resistance of the insulated member.

- The model analysed under the standard fire accordance with ACI 2001, shows 50 mm thick insulation having thermal conductivity of 0.114 N mm/s/mm/c can provide 1 hour fire resistance level. Hence for the same thickness of insulation layer, it was found that FRL would be 2 hours, if the thermal conductivity of the insulation layer is reduced to 0.08N mm/s/mm/c.

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