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Fire Performance of GFRP-RC columns

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الملخص العربى :

البحث يدرس اداء الاعمدة الخرسانية المسلحة بقضبان البوليمرات المسلحة بالالياف الزجاجية (GFRP-RC) أثناء تعريضها لمنحني حريق مصمم. يتضمن البرنامج التجريبي اختبار الحريق لثلاثة أعمدة GFRP-RC بمعمل الهندسة بكلية المطرية هندسة حلوان. أبعاد المقطع العرضي للأعمدة 200×200 مم2 ولها نفس الغطاء الخرساني 20 مم مع اختلاف أطوال الأعمدة (800، 1200، 1600 مم) . تم تحميل جميع الأعمدة بحمل ثابت قدره 330 كيلو نيوتن أثناء الحريق لتمثيل السلوك الحقيقي في المباني .تم تصنيع قضبان GFRP باستخدام راتنجات البوليستر وتم تخشين الاسياخ بخيوط الألياف الحلزونية .جميع الأعمدة انهارت نتيجة الضغط بدون اي ازاحة عرضية ملحوظة. مقاومة الحريق للعنصر الخرساني هي الوقت الذي يستطيع فيه العنصر تحمل الاحمال أثناء الحريق .بناء على النتائج التجريبية، فإن زيادة طول الأعمدة بنسبة 150% و200% تقلل من مقاومة أعمدة GFRP-RC للحريق بنسبة 10% و23%.

الكلمات المفتاحية : قضبان الالياف الزجاجية , الحريق , الاعمدة الخرسانية , الغطاء الخرساني.

Abstract:

The performance of Glass Fiber Reinforced Polymer (GFRP) bars reinforced concrete **columns (GFRP-RC columns) while exposed to design fire curve is presented in this** paper. The experimental program includes fire test of three GFRP-RC columns at el Mattaria faculty of engineering laboratory. Columns have cross section dimensions of 200x200 mm^2 and have the same concrete cover of 20mm with a different columns length (800, 1200 and 1600mm). All columns have a constant load of 330KN during fire to simulate their real behavior in buildings. GFRP bars were manufactured with polyester resin and roughened by helical fiber yarns. All columns failed in compression failure mode without any significant lateral deformation. The fire resistance represents the time that the element can sustain the load during fire. Based on the experimental results, increasing columns length by 150% and 200% reduces the fire resistance of GFRP-RC columns by 10% and 23%.

Key Words - GFRP, Concrete columns, Fire curve, Fire resistance.

1. INTRODUCTION

The use of FRP reinforcement instead of traditional steel has received significant attention from the civil engineering community. FRP reinforcement usage was not limited for flexural concrete elements (beams and slabs) but also it expanded to study its behavior on compression concrete element (columns). Different researchers [1], [2] and [3] studied the behavior of GFRP-RC columns under axial loads while data about their fire performance is still limited. Hui and Xiao [4] investigated the fire behavior of GFRP-RC columns by sets of numerical results. The numerical model used in their research was performed by using ABAQUS [5] software. The main parameters of their study were column`s configuration and concrete cover with a column`s length of 2 meters and column`s end boundary conditions for all numerical models. Previous studies revealed that the fire behavior of FRP-RC elements is different from conventional steel reinforced concrete elements [6]. FRP bars embedded in concrete reduce their burning due to the lack of oxygen, but the resin will degrade and decompose, the degradation and decomposition are depending on resin type and additivies. Various studies [7] and [8] were done on the fire behavior of GFRP-RC beams and slabs. Nigro and Cefarelli [9] studied the fire resistance six concrete one way slabs reinforced with GFRP bars. Three slabs were 3500mm span, 1250mm wide, 180mm depth and concrete cover of 32mm and other slabs were 4000m span,1250mm wide , 180mm depth and concrete cover of 51mm. Furnace temperatures were followed ISO834 fire curve. Numerical investigation was also carried out by SAFIR [10] software to check the results. They developed simplified equations to calculate GFRP bar temperature exposed to ISO834 [11] with a different concrete cover which will help the designer to use a specific concrete cover to reach the required fire resistance. Yu and Kodur [12] investigated numerically the fire performance of concrete beams reinforced with GFRP bars (GFRP-RC beams). They studied the influence of beam configuration, rebar type, concrete cover thickness, axial restraint, fire scenario and insulation layout on the fire resistance of GFRP-RC beams. They concluded that concrete beams reinforced with steel have a higher fire resistance than concrete beams reinforced with CFRP or GFRP bars and beams reinforced with CFRP bars have a higher fire resistance than beam reinforced with GFRP bars. They stated that the existence of axial restraint would enhance the fire resistance of RC beams through arch action reducing beams deflection. They concluded also that the use of insulation material would be very effective to enhance the fire resistance of concrete beams reinforced with FRP bars. Albu-Hassan and Noha [13] studied the fire behavior of GFRP-RC beams, beams were subjected to monolithically mechanical load during elevated temperature from (300 ℃ - 700 ℃). Results from experimental program showed that shear failure was the failure mode for all tested specimens. The results showed also that a reduction of 53% in the ultimate load capacity for GFRP-RC beams at temperature of 700℃, the percentage was taken from the ultimate load capacity at ambient temperature.

2. EXPERMENTAL PROGARAM

2.1. Columns details

Three RC columns reinforced with GFRP bars were tested for investigating their fire performance. Columns have the same cross section dimensions, concrete cover and reinforcement ratio but only differ in column`s height. C1 was 800mm long while the height of C2 and C3 were 1200 mm and 1600mm respectively. Figure.1 and Table.1 show the details of tested columns. GFRP bars and GFRP stirrups were used to reinforce all columns. The resin that used for all reinforcement in the research was the polyester resin. The longitudinal reinforcement for all columns was four bars with a diameter of 12mm. The clear concrete cover for all columns was 20mm. The measured concrete compressive strength was 25 MPa. The modulus of elasticity of GFRP bar at ambient temperature was 40 GPa. Figure.2 (a) shows the reinforcement cage for tested columns and Figure.2 (b) shows all columns after pouring.

Table.1: Details of Test Specimens

Specimen	b and h (mm)	Column's length (mm)	Slenderness Ratio	Longitudinal Rft.	Cover (mm)	Applied load (KN)
C1	200*200	800	13.85	4ø12 GFRP	20	330
C2	200*200	1200	20.78	4ø12GFRP	20	330
C3	200*200	1600	27.71	4ø12GFRP	20	330

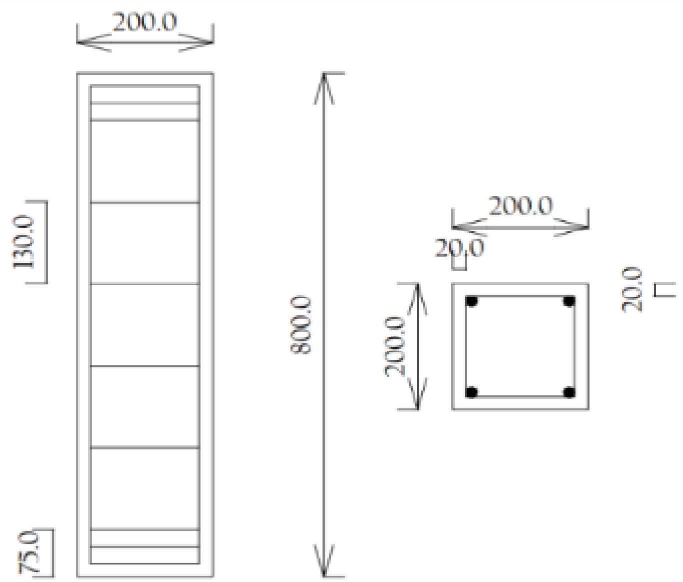


Figure 1. Concrete Dimensions and Reinforcement Details of C1

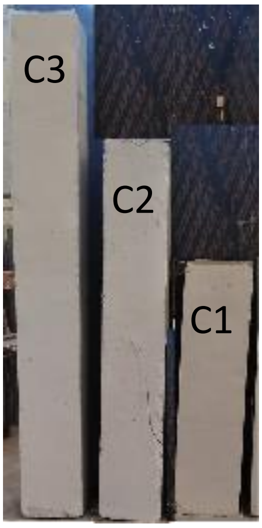


Figure 2. (a): Reinforcement Cage for test specimens, **(b)** Test Specimens after Pouring

2.2. Furnace and Instrumentation details

Figure 3 shows the furnace that used for the research. The diameter and height of furnace are 480mm and 750 mm. The furnace have twelve circular voids, the burners put inside furnace through its voids. All columns were exposed from all sides to the same fire curve, the temperature of furnace was measured through specified temperature detecting machine. Two thermocouples were placed in each test specimen, the first one on the face of bar and the other was on the column centroid. LVDT was used to measure the axial displacement of the column.

Figure 3. The Furnace used in the research

2.3. Test setup

The test setup was presented in Figure.4. The test was started by placing the column inside the furnace, All Columns were loaded gradually until achieving the desired load (330KN) then columns were heated according to the design fire curve. The load was kept constant during heating until failure. All columns were exposed to fire from four faces. Bar and concrete temperatures were measured through the test period by thermocouples. All test data were recorded by data acquisition system.

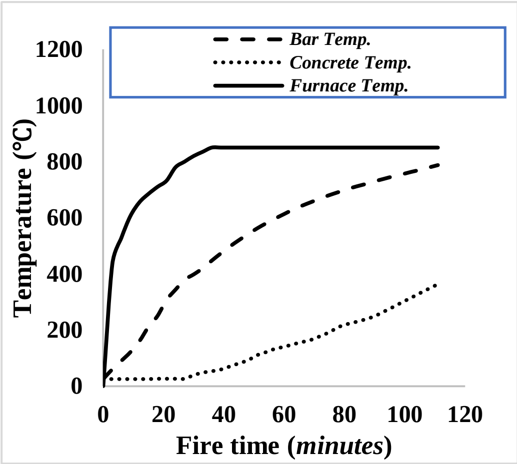
Figure 4. Test Setup

3. TEST RESULTS

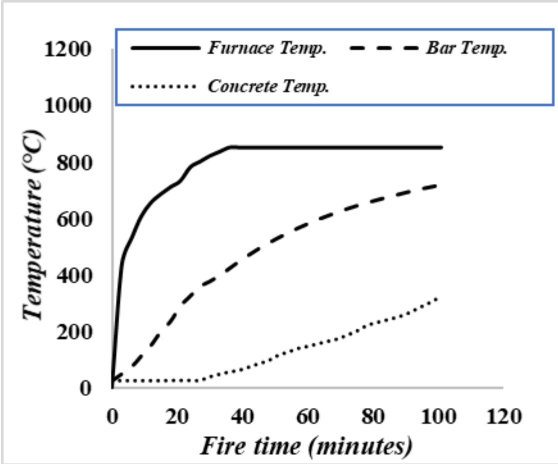
The comparative performance of tested columns is evaluated by investigating the fire resistance, thermal and structural responses.

3.1. Thermal Response

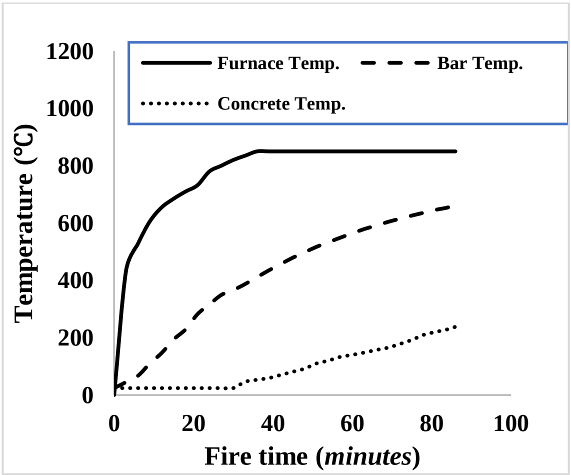
The bar and concrete temperatures measurements were approximately the same for the three tested columns, this due to all columns have the same concrete cover and the same cross section dimensions. No effect for column`s height on temperature distribution inside the cross section. Figure 5 (a), (b) and (c) shows the temperature measurements for all columns.



(a)



(b)



(c)

Figure 5. Temperature Readings for Tested Columns: (a) C1, (b) C2 and (c) C3

3.2. Structural Response

The axial deformations for all columns were measured by LVDT, unfortunately it's very difficult to measure the lateral deformation at the middle of the column. The axial deformation for all columns are presented in Figure 6. It can be seen from this figure that, increasing column`s height would increase column axial displacement. Values of axial displacement for C1 and C2 are approximately the same for the first 60 minutes then C2 values became higher than C1 axial displacement values. All columns were compressed during the fire period and this due to the existence of high applied load during fire.

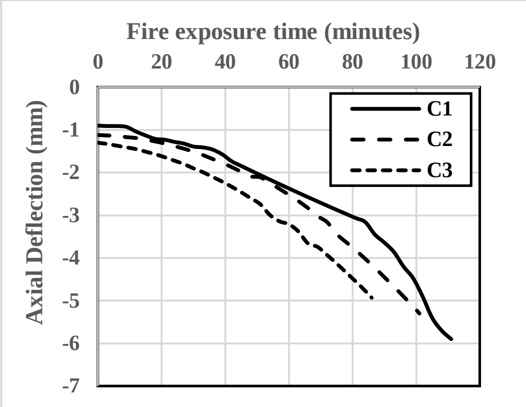


Figure 6. Axial displacement- Fire time curves for All test Specimens

3.3. Fire Resistance

The strength of the column was kept decreasing with increasing fire exposure time, the column will fail when it can not support the applied load. Fire resistance values for tested columns are shown in Figure.7 . C1 has the highest fire resistances of 111 minutes. Increasing column`s height will decrease fire resistance of RC columns. Increasing column length from 800mm to 1200mm and 1600mm reduces the fire resistance by 10% and 23%.

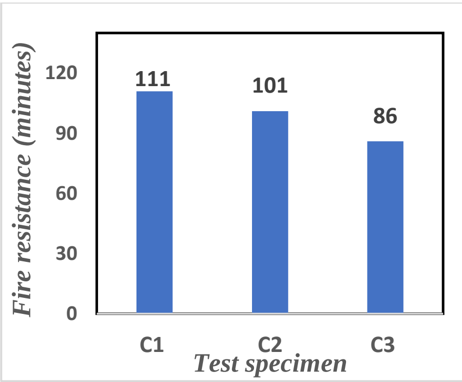


Figure 7. Fire resistances for Test Specimens

3.4 Spalling

Spalling considers one of the important aspects, which could be happened for concrete elements under fire. Spalling is the breaking off the concrete cover from concrete cover, which increase reinforcement and concrete temperatures inside the cross section. All columns in the experimental program suffer from spalling although EC2 states that normal strength concrete has a lower chance for spalling occurrence.

3.5. Failure Modes

Failure pattern for all columns was shown in Figure 8. It was mentioned that, columns C2 and C3 failed in compression failure mode while C1 failed in shear failure mode. It was mentioned also, the color change of GFRP bar due to the decomposition of the resin.

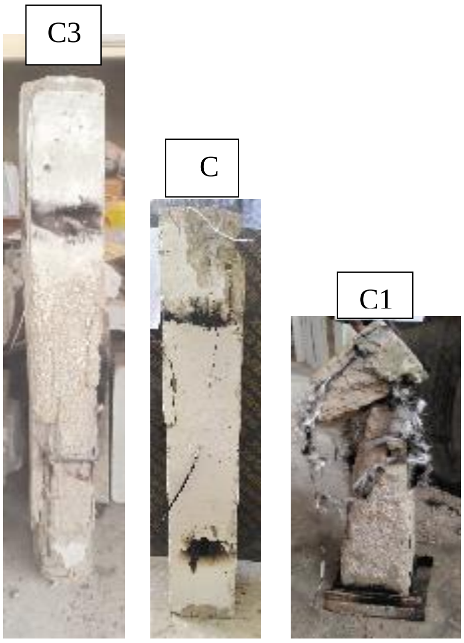


Figure 8. Failure Pattern for all Test Specimens

4. CONCLUSION

Based on this research, the following conclusions were stated:

- For GFRP-RC columns exposed to fire curve with a maximum temperature of 850 ℃, spalling is occurred.
- Slenderness ratio has a clear effect on the failure mode of GFRP-RC columns under fire.
- Protecting a portion of GFRP-RC column from high temperature will enhance the behavior of GFRP bars.

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