Materials and Design 65 (2015) 24–33

Contents lists available at ScienceDirect

Materials and Design

journal homepage: www.elsevier.com/locate/matdes

Effect of elevated temperatures on the mechanical behavior of basalt textile reinforced refractory concrete

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ARTICLE INFO

Article history:
Received 6 July 2014
Accepted 26 August 2014
Available online 3 September 2014

Keywords:
Thermomechanical properties
Textile reinforced refractory concrete
Basalt fiber
High temperatures

ABSTRACT

The work in hand presents the results of an experimental investigation on the thermo-mechanical properties of a textile refractory composite reinforced with polymer coated basalt fibers under tensile loading. The composites were produced as a laminate material using basalt bi-directional fabric layers as reinforcement. A high alumina cement matrix was used in the matrix composition which was designed using the compressible packing method. A series of uniaxial tensile tests was performed under temperatures ranging from 25 to 1000 °C. The cracking mechanisms were discussed and compared to that obtained at room temperature. Thermogravimetry and X-ray diffraction analysis were used to study the deterioration/phase changes as a function of the studied temperatures. Scanning electron microscopy (SEM) was used to study the damage processes in the fiber–matrix interfaces after exposure to high temperatures. The obtained results indicated that the presence and the type of coating can become a deterministic factor in the tensile response of the composite submitted to elevated temperatures. A sudden drop in the serviceability limit state of the composite was observed above 400 °C, caused by the degradation of the polymer used as a fiber surface coating, the degradation of the basalt fiber and by the dehydration process of the refractory matrix.

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, the TRC's are used, currently, in a wide range of applications that include: strengthening and repair in structural elements, protective linings, thin-walled elements, façade elements, bridges and also freeform and lightweight structures. In the last two decades significant improvements in the development of TRC have been achieved resulting in high performance composites that can present uniaxial tensile strength up to 50 MPa and tensile strain up to 5% [3,4]. It is important to consider, however, that in many of these applications the concrete and the textile undergo thermal effects, becoming the study of thermo-mechanical performance of TRC absolutely indispensable [5–7].

Although there is a growing interest in the use of TRC elements, little is known about their thermo-mechanical performance and even less about applications using refractory concrete as a matrix. Conventional fiber refractory concrete present increased ductility and toughness compared to the plain refractory matrix [8,9]. In most cases, the use of a fiber reinforcement in refractory concretes is related to the control of cracking during the heating or drying process (bridging the crack and limiting the crack propagation) [8,10] and as an attempt to reduce the fragmentation process of the concrete when subjected to high temperatures (spalling) [10–12].

It is known that high alumina cement has alkali content typically less than 0.5% of its weight [13]. Therefore, the risk of alkali attack, common to basalt, glass and natural fibers, decreases substantially in refractory concretes. Taking advantage of these properties, several researches used high alumina cements in the past to produce fiber reinforced composites (specially using glass fibers) [14].

Basalt is a low cost material that brings interesting opportunities to the construction industry. Recent researches developed by Larrinaga et al. [15] contributed to explain the mechanical behavior of basalt fabric as a reinforcement in a TRM (textile reinforced mortar). Several basalt layers were used as reinforcement in a non-commercial cement-based mortar containing a redispersible resin

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http://dx.doi.org/10.1016/j.matdes.2014.08.060
0261-3069/

to achieve fire-proof properties. The tensile strength showed to be strongly affected by the reinforcement ratio. There were visible differences in the cracking spacing as well as in the crack width and the strain capacity surpassed 2% for the most of the studied TRM specimens. Sim et al. [16] investigated the applicability of the basalt fiber as a strengthening material for structural concrete members through durability, mechanical, thermo-mechanical and structural tests. The results obtained indicated that, compared to FRP (fiber reinforced polymer) strengthening systems, the basalt fiber strengthening may be a good alternative when characteristics such as moderate structural strengthening and high resistance for fire are simultaneously sought (such as for building structures). When tested under high-temperature (over 600 °C) and compared to carbon and S-glass fibers, only the basalt maintained its volumetric integrity and 90% of the strength.

When a coating is used in the textile reinforcement, the bond performance between fibers and matrix may change with temperature. Recent researches developed by Silva et al. [6] using TRC reinforced with carbon fibers showed that when heating polymer coated carbon fibers TRC under temperatures up to 150 °C a polymer interlocking mechanism between filaments and matrix is observed. This mechanism results in significant increases in the maximum pullout load. Krüger and Reinhardt [5] performed fire tests on four different I-shaped mortar beams reinforced with AR-glass and carbon textiles. The investigation was focused on the load bearing capacity of the composite during a fire test under constant load. In one of the cases a SBR thermoplastic resin was used as coating in the carbon fabric. The results showed to be very dependent on the fire behavior of the used fibers. Due to the softening of the SBR coating (at about 90 °C) the fiber–matrix interface was rapidly impaired, resulting in fiber pullout and, subsequent, failure.

The aim of this article is to investigate the effect of elevated temperatures on the mechanical properties of a textile refractory composite reinforced with basalt fabric submitted to tensile loading. At first, the refractory composites were produced with a cementitious matrix, made of calcium aluminate aggregates and high alumina cement (HAC), reinforced with basalt fabrics. The composites were tested under tensile load after being submitted to different temperatures regime ranging from 25 to 1000 °C. The influence of the number of textile layers on the tensile behavior of TRC was also addressed. The influence of the exposure time on the tensile behavior of basalt TRC was investigated for the temperature of 200 °C. The crack formation was investigated using a high resolution imaging procedure. Crack spacing was measured using image analysis and correlated with the applied strain under tensile loading. Tensile tests on basalt fabric specimens were carried out at room temperature and at 400 °C. The identification of the dehydration reactions caused by the heating regime was addressed using thermo-gravimetric analysis (TGA) and X-ray diffraction (XRD). The present study adds an important knowledge to the existing literature on the thermo-mechanical behavior of textile reinforced concrete.

2. Materials and processing

2.1. Refractory concrete matrix

The matrix used in this research (compressive strength of about 45 MPa) was designed following the compressible packing model (CPM) routine [17,18] and then adapted to the rheology necessary to produce laminated TRC's. As a result of the small diameter of the continuous filaments and the small distance between the reinforcement textile layers, the maximum aggregate diameter had to be less than 1.18 mm. The materials used in the TRC composition were a calcium aluminate cement (Secar 51) with alumina content of about 50%, a synthetic calcium aluminate aggregate (with an alumina content of about 40%) with diameter ranging from 0.001 mm to 1.18 mm and a polycarboxylate superplasticizer in powder. The water/cementitious material ratio of the refractory concrete was 0.35. Table 1 gives the composition of the concrete matrix.

2.2. The 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 is formed by about 800 monofilaments with average diameter of 13 μm. Table 2 presents the properties of coated basalt textile.

2.3. Matrix processing and composite manufacturing

The refractory concretes were produced in a room with controlled temperature of 24 °C ± 1 °C using a planetary mixer (previously moistured) of 5 l capacity. The cementitious materials were homogenized by dry mixing for 60 s prior to the addition of water. The mixture was blended for 5 min. The viscosity modifier agent type Rheomac UW 410 (VMA) was added after 4 min of mixing.

Rectangular plates measuring 400 mm × 250 mm × 13 mm (length × width × thickness) were produced for direct tensile tests using a lamination technique. For the production of the plates, the concrete mixtures were placed in acrylic molds. The process started with a thin concrete layer placed on the bottom of the surface mold. The second phase consisted on positioning the first mesh of basalt textile reinforcement over the fresh concrete (Fig. 1). The basalt fabric was then pressed and smoothed in order to regularize and align the surface of the layer. After the second phase, the procedure was repeated until reaching the desired number of fabric layers. In this study 1, 3 and 5 fabric layers were used as reinforcement in the TRC's, however, samples without fabric layers were also produced. A manual vibration was applied to the samples. After 7 days, the rectangular plates were cut, resulting in 4 specimens of 400 mm × 60 mm × 13 mm (length × width × thickness). In this study, refractory composites were produced without reinforcement and with 1, 3 and 5 layers of basalt fabric (equally spaced), resulting in fiber volume fractions of 0%, 0.59%, 1.79% and 2.98%. The stress was obtained by dividing the load by the nominal area of the specimen cross section. The determination of the cross-sectional area was performed by the average of four measurements (width and thickness) at four different points of each sample.

3. The heating regime

The TRC specimens were heated up to 75, 150, 200, 300, 400, 600 and 1000 °C and subsequently cooled by a natural process inside the furnace. Experiments on specimens stored at room temperature were also carried out. In order to better understand the

Table 1
Mix composition.

Composition	
Dense aggregate (kg/m^3)	1416.2
Cement (kg/m^3)	750
Superplasticizer (kg/m^3)	4.87
Viscosity modifier agent – VMA (kg/m^3)	0.562
Water (kg/m^3)	262.6
Superplasticizer content (%)	0.65
Water/cementitious material ratio	0.35