Construction and Building Materials 162 (2018) 215–228

Contents lists available at ScienceDirect

Construction and Building Materials

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

Behavior of ring-restrained high-performance concrete under extreme heating and development of screening test

Mitsuo Ozawa [a,*], Toru Tanibe [b], Ryota Kamata [b], Yuichi Uchida [c], Keitetsu Rokugo [c], Sirjana Subedi Parajuli [a]

[a] Department of Environmental Engineering Science, Gunma University, 1-5-1, Tenjin-cho, Kiryu, Gunma 376-8515, Japan
[b] Research and Development Laboratory, Taiheiyo Materials, 2-4-2, Sakura, Chiba 285-0802, Japan
[c] Department of Civil Engineering, Gifu University, 1-1, Yanagido, Gifu 501-1193, Japan

HIGHLIGHTS

- This study was estimated thermal stress arising from strain in restraining steel ring.
- The vapor pressure in the restrained concrete is also determined.
- The conditions are those corresponding to RABT 30 rapid heating curve.
- Spalling failure model based on tensile strain failure model is proposed.
- This study was estimated spalling initiation point and spalling depth during heating.

ARTICLE INFO

Article history:
Received 11 June 2017
Received in revised form 19 November 2017
Accepted 26 November 2017

Keywords:
High-performance concrete
Ring-restrained concrete
Tensile strain failure model
Spalling
High temperature
Thermal stress
Vapor pressure
Type of aggregates

ABSTRACT

This study evaluated the behavior of restrained high-performance concrete in response to the extreme heating associated with fire. This was done by estimating the thermal stress based on the strain induced in the restraining steel ring and the vapor pressure in the restrained concrete under the conditions corresponding to the RABT 30 rapid heating curve. The thermal stress was calculated based on the thin-wall cylinder model theory. A spalling failure model based on a tensile strain failure model was proposed. The results indicated that the model was suitable for determining the spalling initiation point as well as the spalling depth.

1. Introduction

High-performance concrete (HPC) is widely used to construct high rise building, bridge and so on, in the world. These structures have spalling risk during the fire.

There are two mechanisms by which concrete can be damaged by fire. The first is restrained thermal expansion resulting in biaxial compressive stress states parallel to the heated surface, which lead to tensile strain in the perpendicular direction (Fig. 1) [1]. The second is a build-up of pressure in the concrete pores owing to the vaporization of the physically/chemically bound water; this results in the tensile loading on the microstructure of the heated concrete (Fig. 2) [2].

Recently, the second mechanism has been investigated by comparing the vapor pressure of water within the concrete pores with its saturated vapor pressure [3–5]. Several studies have examined the synergistic effect that the addition of several types of fibers in various combinations to high-performance concrete (HPC) has on its resistance to spalling on exposure to fire [6,7]. Researchers have also reported the effects that various types of fibers have on the mechanical properties of cement-based materials at high temperatures [8–13].

* Corresponding author.
E-mail address: ozawa@gunma-u.ac.jp (M. Ozawa).

https://doi.org/10.1016/j.conbuildmat.2017.11.144

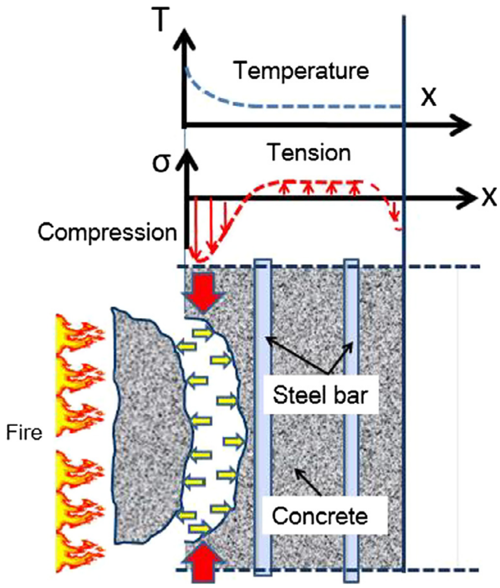

Fig. 1. Thermal stress.

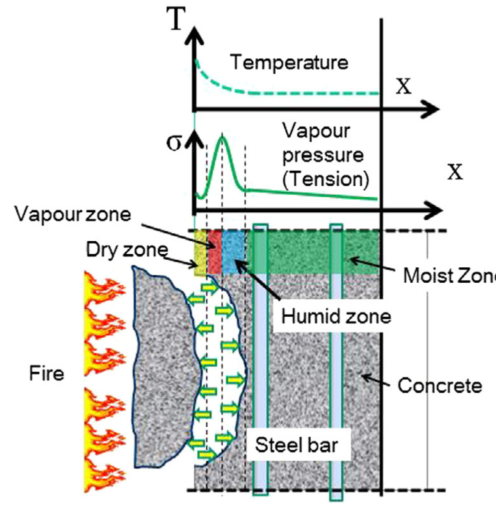

Fig. 2. Vapour pressure.

The addition of synthetic fibers and, in particular, polypropylene (PP) fibers, to HPC is a widely used and has been proved as effective method of preventing explosive spalling (Fig. 3) [14–21].

Lura et al. [22] reported a novel strategy to reduce fire spalling in HPC. This strategy involves the addition of small particles of superabsorbent polymers during mixing. Heijden et al. [23] used nuclear magnetic resonance to analyze moisture migration within concrete when heated to 250 °C. Several studies have assessed the degree of spalling in concrete using acoustic emission measure-

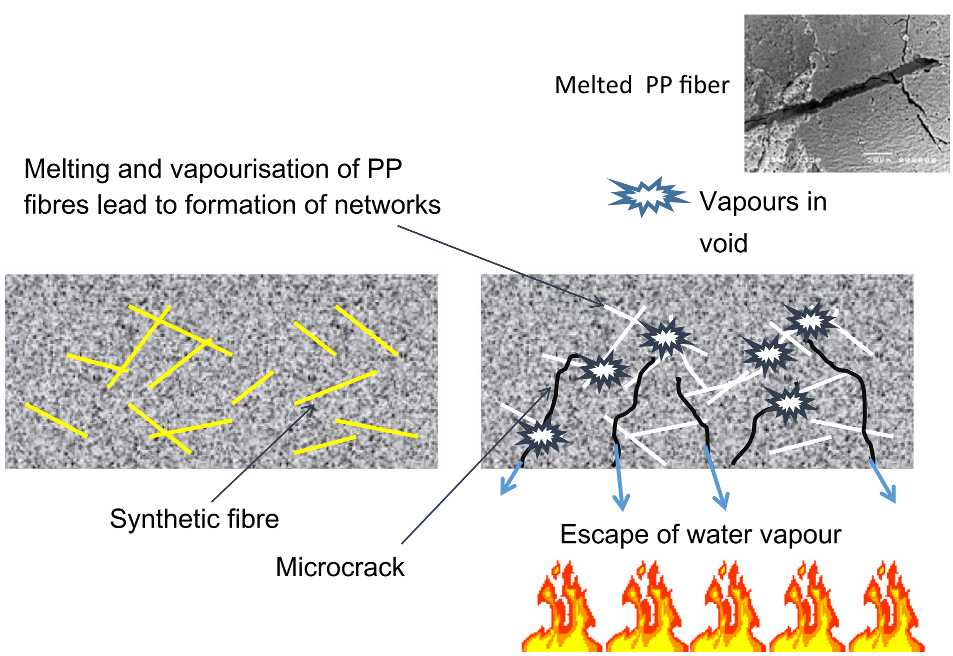

Fig. 3. Effect of PP fibres on spalling.

Table 1
Mixture proportion of concrete.

NO.	Water cement ratio	Unit weight (kg/m^3)										
		Water	Cement	Fine agg.1	Fine agg.2	Fine agg.3	Coarse agg.1	Coarse agg.2	Coarse agg.3	Coarse agg.4	Ad.	PP fiber
AS	0.3	150	500	718	–	–	418	626	–	–	5.0	–
AS-P	0.3	150	500	718	–	–	418	626	–	–	5.0	1.82
AT	0.3	150	500	–	358	372	–	–	–	1169	9.5	–
AT-P	0.3	150	500	–	358	372	–	–	–	1169	10.5	1.82
AL	0.3	150	500	–	358	372	–	–	1095	–	7.5	–
AL-P	0.3	150	500	–	358	372	–	–	1095	–	10.0	1.82