Construction and Building Materials 154 (2017) 204–218

Contents lists available at ScienceDirect

Construction and Building Materials

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

Residual strength of high strength concentric column-SFRC flat plate exposed to high temperatures

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HIGHLIGHTS

- Punching shear of twenty fiber-reinforced interior flat plate specimens was tested.
- High-strength steel-fiber reinforced concrete was used to cast the specimens.
- The residual punching shear strength was investigated after high temperature exposure.
- Other mechanical properties were also investigated after high temperature exposure.
- The incorporation of steel fibers enhanced the behavior of the tested flat plates.

ARTICLE INFO

Article history:
Received 22 March 2017
Received in revised form 13 July 2017
Accepted 17 July 2017
Available online 17 August 2017

Keywords:
Steel fiber reinforced concrete
High temperature
Flat plate-column connection
Punching shear

ABSTRACT

It became well known that steel fibers could significantly improve the mechanical properties of concrete and the ductility of flat plat-column assembly at ambient conditions. The investigation of the contribution of the steel fiber and the high strength concrete under high temperature conditions on the structural behavior of flat plates is still in need. This research presents experimental results of sixteen steel fiber reinforced slabs exposed to four levels of temperature reaching 550 °C, in addition to four control slab specimens. The residual mechanical properties, ultimate slab strength, and deformations were investigated. Relations between the concrete tensile and compressive strengths after exposing to high temperatures were introduced. For all temperature levels and steel fiber contents, the strength of most of the slabs was improved compared to the corresponding strength at room temperature. The highest percentage improvement was recorded for specimens exposed to 150 °C and reinforced with 1% of steel fiber. The strengths of the slabs with 1% and 1.25% of steel fiber and exposed to 550 °C were almost the same as their strengths at ambient conditions, however, slabs with 0.75% showed 13% increase.

1. Introduction

Flat plate-column assembly that is reinforced with suitable flexural reinforcement and without shear reinforcement may fail before the yielding of the flexural reinforcement. This failure type may take place in two-way shear, which is a brittle and catastrophic failure mode. In general, the shear behaviors always associated with many other forces, which make the analysis processes difficult to tackle [1]. The problem is much complicated when the slab system is exposed to high temperatures, where two additional direct and indirect effects arise due to load redistribution and decay in concrete properties [2–4]. Many mechanical models were proposed for predicting the two-way (punching) shear strength under ambient conditions [5–12]. For all, the main two failure mechanisms are related to cracking due to diagonal tension and crashing due to compression inclined struts. Unfortunately, there are few researches available in the literature related to the concentric flat plate-column joints under high temperature conditions [2,13–17]. Moreover, there are no provisions in the practical design codes related to both punching shear problem under fire condition and the effect of steel fiber on punching strength at both ambient [18] and at high temperature conditions.

Punching shear resistance may be improved by increasing the concrete strength because of its contribution in the enhancement of the structures strength. On the contrary, in High Strength Concrete (HSC), spalling [19] and brittleness problems arise. Among the best and cheapest processes to improve the flat plate-column joint is the using of Steel Fiber Reinforced Concrete (SFRC). In spite of the discontinuity and the random distribution of steel fibers,

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http://dx.doi.org/10.1016/j.conbuildmat.2017.07.141
0950-0618/

which decreases its efficiency in sustaining the tensile stress compared to conventional reinforcing bars [20], it shows good results in controlling the propagation of the local cracks, which in turn increases the ductility and energy absorption [18,21,22]. The contribution of steel fibers arises by increasing the bond between the reinforcement bars and the surrounding concrete matrix and bridging the two sides of cracks, which transfers the stresses even in wide crack openings [20,23].

Based on the premises, an experimental program was directed in this research to investigate the residual punching shear strength of SFRC plates after exposure to different levels of high temperature. The combined effect of concrete strength and the presence of steel fibers under high temperatures were also investigated, where SFRC plates with compressive strength of approximately 60 MPa were tested.

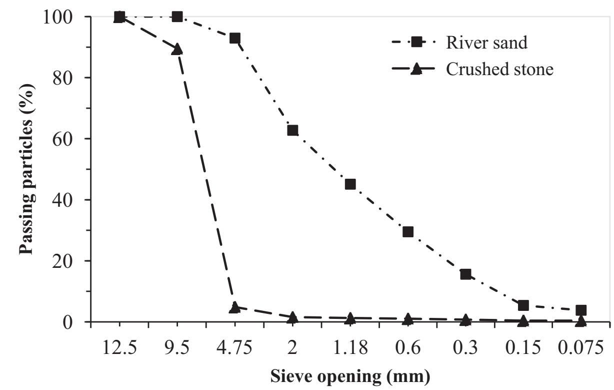

Fig. 1. Sieve analysis of the river sand and the crushed stone.

2. Experimental work

2.1. Materials properties and concrete mixture

Slab panels with high strength concrete and reinforced with steel fibers and conventional steel bars were produced to conduct the experimental work of this study. The concrete mix was designed to achieve a 28-day cylinder compressive strength (f'_c) of 60 MPa, in which higher volume of fine aggregate was used. In all specimens, two types of aggregates were used, crushed stone as coarse aggregate and sand as fine aggregate. The maximum size of aggregate was 10 mm. It is clear in Table 1 that coarse aggregate composes only 37% of the total amount of aggregate, whereas the rest 63% is fine aggregate. Fig. 1 shows the grading of the coarse and fine aggregates.

Portland cement type CEM II/A-LL 42.5R in accordance with EN 197–1 was used. In addition to the increasing of fine particles in the mix, 7% of the cement was replaced by silica fume. It is expected that increasing the fine materials, presence of steel fiber, and the approximately moderate water/(cementitious materials) would decrease the slump. Therefore, the high range water reducer Glenium 51 was used in all mixes. The slump results of the produced mixes are shown in Table 1.

At the first stage of mixing, the fine and the coarse aggregates were mixed together for 10 min before adding the cementitious materials and then all the materials were mixed for 5 min. The water was then gradually added. The slump was checked in this stage, then after, the water reducer was added prior to the adding of the steel fibers. Three percentages of cold drawn glued steel fibers of 0.75, 1, and 1.25% by volume of concrete were used. The characteristic of the steel fibers with hooked-ends that employed in this research are shown in Fig. 2 and Table 2. All casted specimens were kept under laboratory conditions for 24 h. The slabs and the associated cylinders were removed from their molds, and were cured in water pools for 28 days so that both slab and cylinders are exposed to the same curing conditions. The average of three standard cylinders with the same properties and conditions was employed in the structural analysis.

Fig. 2. Steel fibers with hooked-ends.

The experimental program includes four test series. In the first, standard cylinders of 100 × 200 mm subjected to uniaxial compression load were used to evaluate the concrete compressive strength (f'_c) according to ASTM C39. Secondly, similar cylindrical specimens were subjected to indirect tensile load (splitting) to evaluate the concrete tensile strength (f_{ct}) according to ASTM C 496. In the third series of cylinders, the specimens were subjected to compression load to evaluate the Young's modulus according to ASTM C469. The fourth specimen series includes the two-way slab plates, which were tested under monotonic increasing load.

2.2. Specimens' geometry

All tested slab specimens are 500 × 500 × 60 mm square reinforced concrete plates as shown in Fig. 3. The slabs of conventional

Table 1
Concrete mix.

Mix	Steel fiber		W/C	W	C	G	S	S.fm	SP	slump
code	V_f%	kg/m^3		kg/m^3	kg/m^3	kg/m^3	kg/m^3	kg/m^3	kg/m^3	mm
S0	–	–	0.43	216	465	680	1170	35	6.6	97
S0.75	0.75	58.9	0.43	216	465	680	1170	35	6.6	68
S1	1.00	78.5	0.43	216	465	680	1170	35	6.6	62
S1.25	1.25	98.2	0.43	216	465	680	1170	35	6.6	58

W; water, C; cement, G; crashing stone, S; river sand, S.fm; silica fume, WR; high water reducer.