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The Experimental Investigation of Crack Mechanism in High Strength Concrete with Steel and Polypropylene Fiber

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Abstract— **Today, high performance concrete can be produced as easily as normal strength concrete. Concretes are expected to have ductile behavior and have compressive strength, as well. In the recent years, in order to have ductile behavior, researchers have started to strengthen concrete using fibers and have done lots of researches. In this study, normal and high strength concrete with steel and polypropylene fiber are produced, the compressive strength and the tensile strength in split of these concrete is investigated and the crack mechanizm of notching samples are examined.**

Keywords—high strength concrete, crak mechanism, steel fiber, polypropylene fiber)

I. Introduction

Because concrete is commonly used in civil engineering, mechanical behavior of this material should be known much better. Enough information about the cracks occurring because of low tensile strength and distribution of these cracks should be known much better. Using concrete, particularly in the buildings like nuclear plants, dams, defense buildings in all of which cracks are crucial and off-shore structures in which corrosion is effective increased the attention to learn about cracking behavior of this material [1,2].

The beginning of fracture mechanism goes to the Griffith's studies on a brittle material, glass, in 1920s [3]. Later, Orowan and Irwin, applied fracture mechanism on the non-brittle , ductile materials after examining Griffith's studies and changing some points [4]. In the last 40 years, there are important improvements in the experiment techniques and in the breakings of semi-brittle materials like concrete because of the opportunity of computers and usage of numerical analysis methods. With all these developments, application of fracture mechanics on the concrete started to be accepted by the engineers and researchers.

Application of linear elastic fracture mechanism on the concrete is in the beginning of 1960s [5]. Although there were a number of studies on the fracture mechanism of the concrete in the following years, the obtained results have not used on the projects of concrete buildings, yet. The most important reason for this, linear elastic fracture mechanism can not be directly applied on the concrete. In the 1970s it has been said that fracture parameter can not be obtained based on linear elastic fracture mechanism free from size [6]. In the following years, lots of theoretical and experimental studies were completed using nonlinear fracture mechanism models and /or modifying linear elastic fracture mechanism [7-18].

Today, based on the improvements in the technology high strength concrete have been produced as well as normal strength concrete. It's known that as concrete strength increases, its ductility decreases. To increase ductility of concrete as the strength, steel fibers have been used in the production. Fracture energy and crack distribution of high strength concrete which is more brittle comparing normal strength concrete should be known. In this study normal strength and high strength concrete with or without steel and polypropylene fiber are produced, the compressive strength and tensile strength on split of this concrete are examined and crack mechanism of notching samples are investigated.

II. Experimental Study

A. *Production of Experimental Samples*

In this study, in the production of normal and high performance concrete, limestone aggregate with the maximum aggregate size, 16 mm is used. Some of physical properties of used aggregate are given in Table 1.

Table 1. The physical properties of aggregate

Aggregate size	Loose density (kg/m^3)	Dry density (kg/m^3)	Saturated density (kg/m^3)	Water absorption (%)
Coarse (>4 mm)	1438	2706	2718	0.42
Fine (<4mm)	1492	2671	2680	0.52

CEM I 42,5 R type Portland cement is used in the production of the concrete. And some of the properties of this cement are given in Table 2. In the production of normal and high strength concrete with steel fiber, same sized steel fiber is used. Properties of steel fiber are given in Table 3 and that of polypropylene fiber are in Table 4.

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Table 2. Some properties of Portland cement

Physical properties			*Mechanical properties*		
Density (g/cm³)		3.10	Age (days)	Average flexural strength (MPa)	Average compressive strength (MPa)
Specific surface (Blaine), cm²/g		3682	2	5.61	28.7
Setting time (Vicat)	Initial (hours)	2.00	7	7.35	43.7
	Final (hours)	3.58	28	8.55	53.2

Table 3. Properties of steel fiber used in the concrete production.

Fiber type	Length (mm)	Diameter (mm)	Appearance Ratio (length/diameter)	Weight (g/cm^3)	Tensile Strength (MPa)
RC 65/35	35	0.55	64	7.85	1100

Table 4. Properties of polypropylene fiber used in the concrete production.

Fiber type	Length (mm)	Diameter (mm)	Extension (%)	Density (g/cm^3)	Tensile Strength (MPa)
M19	19	20	0.91	M19	700

Using the quantities given in table, six standard cylinder samples with 150 mm diameter and 300 mm high and six notching samples (Fig. 1) are produced. In order to compare, ordinary and high strength concrete without using steel and polypropylene fiber are produced. Produced concrete are taken out of their molds one day later and kept in the water with the temperature of 22°C ± 2°C during 28 days (Fig. 3). In the end of this period, each samples taken out of water are examined. Three of them are tested to define compressive strength under loading and the other three are to define tensile strength on split (Fig. 4).

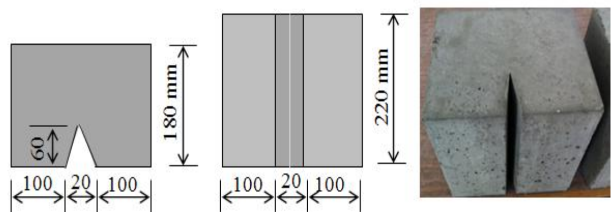

Figure 1. The dimension of test specimens.

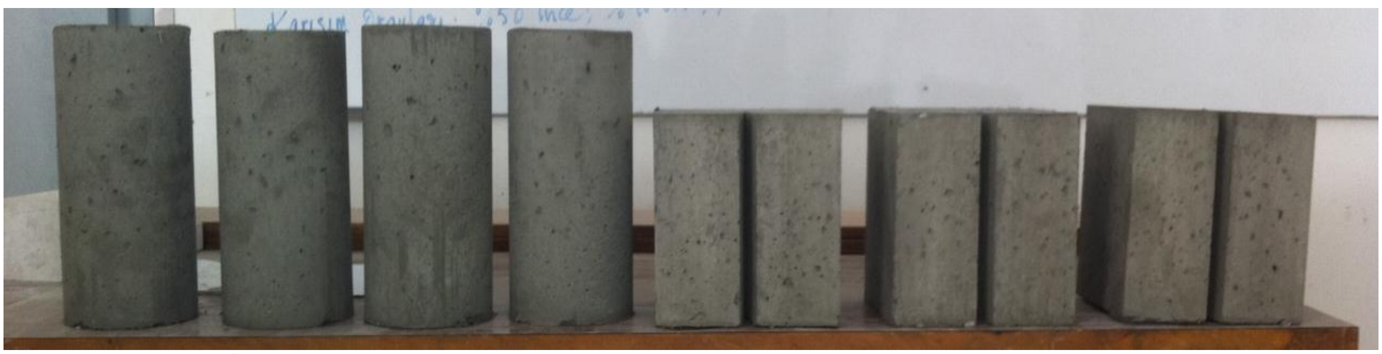

Figure 2. An appearance of experimental samples.

B. *Process of Experiments*

Size of experiment samples produced to examine fracture energy and crack distribution of ordinary and high performance concrete with steel and polypropylene fiber are given in Fig. 1. Mix design of ordinary and fiber concrete used in the production of experiment samples are given in Table 5.

Figure 3. Experimental samples are in the cure.

Table 5. Mix design of ordinary and high strength concretes.

Concretes	W/C	Cement (kg/m^3)	Water (kg/m^3)	Total aggregate (kg/m^3)	Absorbed water (kg/m^3)	Admixtures		Fibers (kg/m^3)	
						SP (kg/m^3)	SF (kg/m^3)	Steel	Polyfibers
HSC	0.30	500	150	1789	9.5	22	50	10	0.9
OC	0.50	350	175	1829	11.70	-	-	10	0.9
HSC: high strength concrete , SP : superplasticizer admixture,				OC: ordinary concrete SF: silica fume					

Figure 4. Compressive strength and tensile strength on split experiment.

The result of compressive strength and tensile strength on split are given in Table 6. To examine fracture energy and crack distribution of normal and high strength concrete with steel and polypropylene fiber, in the experiment on the produced notching samples the test set-up given in Fig. 5 is used. With the given test set-up, load-cracking wide and load-cracking length are measured.

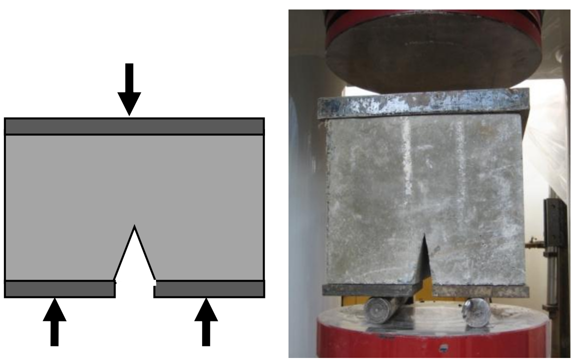

Figure 5. Test set-up of notching samples.

C. *Evaluation of Test Results*

In this study, compressive strength and tensile strength on split of normal and high strength concrete with or without steel and polypropylene fiber are examined. According to this, compressive strength of steel fiber concrete is 10% more than that of concrete without steel fiber, and that of polypropylene fiber concrete is 3% more than that. Steel fiber increases compressive strength a little nut polypropylene fiber does not increase, as well. Steel fiber increases tensile strength on split with the ratio of 19%, and polypropylene fiber increases 10%.

In the high strength concrete, steel fiber addition increases compressive strength 11%, polypropylene fiber addition increases this 3%. Polypropylene fiber adding does not dramatically effect compressive strength in high strength concrete. Steel fiber addition increases this 6%. Because behavior of high strength concrete is more brittle than behavior of normal strength concrete, fiber addition has lower effect in the high strength concrete. Fracture types of concrete with fiber are given in Fig. 6.

Loading-cracking mouth open curves obtained from the experiments done on the notching samples produced to investigate fracture energy and crack distribution of normal and high strength concrete with steel and polypropylene fiber are given in Fig. 7 for normal strength concrete and in Fig. 8 for high strength concrete.

As seen in the figure, in normal strength concrete cracks stay approximately the same until 4 kN loading but in normal strength fiber free concrete, after this loading, crack gets quickly bigger. In fiber free samples, after 15 kN loading and crack was 1 mm, then, after this loading level crack went opening and became 2.25 mm on the loading 12.50 kN and reached the samples top level (120 mm) and lost its loading capacity in a brittle way. In the ordinary concrete with polypropylene fiber crack opened 0.35 mm under 15 kN loading. After this loading level, when crack opening was 10 mm, crack length reached 120 mm and lost its loading capacity in the level of 5 kN loading in a ductile way. In the ordinary concrete with steel fiber, under 20 kN loading crack opening was 0.3 mm. After this loading level, when crack width was 5.2 mm, crack length reached 120 mm, and lost its loading capacity at the level of 10 kN loading. In these samples under bending effect, the most load was carried with the minimum crack width in the concretes with steel fiber. Although the maximum loading was the same in normal strength concrete with or without polypropylene fiber, crack width was on the fiber free samples under the same loading.

Table 6. Compressive strength and tensile strength on split of experiment samples.

Concretes	OC	OC-SF	OC-PF	HSC	HSC-SF	HSC-PF
Compressive strength (MPa)	23.5	25.8	24.2	64.8	72.2	66.7
Split tensile strength (MPa)	2.29	2.73	2.53	3.96	4.52	4.21

OC-SF: Ordinary concrete with steel fiber
OC-PF: ordinary concrete with polypropylene fiber
HSC-SF: High strength concrete with steel fiber
HSC-PF: High strength concrete with polypropylene fiber

Figure 6. Fracture types of normal and high strength concrete with fiber.

But, after maximum loading level, polypropylene fiber made the sample break slowly and escaped from loading until crack opening was 10 mm. In other word, it had ductile behavior. Steel fiber also showed the similar behavior but they did not show the same effect because they scraped though the crack.

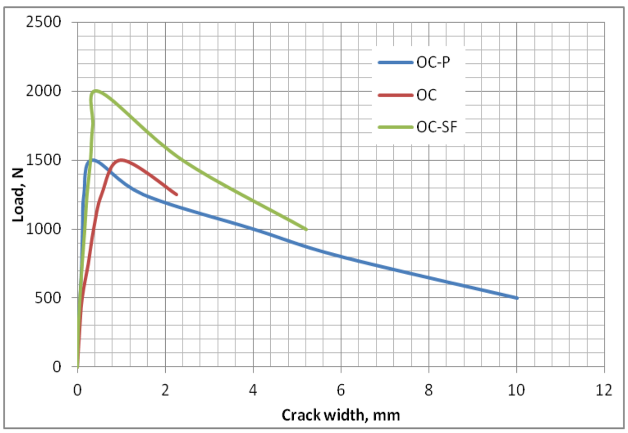

Figure 7. The Load-Crack relations of normal strength concrete.

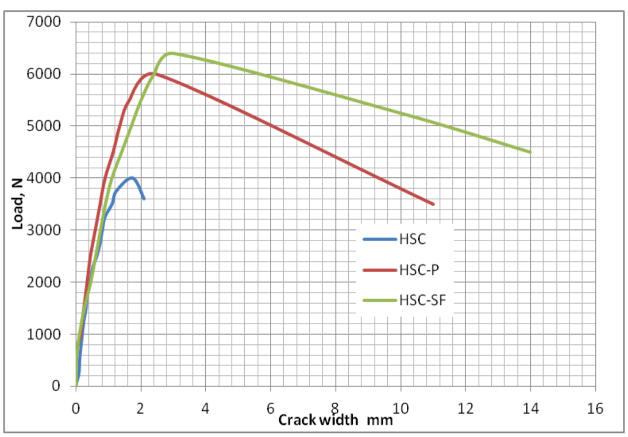

Figure 8. Loading-crack relationship in high strength concrete.

As seen in this figure, in the high strength concrete until 20 kN loading crack openings stayed the same, but after this loading level, in high strength concrete without fiber crack opened quickly. In concrete samples without fiber on the 40 kN loading level, crack opening was 1.75 mm after this loading level crack went on opening and when the load was 36 kN, crack opening was 2.1 mm crack length reached the top of samples (120 mm) and lost its loading capacity in a brittle way. In the high strength concrete with polypropylene fiber, 60 kN loading level, crack opened 2 mm. After this loading level, when the crack width was 10 mm, crack length reached 120 mm and lost its loading capacity, in a ductile way. In the high strength concrete with steel fiber, on the 64 kN loading level, crack width was 3 mm, after this loading level, when crack width was 14 mm, crack length reached 120 mm and lost its loading capacity at the level of 45 kN loading. In these samples under bending effect, the most load was carried in the concrete with steel fiber with the maximum crack width. Maximum loading was more in high strength concrete with polypropylene fiber samples than that in samples without fiber.

In high strength concrete, both steel and polypropylene fibers made the breaking slow under maximum loading. In high strength concrete, steel fiber carried more loading. Fibers in high strength concrete, because the porosity ratio of concrete was low, did not scrape through the concrete, but broke and lost the loading capacity. The reason of having wider crack opening in normal strength concrete with polypropylene fiber than concrete with steel fiber was because steel fiber was not so uniform as polypropylene fiber scraped through the concrete quickly. But in high strength concrete steel fiber did not scrape through the concrete, just broke. So the crack opening was wider then concrete with polypropylene fiber (Fig. 9).

Figure 9. Distribution of steel and polypropylene fiber in the concrete.

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III. Conclusion

Results obtained from this study were given below.

- Comparing concrete without fiber, compressive strength of steel fiber concrete increased 10%, and polypropylene fiber concrete increased 3%.
- Tensile strength on split increased 19% with steel fiber addition and 10% with polypropylene fiber addition.
- Because behavior of high strength concrete is more brittle than that of normal strength concrete, the effect of fiber addition was lower in high strength concrete.
- In these samples under bending effect, the most loading was carried in the steel fiber concrete with the minimum crack width.
- In the high strength concrete, both polypropylene fiber and steel fiber made the samples break slower after maximum loading.

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