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Experiment Observations of the Effects of Fiber Types on the Post-peak Behaviors of Steel Fiber Reinforced Concretes under Tension

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1. Introduction

Concrete is one of the major construction materials that are used to form the containing structures with the function as a radiation barrier for nuclear power plants. While current (steel reinforced) concrete structures for nuclear power plants provide reliable serviceability regarding the requirements of design codes, further safety requirement has been issued with the considerations of the impact of a large, commercial aircraft. U.S. NRC (Nuclear Regulatory Commission) announced the new regulatory code, 10CFR50.150 related to an aircraft impact assessment (AIA). The goal of AIA is to enhance the safety and robustness of new reactor designs at the design stage. To enhance the safety against aircraft impact, two approaches can be simply suggested, increase of barrier wall thickness and/or application of double containment structures. However, these two approaches expect much higher construction costs and much longer building period. Even also, when the thickness of concrete structure is increased, special cares will be expected during the process of concrete placement because of the cracking behavior of mass concrete due to hydration heat.

To avoid the pre-described problems and difficulties, strengthening of the concrete properties could be an alternative and the increase of fracture toughness of concrete itself will be the practical approach to enhance the impact resistivity.

With this consideration, this research observed the effects of steel fiber reinforcement on the enhancement of fracture toughness for possible future application to nuclear power plant structures.

2. Experimental program

2.1 Mixture Design

As a base concrete mixture, this research used concrete mixture with specified compressive strength of 42 MPa (6,000psi) that has been being used for nuclear power plants in Korea (Table 1). The base mixture is composed with binders in which 20% of ordinary portland cement is replaced by flyash. Within this base mixture, three different types of steel fibers (smooth, hooked and twisted) were added with the volume fraction of 0.75%. The shape information and mechanical properties of fibers can be found in Table 2.

The mixtures were manufactured according to the specification of concrete production for nuclear power plant[1] with target slump of 120±25 mm and air content of 4.5±1.5%.

Table 1 : Mixture proportions

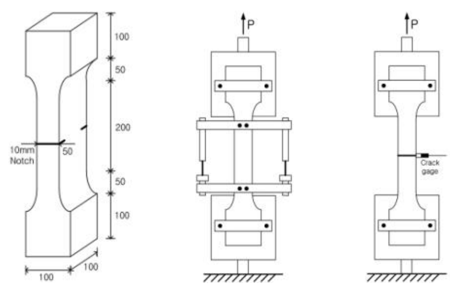
S/a (%)	G_{max} (mm)	W/B (%)	Unit Weight (kg/m^3)						
			W	C	FA	Agg	S	WRA	AEA
44.4	20	40	162	325	81	938	748	2.60	0.29

Table 2 : Type of steel fiber

Fiber type	Diameter (mm)	Length (mm)	l/d	Strength (MPa)
Smooth	0.3	30	100	2,300
Hooked	0.3	30	100	2,311
Twisted	0.375	30	80	2,300

2.2 Test Method

In this research, fiber reinforced concretes were manufactured using twin-shaft mixer. To evaluate the properties of fresh concretes, slump test and air content test were conducted based on KS F 2402 and KS F 2421, respectively. For the evaluations of material properties of hardened concretes, series of tests were conducted. The compressive strength was measured using ∅ 100×200 mm specimens that were manufactured and tested according to KS F 2403 and KS F 2405. The mechanical behaviors under tensile loads were evaluated by two types of direct tension tests as described in Fig. 1[2, 3]. One of the direct tension tests used dog-bone shape specimens without notch (Fig. 1 (b)) and the deformation value was measured by LVDT. The other test was conducted using notched specimen (Fig. 1 (c)) and the crack mouth opening displacement was measured by crack gauge.



(a)Specimen (b)Direct tension (c)Direct tension(Notched)

Fig. 1. Direct tension tests

From the tests results, the effects of fiber shapes on the post-peak behaviors such as the relationships between tensile stress and strain and between the tensile stress and crack mouth opening displacement were observed.

3. Result and discussion

The compressive strengths of all steel fiber reinforced concrete mixtures satisfied the target strength value of 42 MPa (6,000 psi) and the differences were small enough to be negligible. Therefore, it could be said that fiber type has little effect on the compressive strength.

In the case of slump, only the hooked type fiber reinforced concrete mixture satisfied the target slump. The other mixtures with smooth and twisted type fibers had very low slump values under 50 mm showing fiber balling.

From the direct tension tests, post-peak stress-strain curve and stress-crack mouth opening displacement (CTOD) curve of each mixture were obtained as shown in Fig. 2 and Fig. 3. From the test results, fracture energy of each mixture was calculated and the concrete mixture with twisted type fiber showed the highest value comparing to the other mixtures (Table 3). Also, it was observed from the stress-CTOD curve (Fig. 3) that twisted type and hooked type fibers provided both tension softening and tension stiffening effects while smooth type fiber only provided tension softening effect. From these observations, it could be discussed that twisted type fiber provides much better crack bridging effect than the other fiber types.

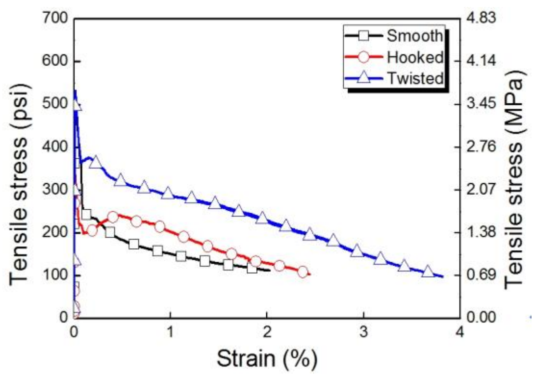


Fig. 2. Post-peak stress vs. strain (un-notched)

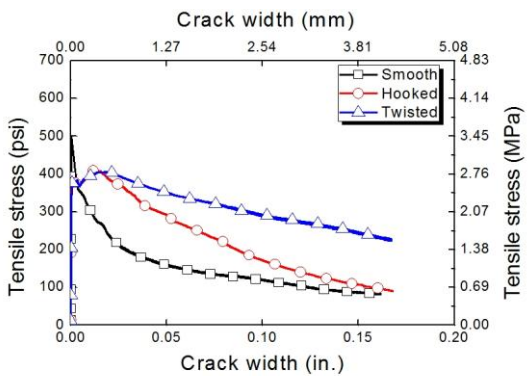


Fig. 3. Stress vs. CTOD (notched)

Table 3 : Test results

Fiber type	f_c (MPa)	f_t (MPa)	G_f (N·m/m^2)
Smooth	51.03	3.45	5,232
Hooked	50.74	2.82	7,877
Twisted	52.48	2.79	13,579

However, as discussed previously, concrete with hooked type fiber showed very low slump value with fiber balling. Therefore, regarding the test results and workability, further researches are expected to improve the workability of fiber reinforced concrete mixtures and to select the best fiber type for the construction of nuclear power plants.

4. Conclusion

This research investigated the applicability of steel fibers to concrete mixtures used for nuclear power plant structures. Three different types of steel fibers were used and series of tests were conducted to observe the workability and fracture behaviors.

From the experimental results, it was observed that twisted type steel fiber provides the highest fracture toughness comparing to the other fiber types. However, because of the very poor workability of concrete with twisted type fiber, further researches are expected.

ACKNOWLEGMENT

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