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Experimental research for the effect of high temperature on the mechanical properties of steel fiber-reinforced concrete

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HIGHLIGHTS

- Steel fiber addition effects positively on compressive strength until 1000 °C.
- Modulus of elasticity values was generally in parallel with compressive strength.
- Particularly 1.0% fiber rate decreased strength loss more than other fiber rates.

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ABSTRACT

It is widely known that addition of steel fibers to concrete improves properties of concrete having brittle behavior. This affects the behavior in a positive way particularly by increasing ductility of the concrete. In this study, the results of the effect of high temperature on steel–fiber concrete were investigated. RC80/60 BN type steel–fibers were added to experimental concrete as in the rates of 0%, 0.5%, 1% and 1.5% by volume and concrete cylinder samples with 7, 28 and 90-day were tested. Produced cylinder samples were exposed to 900 °C, 1000 °C, 1100 °C and 1200 °C temperatures in the furnace. The effect of temperature was applied to samples within 6 h in experiments.

In this study, compressive strength, modulus of elasticity and toughness values of fiber-concrete were given comparatively according to different fiber ratios, concrete age and varying temperature effects. Consequently, compressive strength, modulus of elasticity and toughness values of fiber-concrete substantially decreased by the effect of high temperature as it was expected. When it was examined the results with regard to percentage of steel fiber, samples of 1.0% fiber additive had specifically the lowest of compressive strength losses. Additionally in comparing results of compressive strength losses on high temperature effect were lower at 900 °C and 1000 °C than at 1100 °C and 1200 °C temperatures. Determined results of 1100 °C and 1200 °C temperatures were closed with each other. Namely compressive strength values reached the lowest value after 1100 °C.

1. Introduction

In order to improve the properties of the concrete, steel fiber additive agents can be added to the concrete [1,2]. Steel fibers are also among these substances and in recent years, they have been commonly used in concrete. The aim of producing fiber-concrete is to increase toughness of the material, its resistance against impact effects, its flexural strength and other mechanical properties. The concretes including fiber have wider range of usage areas such as field concrete, paving, industrial constructions, slope stabilization and retaining wall construction, hydraulics, construction buildings when compared to normal concretes [3–8].

Concrete may be subjected to various effects such as wearing, freezing–thawing, chemical medium, dynamic loads throughout its physical life. One of them is high temperature and fire. The effect of high temperature can be seen particularly in airport aprons, industrial ground and chimney operating under high temperature, plants producing chemical materials with high fire risk and industrial constructions.

The actual behavior of the concrete exposed to high temperatures depend on many environmental factors such as the properties of materials building up the concrete, heating rate, maximum temperature at which it was exposed to and the period of this exposure, cooling method after maximum temperature and loading level at the time of cooling [9,10].

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Cement hydrated with the effect of high temperature is dehydrated by loosing water. $Ca(OH)_2$ present in the content of cement in the concrete is dehydrated at temperatures in the range of 400–600 °C and is converted to CaO. As a result of this conversion by the liberation of water, shrinkages in the current volume occur up to 30% and significant decreases are observed in compressive strength of the material. With the fire-extinguishing intervention of the fire by water, concretes loses water at high temperatures, it reacts with CaO conversely to its reaction with the effect of water and again results in $Ca(OH)_2$ [9–12]. In addition to hydration and dehydration between C–S–H at high temperatures, aggregate during heating step and thermal disconformity occur within the cement, moreover, the pore pressure of the water collected in the pores of the cement causes formation of expansions in the volume of the concrete [13,14]. As a result of these shrinkages and expansions occurred in the concrete, deep cracks occur. This also causes undesired decrease in compressive strength of the concrete.

In fired constructions, damages can be observed particularly on concrete bearings from outside to inside depending on degree of the temperature and effective time. Measurements indicated that the loss of strength in reinforced concrete bearings decreases from outside to inside and a part what we call as a shell is formed [15]. Therefore, the contribution of addition of steel–fiber to the compressive strength should not be ignored since core concrete will incur less strength losses than shell concrete. Because it is considered that it will provide very important contribution by prevention of crack development.

The aim of this study was to investigate the contribution of steel–fiber empirically to the loss of compressive strength of concrete material which was exposed to high temperature effect. Steel–fiber will come into prominence as an important auxiliary material for the prevention of shrinkages and expansions that might occur due to the effect of high temperature and formation of cracks in the cement paste.

2. Material and method

2.1. Material and concrete mixture

Three types of aggregates such as coarse graver, fine graver and crushed sand were used in the production of concrete. Specific gravity and absorption experiments were performed depending on the aggregates used [16]. In the mixture of concrete, coarse gravel with a rate of 35%, fine gravel with a rate of 25% and crushed sand with a rate of 40% were added [17]. In the production of experimental concrete, CEM I 42,5 cement was used. Cylinder concrete samples were produced without steel–fiber and with steel–fiber in the volumetric rates of 0.5%, 1.0% and 1.5%.

Steel fiber added to experimental samples was used as RC80/60 BN type. Tensile strength of steel fiber was minimum 1050 N/mm^2. The properties of this steel fiber are given in Table 1 and its schematic diagram is given in Fig. 1.

In cylinder concrete samples produced with steel fiber additive in this study [18–20], the rate of water/cement was 0.60 and its slump value was kept constant in the range of 12 cm ± 2 cm with super plasticizer for additive free concrete samples. Concrete mixture values and amounts of fiber added for 1 m^3 concrete are given in Table 2.

Experimental samples were produced without steel fiber additive in normal concrete class and with steel fiber additive in the volumetric rates of 0.5%, 1.0%, 1.5%. The samples were produced after their exposure to 900 °C, 1000 °C, 1100 °C and 1200 °C temperatures at the concrete age of 7, 28 and 90-day in 4 × 4 × 3 × 3 pieces and their experiments were carried out [18–22,24]. The appearances of the samples are given in Fig. 2.

Table 1
Properties of steel fiber.

	Steel fiber
Length *l* (mm)	60
Diameter *d* (mm)	0.75
Slenderness (l/d)	80
Density (g/cm^3)	7.48
Tensile strength (N/mm^2)	min 1050

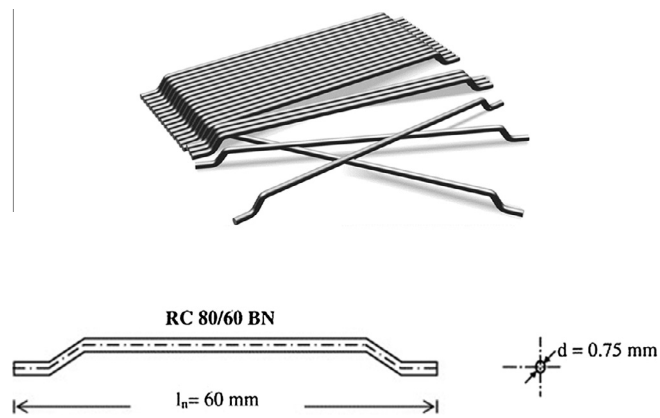

Fig. 1. The steel fiber used in the experiments.

2.2. Temperature application for experimental samples

Cylinder samples produced with and without steel fiber additive were exposed to the effect of temperatures beginning from 7th, 28th and 90th day after production. The samples were removed from curing pool the day before and put it on to dry for 24 h. In order to prevent damaging of samples because of sudden and excess expansion of the water within their structure depending on increasing temperature in high-temperature kiln, the samples were kept in a drying oven at 105 ± 5 °C for 6 h to remove *water absorbed by concrete* before kilning.

In order to supply high temperature, electrical high-temperature kiln was used with a capacity of heating up to 1200 °C. Temperatures of 900 °C, 1000 °C, 1100 °C and 1200 °C were applied respectively to the cylinder samples.

The kilning period in high-temperature kiln was taken as totally 6 h including controlled-increasing time of temperature and heating time in the case of steady-temperature (900 °C, 1000 °C, 1100 °C and 1200 °C). Applying high temperature within 6 h were including rising time until target temperature value. After 6-h heating period, the furnace door was kept closed and let it cool down by itself until its temperature reaches to room temperature to prevent exposure of experimental samples to sudden temperature variations. The samples to which different temperature were applied are given in Fig. 3.

2.3. Determination of properties of compressive strength

After exposure of cylinder samples to thermal effect for totally 6 h on the 7th, 28th and 90th day following their production and cooling them down to room temperature, they were subjected to experiments related with compressive strength [23,24]. In order to compute modulus of elasticity, a compressometer was con-

Table 2
Concrete mixture value.

Specimen	W/C	Steel fiber		W	C	C.S.	F.G	C.G.	A	Slump value
Series		%/V	kg/m^3	kg/m^3	kg/m^3	kg/m^3	kg/m^3	kg/m^3	kg/m^3	mm
SFC 0	0.6	–	–	205	341	700	438	613	3.41	120
SFC 0.5	0.6	0.5	37.4	205	341	700	438	613	3.41	100
SFC 1.0	0.6	1	74.5	205	341	700	438	613	3.41	20
SFC 1.5	0.6	1.5	112.2	205	341	700	438	613	3.41	10

W: water, C: cement, C.S.: crushed sand, F.G.: fine gravel, C.G.: coarse gravel, A: admixture.