

Experimental study of thermomechanical behavior of the carbon textile reinforced refractory concrete subjected to the constant load and temperature heating

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Abstract. The carbon textile reinforced refractory concrete is an alternative material to strengthen or reinforce the structure in elevated temperature environment or usually subjected to fire. This composite is one perfect combination between carbon textile reinforcement which ensures high capacities (mechanical strength and stiffness) at elevated temperature, and refractory concrete matrix which ensures thermal protection and loading retransmission into textile reinforcement. The aim of this paper is to identify the rupture temperature and exposure duration of carbon TRC in thermomechanical condition. This paper presents original experimental results on carbon TRC specimens subjected to 5 applied force levels (from 10% to 75% in comparison with the maximal strength of this material at room temperature) and temperature increasing. As the results, the studied carbon TRC specimen can exhibit up to the temperature of 670 °C in 23 minutes corresponding with applied force level of 50%. The rupture temperature and exposure duration of carbon TRC decreased progressively with increasing of applied force level. In comparison with experimental result on carbon textile specimen, the contribution of refractory matrix as thermal protection was found and analyzed. The exposure duration of the carbon TRC in case of fire could be calculated thanks to the temperature heating curve according to the standard ISO – 834.

Keywords: Textile - Reinforced Concrete (TRC), Carbon Textile, Refractory Concrete, Elevated Temperature, Thermomechanical Behavior.

1 Introduction

The textile-reinforced concrete composite (TRC) is an alternative material to strengthen or reinforce the civil engineering structures. This composite is one reasonable combination between textile reinforcement and cementitious matrix. The textile reinforcement ensures TRC mechanical strength, to against the weakness and cracking sensitivity of cementitious matrix thanks to its high strength and Young's modulus. On the other hand, cementitious matrix ensures loading retransmission between the textiles and protection from the environment. In case of fire or exposure to high temperature in the civil engineering structures, the high temperature resistance of TRC composite is important factor for structure strength durability. In TRC material,

fire resistance of textile reinforcement influenced greatly on that of TRC. With high strength and Young's modulus, the reinforcement by using the carbon textile was performed successfully in several previous research [1-2]. Furthermore, the contribution of cementitious matrix as thermal protection is also important for the fire resistance of TRC composite. Refractory matrix is perfect choice for fire application. This matrix is based on calcium aluminate cement (CAC) [3] or other cement with a high alumina content [4]. The refractory matrix has been used successfully to manufacture the basalt TRC composite for elevated temperature application in [5]. So, it would be interesting to combine carbon textile with refractory matrix to manufacture a good TRC for fire application. This paper presents an experimental study on thermomechanical behaviour of carbon TRC subjected to constant tensile loading and temperature increasing (as in case of fire). Firstly, carbon TRC specimens were tested in tensile at room temperature in order to identify its resistance. Then, the carbon TRC specimens were subjected to 5 applied force levels (from 10% to 75% in comparison with its strength at room temperature) and temperature increasing in order to determine the rupture temperature and exposure duration at high temperature. As the results, the studied carbon TRC specimen can exhibit up to the temperature of 670 °C in 23 minutes corresponding with applied force level of 50%. The rupture temperature and exposure duration of carbon TRC decreased progressively with increasing of applied force level. In comparison with experimental result on carbon textile specimen, the contribution of refractory matrix as thermal protection was found and analyzed. The exposure duration of the carbon TRC in case of fire could be calculated thanks to the temperature heating curve according to the standard ISO – 834 [6].

2 Experimental works

2.1 Equipment used

The test machine (TM20kN - 1200°C) has mechanical capacity of 20kN and equipped a cylindrical furnace to generate temperature around of specimens. The furnace can provide the temperature up to 1200°C with maximum heating rate of 30°C/min. The temperatures in the furnace and on the surface of test sample are controlled by thermocouples. The laser sensor equipped on the machine is used to measure the longitudinal deformation of specimens for the test at room temperature. This equipment was used in some authors' previous research [1,7].

2.2 Carbon TRC and specimens

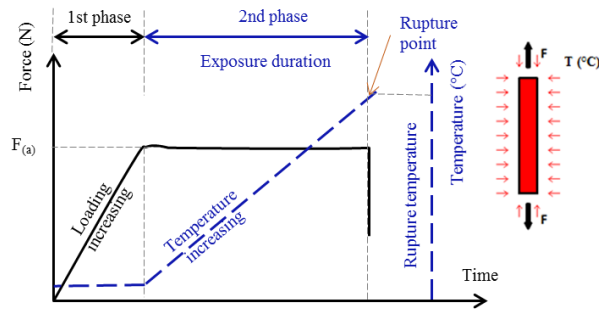
The carbon TRC (called F.GC1 in this study) is based on the refractory matrix and reinforced by GC1 carbon textile. The refractory matrix consists of a silico-aluminous-calcic synthetic aggregate (maximum diameter less than 1.25 mm) and the CAC cement. The high aluminate content of this cement (about 50%) gives good thermal characteristic to the matrix. The dimensions of F.GC1 specimens are 740 mm x 65 mm x 11.5 mm (length x width x thickness). The reinforcement ratio calculated by the volume fraction between the GC1 carbon textile and the composite (V_f/V_{total}) is 0.88%. Table 1 shows the properties of materials used in this study.

Table 1. Materials used for carbon TRC composite

Composition of refractory concrete		GC1 Carbon textile	
Aggregate (kg/m ³)	1676	Ultimate strength (MPa)	2617
Cement (kg/m ³)	669	Young's modulus (GPa)	256
Superplasticizer (kg/m ³)	4.34	Density (g/cm ³)	3.43
Viscosity modifier agent – VMA (kg/m ³)	0.51	Grid geometry (long x trans) (mm x mm)	46x41
Water (kg/m ³)	234.2	Type of coating	Epoxy resin
Water/cement ratio	0.35	Cross-sectional area (mm ²)	1.85

2.3 Test procedure

The procedure of thermomechanical test at constant force (TMCF) consists of two phases as presented in Fig 1. The first is to apply the quasi-static loading monotonically to the specimen up to the applied force level with the loading rate of 200 $\mu\text{m}/\text{min}$. The second is to maintain this force and increase the temperature around the TRC specimen with the temperature rate about 30 $^{\circ}\text{C}/\text{min}$ from room temperature until the rupture. The temperature corresponding to the rupture point of the test specimen is identified as the rupture temperature (T_r). The time of the second phase is called the exposure duration at high temperature (see Fig 1).

**Fig 1.** Loading path for thermomechanical tests in TMCF regime

2.4 Summary of specimens and tests

Table 2 shows the list of the specimens and the tests carried out. There are 18 tests carried out on the specimens of carbon TRC at room temperature and different loading levels varying from 10% to 75%.

3 Results

3.1 Test results at room temperature

Fig 2 shows the "stress-strain" curves of the mechanical behavior of F.GC1 at room temperature. From Fig 2, it can be found that F.GC1 samples give a strain hardening behavior with three phases as presented in the literature. The average ultimate tensile

strength of F.GC1 specimens is 12.67 MPa, corresponding with a maximum axial strain of 0.866%. Table 3 shows all values at the typical points of F.GC1 composite at room temperature.

Table 3. List of tests carried on the carbon TRC specimens at room temperature and at TMCF regime

Specimens	Dimen- sions	Loading levels (%)	Num- ber of tests
F.GC1 – 25°C – a,b,c		-	3
F.GC1 – 10% – a,b,c	S=11.5 x 65 (mm ²);	10	3
F.GC1 – 25% – a,b,c		25	3
F.GC1 – 50% – a,b,c		50	3
F.GC1 – 65% – a,b,c	l=740 (mm)	65	3
F.GC1 – 75% – a,b,c		75	3
Total of tests		18	

Table 2. Results of direct tensile tests carried out on F.GC1 specimens at room temperature

Specimens	Force (kN)	Ultimate strength (MPa)	Ultimate strain (%)
F.GC1 – 25°C – a	9.38	12.88	0.789
F.GC1 – 25°C – b	9.67	13.16	0.899
F.GC1 – 25°C – c	9.19	12.24	0.910
Average	9.41	12.76	0.866
Standard deviation	0.24	0.48	0.066

3.2 Test results in TMFC regime

Fig 3 shows the results of test performed on F.GC1 specimens in TMCF condition with different levels of applied force. As results, F.GC1 specimens can subject to thermomechanical action up to the temperature of 760 °C corresponding with the imposed force of 1kN (11% compared to its ultimate force at room temperature). From Fig 3, it can be found that the rupture temperature of F.GC1 gradually decreases when the imposed force level increases. With an applied force level of 75% (7.1 kN), its rupture temperature is 274 °C. All values obtained from the TMCF tests are presented in Table 4 below.

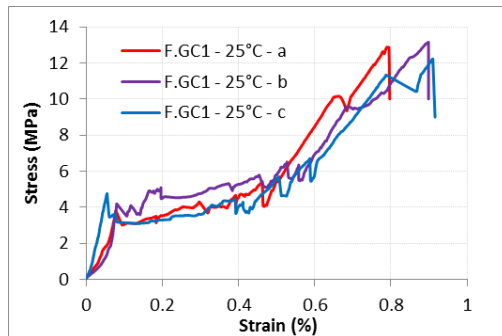


Fig 2. Mechanical behaviour of F.GC1 at room temperature

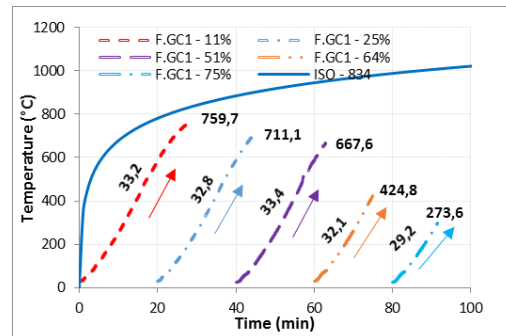


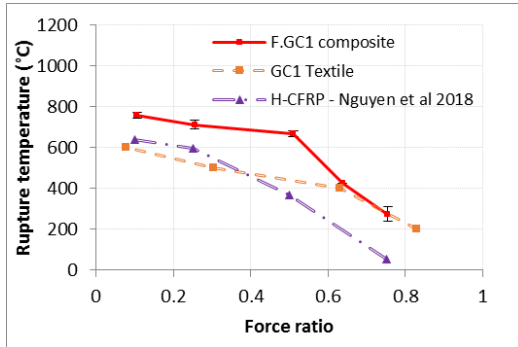
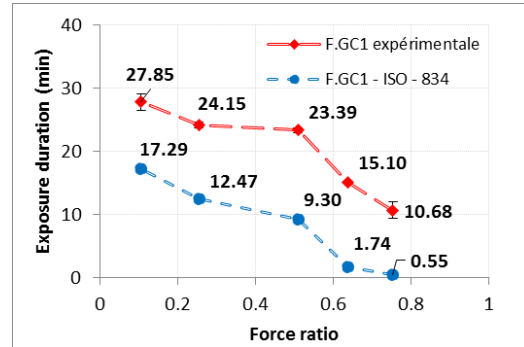
Fig 3. Temperature increasing as a function of time with different levels of applied force

Table 4. Results of thermomechanical tests carried out on F.GC1 specimens in TMCf regime

Specimens	Applied force (kN)	Force level (%)	Rupture temperature (°C)	Exposure duration (min)	Temperature rate (°C/min)
F.GC1 – 11%	1.0	11	759.7 (13.8)	27.9 (1.3)	33.2 (0.5)
F.GC1 – 25%	2.4	25	711.1 (21.2)	24.2 (0.5)	32.8 (0.1)
F.GC1 – 51%	4.8	51	667.6 (23.4)	23.4 (0.4)	33.5 (0.3)
F.GC1 – 64%	6.0	64	424.8 (1.3)	15.1 (0.2)	32.1 (0.4)
F.GC1 – 75%	7.1	75	273.6 (37.3)	10.7 (1.3)	29.2 (0.2)

4 Discussion

Fig 4 presents the evolutions of rupture temperature of F.GC1 depending on the applied loading level. With the applied force below the critical value of matrix cracking, the F.GC1 specimens gave good values of rupture temperature and exposure duration. In comparison with the experimental results on GC1 specimens, an improvement in fire resistance can be found in Fig 4 with the same applied force level. When the applied force increases, heat transfer in the matrix happens more quickly, depending on the appearance, density and opening of cracks on the specimen corps. So, the contribution of refractory matrix as thermal protection is decreased clearly. With applied force level higher than 50%, F.GC1specimens is completely cracked and their cracks are widened on its corps under tensile force. So, the refractory matrix almost loses its contribution as thermal protection for the GC1 textile. Concerning the results of temperature exposure duration, the similar evolution of its value as a function of applied force level could be found. In comparison of the experimental results with the temperature curve in ISO-834, it could predict the exposure duration of F.GC1 in case of fire according to that. Fig 5 presents the evolution of exposure duration at high temperature as a function of applied force level, comparing between experimental results obtained and predicted results as following the ISO – 834 curve. From Fig 5, it could be observed a difference about 10 min between both values.

**Fig 4.** Evolution of rupture temperature as a function of the applied loading level**Fig 5.** Evolution of the exposure duration at high temperature according to the applied loading level

5 Conclusion

As results obtained, some conclusions could be drawn for this work. The reinforced textile concrete F.GC1 has better capacity in TMCf condition in comparison with GC1 carbon textile and the Handmade- Carbon Fibre Reinforced Polymer (H-CFRP) composite [7] thanks to the contribution of refractory matrix as thermal isolation. This matrix contribution depends on the appearance, density and opening of cracks that are results of mechanical loading corresponding with each level of applied force. The exposure duration of F.GC1 at high temperature in case of fire could be predicted from the obtained experimental results.

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