5th International RILEM Symposium on Self-Compacting Concrete
3-5 September 2007, Ghent, Belgium

SPALLING BEHAVIOUR OF SMALL SELF-COMPACTING CONCRETE SLABS UNDER STANDARD FIRE CONDITIONS

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Abstract

In this study, standard fire test were carried out on SCC with water/cement ratio of 0.41 and 0.48 and HPC with w/c ratio of 0.33, on specimens 300 × 300 × 150 mm. Polypropylene fibers (PP fibers) were added to the concrete in order to examine the reduction of spalling damage at elevated temperatures. The experiments were carried out at curing ages of 3 months and 9 months. The temperature increase in the furnace followed the standard ISO 834 curve. It was concluded that explosive spalling occurred on some SCC samples after about 20 minutes of fire exposure. The relations between temperature history, internal pore vapour pressure and microstructural changes of SCC at high temperatures are discussed.

1. INTRODUCTION

When high performance concrete (HPC) is exposed to fire, explosive spalling may occur [1]. The moisture content has been regarded as a main reason for spalling in most investigations. A higher concrete density also contributes to higher vapour pressures, possibly causing spalling. Thermal stresses may also contribute to the tendency for explosive spalling. From published data, the pore pressure for unsealed TC did not exceed 1 MPa, compared to 2~3 MPa for unsealed HPC [2, 3]. This means that the pore pressure alone is not large enough to cause the explosive spalling directly.

In this study, fire spalling is studied on small self-compacting concrete slabs under standard ISO 834 fire conditions. Samples with two different water/binder ratio were investigated at the age of 3 and 9 months. Polypropylene fibers (PP fibers) with a dosage of 0.5 and 1 kg/m^3 were added to the concrete in order to examine the reduction of spalling damage at elevated temperatures. The relation between temperature history, internal pore vapour pressure and microstructural changes of SCC at high temperatures will be discussed in the paper.

2. MATERIALS AND SAMPLE PREPARATION

2.1 Materials and samples

The SCC mixtures were prepared with Portland cement and limestone filler (98% $CaCO_3$). The chemical and physical properties of cement and limestone powder are presented in [4].

The specimens of SCC are made with a w/c ratio of 0.41 and 0.48 respectively, and compared to HPC with a w/c ratio of 0.33. Mix proportions are listed in Table 1. In a second series of specimens, PP fibers with length 12mm and diameter 18μm were added to the concrete (Table 2, designations PPF05 and PPF1). The dimensions of the specimens are 300 × 300 × 150 mm. Thermocouples and pore pressure sensors were positioned prior to casting (Figure 1). After casting, the samples were cured at 20°C and 100% RH for 1 month. Then, the specimens were moved to a curing room with 20°C and 65% RH untill testing.

Table 1 Mix proportions of SCC and HPC (kg/m^3)

	SCC01PPF0	SCC02PPF0	HPCPPF0
Portland cement I 52.5	400	400	400
Water	165	192	132
Sand	853	782	650
Aggregate 4-8 mm	300	300	530
8-16 mm	400	340	720
Limestone powder	200	300	-
Glenium 51 (liter)	3.2	2.7	-
Superplasticizer Rheolbuild	-	-	8.45
Total powder content	600	700	400
Water/cement ratio	0.41	0.48	0.33
Water/powder ratio	0.28	0.27	0.33

Table 2 Mix proportions of SCC and HPC with PP fibres (kg/m^3)

	SCC				HPC	
	SCC01PPF05	SCC01PPF1	SCC02PPF05	SCC02PPF1	HPCPPF05	HPCPPF1
Portland cement I 52.5	400	400	400	400	400	400
Water	165	165	192	192	132	132
Sand	853	853	782	782	650	650
Aggregate 4-8 mm	300	300	300	300	530	530
8-16 mm	400	400	340	340	720	720
Limestone powder	200	200	300	300	-	-
Glenium 51 (liter)	*4.42*	*5.55*	*3.25*	*3.5*	-	-
Superplasticizer	-	-	-	-	*7.0*	*8.45*
PP Fiber	0.5	1	0.5	1	0.5	1
Total powder content	600	600	700	700	400	400
Water/cement ratio	0.41	0.41	0.48	0.48	0.33	0.33
Water/powder ratio	0.28	0.28	0.27	0.27	0.33	0.33

2.2 Methods

A group of 9 specimens was placed in a 3000× 3000 × 200 mm wall in refractory concrete provided with square openings with side lengths equal to 300 × 300 mm with a distance of 300 mm in between. The experiments were carried out on the samples at curing ages of 3 months and 9 months respectively. The temperature increase in the furnace followed the standard ISO 834 curve (Figure 2). The test lasted 90 minutes. During the experiments, the internal pore vapour pressure and the internal temperature were measured by self-developed pore pressure sensors and thermocouples at 10, 20 and 30 mm depths from the surface. 30

minutes after the fire test, the specimens were moved away from the furnace and the exposed concrete surfaces were investaged visually for possible spalling damage.

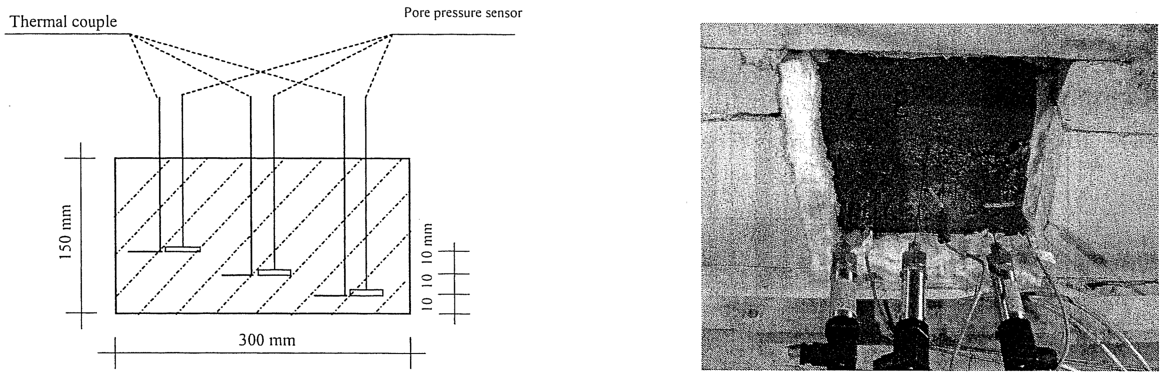

Figure 1. Illustration of the sample preparation (left) and the testing system (right)

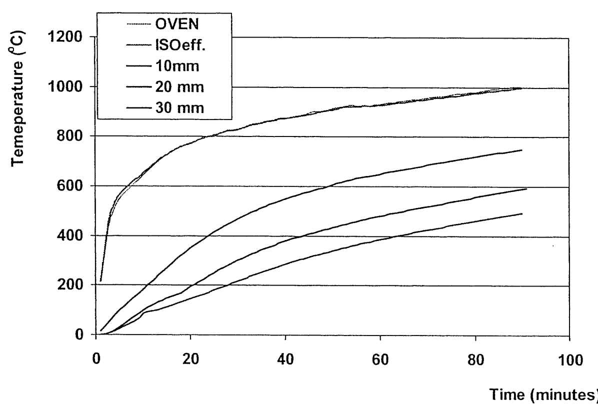

Figure 2. Furnace temperature follows ISO 834 curve and temperature at 10, 20 and 30 mm from the exposed surface of the sample

3. RESULTS AND DISCUSSIONS

3.1 Water content and weight loss

The moisture content of the samples is shown in Figure 3. It is reasonable that for longer curing periods, lower moisture contents are obtained. The samples with high water/powder ratio also show higher moisture content. As reported, the moisture content is a very important factor determining the vapoure pressure in the capillary pores [5]. Compared to the sample without PP fibres, the moisture content and weight loss of SCC02 are higher. This implies that the SCC02 samples might have a higher spalling probability. The weight loss of the samples after the fire test shows a similar tendency as the moisture content (Figure 3 right).

3.2 Visual inspection

Explosive spalling was found only on the SCC02 sample without PP fibres at a curing age of 3 months. This sample showed the highest moisture content of all samples (Figure 3). No explosive spalling was observed on the samples at a curing age of 9 month.

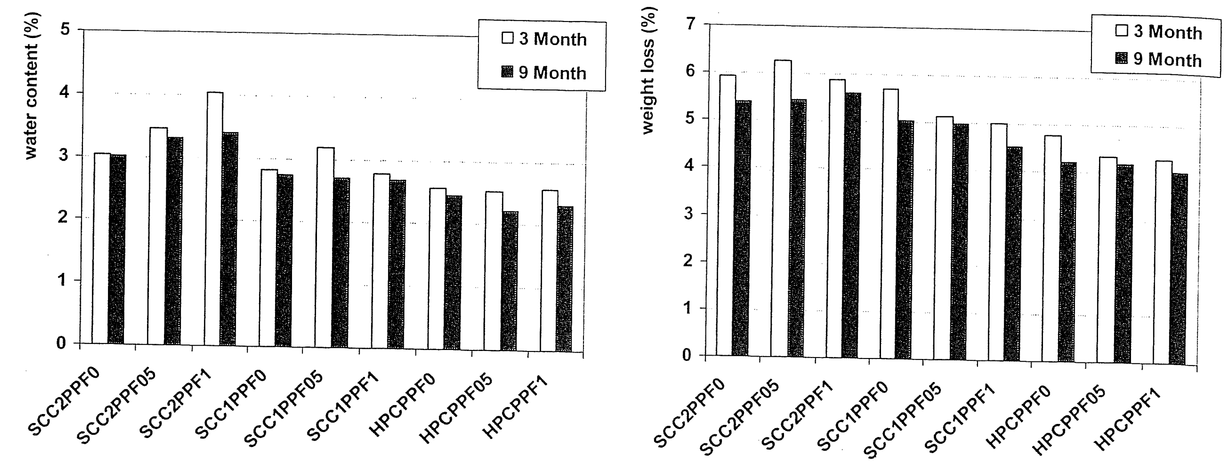

Figure 3. Moisture content before (left) and weight loss after fire test (right)

3.3 Internal vapour pressure

In general, the internal vapour pressure starts to increase after 2 to 5 minutes. The highest internal pressure appears between 8 to 25 minutes depending on the type of concrete, the amount of PP fibres and the curing age of concrete. From Figure 4 it can be found that the highest internal pore pressure of 2.52 MPa was recorded for a HPC sample at 3 months old. This value is lower than 3.8 MPa reported by Kalifa et. al [6], where a radiant heater up to 600°C was used on HPC with a compressive strength of 100 MPa. For SCC, the highest value of 1.28 MPa was recorded in SCC02 without PP fibres at 9 months. The corresponding temperature was 200 °C, after 18 minutes of fire. A similar result of 1.7 MPa was reported by Jansson [7] on SCC specimen with water/binder ratio of 0.50 at 3 months old. No spalling was found on these two HPC and SCC samples.

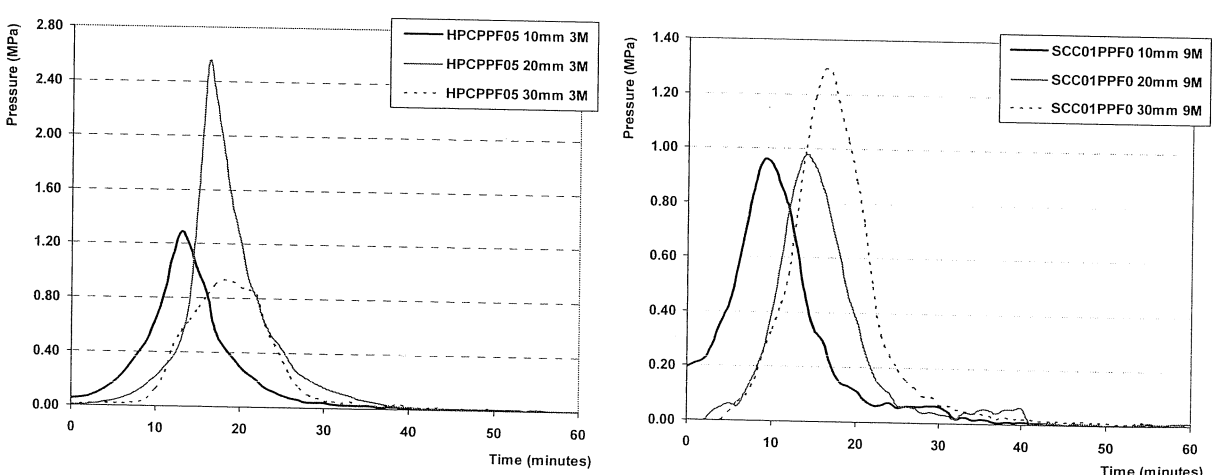

Figure 4. Highest pore pressure of HPC (left) and SCC samples (right)

3.3.1 Influence of the type of concrete and the depth on the pore pressure

Figure 5 shows the development of internal pore pressure for the samples without PP fibres at all depths at 9 months. The pore pressure development in HPC samples is much faster than in SCC samples. The pore pressure build up in SCC01 is also faster than SCC02. This may be due to the denser microstructure.

For most samples, the highest pore pressure was found at a depth of 10 to 20 mm from the heating surface. This is not in agreement with the results reported by Kalifa [6] where the highest pore pressure measured on HPC sample was 30 mm from the surface. However, it is in agreement with the results obtained by Jansson [7]. The disagreement with Kalifa could be due to the fact that the heating rate followed an ISO 834 curve, where a radiant heating was used by Kalifa [6].

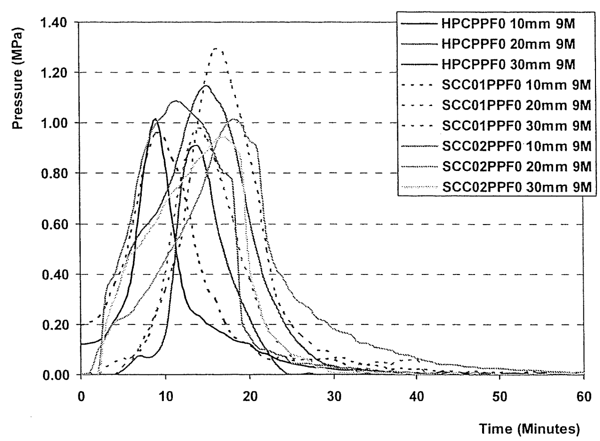

Figure 5. Influence of the type of concrete

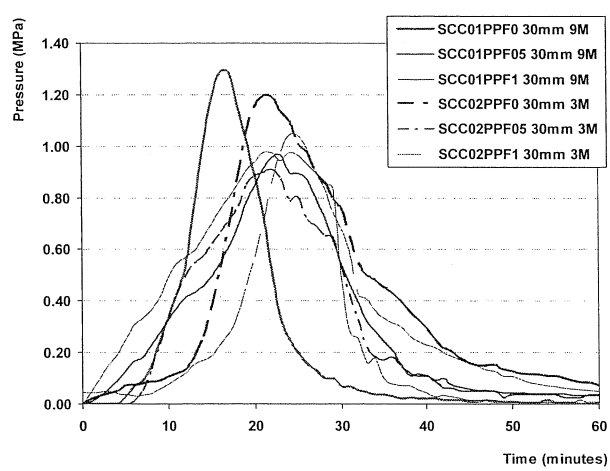

Figure 6. Influence of the amount of PP fibres

3.3.2 Influence of curing time

For both HPC and SCC the internal pore pressures at 9 months are higher and develop faster than that at 3 months. This may be due to the denser microstructure of samples with a longer curing period [1].

3.3.3 Influence of PP fibre content

The measured pore pressures for SCC01 at 9 months and SCC02 at 3 months at a depth of 30 mm are shown in Figure 6 in order to investigate the influence of the amount of PP fibres on the spalling behaviour. It can be found that the presence of PP fibres did reduce the pore pressure in the concrete. A content of 0.5 kg/m^3 of PP fibres is as sufficient in reducing the pore pressure as 1 kg/m^3. How the presence of PP fibres reduces the damage on the microstructure when concrete exposed to high temperature was discussed in [8]. This is also in agreement with results reported by Kalifa et. al [6] and Bostrom et al [9].

4. CONCLUSIONS

Some general conclusions from the fire test can be drawn as follow:

- In this experiment, explosive spalling was found only for the sample with higher water/cement ratio at a curing age of 3 months. The moisture content is the main influencing factor which determines explosive spalling of concrete at high temperature.
- The highest pore pressure measured in HPC samples was 2.52 MPa while the highest pore pressure in the SCC samples was 1.27 MPa at a depth of 10 mm. The corresponding temperature was 200 °C, after 18 minutes of fire.
- The internal pore pressure at 9 months is higher and develops faster than at 3 months, probably due to the denser microstructure.
- The presence of only 0.5 kg/m^3 of PP fibers in concrete leads to an effective reduction in pore pressure.

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