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Experimental Investigation of Fire-damaged Reinforced Concrete Columns Retrofitted with CFRP Jackets

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Abstract

This paper presents the compressive behaviour of circular reinforced concrete (RC) columns exposed to fire following the ISO834 standard fire curve for 1 hour, air cooled, and then retrofitted with 1 or 2 layers of transverse carbon fibre reinforced polymer (CFRP) wraps. Total 5 circular RC columns (ϕ300mm x 1000mm) were tested to investigate the effects of concrete restoration of the fire-damaged concrete, and the amount of CFRP layers. The investigated compressive behaviour of columns included load-displacement relationship, CFRP load-strain response and failure mode. For the unretrofitted columns, the test results showed that the ultimate capacity and stiffness of fire-damaged RC columns was decreased due to the deterioration of concrete at elevated temperatures. CFRP jackets could effectively restore the stiffness and improve the ultimate capacity of fire-damaged circular columns. Restoring the damaged concrete by replacing loose concrete could help restore the stiffness of fire-damaged columns.

Keywords: Fire, Circular RC Columns, CFRP Jacket

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Introduction

Reinforced concrete (RC) structure has relatively good fire resistance, compared with steel and wood structures, because concrete has low thermal conductivity, high heat capacity. Concrete could be considered as an effective fire resistance shield for the RC structure. RC structures are rarely collapsed in the fire base on the thermal properties of concrete, and could be repaired successfully. Therefore, repairing and strengthening of fire-damaged RC structures have become popular in the last few decades for both environmental and economic benefits. Carbon fiber reinforced polymer (CFRP) jackets, which is lightweight, high strength, corrosion resisted, and easy constructed, has been widely used to repair and strengthen the existing RC structures. In this study, five circular RC columns were tested, and the experimental results showed CFRP jackets could effectively restore and improve the ultimate capacity of fire-damaged circular RC columns. Replacing loose concrete could effectively help restore the stiffness of fire-damaged columns.

Experimental Program

Specimen Preparation

A total of 5 circular RC columns (ϕ300mm x 1000mm) were tested, and the objective of this experimental program is to observe the effectiveness of CFRP jackets for repairing fire-damaged circular RC columns. The condition for each specimen is described as below;

(1) No fire-damaged and no retrofitted column, labelled as RTR
(2) 1 hour fire exposed and non-retrofitted column, labelled as FDR
(3) 1 hour fire exposed and retrofitted by 1 layer of transverse CFRP wrapping with loose concrete removed, labelled as CJ1
(4) 1 hour fire exposed and retrofitted by 2 layers of transverse CFRP wrapping with loose concrete removed, labelled as CJ2
(5) 1 hour fire exposed and retrofitted by 2 layers of transverse CFRP wrapping with loose concrete, labelled as CJL2

Figure 1 shows the cross-sectional details for the specimen, and all specimen were confined by 6mm spirals with 40mm spacing. These columns were identical and casted from the same batch, and the average compressive strength of concrete at the test day was 50MPa.

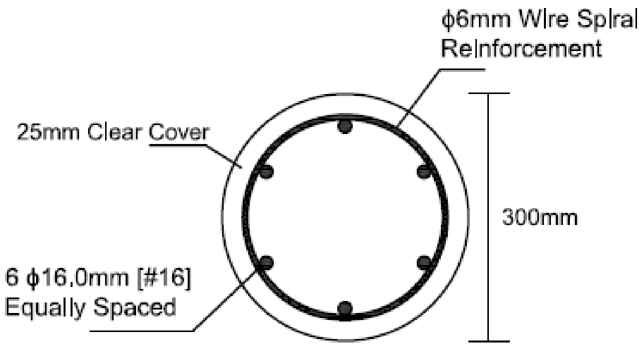

Figure 1 Cross-sectional Details of Specimen

Heading and Cooling Procedure

4 columns exposed to fire for 1 hour in the gas furnace, and the temperature in the furnace followed the ISO834 standard fire curve.[1] One column was instrumented with type-K thermocouples to investigate the cross-sectional temperature distribution during heating and cooling procedure. Thermocouples were located at concrete core, 50mm and 100mm from concrete core at mid-height. The temperature in the furnace was controlled by two type-K thermocouples attached on the furnace walls. After 1 hour fire exposure, the furnace was turned off, and the door was opened to let columns cool down to the ambient temperature by air. The maximum temperature at each location are summarized in Table 1, and temperature in the column for both heating and cooling procedure is plotted in Figure 2.

Table 1 Maximum temperature in the column during heating and cooling procedure

Location	Concrete Core	50mm from Concrete Core	100mm from Concrete Core	Furnace
Max. Temperature (°C)	160.5	163.4	209.6	864.4

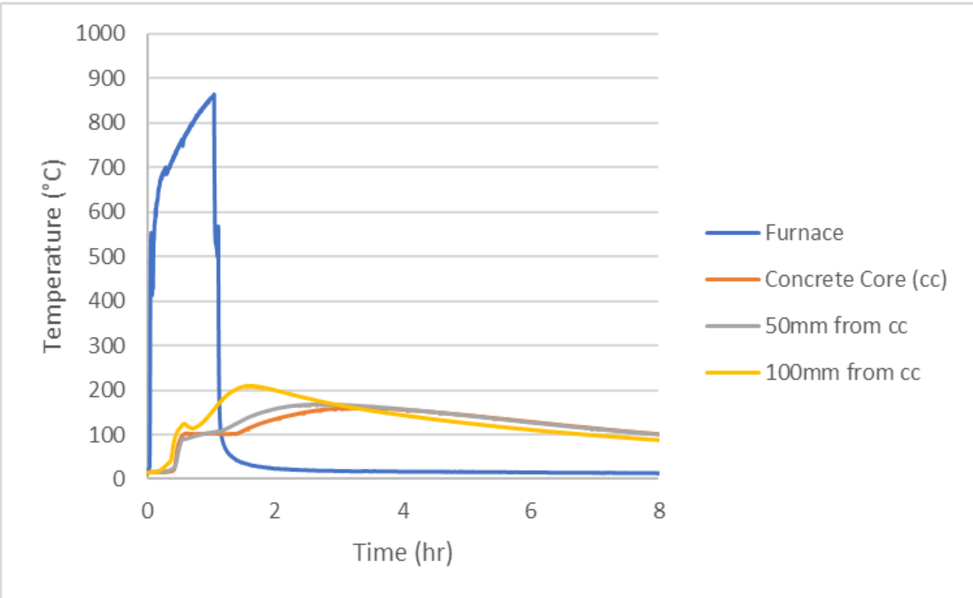

Figure 2 Temperature vs. time for fire-exposed columns

Retrofitting and Compressive Tests

After fire exposure, concrete cover was severely damaged. Loose concrete was left in one fire-damaged column and the other two fire-damaged columns had loose concrete removed by steel wire brush. High strength mortar was applied to fill out the spalling area and enlarge the cross section diameter from 300mm to 370mm. The final step for retrofitting is to wrap CFRP jackets around fire-damaged columns.

After being repaired, all columns were tested to failure under axial compression using a testing machine with 10000kN capacity, and the loading rate was set as 1kN/s. Two steel plates with 300mm diameter were placed at top and bottom to make all columns have the same loading area.

Test Results and Discussions

Table 2 shows the ultimate capacity and failure mode of undamaged, fire-damaged and retrofitted columns. Load displacement relationship for each specimen are shown in Figure 3.

Table 2 Compressive test results

No.	Specimen Label	Ultimate Capacity (kN)	Failure Mode
1	RTR	3957	Concrete Crush
2	FDR	3465.1	Concrete Crush
3	CJ1	5074	CFRP Rupture and Concrete Crush
4	CJ2	6397.3	CFRP Rupture and Concrete Crush
5	CJL2	6250.8	CFRP Rupture and Concrete Crush

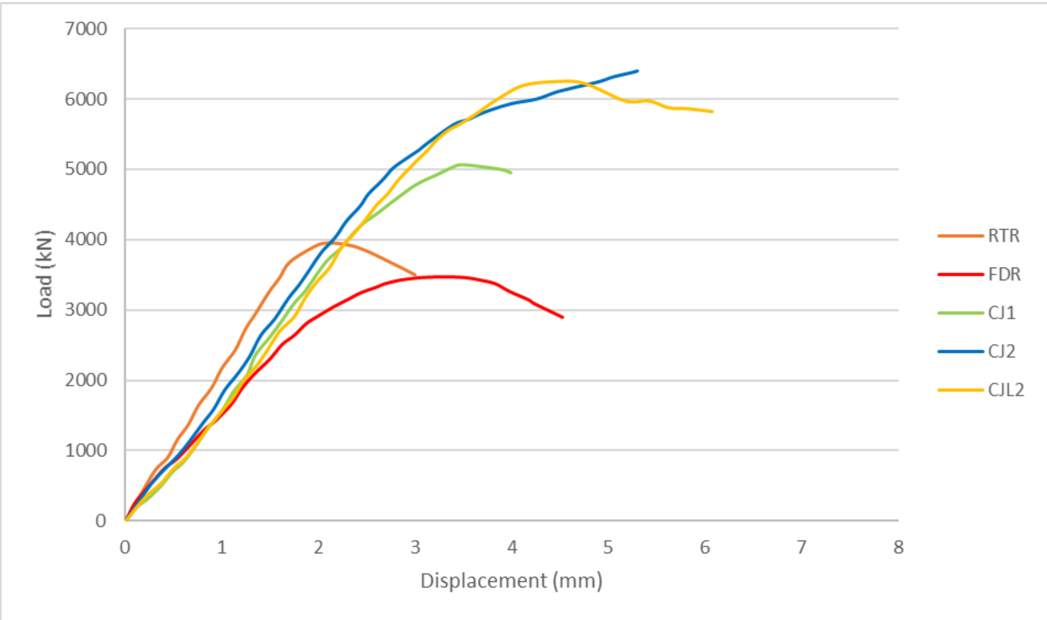

Figure 3 Load-displacement relationships for columns

Based on the test results, the ultimate capacity for RC column decreased 12.4% after 1 hour fire exposure. 1 layer of CFRP jacket could restore and increase 28.15% on the ultimate capacity, and 2 layers of CFRP jackets could effectively increase 61.67% on the ultimate capacity. Applying CFRP jackets without removing loose concrete could reach the same level on the ultimate capacity restoration. However, removing loose concrete from fire-damaged columns could effectively help restore the stiffness.

Conclusion

Concrete is an effective shield for RC column due to its thermal properties. Large temperature gradient could be developed between concrete core and concrete cover, when RC column is under fire. Concrete cover gets loose and severely damaged due to the deterioration of concrete at elevated temperature. CFRP jackets can effectively restore and improve the ultimate capacity of fire-damaged circular RC column. CFRP jacketing with or without replacement of loose concrete could effectively restore and improve the ultimate capacity, but replacement of loose concrete could also effectively improve the stiffness of fire-damaged column.

References

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