Size and Shape Effect of Fire Damaged Concrete Column on Confinement of Ultra High Performance Fibre Reinforced Concrete (UHPFRC)

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ABSTRACT

In this paper, the investigation of ultra high performance fibre reinforced concrete as repair material to reinstate the load carrying capacity of fire damaged in concrete columns is discovered. This is because the usage of UHPFRC material is highly demand in the construction industry specially in the strengthening and retrofitting of concrete structures due to its significant improvement in durability. However, there are limited previous research that study the size and shape effect of UHPFRC jacket concrete columns. The purpose of this study is to examine how cross sectional of square and rectangular columns being the most important indicator on fire damaged concrete strengthened with UHPFRC. A simulation work is utilized using finite element method (FEM) in ABAQUS software as methodology. Whereas graph of force-displacement is obtained from the software and compressive behaviour of the columns are measured and compared. the ratio of maximum strength gained for smaller and larger specimen was 1.30:1.35. Also, it was found that the maximum strength of rectangle jacketed column is relatively high (1690690 N) compared to the maximum strength of square jacketed column (1039200 N). Subsequently for the highest specimen of stiffness, there is 74.33% of ultimate compressive strength attributed in jacketed column on comparing with the normal concrete column. From these results, it can be concluded that performance concrete column strengthened with UHPFRC is much better than the normal concrete column due to addition of fibre in the material influence the cracking behaviour.

Keywords: Cross sectional area, corner radius, aspect ratio, compression test, ultra high performance fiber reinforced concrete.

1. INTRODUCTION

Nowadays, usage of fibre reinforced polymer (FRP) composite has gaining interest in many countries for the repair and rehabilitation of concrete structures due to its outstanding corrosion resistance and high strength-to-weight ratio (Mosallam *et al*., 2015). In which, confining material for the retrofitting of existing reinforced concrete columns with FRP jackets is one of the popular applications of FRP composites. However, FRP cannot reinstate the load carrying capacity of square and rectangular concrete column due to their cross sections are containing some ineffectively confined concrete regions and the intensification of stresses at corners (Yaqub & Bailey, 2011).

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So, ultra high performance concrete (UHPC) is recommended to be use as a substitute to FRP. It is a new generation of cementitious material that is advanced with high strength, ductility and durability for repair and rehabilitation works (Azmee & Shafiq, 2018). Its high compressive strength (>150 MPa), tensile strength (>8 MPa) combined with enhanced flowability, and very dense microstructure are the key characteristics (Zhang *et al*., 2020a; Zhang *et al*., 2020b).

Since structural members are at risk of exposure to extreme surrounding conditions such as fire during their service life, investigating their behaviour against fire is inevitable. When concrete members are exposed to elevated temperatures, the physical structure and chemical composition of the concrete change significantly (Gencel, 2012). It also degrades the mechanical properties of concrete that includes compressive strength and modulus of elasticity, which may lead to the failure of concrete structures (Dadmand *et al*., 2022).

Degradation of bond strength at elevated temperature may significantly influence the load capacity of the concrete. So, rehabilitation works are required to recover the structural integrity of heat-damaged concrete. Shamseldein *et al*. (2018) investigated the different repairing techniques and materials for heat- damaged RC elements. The researchers stated that these methods were conducted by breaking off the deteriorated concrete layers, preparing the surface for the application of the repairing material then replacing the damaged concrete layers with different repairing materials. Therefore, UHPC can be considered as an excellent candidate for the repair and rehabilitation of critical concrete structures, which is exposed to the extreme surrounding conditions (Brühwiler, 2012).

In this paper, various sizes of square and rectangular concrete columns that is strengthened with the UHPFRC were simulated under the compression damage in order to close the gaps. This paper aims at highlighting the effect of size and shape on the compressive behaviour of fire damaged concrete columns jacketed with UHPFRC.

2. SIMULATION PROCEDURE

In this study, the simulation for the modelling work was utilized in software of ABAQUS by using finite element method (FEM). It is a 3D non-linear analysis using numerical method to simulate and notice failures in composite structural elements (Kartheek & Das, 2020).

In this paper, there were total of 4 models created in ABAQUS which two various sizes for each normal concrete columns and UHPFRC-jacketed concrete columns. Sizes used for square specimen are 100x100 mm and 150x150 mm while sizes used for rectangular specimens are 150x100 mm and 200x150 mm. To differentiate the specimens, each concrete column was given a name where “S” refers to square column and “R” refers to rectangular column.

The elastic modulus of concrete, UHPFRC, and steel reinforcement is 20 GPa, 50 GPa and 210 GPa, while its Poisson’s ratio is 0.2, 0.2 and 0.3, respectively. The density of concrete, UHPFRC, and steel reinforcement is 2400 kg/mm^3, 2500 kg/mm^3 and 7850 kg/mm^3, respectively. Moreover, solid elements (C3D8R) were used to model concrete and UHPFRC while wire elements (B31) were used for modelling longitudinal reinforcement and transverse reinforcement.

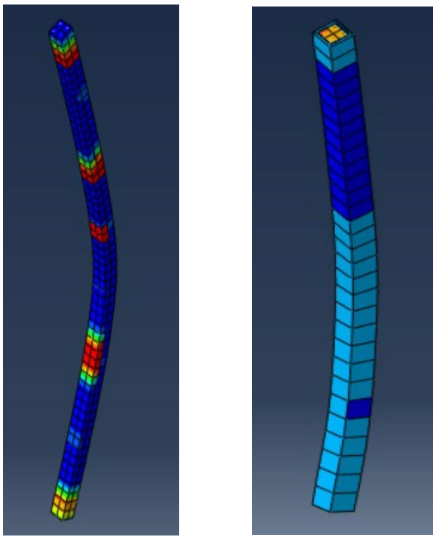
The longitudinal reinforcement that was utilized for the model is 4 numbers of reinforcement bars with diameter of 20 mm. Also, the transverse reinforcement of 6 mm diameter with 100 mm centre-to-centre spacing are utilized for the model. For UHPFRC jacket, the thickness used on the outer surface of the concrete columns was 15 mm.

After the model was created in the software, analysis of the columns was run in order to examine the effect of the specimen sizes and shape before and after it were jacketing with UHPFRC. To obtain the results, compression damage is applied in ABAQUS for the simulation of the concrete column subjected to axial load which the compressive behaviour of UHPFRC as jacketing material on the columns were discovered.

A graph of force-displacement curve was plotted based on the results from the software. From the plotted graph, three main parameters of the compressive behaviour including ultimate load carrying capacity, ductility and stiffness of the damaged concrete columns jacketed with UHPFRC was observed and compared.

3. RESULTS AND DISCUSSION

According to Eurocode, the loading exerted on the column was manual calculated to be 100 N. Figure 1 shows an example model of 100x100 mm square column that was analysed in ABAQUS. Figure 1(a) represents the unconfined column which is known as control specimen while Figure 1(b) represents the specimen that is jacketed with UHPFRC. According to the colour shown on the column, green to blue colour means that it undergoes less compression damage and orange to red colour means that it is riskly damaged.



(a) Control Specimen

(b) Jacketed Specimen

Figure 1. Example visualisation of square concrete column model.

The force versus displacement curve for various size of square concrete columns are presented in Figure 2. For CS1, the control specimen has a maximum force of 437730 N, a maximum displacement of 7.18984 mm and the corresponding stiffness is 60.88 kN/mm. The jacketed specimen has a maximum force of 569644 N, a maximum displacement of 7.31591 mm and the corresponding stiffness is 77.86 kN/mm. Meanwhile for CS2, the control specimen has a maximum force of 955824 N, a maximum displacement of 7.523 mm and the corresponding stiffness is 127.05 kN/mm. The jacketed specimen has a maximum force of 1039200 N, a maximum displacement of 8 mm and the corresponding stiffness is 129.90 kN/mm. This can be said that the UHPFRC-jacket concrete column of CS2 is 1.67 times stiffer than the CS1 specimen that is jacketed with UHPFRC.

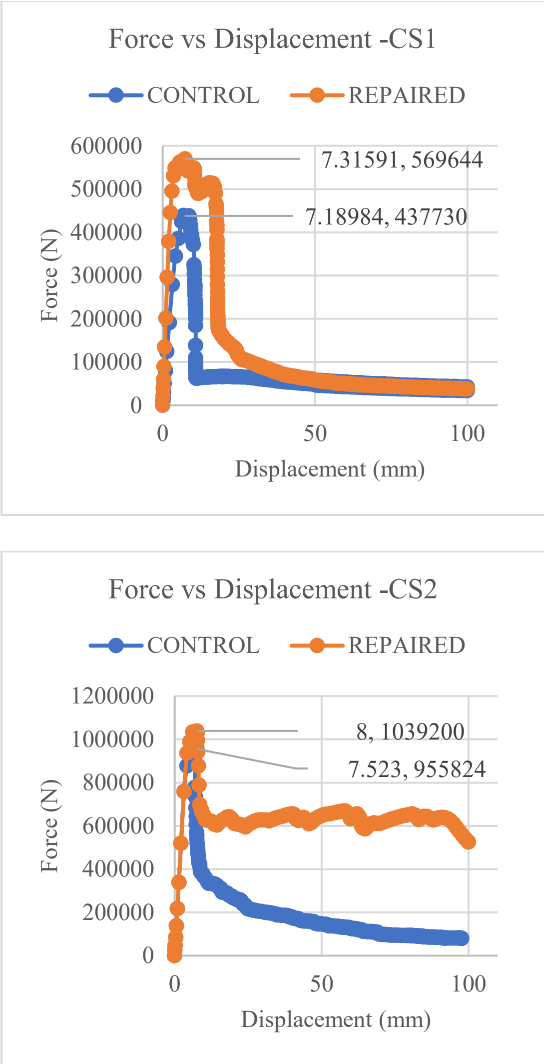


Figure 2. Force vs displacement curve of square concrete column.

Meanwhile, Figure 3 shows the force versus displacement curve for various size of rectangular concrete columns. For CR1, the control specimen has a maximum force of 827732 N, a maximum displacement of 6.86406 mm and the corresponding stiffness is 120.59 kN/mm. The jacketed specimen has a maximum force of 1098550 N, a maximum displacement of 5 mm and the corresponding stiffness is 219.71 kN/mm. Meanwhile for CR2, the control specimen has a maximum force of 1256670 N, a maximum displacement of 6 mm and the corresponding stiffness is 209.45 kN/mm. The jacketed specimen has a maximum force of 1690690 N, a maximum displacement of 6 mm and the corresponding stiffness is 281.78 kN/mm. This can be said that the UHPFRC-jacket concrete column of CR2 is 1.28 times stiffer than the CR1 specimen that is jacketed with UHPFRC.

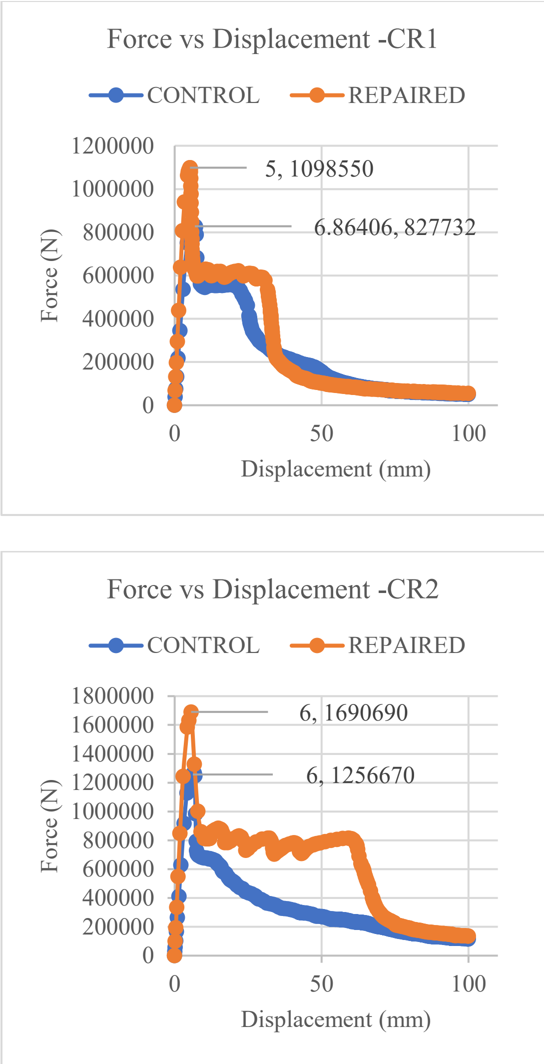


Figure 3. Force vs displacement curve of rectangular concrete column.

Based on the findings, the ratio of maximum strength gained for smaller and larger specimen was 1.30:1.35. This can be concluded that the increment of column sizes lead to great load carrying capacity which reduced its shear stress, and thereafter improve the ductility.

Also, it was found that the rectangular specimen has better performance and more ductile than the square specimen. This is because the maximum strength of rectangle jacketed column is relatively high (1690690 N) compared to the maximum strength of square jacketed column (1039200 N).

Subsequently for the highest specimen of stiffness, there is 74.33% of ultimate compressive strength attributed in jacketed specimen on comparing with the control specimen. It is clear that concrete column strengthened with UHPFRC is more efficient in bearing the axial load and has higher ductility than the normal concrete column. The improved properties of concrete columns are due to the enhanced properties of the UHPFRC as jacketing material.

4. CONCLUSION

In this paper, the interface between the concrete and the jacketing material (UHPFRC) was analysed in ABAQUS software. A 3D nonlinear FEM was utilized to discover the compressive response of unconfined concrete column by externally jacketing it with UHPFRC through simulation work. The findings of the study discovered that larger size of jacketed specimen has the highest compressive strength compared to that of smaller size. Meanwhile, in terms of shape effect, the rectangular column of jacketed specimen has higher stiffness than the square column of jacketed specimen. As conclusion, UHPFRC jacket concrete column exhibited a higher load carrying capacity than the normal concrete column. This is because there is improvement in bond interface between the concrete column and the jacketing material. Therefore, UHPFRC is recommended to be used as a repair material in rehabilitation and strengthening the damaged concrete column.

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