Fire Safety Journal 71 (2015) 324–331

Contents lists available at ScienceDirect

Fire Safety Journal

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

High temperature behaviour of polypropylene fibres reinforced mortars

Mohammed Ezziane [a,b], Tahar Kadri [a], Laurent Molez [b,c,*], Raoul Jauberthie [b,c], Ali Belhacen [a]

[a] Department of Civil Engineering & Architecture, Laboratory LMPC, University of Mostaganem-27000, Algeria
[b] Laboratoire de Génie Civil et de Génie Mécanique (LGCGM)-EA 3913, Institut National des Sciences Appliquées, 20 avenue des buttes de Coësmes, CS 70839, 35508 Rennes cedex 7, France
[c] Université Européenne de Bretagne, France

ARTICLE INFO

Article history:
Received 19 July 2013
Received in revised form
24 November 2014
Accepted 30 November 2014
Available online 19 December 2014

Keywords:
Polypropylene fibre mortar
Mechanical behaviour
Fracture energy
Fire test
Spalling
Punching shear test

ABSTRACT

The aim of this paper is primarily experimental and is intended to analyse the behaviour of two cementitious materials, before and after heat treatment: one unreinforced (i.e. without fibres) and the other reinforced (with polypropylene fibres).

At room temperature and after heating up to 500 °C, the bending strength is improved by the presences of fibres. The residual young modulus is slightly higher for the fibres reinforced samples.

As the temperature increases, the strength gain due to fibres inclusion is reduced. Beyond 500 °C, the bending strength is lower for the fibre reinforced cementitious material compared to those without fibres. Fracture energy is also improved for the fibre mortars at room temperature. At 400 °C this improvement decreases gradually with the introduction of polypropylene fibres. Beyond this temperature and due to the introduction of polypropylene fibres, the fracture energy is reduced.

Another test is developed: rapid heating due to exposure to a flame. The temperature in the front side reaches in few seconds 1000 °C. At this temperature and after one hour of exposure, the opposite side reached 140 °C. After cooling, the punching shear strength of the fibre mortar is definitely weaker than of the mortar without fibre.

1. Introduction

The polypropylene fibres are used in the mortars and concrete to decrease the plastic shrinkage, cracking and micro-cracking of surface [1]. They increase cohesion and reduce slump [2]. While inclusion of metal fibres improves the fire resistance [3], the presence of polypropylene fibres in the material does not [4]. Only the effect limiting spalling at high temperatures is about to be unanimously recognised. This action is primarily studied in high performance concrete i.e. with low water/cement ratio [4–6].

However, during a fire, very strong thermal gradients take place in first centimetres of concrete and the thermal damage rapidly decreases from a maximum to nil [7,8]. So, in these first centimetres, where temperatures are less than a critical temperature, polypropylene fibres should still have an effect on mechanical behaviour. The objective of this work is then to examine the effect of the temperature on the residual behaviour of the polypropylene fibre mortars. In addition to the classical flexural strength, we focus to the cracking behaviour and more particularly to the fracture energy and to the stress intensity factor. These characteristics are important in connection with the crack resistance and in particular with the resistance to spalling.

In this paper two type of heating were studied: low rate heating (2 °C/min) and high rate heating (rate similar to ISO 834 standard fire). These two studies allow to separate physicochemical effects and temperature gradient effect.

2. Materials

To ensure an effective bridging of the cracks (to limit the crack opening), the dimension of the selected fibres must be greater than those of the aggregates [4]. At room temperature, the aim of the polypropylene fibres in the composite matrix is to ensure a macro cracking bridging and to maintain high post peak strength at a very large crack [9]. In this study cementitious mortars were studied, and then, 12 mm monofilament polypropylene fibres

* Corresponding author at: Laboratoire de Génie Civil et de Génie Mécanique (LGCGM)-EA 3913, Institut National des Sciences Appliquées, 20 avenue des buttes de Coësmes, CS 70839, 35508 Rennes cedex 7, France.
E-mail address: Laurent.Molez@insa-rennes.fr (L. Molez).

http://dx.doi.org/10.1016/j.firesaf.2014.11.022
0379-7112/

Table 1
Characteristics of test fibres (given SIKA).

Fibre	Length L (mm)	Diameter Ø (μm)	Ratio L/Ø	Density ρ (kg/m^3)	Young Modulus E (GPa)	Melting point (°C)	Tensile strength σ (GPa)
Polypropylene	12	18	667	910	6	170	0.55

were chosen. Characteristics of the fibres (given supplier: SIKA) are detailed in Table 1.

A Portland cement is used: CEM1 52.5 N CE CP2 NF. This cement is made up mainly of clinker 95%, whose details of the chemical and mineralogical compositions are reported in Table 2.

The mortars are made with standardized sand according to CEN 196-1 standard with the ISO 679. The mass proportions of cement, sand and water are 1:3:0.5. The volume proportion of added fibres in the fibre mortars is 0.58% (i.e. 5.2 kg/m^3). Water was added to cement and mixed to obtain a homogeneous paste; sand then gradually added to the paste and mixed until homogeneous. Fibres were added at the final stage and dispersed manually. The constituents were mixed for two minutes after the introduction of the fibres.

The specimens were then stored in a wet room (20 °C, 95% RH) for 7 days and then stored in dry room (20 °C, 50% RH) up to an age of 28 days. Under these conditions, a significant portion of free water in the cement matrix had evaporated [10].

3. Slow heating

3.1. Heat exposure in an oven

Samples, $4 \times 4 \times 16$ cm^3, were heated in an electric furnace to the desired temperature at a rate of 2 °C/min. The exposure temperature was maintained during one hour (1 h) and cooling to room temperature was carried out in the closed and disconnected furnace (approximately −0.3 °C/min). The controlled temperature is measured in oven chamber (i.e. not in samples). This process conducts to low thermal gradients. The damages in mortar are mainly of physicochemical origin [11].

3.2. Flexural strength

After cooling, samples were then tested in a four-point bending configuration. Six specimens were tested for each condition (mortar type and heating temperature). The load is measure with a 50 kN load cell. A template is attached to the specimen to measure deflection using two LVDTs (+/−1 mm) (Fig. 1).

The bending test results carried out on unreinforced mortar (MN) and fibre reinforced mortar (MNP) are presented in Fig. 2. The post peak residual load clearly highlights the role of fibres when samples are not heated. The stress transfer between the faces of the cracks is significant and result is an increased ductility. As already observed by other authors [12–14], this phenomenon attenuates very quickly between 400 and 500 °C and disappear beyond 500 °C. Fig. 3 represents the evolution of the bending strength with respect to the exposure temperature. The polypropylene fibres have a positive role until 400 °C as it was stated previously. The experimental values are reported in Table 3.

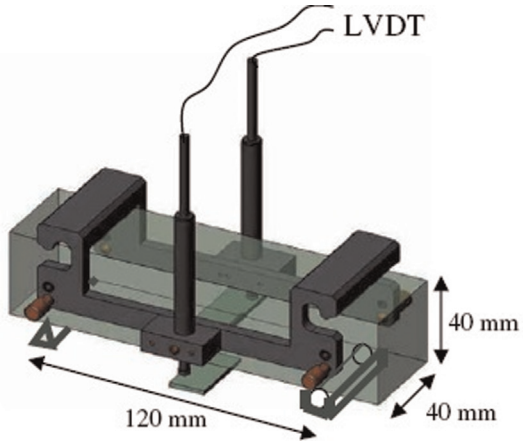

Fig. 1. Four-point sample with measuring *template*.

3.3. Young modulus

Young modulus is defined as the elastic (and linear) stage of the load-deflection curve. The evolution of the residual Young modulus with respect to the exposure temperature is shown in Fig. 4 and Table 4.

According to the test results, we notice that the modulus of the sample with fibre is greater than that of the non-fibre samples. The variation is accentuated until 400 °C. At 500 °C; they are identical and beyond this temperature; the young modulus of the fibred samples becomes almost zero.

3.4. Fracture energy

The fracture energy is defined as the area under the stress–strain curve of the four-point bending test [15]. Fig. 5 and Table 5 show the test results of the fracture energy with respect to the exposure temperature. When the samples are not heated, the fracture energy of the fibre specimen is about three times the energy of the non-fibre sample. This difference in fracture energy tends to converge and nullify at about 500 °C. Above 500 °C, gain increase in fracture energy decreases for samples with fibres.

3.5. Stress intensity factor

The stress intensity factor K_I characterizes the resistance of material to the propagation of the crack and to the damage [16–18]. This parameter can be deducted from the calculation of the fracture energy G_f and of the Young modulus E. It is defined by the following relation:

$$K_I = (G_f E)^{0.5} \quad (1)$$

Table 2
Chemical and mineralogical composition of cement CEM I 52.5.

Elements	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	K_2O	NaO_2	SO_3	IR	LOI	Free CaO
%	22.40	2.96	2.33	66.60	0.95	0.15	0.10	2.13	0.20	1.59	0.50
C_3S=65.3 C_2S=18.6 C_3A=4.35 C_4AF=7.14											

IR: insoluble residue; LOI: loss on ignition.