Available online at www.sciencedirect.com
ScienceDirect
Construction and Building Materials 23 (2009) 107–116
Construction and Building MATERIALS
www.elsevier.com/locate/conbuildmat

Improvement of residual compressive strength and spalling resistance of high-strength RC columns subjected to fire

Cheon-Goo Han, Min-Cheol Han *, Young-Sun Heo

Division of Architectural Engineering, Cheongju University, Cheongju, Chungbuk 360-764, Republic of Korea

Received 10 July 2007; received in revised form 9 January 2008; accepted 29 January 2008
Available online 24 March 2008

Abstract

This paper investigates the spalling properties of high-strength concrete in order to improve the residual compressive strength and spalling resistance in specimens subjected to 3 h of unloading fire conditions. This study consists of three series of experiments with eighteen different specimens varying in fiber type and content, finishing material and simultaneous fiber content and lateral confinement. They were fabricated to a 300 × 300 × 600 mm mock-up size. Results of the fire test showed that the control concrete was explosive, while the specimens that contained more than 0.1 vol% of polypropylene (PP) and polyvinylalcohol (PVA) fibers were prevented from spalling. One specimen, finished by a fire endurance spray, exhibited even more severe spalling than the control concrete. The specimen containing 0.1 vol% of PP fiber and using a confining metal fabric at the same time, showed the most effective spalling resistance; in particular, the residual compressive strength ratio was even higher than that of the control concrete before the fire test. It was demonstrated that adding fibers in concrete prevented the spalling occurrence and confining metal fabric around the main bars of concrete specimens can secure the strength of structures during the conditions of elevated temperature.

Keywords: High-strength concrete; Temperature; Spalling resistance; Residual compressive strength

1. Introduction

Buildings, in recent years, have increased in height, and high-strength concrete is now used in construction instead of "normal" strength concrete. Unlike typical concrete, high-strength concrete has the dense internal system of pore structures, which causes spalling in fires [1–4]. The spalling can be defined as a phenomenon in which the surface of the concrete scales and then falls off from the structure along with explosion at elevated temperature. Ultimately, spalling in high-strength concrete can result in the collapse of the reinforced concrete (RC) structure.

Many researchers have pointed out that the occurrence of spalling in RC structures using high-strength concrete must be prevented. It is well known that spalling is prone to occur under certain conditions, such as low water to cement ratios, high moisture content and exposure to abrupt increases in temperature [2,10,11].

Various studies on the spalling resistance of high-strength concrete have been reported. Kalifa et al. [4] gave appropriate amounts of fiber to prevent spalling in high-strength concrete which had less than 100 MPa of compressive strength. Bilodeau et al. [5] studied the spalling resistance in concrete using a lightweight aggregate. He also suggested optimal fiber contents. In addition, Peng et al. [6] recently investigated a spalling prevention method that utilized hybrid fibers, but this study did not provide a specific alternative plan to improve the residual compressive strength, which is crucial in an actual fire event. Xiao and Falkner [7] compared the residual compressive strength of specimens with and without additional fiber. He concluded, however, that increasing the fiber content alone does not guarantee an improvement of the residual compressive strength in structures.

* Corresponding author. Tel./fax: +82 43 229 8480.
E-mail address: twhan@cju.ac.kr (M.-C. Han).

0950-0618/$ - see front matter © 2008 Elsevier Ltd. All rights reserved.
doi:10.1016/j.conbuildmat.2008.01.011

This study presents improvements of spalling resistance and residual compressive strength as related to diverse fiber types, covering materials and confinement conditions, which are based on a previous study [3,9].

2. Experimental design and methods

2.1. Experimental design

Table 1 shows the experimental details of this study. Water to binder ratio (hereafter W/B) is fixed at 0.34 with a fly ash content of 15% cement replacement by mass. In total, 18 reinforced concrete (hereafter RC) columns of 300 × 300 × 600 mm in size were fabricated for specimens (see Table 1 and Fig. 1). A control concrete was used without fiber, covering material or confinement. In series I, six RC columns with different fiber types containing various ratios, such as 0.1 and 0.2 vol% of polypropylene (hereafter PP), cellulose (hereafter CL) and polyvinyl alcohol (hereafter PVA) fiber, were prepared. In series II, eight RC columns were used with various covering materials, including 1–3 mm thick fireproof paint, 20 mm thick fireproof spray, 20 mm thick plastering and 30 mm thick fireproof panels with three different types of construction methods. The construction methods for the fireproof panels were classified as either a commercially available method in which the fireproof panels were spaced by fasteners (hereafter FPSF), or created-new-manufactured methods in which the fireproof panels were spaced by fixing metals (hereafter FPS) and were attached by fixing metals (hereafter FPA), respectively (see Fig. 2). Lastly, in series III, three combinations of PP fiber and metal fabric confinement were simultaneously applied to the concrete. They were the RC columns containing 0.1 vol% of PP fiber and confining either 1.2 mm (M_1), 1.6 mm (M_2) or 2.3 mm (M_3) thick metal fabric at the same time.

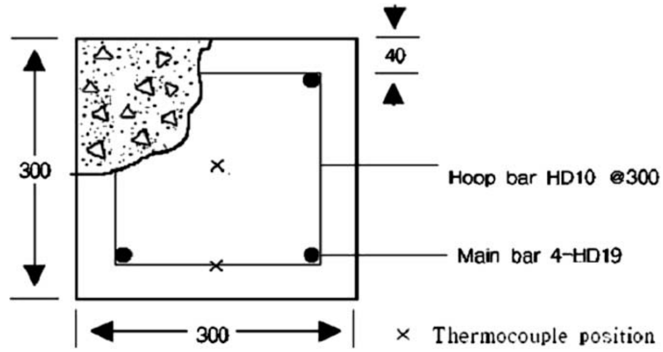

Fig. 1. Section detail of RC column and location of thermo couples.

Target slump flow of the control concrete was set up in 600 ± 100 mm, which is the high fluidity range, and the air content was 4.5 ± 1.5%. Other specimens also employed this value. Experimental properties of fresh and hardened

Table 1
Experimental design

Series	Mix	Spalling resistance methods						Parameters measured	
		Fiber type and content		Covering materials		Confinements			
		Type	Content (% by volume)	Type	Thickness (mm)	Type	Thickness (mm)	Fresh concrete	Hardened concrete
Control	–	–	–	–	–	–	–		Compressive strength
I	PP0.1	Polypropylene	0.1	–	–	–	–	Slump	
	PP0.2	Polypropylene	0.2						
	CL0.1	Cellulose	0.1						
	CL0.2	Cellulose	0.2						Fire test (3 h)-temperature history[a]
	PVA0.1	Polyvinylalcohol	0.1						
	PVA0.2	Polyvinylalcohol	0.2						
II	Pt1	–	–	Fireproof (F) paint	1	–	–	Slump flow	
	Pt2			F paint	2				Spalling appearance
	Pt3			F paint	3				
	Sy20			F spray	20			Air content	Residual compressive strength
	Pr20			Plastering	20				
	FPSF			F panel spaced by fasteners	30				
	FPS			F panel spaced by fixing metals	30			Unit weight	
	FPA			F panel attached by fixing metals	30				LVDT test[b]
III	$PP + M_1$	Polypropylene	0.1	–	–	Metal	1.2		
	$PP + M_2$		0.1			fabric	1.6		
	$PP + M_3$		0.1				2.3		Weight loss ratio

[a] It is only tested in control, PP0.1, Pt1, Pt3, Sy20 and FPA.
[b] It is only tested in control, PP0.1 and $PP + M_3$.