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CONFINEMENT OF HEAT-DAMAGED RC CIRCULAR COLUMNS USING CFRP FABRICS

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ABSTRACT

The confinement of concrete with fibre-reinforced polymer (FRP) composites can significantly enhance its strength and ductility. This is due to their high strength-to-weight and stiffness-to-weight ratios and their ability to be readily formed into various cross-sectional shapes. Most of the available ambient temperature studies for achieving the compression strength and ductility of confined concrete have been done on standard cylinders. However, there is a lack of knowledge on confinement of circular RC columns, in which the concrete is damaged by fire and then uniformly confined using carbon fibre-reinforced polymer (CFRP) sheets. This paper presents a residual confinement study based on 10 identical circular RC columns with dimensions of Ø 204 × 750mm, previously damaged by elevated temperatures and retrofitted externally using CFRP fabrics and then tested under axial compression. The testing involved the RC columns being loaded during both the heating and cooling phases as would be the case with real structural elements in a fire. The results indicate that CFRP fabric can considered an excellent technique for strengthening heat-damaged RC columns.

KEYWORDS

CFRP confinement, RC columns, retrofitting, residual compressive strength, heating.

INTRODUCTION

In general, concrete structures have good fire-resistance. The properties of concrete when exposed to elevated temperatures have been considered by many researchers since the1940s (Husem, 2006, Chen et al., 2009). The effects of elevated temperatures on concrete behaviour have also been studied by (Khoury et al., 1985, Schneider, 1988, Khoury, 1992, Chang et al., 1994) including the effect of temperatures above 1000 ℃. When concrete is subjected to elevated temperature, various physical, chemical and mechanical processes take place, resulting in the deterioration of the concrete (Heikal, 2000, Chang et al., 2006) with an irreversible loss of stiffness and strength (Bastami and Aslani, 2010). The effect of heating starts in the form of surface cracking (Ali et al., 2004). (Arioz, 2007) noted that surface cracks became visible when the temperature reached 600 ℃, became more pronounced at 800 ℃ and even more so when the temperature increased to 1000 ℃. Of particular importance in assessing buildings after a fire is a sound understanding of the residual properties of concrete - i.e. the strength characteristics after cooling following heating due to a fire. These are now considered.

In the past few decades, research has demonstrated that for a compression member, the use of FRP wrapping can result in an increase in load-carrying capacity and ductility. Research has also confirmed the use of FRP-composite materials as a preferred solution for the repair, strengthening and retrofitting of existing structures. In terms of the repair of post-heated concrete members, only a few studies have considered the use of FRP fabrics for subsequent strengthening (Saafi and Romine, 2002, Cleary et al., 2003, Bisby et al., 2011, Yaqub and Bailey, 2011, Al-Kamaki and Al-Mahaidi, 2013). The maximum target temperature in those studies was about 700 ℃.

To date, most testing has been undertaken on small specimens and there is little information on the residual post-heated strength of larger RC-loaded columns. This could be due to the fact that most of the available electrical furnaces are small and not capable of applying load during the heating and cooling phases. In addition, the furnaces described in the literature do not appear to be able to follow the (ISO 834, 2012) temperature-time curve. Since the ISO 834 heating curve is taken as being representative of building fire exposure, it is helpful to undertake testing which follows this heating curve up to the target temperature. To the best of the authors' knowledge, there is no current research available on the repair of post-heated behaviour of RC-loaded circular columns using CFRP.

The main purpose of this research is to investigate experimentally the feasibility and effectiveness of wrapping heat-damaged RC-loaded columns with CFRP fabrics by comparing the resulting strength with that of unwrapped damaged and undamaged RC columns.

EXPERIMENTAL PROGRAM

Materials Used and Preparation of Specimens

The same concrete mixture was used for all specimens. The RC columns were constructed using ready-mix normal strength concrete prepared by a local supplier. The ambient compressive strength of the concrete was 32 MPa (28 day strength based on 100mm dia. cylinders); the slump was 80 mm. The maximum aggregate size was 14 mm. All of the RC columns were reinforced with Ø 10 mm longitudinal deformed bars and Ø 6.0 mm transverse deformed circular ties and all had a concrete cover of 20 mm to the circular ties. Only one type of carbon fibre-reinforced polymer (high tensile unidirectional CFRP sheet (CF 230/4900 400/30)) was used in this test program for wrapping the columns. This will be referred to hereafter as "CFRP". The mechanical properties of the CFRP were obtained through tensile testing of flat coupons following (ASTM D 3039/D 3039M, 2008, BS EN ISO 527-5, 2009) recommendations using an Instron testing machine. The fibre modulus was obtained from the linear elastic characteristics of CFRP with strains measured using a (Vic-3D, 2010) digital image correlation camera as well as conventional strain gauges. The epoxy adhesive (product name: MBrace Saturant) resin system consists of a main resin component (Part A) and a hardener (Part B), which are mixed together at a specific volume ratio (3A:1B) for about 5 minutes. This adhesive mixture was used when wrapping the columns with CFRP sheet. The material characteristics of the CFRP fibre were provided by the manufacturer (BASF Construction Chemicals Australia Pty Ltd). These are shown in Table 1 along with the test results of CFRP sheet for all coupons.

The test program involved the fabrication, instrumentation and testing of ten identical RC columns (Ø 204 × 750mm. The heated RC columns were subjected to a stress of 30% of maximum load at ambient temperature (25 ℃) while they were heated to elevated temperatures. Two columns were not heated and tested while four were exposed to 800 ℃ and four exposed to 1000 ℃ in the electric furnace, with the temperature being kept constant at the target temperature for two hours and then cooled down to room temperature. Of the heated RC columns, four were confined with one layer of CFRP following heating and cooling.

Table 1. Material characteristics of CFRP sheet & Adhesive epoxy

Characteristics	CFRP sheet		Adhesive epoxy manufacturer's data ASTM D638
	Manufacturer's data	Experimental results, 1 layer	
Ultimate tensile strength (MPa)	4900	4279.7	> 50
Fibre modulus (GPa, MPa)	230	239.5	> 3000
Tensile strain capacity %	2.1	1.8	2.5

Specimen Heating, Cooling Regimes and Specimen Loading Cycle

Of the ten RC columns, four were individually subjected to 800 ℃ and four to 1000 ℃ in the electric furnace while under a preload of 30% (360kN) of maximum compressive load at ambient temperature. They were then cooled to the room temperature. The constant load of 360kN was applied using a special hydraulic jacking system. The temperature of the electrical heating furnace was increased according to (ISO 834, 2012) up to the target temperature, at which point the temperature was maintained for 2 hours in an attempt to obtain uniform temperatures throughout the RC columns (Figure 1a). Finally, the furnace was turned off, the door opened after 30 minutes and the specimens were cooled to ambient temperature. The RC columns were tested after having been cooled to ambient temperature as the mean value of the two tests per target temperature (Figure 1b). The heating inside the furnace was controlled by putting one Type K thermocouple inside the furnace in addition to six built-in thermocouples attached to the furnace walls. Two of the columns at each temperature were instrumented internally with thermocouples. The residual compressive tests were conducted using a 5MN MTS testing machine with the speed of cross-head movement being 0.5 mm/min. Figure 2a and Figure 2b present the heating-cooling cycles for 800 ℃ and 1000 ℃ for RC circular columns of Ø 204 × 750mm.

(a) (b)

Figure 1. Tetlow furnace for heating Ø204 × 750mm RC columns and test set-up

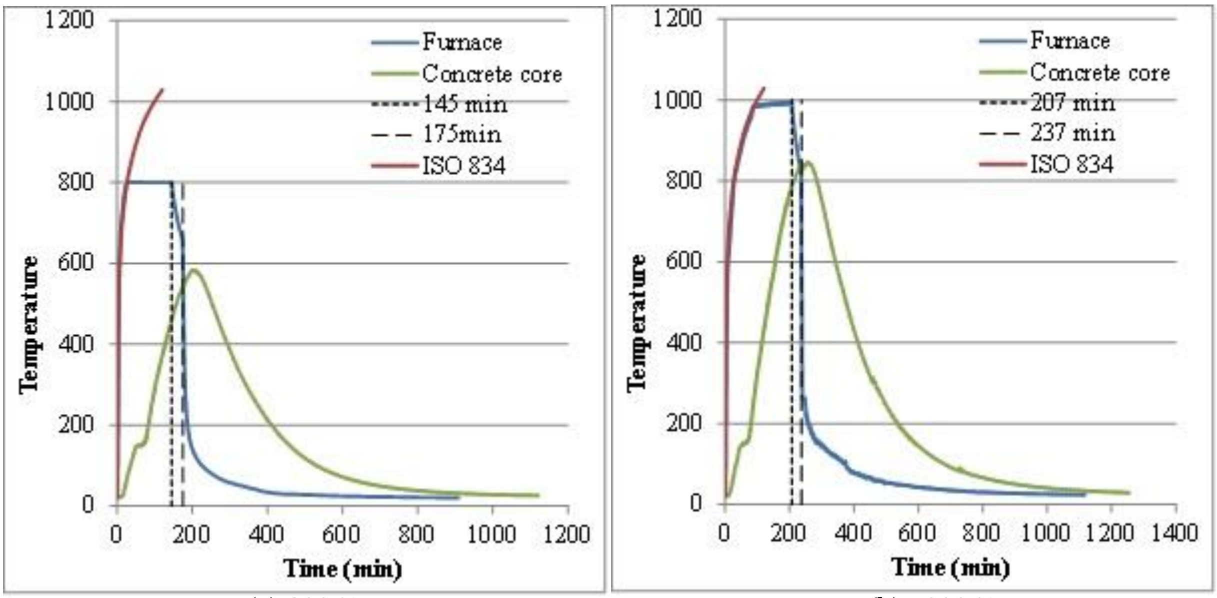
Applying the Reinforcement of CFRP

The wet lay-up method was used for CFRP wrapping. First, the RC circular columns were sand-blasted to provide better adhesion for the CFRP wrapping. A thin coat of the MBrace Primer was then applied and permitted to cure for a minimum of one hour. The epoxy (MBrace Saturant) was applied on top of the primer layer and also to the CFRP sheets. The CFRP sheet was then pressed onto the concrete surface using a hand roller. For each layer of CFRP wrapping, an overlap zone was provided by adding a 150mm length of CFRP in the longitudinal fibre direction to the circumference of the CFRP-wrapped RC columns. The wrapped RC columns were cured for seven days before testing.

RESULTS AND DISCUSSION

Evolution of Temperature in Furnace and Concrete Core

Figure 2a and Figure 2b present the heating-cooling cycles for 800 ℃ and 1000 ℃ for RC circular columns of Ø 204 × 750mm. It was observed that the furnace temperature followed the ISO 834 fire curve reasonably well up to the target temperature in the four tests. It will be noted that the temperature measured by thermocouple at the concrete core remained unchanged up to 10 min for both 800 ℃ and 1000 ℃, and then started to increase gradually with the greatest increase observed for the RC columns exposed to 1000 ℃. The temperature of these thermocouples reached 464 ℃ after 145min (i.e. time after the furnace was turned off), while the temperature of the furnace reached around 800 ℃ and 544 ℃ after 175min (i.e. the time when the furnace doors were opened), finally reaching a maximum temperature of 583 ℃. On the other hand, for the RC columns exposed to 1000 ℃, the core thermocouple temperature reached 790 ℃ after 207min (i.e. time when the furnace was turned off), 839 ℃ after 237min (i.e. time when the furnace doors were opened), finally reaching a maximum of 845 ℃.

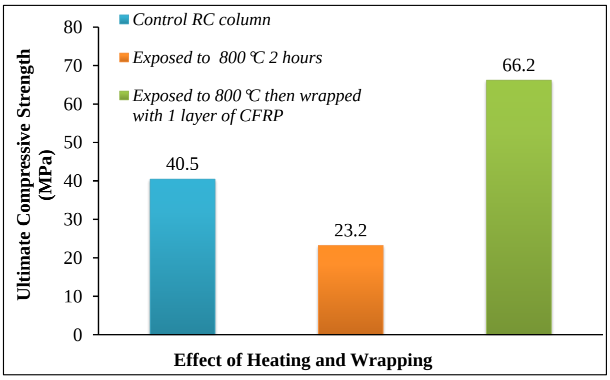


(a) 800 ℃ test (b) 1000 ℃ test

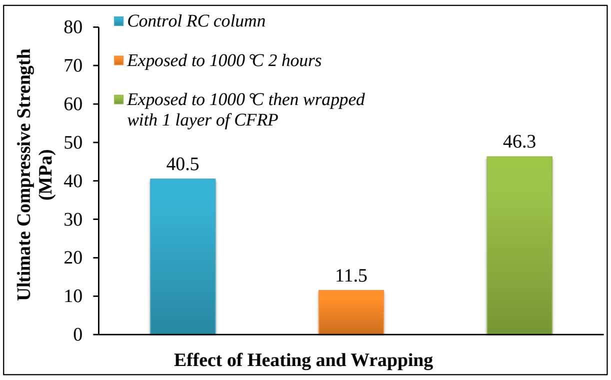
Figure 2. Heating-cooling cycle of the RC columns

Effect of Temperature on Residual Strength & CFRP Strengthening on Strength Recovery

Exposure to fire or high temperature has a major influence on the mechanical properties of concrete. One of these properties is the compressive strength. The residual strength of RC columns is expressed as a ratio of the strength of the companion RC columns at ambient temperature (25 ℃). Figure 3(a) and Figure 3(b) show the reduction in the compressive strength of RC circular columns reached a maximum of 42.7% and 71.6% (average of two specimens) after being exposed to furnace temperatures of 800 ℃ or 1000 ℃ for two hours respectively. The strength of RC columns increased by 63.5% and 14.3% respectively more than the companion RC columns at ambient temperature after being confined by one layer of CFRP. It was observed that using only one layer of CFRP fabric can restore almost all the lost strength after the fire regime.



(a) 800 ℃ test



(b) 1000 ℃ test

Figure 3. Effect of heating and wrapping on RC circular columns

CONCLUSIONS

1. The ISO 834 heating curve is reasonably taken as being representative of building fire exposure. It is helpful to undertake testing which follows this heating curve up to the target temperature.
2. Real columns that are damaged in fire are subject to load throughout the heating and cooling process. The purpose of the testing described in this paper was to simulate this situation in that loading was applied during the heating/cooling phases.
3. The results indicate that CFRP confinement enhances the compressive strength of both heat-damaged plain cylinders and RC columns. The strength of heat-damaged RC columns after exposure to furnace temperatures of 800 ℃ and 1000 ℃ for more than two hours increased by 63.5% and 14.3% respectively more than the companion RC columns at ambient temperature after being confined by one layer of CFRP
4. The use of CFRP can be an effective means of providing external confinement of concrete for reinstating and enhancing the strength of heat-damaged RC circular columns.

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REFERENCES

Al-Kamaki, Y. S. S. & Al-Mahaidi, R. Compressive strength of concrete damaged by elevated temperature and confined by CFRP fabrics. *Fourth Asia-Pacific Conference on FRP in Structures, APFIS*, 2013 Melbourne, Victoria, Australia, paper no. 77.

Ali, F., Nadjai, A., Silcock, G. & Abu-Tair, A. 2004. Outcomes of a major research on fire resistance of concrete columns. *Fire Safety Journal*, 39**,** 433-445.

Arioz, O. 2007. Effects of elevated temperatures on properties of concrete. *Fire Safety Journal*, 42**,** 516-522.

ASTM D 3039/D 3039M 2008. *Standard test method for tensile properties of polymer matrix composites materials,* West Conshohocken, PA, USA, Annual Book of ASTM Standards.

Bastami, M. & Aslani, F. 2010. Preloaded high-temperature constitutive models and relationships for concrete. *Scientia Iranica*, 17**,** 11-25.

Bisby, L. A., Chen, J. F., Li, S. Q., Stratford, T. J., Cueva, N. & Crossling, K. 2011. Strengthening fire-damaged concrete by confinement with fibre-reinforced polymer wraps. *Engineering Structures*, 33**,** 3381-3391.

BS EN ISO 527-5 2009. *Plastics-Determination of tensile properties Part 5: Test conditions for unidirectional fibre-reinforced plastic composites*. West Conshohocken, PA, USA: ISO international standards.

Chang, W. T., Wang, C. T., Huang, C. W. & Yun-Seng, G. 1994. Concrete at temperatures above 1000 ℃. *Fire Safety Journal,* 23**,** 223-243.
Chang, Y. F., Chen, Y. H., Sheu, M. S. & Yao, G. C. 2006. Residual stress-strain relationship for concrete after exposure to high temperatures. *Cement and Concrete Research,* 36**,** 1999-2005.
Chen, Y. H., Chang, Y. F., Yao, G. C. & Sheu, M. S. 2009. Experimental research on post-fire behaviour of reinforced concrete columns. *Fire Safety Journal,* 44**,** 741-748.
Cleary, D. B., Cassino, C. D., Tortorice, R., Newell, J. A. & Tyers, B. W. 2003. Effect of elevated temperatures on a fiber composite used to strengthen concrete columns. *Journal of Reinforced Plastics and Composites,* 22**,** 881-895.
Heikal, M. 2000. Effect of temperature on the physico-mechanical and mineralogical properties of Homra pozzolanic cement pastes. *Cement and Concrete Research,* 30**,** 1835-1839.
Husem, M. 2006. The effects of high temperature on compressive and flexural strengths of ordinary and high-performance concrete. *Fire Safety Journal,* 41**,** 155-163.
ISO 834 2012. *Fire resistance tests – Elements of building construction*, International Organization for Standardization, Geneva, Switzerland.
Khoury, G. A. 1992. Compressive strength of concrete at high-temperatures - A reassessment. *Magazine of concrete research,* 44**,** 291-309.
Khoury, G. A., Grainger, B. N. & Sullivan, P. J. 1985. Strain of concrete during first heating to 600 C under load. *Magazine of concrete research,* 37**,** 195-215.
Saafi, M. & Romine, P. Effect of fire on concrete cylinders confined with GFRP. *Proceedings of the 2nd international conference on durability of fiber reinforced polymer (FRP) composites for construction (CDCC'02),* Montreal, PQ, Canada, 2002. 512-521.
Schneider, U. 1988. Concrete at high temperatures - A general review. *Fire Safety Journal,* 13**,** 55-68.
Vic-3D 2010. *The Vic-3D™ measurement system,* Dutchman Blvd, Irmo, SC 29063, USA, Correlated solutions.
Yaqub, M. & Bailey, C. G. 2011. Repair of fire damaged circular reinforced concrete columns with FRP composites. *Construction and Building Materials,* 25**,** 359-370.