Influence of different charges in cement-based matrix of textile-reinforced concrete (TRC) on its thermomechanical and thermal behaviours at different temperatures

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RÉSUMÉ. Le but de cette étude est de développer un TRC en matériau composite avec une matrice alumineuse pouvant améliorer sa résistance au feu. Les composites TRC étudiés sont composés de deux couches de grille de carbone intégrées dans une matrice chargée. Deux types de chargement de matrice ont été testés sous chargements thermique et mécanique. La première matrice est formée d'un ciment alumineux chargé de fibre de mat alkali-résistant (MatAR) et la seconde est un mortier alumineux ayant une granulométrie étalée, chargé de fibres de polypropylène (PPS). Lorsque la température varie de 25 ° C à 120 ° C, la résistance mécanique du TRC avec le polypropylène (TRC-PPS) est plus élevée que celle du TRC avec le mat AR (TRC-MatAR). Par contre entre 120°C et 400°C, la résistance mécanique du TRC-PPS diminue de 80% alors que celle du TRC-MatAR évolue significativement. Au final, les résistances mécaniques des deux TRC sont similaires lorsque la température est autour de 600 ° C. Une analyse thermomécanique (TMA) et une mesure de la diffusivité thermique complètent la caractérisation des matériaux en fonction de la température et relient l'effet de la température sur la microstructure au comportement thermomécanique global des composites TRC.

ABSTRACT. The aim of this study is to develop a composite material TRC with an aluminous matrix that can improve its resistance to fire. The studied TRC composites were made with two layers of carbon grid integrated in a filled matrix. Two types of filled aluminous cement were tested under thermal and mechanical loadings. The first matrix was aluminous cement filled with alkali resistant chopped strand mat (MatAR) and the second one was an aluminous mortar filled with polypropylene fibres (PPS). When the target temperature varies from 25°C to 120°C, the ultimate stress of the TRC with polypropylene (TRC-PPS) is higher than that of the TRC with mat AR (TRC-MatAR). On the other hand between 120 ° C and 400 ° C, the ultimate stress of the TRC-PPS decreases approximately 80% while that of the TRC-MatAR significantly evolves. At the end the mechanical resistance of both TRCs when the temperature is around 600 ° C. A thermomechanical analysis (TMA) and a measurement of the thermal diffusivity complete the characterization of the materials as a function of the temperature and relate the effect of the temperature on the microstructure and on global thermomechanical behaviour of the TRC composites.

MOTS-CLÉS : TRC, fibre de polypropylène, mat AR, température, comportement thermomécanique, comportement thermique

KEY WORDS: TRC, polypropylene fibres, mat AR, temperature, thermomechanical behaviour, thermal behaviour

1. Introduction

Textile reinforced concrete (TRC), is a new composite material composed of multi-axial textiles and fine concrete. The material exhibits several advantages. From these benefits, the good fire-resistance capability and elevated temperature mechanical performance of TRC was focused in this study. Thus fire-protection is a prominent issue in TRC studies and is also a key problem that needs to be addressed when TRC panels are to be extensively applied. Unfortunately, few studies have been conducted on the elevated temperature mechanical behavior of TRC [BUT 2014], [NGU 2016], [DON 2017], [TLA 2018] and [VAR 2018]. Furthermore, other studies analyzed the fire resistance of concrete with different microfibers. Mirza et al [MIR 2002] found that alkali-resistant glass fibers are highly effective in controlling restrained shrinkage cracking of lightweight concrete and in controlling the negative impacts of exposure to elevated temperatures. Serrano et al [SER 2016] showed that incorporating polypropylene fibers are good alternative additives for traditional concrete, since they improve the strength and behavior of concrete in case of fire. In order to improve elevated temperature resistance performance of TRC, this paper focused on the thermomechanical behavior of two types of TRC with different charges in the matrix and same textile reinforcement. The charges added to the TRC matrix are the AR chopped strand mat glass textile and polypropylene fibers. First, the mechanical behavior of TRC composites was characterized at 25°C. Stress/strain relationships of TRC composites were determined and the crack width as a function of the axial stress for both types of TRC was measured. Then, in order to investigate the effect of different charges in cement-based matrix on thermomechanical behavior of TRC, a combined thermal and mechanical load was followed. Additionally, a thermomechanical analysis (TMA) and a measurement of the thermal diffusivity complete the characterization of the materials as a function of the temperature and show effects of temperature on microstructure and on global thermomechanical behaviour of the TRC composite.

2. Specimens

In this study, two textile reinforced composites (TRC-MatAR and TRC-PPS) are made with 2 layers of coated carbon grid and two different charged aluminous cements. The first aluminous matrix is made of aluminous cement filled with AR chopped strand mat glass textile (MatAR) and the second one is formed of aluminous mortar filled with polypropylene fibers (PPS). A biaxial textile made of carbon fiber grid (with a mesh size of 7mmx7mm) coated with resin epoxy was used as the composite internal reinforcement in this experiment. The choice of the size of a TRC-MatAR or TRC-PPS composite specimen mainly depends on the used furnace volume of the thermomechanical machine TM20kN-1200C used in this study. The cross section of the composite specimens may not exceed 50 mm x 10 mm and a length of 700 mm was chosen.

3. Characterization techniques

This section presents uniaxial tensile tests at ambient temperature, that at different temperatures and thermal analysis carried out in this study.

3.1. Uniaxial tensile tests at ambient temperature

Uniaxial tensile tests on the TRC plates were conducted using the TM20kN-1200C machine with a mechanical loading under a controlled displacement of 1mm/min. During uniaxial tensile test, the TRC axial strain was measured by a laser sensor [NGU 2016] and with the digital image correlation technique (DIC), the crack width of both types of TRC was evaluated as a function of the applied axial stress.

3.2. Uniaxial tensile tests at different temperatures

In order to investigate the effect of different charges in cement-based matrix on thermomechanical behavior of TRC subjected to a combined thermal and mechanical loading, the TRC sample was first placed inside the furnace and then heated to the required temperature. The temperature in the furnace increases to a required temperature level ranging from 25°C to 600°C with a corresponding heating rate ranging from 2.5°C/minute to 20°C/minute. Once the required temperature is reached, a tensile uniaxial load is applied and the laser sensor records the axial strain of the TRC specimen [TLA 2018], [NGU 2016].

3.3. Thermal analysis

A thermomechanical analysis (TMA) follows the thermal strain measurement of TRC according to several temperature levels. This analysis deal with dilatometric evolution of TRC as a function of the temperature. Then a measurement of the thermal diffusivity of TRC completes the characterization of the studied material as a function of the temperature and shows effects of temperature on microstructure and global thermomechanical behaviour of the TRC composite.

4. Results and analysis

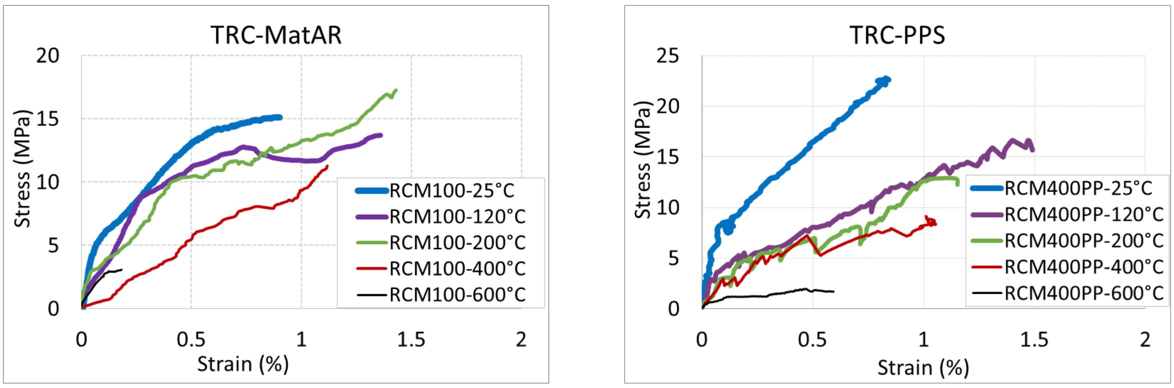
This section presents the thermomechanical and thermal behaviours of the studied TRCs exposed to different temperatures.

4.1. Thermomechanical behaviour of TRCs

Stress/strain relationships of TRC-MatAR and TRC-PPS composites were shown in Figure 1. These curves allow identifying characteristic parameters (ultimate stress, maximun thermomechanical strain, stiffness) of each TRC and compare their mechanical behavior at different temperatures. Figure 1 showed that the mechanical resistance of TRC-PPS is better than that of TRC-MatAR at 25°C. Cement-based matrix with polypropylene fibers increases load transfer and ultimate tensile axial stress of TRC. At 25°C, the ultimate tensile axial stress of TRC-PPS is about 26% higher than that of TRC-MatAR while the initial stiffness and the stiffness of the post cracked composite of these two TRCs are almost the same. Figure 2 shows the crack width evolution as a function of the axial stress for TRC-PPS and TRC-MatAR (tensile tests carried out at 25°C). This figure shows that for the same axial stress level (25MPa), the crack widths of these TRC are similar. The use of PPS matrix contributed to higher ultimate axial stress (30MPa) of TRC-PPS. This stress corresponds to a higher crack opening for TRC-PPS (Figure 2). The use of cement with AR chopped strand mat glass textile (Mat AR) promotes multiple cracking for TRC-MatAR. The tensile behavior of TRC was also determined at 120°C, 200°C, 400°C and 600°C. Figure 1 allows comparing the effect of the matrix filled with different materials (PPS or MatAR). When the temperature varies from 25°C to 120°C, the ultimate stress of TRC-PPS is higher than that of TRC-MatAR. At 120°C, ultimate stress levels of both TRC composites are close. The ultimate stress of the TRC-PPS decreases between 120°C and 600°C in a linear manner (Figure 3). While the ultimate stress of the TRC-MatAR significantly evolves between 120°C and 400°C. At the end the ultimate stresses of both TRCs are close when the temperature is around 600°C.

4.2. Thermal behaviour of TRCs

Figure 4 shows the dilatometric evolution of TRC composites as function of the temperature that is obtained by the thermomechanical analysis (TMA). When TRC-PPS and TRC-MatAR are exposed to temperature that evolves from 25°C to 150°C, the thermal axial strain of the first one, TRC-PPS, undergoes a slight expansion about 0.05% while the second one, TRC-MatAR, expands about 0.2% (Figure 4). After 150 ° C, the two TRCs undergo a significant contraction. This contraction is almost stabilized after 300°C for TRC-PPS and decreases for TRC-MatAR. Then with regard to thermal diffusivity for both TRCs (Figure 5), it is seen that the diffusivity of TRC-PPS decreases between 25°C and 300°C in a constant way before it almost stabilizes between 300°C and 600°C. While the diffusivity of TRC-MatAR, which is 5 times less than that of TRC-PPS at 25 ° C, slightly varies with temperature and always remains less than 0.5 mm^2/s.



(a) (b)

Figure 1. *Stress-strain curves at different temperatures of TRC-MatAR (a) and TRC-PPS (b)*

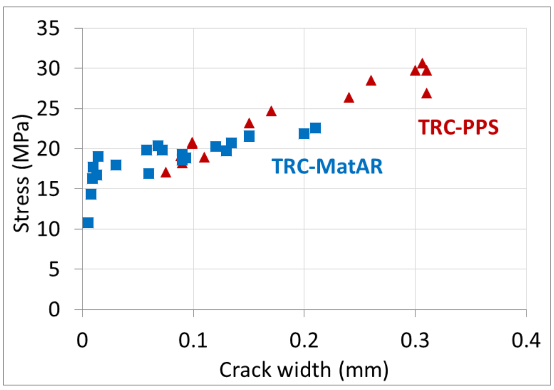


Figure 2. *Stress-crack width*

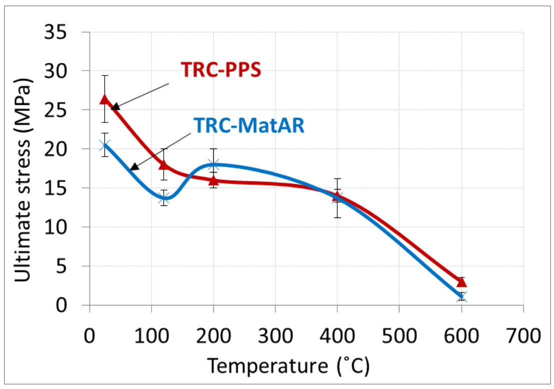
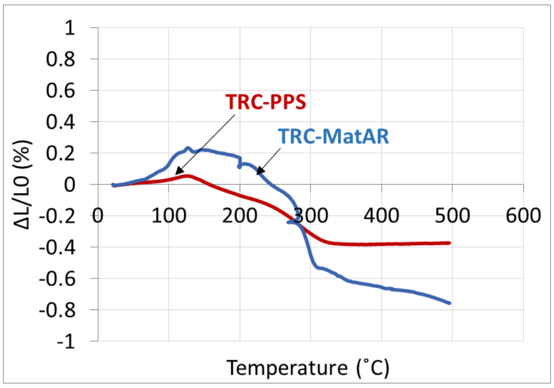


Figure 3. *Ultimate stress-temperature*



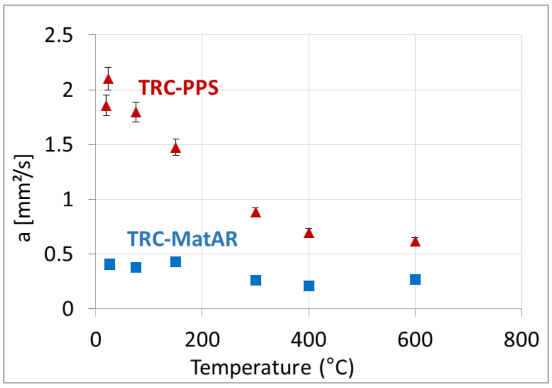


Figure 4. *Dilatometric evolution of the studied TRC*

Figure 5. *Diffusivity evolution of the studied TRC*

5. Conclusion

Results in this study show effects of temperature on microstructure and global thermomechanical behaviour of the TRC composites constituted from two different matrices. It seems that the cement-based matrix with PP improves the load transfer and then the resistance of the TRC up to 150°C compared to the TRC with aluminous cement charged with Mat AR. On the other hand, polypropylene fibers integrated in the aluminous matrix prove appropriate for controlling the crack opening during heating processes while Mat AR fibers create a greater thermal insulation at high temperature.

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