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Tensile strength of a calcium-aluminate cementitious composite reinforced with basalt textile in a high-temperature environment

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ABSTRACT

The effect of elevated temperatures on basalt textile reinforced calcium aluminate cementitious composite is reported. After being exposed for 1 h at various constant temperature levels, samples were tested in hot as well as after cooling down at room temperature conditions (termed as residual tests). Targeted constant temperatures considered varied from 25 up to 400 °C, representing the range that affects the main dehydration of hydration products present in the matrix. The residual mechanical response of basalt fabric at similar temperature ranges was also measured. Thermogravimetry and X-ray diffraction analysis were used to study phase changes as a function of temperature. Scanning electron microscopy (SEM) was used to study damage processes in the fiber–matrix interfaces. Results indicate that the tensile strength of composites in residual conditions is higher than that in hot conditions. This traced back the mechanism that the fabric-coating visco-elastic/plastic interface changes with temperature, which affects the textile-cementitious adhesion properties. When the composite was tested in hot conditions, a much more aggressive loss of the load-carrying capacity was observed. With increasing temperature, the hot tests, showed a significant reduction in tensile strength, elastic modulus and strain capacity. Ultimate direct tensile strength values obtained under hot condition were, on average, 50% lower than the residual ones.

1. Introduction

Textile reinforced concretes (TRC) are a new generation of cementitious materials with enhanced tensile strength and ductility [1,2]. With its excellent mechanical properties, TRC's are used, currently, in a wide range of applications that include: strengthening and repair in structural members, protective linings, thin-walled elements, façade panels, bridges and also freeform and lightweight structures. It is important to consider, however, that in many of these applications both concrete and textile may be affected by thermal effects, which make a thorough study on the thermo-hydro-chemo-mechanical performance of TRC mandatory [3–5]. Although there is a growing interest in the use of TRC elements, little is known about their thermo-mechanical performance and even less about TRC applications using refractory concrete/mortar as a matrix [6]. As reported by Colombo et al. [7], there are still only a few results available in literature about the fundamental properties of TRC's exposed to extreme conditions such as high temperature and fire conditions.

The response of refractory concrete members when submitted to elevated temperatures largely depends on the thermo-hygro-chemo-mechanical properties of the concrete phase, determined by the multi-scale matrix structure of the cementitious and aggregate composite, as well as on the environmental conditions such as humidity, heating rate, exposure time and presence of gases. The mechanical properties of refractory concrete specimens pre-heated at particular temperature levels do not correspond to the properties of such specimens obtained after being cooled down to room temperature again, and tested under ambient conditions [8–10]. Most measurements are generally done at room temperature (past cooling, residual tests), after an accumulation period at a

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given target temperature. This was to avoid complex assembling's of devices necessary to carry out tests at high temperature, such as instrumenting LVDT's for high temperature, coupling ovens/thermostatic chambers to a universal testing machine, installing high temperature resistant parts, applying insulated thermocouples and installing advanced cooling systems.

Designing concrete structures to resist elevated temperatures (e.g. tunnel lining, fire barriers, cooling towers and encapsulation elements), requires specific knowledge on the thermo-mechanical properties of the used materials. In this context, parameters such as strength, elastic modulus, toughness and brittleness during and after heat treatment under elevated temperatures are required. Moreover, to gain a fundamental understanding of the degradation mechanism involved, mechanical results should be accompanied by microstructural and chemical analysis.

Studies reported by Soro et al. [11] revealed that it is possible to develop refractory composites reinforced with long parallel fibers (e.g. low-cost glass fibers) showing ductile residual behavior even after dehydration of the main hydrated products (~400 °C). Colombo [12] showed the applicability of TRC's (reinforced with AR-glass fabric) in sandwich panels with the purpose of saving energy in new and existing buildings (energy retrofitting). In this study the durability of TRC when exposed to freezing-thawing cycles was investigated. According to the authors, curing conditions, both heating and cooling, may affect the matrix shrinkage, and consequently the bond strength inside the composite material. In relation to the freeze-and-thaw cycles, mechanical performances of TRC's are directly related to their self-healing and late hydration capacity since matrix cracking may occur during these thermal cycles.

Coatings applied to a textile fabric can improve the durability (e.g. against corrosive alkaline environment or high temperatures). However, when exposed to elevated temperatures, some types of coating change their chemical and mechanical properties, leading to a reduced bond performance between fiber and matrix [6]. Recently, researchers, developed a system (Silva et al. [4]), that uses TRC reinforcement with carbon fibers and showed that when heating the polymer-coated carbon fibers TRC under temperatures up to 150 °C, a polymer-based interlocking mechanism between the filaments and matrix revealed. This mechanism resulted in a significant increase of the maximum pullout load.

Therefore, the aim of this paper is to investigate the effect of elevated temperatures on the mechanical properties of textile refractory composites reinforced with a basalt fabric submitted to tensile loading under different thermal testing conditions, i.e. hot and residual. At first, refractory composites were produced with a cementitious matrix made of synthetic calcium aluminate aggregates and calcium aluminate cement (CAC), then reinforced with basalt fabrics. The composites were tested in tension after being submitted to different temperature regimes, with targeted constant temperature levels ranging from 25 to 400 °C. During high-temperature testing, specimens were loaded after having been exposed to the targeted temperature for 1 h, while the residual test specimens were loaded at room temperature, so after having experienced the same thermal exposure time, these specimens were cooled down to room temperature. The microstructure of the composites was characterized by scanning electron microscopy (SEM), thermo-gravimetric analysis (TGA) and powder X-ray diffraction (XRD) and then related to their mechanical properties.

2. Materials and methods

2.1. Refractory matrix

The matrix used in this research (compressive strength of about 45 MPa) was designed according to the compressible packing model (CPM) procedure [13,14] and adjusted to achieve a rheology necessary to produce the laminated TRC's. Because of the small diameters of the continuous filaments and small distances between the reinforcement textile layers, the maximum aggregate size had to be less than 1.18 mm in diameter. The materials used in the TRC composition were a calcium aluminate cement (Secar 51 from Kerneos Inc.) with an alumina content of about 51%, a synthetic calcium aluminate aggregates (Alag from Kerneos Inc.) with an alumina content of about 40% and diameters ranging from 0.001 mm to 1.18 mm, and a powder polycarboxilate superplasticizer (Peramin CONPAC 500 from Kerneos Inc.). Table 1 presents detailed information about the chemical composition of the cement and of the synthetic calcium aluminate aggregate. The water-cement ratio of the refractory matrix was 0.35. Mix-design details of the referred matrix are provided in Table 2.

2.2. Basalt fabric

A basalt textile, commercialized by the Zhejiang GBF Basalt Fiber Co. Ltd., China, was used as reinforcement for the TRC specimens. The basalt textile was produced with a styrene-acrylic latex coating (43 g/m^2). The warp as well as the weft contains about 800 monofilaments with an average diameter of 13 μm. Table 3 presents the properties of the used coated basalt textile.

2.3. Matrix processing and composite manufacturing

The refractory composites were produced in a temperature controlled room at 24 °C ± 1 °C using a planetary mixer (moistured in advance) with a 5 L capacity. The dry cementitious materials were homogenized for 60 s, prior to water addition. The mixture was blended for 5 min. The viscosity modifying agent type Rheomac UW 410 (VMA) was added 4 min later. Rectangular TRC fabric plates, measuring 400 mm × 250 mm × 13 mm (length - × width × thickness), were produced for the direct tensile tests using a consistent lamination technique. For preparation of these plates acrylic molds were used. First, a thin refractory matrix layer was placed at the bottom of the mould. After that, the first basalt textile reinforcement fabric layer was placed on top of the fresh matrix (Fig. 1). The basalt fabric was then stretched and aligned in order to regularize and smoothen the first surface layer. Next, this procedure was repeated until reaching the desired number of 5 equally-spaced fabric layers, resulting in a fiber volume fraction of

Table 1
Chemical composition of the cement and of the synthetic calcium aluminate aggregate.

Cement		Aggregate	
Compound	Content/%	Compound	Content/%
Al_2O_3	51.45	Al_2O_3	39.88
CaO	38.51	CaO	36.02
SiO_2	3.07	SiO_2	2.79
Fe_2O_3	1.76	Fe_2O_3	14.48
TiO_2	1.89	TiO_2	1.61
SO_3	0.61	SO_3	1.05
K_2O	0.42	K_2O	0.19
ZrO_2	0.12	ZrO_2	0.09
MnO	0.02	MnO	0.19
SrO	0.05	SrO	0.03
Ga_2O_3	0.01	Ga_2O_3	0.15
Y_2O_3	0.01	Y_2O_3	0.01
Ta_2O_5	0.03	P_2O_5	1.77
Cr_2O_3	0.07	V_2O_5	0.06
NbO	0.01	LOI	1.68
LOI	1.96		