BOND PERFORMANCE OF CFRP STRENGTHENED CONCRETE SUBJECTED TO FIRE

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Abstract: CFRP (Carbon Fibre Reinforce Polymer) strengthening system has recently emerged as a practical alternative for the flexural strengthening of reinforced concrete structures because of its efficiency in terms of structural performances, costs, labour and time savings. While CFRP is widely used in bridge construction, it can also be taken advantage of for strengthening concrete members such as beams, columns and slabs. Even though structural engineers are interested in using CFRP for the strengthening work of concrete members in buildings, always hesitation occurs due to lack of knowledge of its fire performance. Therefore it is essential to assess and develop the needed information on fire resistance of CFRP strengthened concrete structural members. The epoxy adhesive used to create the bond is known to be very sensitive totemperature and its mechanical properties deteriorate rapidly with exposure toelevated 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 to buildings.In this study the behaviour of insulated CFRP/concrete members subjected to standard fire condition is explored. A finite element model, developed by using commercially available software ANSYS was used to simulate the thermal behaviour of the insulated composite structure.

Keywords: CFRP, ANSYS, Standard fire, Composite, Finite Element Model

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1. Introduction

Now-a-days it is becoming a worldwide trend to use fibre reinforced polymer (FRP) composites for strengthening purposes of reinforced concrete structures. FRP has several added advantages to be used as an alternative to the traditional structural materials such as steel reinforcement. It has high corrosion resistance and a high strength to weight ratio. Most existing solutions for the improvement of structural durability are expensive or complicate initial construction. It is generally expected that the use of FRP, as opposed to steel, will reduce these maintenance costs by a significant amount in the long-term. Furthermore, the use of composites in the rehabilitation of existing structures reduces the overall costs while reducing the construction period.

Although FRP strengthening has an enormous economic potential for use in multi-storey buildings, parking garages and industrial structures, it is still used mainly in bridgeengineering work. The fire resistance of concrete members strengthened with Carbon fibre reinforced polymer (CFRP) is an extremely crucial area that needs to be investigated prior to implementing CFRP composite materials in buildings. Although it was found that the behaviour of CFRP strengthened concrete structures at ambient temperatures is satisfactory, there is a lack of information regarding the behaviour of CFRP strengthened concrete members at high temperatures. Therefore the performance of bond between CFRP sheets and concrete is an issue that must be addressed in order to achieve safe and properly designed building structures with fire safety.

The current paper presents the results of a detailed investigation of thermal behaviour of CFRP-concrete composite based on a numerical study using ANSYS.

2. Fire performance of CFRP and Concrete composite

When a reinforced concrete member is strengthened with CFRP, the resulting member's -fire resistance will depend on the properties of the original concrete member as well as the properties of CFRP and the adhesive used. Carbon fibres have very good thermal stability and are relatively unaffected by temperatures in excess of 1000°C. But the epoxy adhesive is very sensitive to 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, 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 also affects the aesthetic appearance of the structure.

3.Finite element model

Full-scale fire tests, to find out the bond performance of CFRP-concrete members 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 conditions. A finite element model was developed by using ANSYS (version 12.1) based on theory of Fourier's law for heat conduction. The model consists of mainly three materials including concrete block, epoxy and a CFRP layer. For modelling purposes, Plane 55 element was used initially which is a plane element with a 2-D thermal conduction capability. The material properties were found from literature and assumed to be isotropic. A dense mesh was employed at CFRP and adhesive layers as a higher accuracy was expected at the critical region. There were no structural loads applied on the model. It was assumed that heat conducted to the model surfaces are convected away by surrounding fluid. The model outer surfaces were exposed to the fluid having a convection coefficient of 0.04NS/mm/°C.

3.1 Heat transfer without insulation

CFRP/concrete with no insulation was analysed 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.

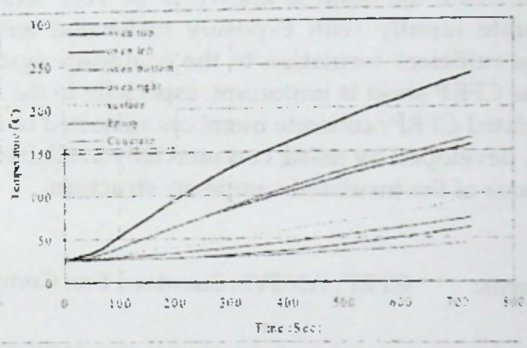

Figure 1: Experimental temperature distribution

The temperature variation at CFRP/Epoxy interface is shown in Figure 2.

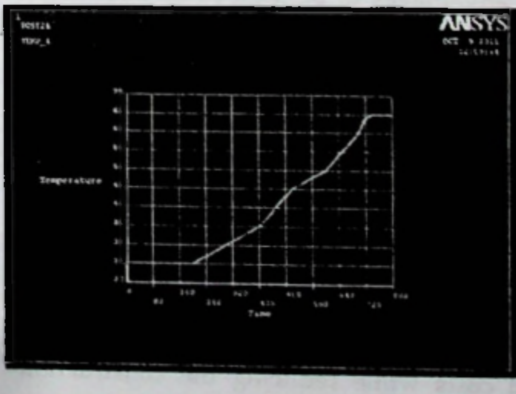

Figure 2: Temperature variation at CFRP/Epoxy interface

The temperature variation at the CFRP-epoxy interface, predicted by the model are compared with experimentally measured temperatures in the specimen as illustrated in Figure 3.

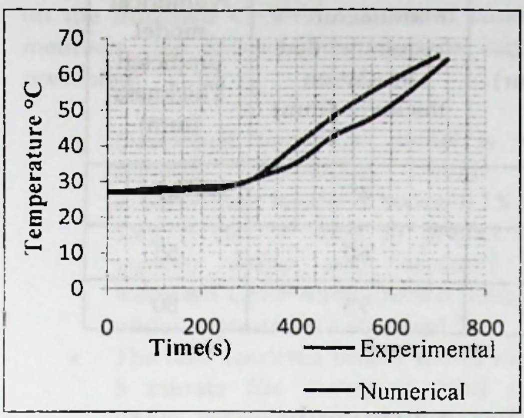

Figure 3: Comparison between Experimental and Numerical results

The temperature distributions agree well with those measured experimentally, with a difference of approximately 1% for concrete-epoxy interface and 5% on CFRP surface. Hence this numerical model can be considered accurate and can be confidently used to predict the temperature distributions of CFRP strengthened members under different fire scenarios.

Based on the finite element model developed as above, simulation ofheat 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. These analyses are useful because standard fire condition is usually adopted for structural fire engineering design for buildings.

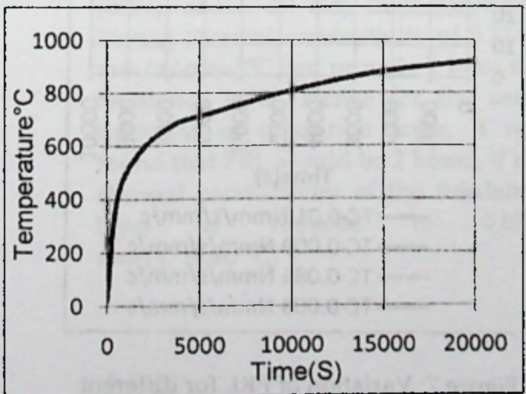

Figure 4: Standard Fire Curve (ACI, 2001)

When the model was analysed, the specimen reached the failure temperature of about 73°C after a little more than 355 seconds of exposure to the fire.

3.2 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 analysed for a series of different thicknesses of insulation layer. The insulation thickness of the CFRP layer was varied from 40 mm to 80mm. Here the temperature variation curves are depicted only regarding the specimen having 50 mm thick insulation layer. The resultant temperature variation within the most sensitive interface, CFRP/epoxy, having 50 mm insulation thickness is illustrated in Figure 5.

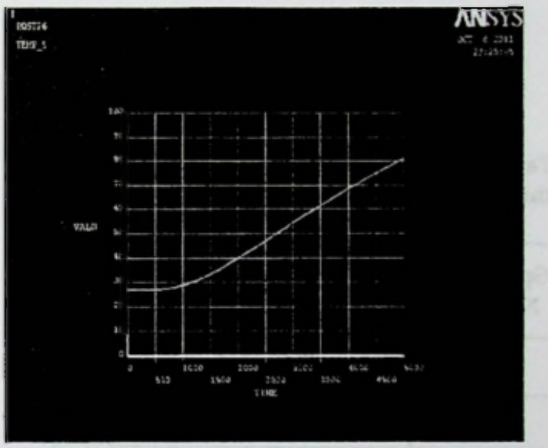

Figure 5: Temperature variation of CFRP/Epoxy interface

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.

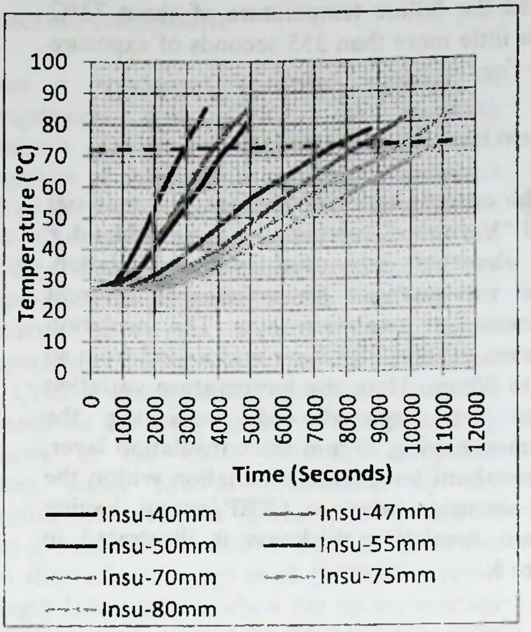

Figure 6: Temperature variation for different insulation thicknesses

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

4. Parametric study

According to the manufacturer data thermal conductivity of insulation is 0.114Nmm/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.Figure 7 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.

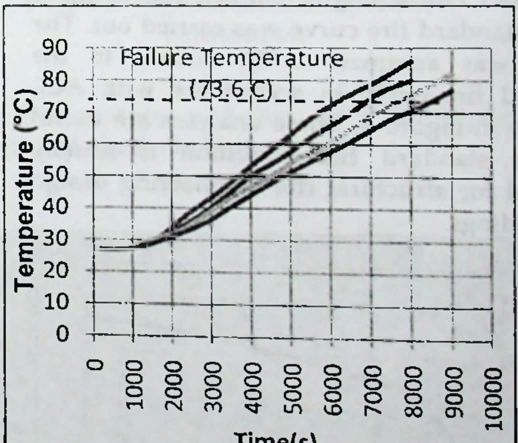

Figure 7: Variation of FRL for different thermal conductivity of insulation layer

5. 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 insulated and insulated CFRP strengthened members under exposure to a standard fire.
- The non insulated model shows nearly 5 minute fire resistance level only, 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 an important factor affecting the fire resistance of the insulated member.
- The model analysed under the standard fire in accordance with ACI (2001), shows 50 mm thick insulation having thermal conductivity of 0.114N 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.

References

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