Available online at www.sciencedirect.com

SCIENCE DIRECT®

Cement & Concrete Composites 27 (2005) 49–54

Cement & Concrete Composites

www.elsevier.com/locate/cemconcomp

Fracture toughness of geopolymeric concretes reinforced with basalt fibers

Dylmar Penteado Dias, Clelio Thaumaturgo *

Departamento de Engenharia Mecânica e de Materiais (DEMM), Instituto Militar de Engenharia (IME), Praca General Tiburcio 80 (De 4), Praia Verhelha, Rio de Janeiro, RJ 22290, 270, Brazil

Received 15 October 2002; accepted 20 February 2004

Abstract

The purpose of this work was to investigate the influence of the volumetric fraction of the fibers on the fracture toughness of geopolymeric cement concretes reinforced with basalt fibers. The values of fracture toughness, critical stress intensity factor and critical crack mouth opening displacement were measured on 18 notched beams tested by three-point bending. The a_0/h (notch height/beam height) ratio was equal to 0.2 and the L_0/h (distance between the supports/beam height) ratio was equal to 3.

According to the experimental results, geopolymeric concretes have better fracture properties than conventional Portland cement. They are also less sensitive to the presence of cracks.

Keywords: Geopolymeric cement; Fracture toughness; Critical stress intensity factor; Critical crack mouth opening displacement; Notched beams; Basalt fibers

1. Introduction

The inorganic polymeric cement known as geopolymer [1] is being currently investigated by the composite materials group at the Instituto Militar de Engenharia (IME) as a cementitious material (as a partial or total replacement of Portland cement) in the production of mortars and concretes [2–7].

2. Objectives

The requirements imposed on construction materials are so demanding and diverse that no material is able to satisfy them completely. This has led to a resurgence of the ancient concept of combining different materials in a composite material to satisfy diverse user requirements [8].

Several studies have shown that fiber reinforced composites are more efficient than other types of composites. The essence of composite materials technology is the ability to put the fibers in the right places, at the right orientations and with an adequate volume fraction [9].

The main purpose of the fibers is to provide a control of cracking and to increase the fracture toughness of the brittle matrix through bridging action during both micro and macrocracking of the matrix. Debonding, sliding and pulling-out of the fibers are the local mechanisms that control the bridging action [10].

In the beginning of macrocracking, bridging action of fibers prevents and controls the opening and growth of cracks. This mechanism increases the demand of energy for the crack to propagate. The linear elastic behavior of the matrix is not affected significantly for low volumetric fiber fractions. However, post-cracking behavior can be substantially modified, with increases of strength, toughness and durability of the material [11].

The purpose of this study was to evaluate the fracture toughness (critical stress intensity factor—K_{Ic}) and critical crack mouth opening displacement ($CMOD_c$) of geopolymeric concretes reinforced by different volumetric fractions of basalt fibers (0%, 0,5% and 1% by volume). The basalt fibers were chosen due to their chemical compatibility with alkaline environments [12].

---

* Corresponding author.
E-mail addresses: clefetati@ig.com.br, imes4cle@epq.ime.eb.br (C. Thaumaturgo).

0958-9465/$ - see front matter © 2004 Elsevier Ltd. All rights reserved.
doi:10.1016/j.cemconcomp.2004.02.044

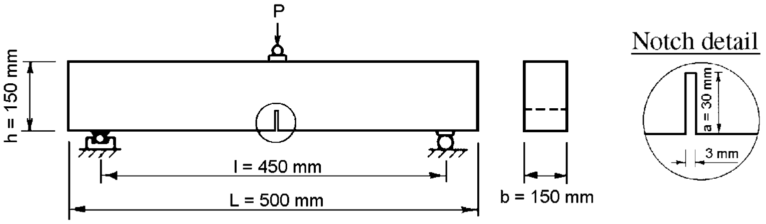

Fig. 1. Testing of notched beam specimens.

The experimental results were compared to those for high early strength Portland cement, since the main characteristic of the geopolymeric cement is an ultra-rapid strength gain.

3. General considerations

Three-point bending, single-edge, notched beam specimens, with a fixed span-to-depth ratio equal to 4 and a limited range of crack-to-depth ratios from 0.4 to 0.7, are the current standard [13–16] for the measurement of the critical stress intensity factor and of fracture toughness. Achieving reproducible results is easier with larger span-to-depth ratios (greater than 2.5) and deeper cracks [17,18].

The values of the critical crack mouth opening displacement ($\mathrm{CMOD_c}$) and the critical stress intensity factor for mode I cracking (K_{Ic}), using a three-point bending single edge notched beam (Fig. 1), were calculated according to Ref. [17], because the dimensions of the specimens used in this work were not in accordance with the international standards.

4. Experimental procedure

4.1. Materials and sample preparation

In order to determine the fracture properties of the concretes reinforced by basalt fibers, 18 notched beams were tested by three-point loading. The dimensions of all specimens were 150 mm × 150 mm × 500 mm with a notch height to beam height (a_0/h) ratio equal to 0.2 and a free span to beam height (L_0/h) ratio equal to 3.

The high early strength Portland cement (CPV ARI PLUS), designated as PC, was provided by Holdercim Brasil S/A. The geopolymeric cement, designated as PSS—Poly(Siloxo-Sialate), was synthesized at the Instituto Militar de Engenharia (IME) [2]. PSS cements consist of chains and ring polymers with $\mathrm{Si^{4+}}$ and $\mathrm{Al^{3+}}$ in IV-fold co-ordination with oxygen and range from amorphous to semicrystalline. The PSS network consists of $\mathrm{SiO_4}$ and $\mathrm{AlO_4}$ tetrahedra linked alternately by sharing all the oxygen. Positive ions ($\mathrm{Na^+}$, $\mathrm{K^+}$ or $\mathrm{Ca^{2+}}$) are present in the framework cavities to balance the negative charge of $\mathrm{Al^{3+}}$ in IV-fold co-ordination (Fig. 2). Metakaolin is a pozzolanic material used in this study to manufacture the PSS. The PSS empirical formula proposed is [1]

$$\mathrm{M}_n[-(\mathrm{SiO_2})_z - \mathrm{AlO_2}]_n,\ \mathrm{wH_2O}$$

where M is a cation such as potassium, sodium or calcium, n is a degree of polycondensation and $z = 1$, 2 or 3.

The basalt fibers used in this work were manufactured by Albarrie Canada Inc. with an average length of 45 mm and an average diameter of 9 μm. The mechanical properties of the basalt fibers, as provided by the manufacturer, are summarized in Table 1. A semi-quantitative chemical analysis of the basalt fibers (Table 2) was obtained by Energy Dispersive Spectroscopy

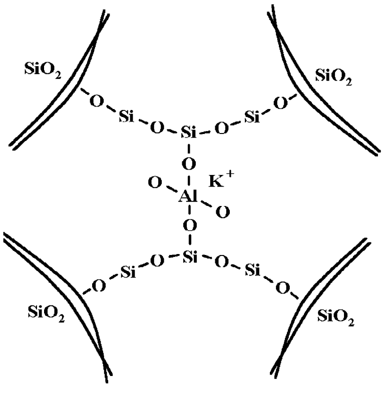

Fig. 2. Geopolymeric cement (PSS) network.

Table 1
Physical and mechanical properties of basalt fibers

Density (g/cm^3)	Linear thermal expansion 0–300 °C (ppm/°C)	Tensile strength (MPa)	Modulus of elasticity (GPa)	Ultimate strain (%)
2.8	8.0	4.810	89	3.15