Construction and Building Materials 113 (2016) 456–469

Contents lists available at ScienceDirect

Construction and Building Materials

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

Influence of different fibers on the change of pore pressure of self-consolidating concrete exposed to fire

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HIGHLIGHTS

- Pore pressure of FRSCC during fire was investigated.
- Influence of different fibers on the change of pore pressure was analyzed.
- An empirical formula was proposed to predict the relative maximum pore pressure of FRSCC exposed to fire.

ARTICLE INFO

Article history:
Received 7 November 2015
Received in revised form 4 March 2016
Accepted 16 March 2016
Available online 22 March 2016

Keywords:
Pore pressure
Spalling
Fire
Fibers
Self-consolidating concrete
Hybrid effect

ABSTRACT

The focus of this paper is given to investigate the effect of different fibers on the pore pressure of fiber reinforced self-consolidating concrete under fire. The investigation on the pore pressure-time and temperature relationships at different depths of fiber reinforced self-consolidating concrete beams was carried out. The results indicated that micro PP fiber is more effective in mitigating the pore pressure than macro PP fiber and steel fiber. The composed use of steel fiber, micro PP fiber and macro PP fiber showed clear positive hybrid effect on the pore pressure reduction near the beam bottom subjected to fire. Compared to the effect of macro PP fiber with high dosages, the effect of micro PP fiber with low fiber contents on the pore pressure reduction is much stronger. The significant factor for reduction of pore pressure depends mainly on the number of PP fibers and not only on the fiber content. An empirical formula was proposed to predict the relative maximum pore pressure of fiber reinforced self-consolidating concrete exposed to fire by considering the moisture content, compressive strength and various fibers. The suggested model corresponds well with the experimental results of other research and tends to prove that the micro PP fiber can be the vital component for reduction in pore pressure, temperature as well spalling of concrete.

1. Introduction

Fire poses one of the most serious risks to concrete for underground construction and above ground structure because it often results in explosive spalling of concrete. Reinforcing bars directly exposed to fire due to concrete spalling will further aggravate the fire risk, since it is very likely to cause sudden failure of concrete structures during fire exposure [1–5]. Two main mechanisms can explain the fire spalling of concrete [6–9]. One is related to the thermo-mechanical process [6,9], which is associated with the temperature field and the mismatch of thermal expansion between cement matrix and aggregate in concrete, as illustrated in Fig. 1a. The other one is related to the thermo–hydral process (pore pressure theory), which is directly related to the mass transfer of vapour, water and air in the porous network. This thermo–hydral process will result in building up high pore pressures and pressure gradients, as shown in Fig. 1b [9]. According to pore pressure theory, the vapour pressure will dramatically increase at the boundary between the vapour zone and humid zone (Fig. 1b). Around the peak of the vapour pressure, since high vapour pressure in concrete generates a large tensile stress, concrete spalling would occur [10,11].

Quantitative analysis of pore pressure in concrete is one of the difficulties to investigate the fire spalling. The previous studies usually focus on the pore pressure development in ordinary concrete and high-strength concrete exposed to electric heating [12–16,20]. However, the investigation on the pore pressure of

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http://dx.doi.org/10.1016/j.conbuildmat.2016.03.070
0950-0618/

Notation

PC concrete specimen without fibers
SF steel fiber
PPF polypropylene fiber
SCC self-consolidating concrete
FRSCC fiber reinforced self-consolidating concrete
SF40 steel fiber reinforced SCC with fiber dosage of 40 kg/m^3
Micro PPF1 micro PP fiber reinforced SCC with fiber dosage of 1 kg/m^3
Macro PPF4 macro PP fiber reinforced SCC with fiber dosage of 4 kg/m^3
SF40+Macro PPF4 fiber cocktail reinforced SCC with 40 kg/m^3 macro steel fiber and 4 kg/m^3 macro PP-fiber
SF40+Micro PPF1 fiber cocktail reinforced SCC with 40 kg/m^3 macro steel fiber and 1 kg/m^3 micro PP fiber
SF40+Macro PP2+Micro PPF05 fiber cocktail reinforced SCC with 40 kg/m^3 macro steel fiber, 2 kg/m^3 macro PP fiber and 0.5 kg/m^3 micro PP fiber
HPC high-performance-concrete
P_R pore pressure reduction
D_R decreasing ratio of pore pressure
PRMPP predicted relative maximum pore pressure
MRMPP measured relative maximum pore pressure

concrete and fiber reinforced self-consolidating concrete (FRSCC/SCC) during fire exposure is very limited [17,18], although SCC/FRSCC are gaining considerable interest in concrete structures and underground constructions like shield tunnel segment.

This paper presents an experimental study of the fiber effect on the pore pressure in SCC during fire exposure. Steel fiber, micro polypropylene (PP) fiber, macro PP fiber and the composition were employed in this study. Influence of mono fiber and hybrid fibers on the pore pressure–time and temperature relationships of SCC were investigated. The effect of different mixes of fibers is presented in this paper. The study of pore pressure development leads to a better understanding of spalling in SCC and FRSCC during fire exposure.

2. Experiment

2.1. Materials

In this program, the mix design of FRSCC was as follows: Cement (P.O 52.5R), fly ash, fine sand, crushed stone were used. The amount of superplasticizer (Sika, polycarboxylic acid type, ASTM C494 type F, the highest water reduction is up to 30%) was 1.2 wt.% of binder content. The base mix design of SCC without fiber reinforcement is illustrated in Table 1.

The investigated fibers can be divided into micro fibers ($l < 3$ cm) and macro fibers ($l \geqslant 3$ cm). The micro PP fibers are mainly used to decrease the shrinkage cracks and to prevent the spalling [3–5] at the high temperature. The steel fibers are used for increasing the flexural toughness and for restricting and bridging the macro cracks before heating and to enhance the residual behavior during and after the high temperature. Images and basic properties of fibers used in this study are shown in Fig. 2 and Table 2, respectively. The various fiber contents (kg/m^3), the air content and the compressive strengths of different mixtures before heating are summarized in Tables 3 and 4.

From Tables 3 and 4, it can be seen that the air content of the fresh concrete increases with the increasing of fiber dosage. The compressive strength of all series was between 60 and 70 MPa. The moisture content of the concrete specimens was between 4% and 5% by mass. The specimens with a size of 150 mm × 150 mm × 550 mm were employed for pore pressure tests. During the moulding of concrete, metal tubes were inserted. The end of the tube was placed at different pressure measurement points, i.e. depth of 10, 20 and 30 mm, as illustrated in Fig. 4a. After casting, all the specimens were stored in a standard curing room of concrete with molds for 24 h. Thereafter they were demoulded, subjected to 20 °C water and cured for 28 days.

2.2. Fire test setup

As shown in Fig. 3, the pressure gauge [12,13] was made of porous sintered metal net with evenly distributed pores of diameter 4 μm. A metal tube with inner diameter of 2 mm was connected with the metal cup. Prior to heating, the metal tube was filled with silicon oil having a fire point of 315 °C. The fire test set-up is demonstrated in Fig. 4a.

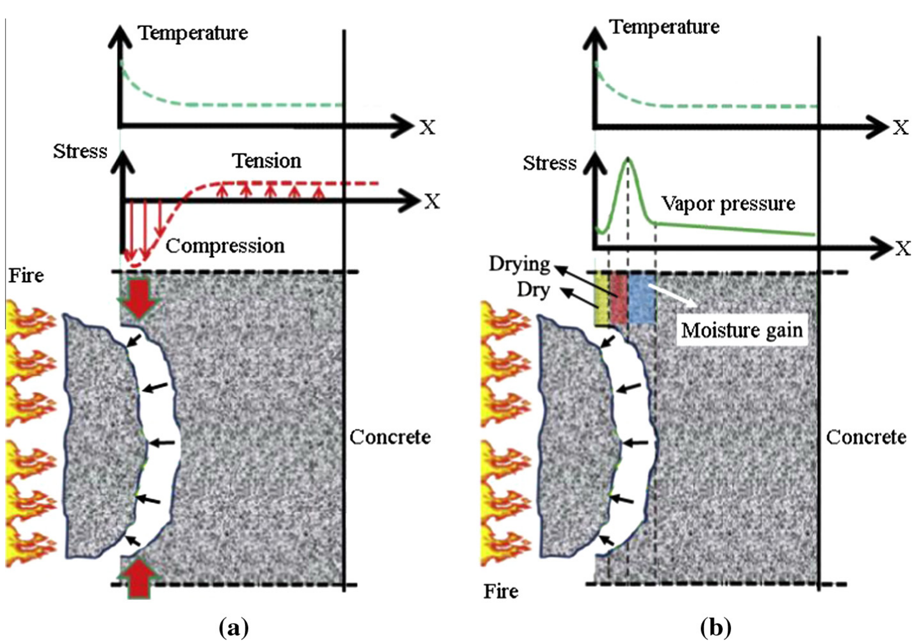

Fig. 1. Mechanisms of concrete spalling (**a**) Thermal stress theory; (**b**) Pore pressure theory [9].