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EFFECT OF RECYCLED MATERIALS ON THE TENSILE BEHAVIOR OF STEEL FIBER-REINFORCED CEMENT COMPOSITE

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Conventional cement composite is generally produced with ordinary Portland cement (OPC) as a binder. However, during manufacturing the cement composite, large amount of carbon dioxide (CO_2) are emitted. Therefore, fly ash is proposed to be replaced to OPC in order to reduce CO_2 emission of cement composites. For reinforcing fibers, micro steel fibers were used. For investigating mechanical properties of steel fiber-reinforced cement composites (SFRCCs), direct tension tests were conducted. The test results showed that fly ash improves tensile strength and ductility of SFRCCs. However, tensile strength of the SFRCC decreased as replacement ratio of recycled fine aggregate increased. The use of recycled materials in FRCC helps to save natural resources and promote sustainability in civil engineering materials.

Keywords: Fiber-reinforced cement composites (FRCCs), Recycled fine aggregate, Fly ash, Carbon dioxide (CO_2), Tensile strength, Ductility.

1 INTRODUCTION

It is well known that fiber-reinforced cement composites (FRCCs) show higher tensile strength and larger ductility compared to conventional concrete. However, the FRCCs consumes larger amount of binder such as cement, hence much more CO_2 are emitted during manufacturing process of the FRCCs. Recently, recycled materials such as Ground granulated blast-furnace slag (GGBS) and fly ash (FA) are considered as alternative binders to cement, as well as a way of reusing available industrial by-products (Babu and Kumar 2000, Berndt 2009, Li and Zhao 2003). Furthermore, there are many researches about mechanical properties and structural application of recycled aggregate concrete (Choi *et al*. 2012, Kim *et al*. 2015, Silva *et al.* 2015, Xiao and Zhang 2005). The aim of this study is to evaluate the effect of recycled materials on the tensile behaviors of steel fiber-reinforced cement composites (SFRCCs). In this study, ordinary Portland cement (OPC) and natural sand were partially replaced with FA and recycled sand (RS), respectively. The replacement ratios of FA and RS (25% and 50%) were main variables. The test results of the SFRCC with recycled materials are compared to the OPC mortar-based SFRCC, with a view to identifying their tensile behaviors. The utilization of recycled materials in FRCCs will be helpful in conserving existing natural resources, and in reducing environmental problems and greenhouse gas emissions associated with the Portland cement production.

2 MATERIALS FOR SFRCCS

FA and Type I OPC were used as binders for SFRCCs. The chemical compositions of the FA and OPC used in this study are given in Table 1. The specific surfaces for the OPC and the fly ash were 3,250 and 3,990 cm^2/g, respectively.

Table 1. Chemical composition (% by mass) of FA and OPC.

Component	SiO_2	Al_2O_3	CaO	Fe_2O_3	MgO	SO_3	LOI
FA	50.7	20.7	3.61	6.37	1.08	0.54	3.04
OPC	20.9	5.39	64.7	2.38	1.51	1.65	2.78

Locally available sea sand (maximum particle size of 2.5 mm) and recycled sand (maximum particle size of 2.5 mm) were used as fine aggregates. The recycled sands were obtained by processing waste concrete from an apartment building in Korea. As listed in Table 2, density and water absorption of the recycled sand were 2.44 g/cm^3 and 4.32%, respectively, which meet KS L 2573 (2014).

Table 2. Physical properties of recycled sand and sea sand.

Physical property	Recycled sand	Sea sand
Density (g/cm^3)	2.44	2.59
Water absorption (%)	4.32	0.76

As reinforcing fibers, micro steel fibers shown in Figure 1 were used. The mechanical properties of the steel fiber are listed in Table 3. Materials used for SFRCCs are seen in Figure 1.

Table 3. Mechanical properties of micro steel fiber.

Density (g/cm^3)	Length (mm)	Diameter (μm)	Aspect ratio	Tensile strength (MPa)	Elastic modulus (GPa)
7.85	12~14	180~230	52~77	2,580	206

(a) Sea sand (b) recycled sand (c) Micro steel fiber

Figure 1. Materials used for SFRCCs.

Table 4 shows mixture proportions of SFRCCs used in this study. Five types of SFRCCs mixes were prepared with a water-to-binder ratio of 0.45. The percentage of the steel fiber added was fixed to 1.0% by volume of the binder. In this study, for high water absorption of recycled sand, the mixing water compensation method was used.

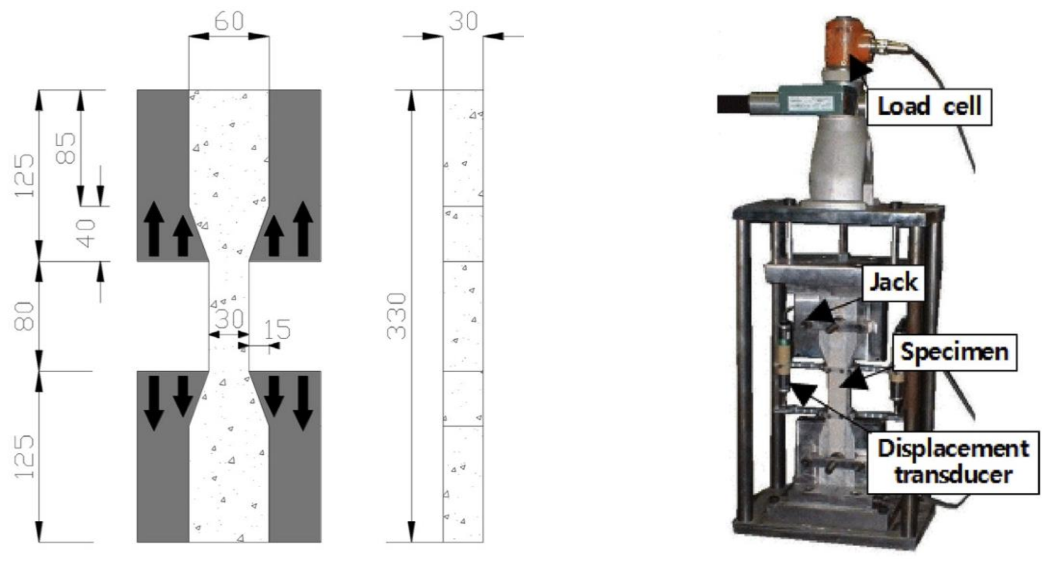
Table 4. Mixture proportions of SFRCCs.

Mixture	W/B	Unit weight (kg/m^3)						
		W	C	FA	NS	RS	SF	SP
OPC	0.45	334	743	-	1,114	-	18.51	0.59
FA25RS25	0.45	346	557	186	835	278	18.51	0.59
FA25RS50	0.45	358	557	186	557	557	18.51	0.59
FA50RS25	0.45	346	371	371	835	278	18.51	0.59
FA50RS50	0.45	358	371	371	557	557	18.51	0.59

* W/B: water-to-Binder ratio, W: water, C: cement, FA: fly ash, NS: natural sand, RS: recycled sand, SF: steel fiber, SP: superplasticizer

3 MIXING AND TEST METHOD

To produce SFRCCs, the binder and the fine aggregate were initially dry-mixed for a minute. After the dry mixing, water including a superplasticizer was added. The required quantities of steel fibers were then added separately in small amounts to avoid fiber balling. The freshly mixed SFRCCs were poured in prismatic (100 mm × 100 mm × 400 mm) as per KS L ISO 679 (2006) and dumbbell-shaped steel molds [Figure 2(a)] for compressive and direct tensile tests, respectively. Each mix was kept in a mist room at 23 °C and 95% relative humidity for 24 h until demolding. After demolding, specimens for wet curing were preserved in water at 20 ± 2 °C.



(a) Detail (unit: mm) (b) Test set-up

Figure 2. Direct tensile strength test.

4 TEST RESULTS AND DISCUSSIONS

Figure 3 shows 28-day compressive strengths of SFRCCs. OPC specimen that has no recycled materials showed a compressive strength of 61 MPa. FA25RS25 and FA25RS50 specimens showed 8% and 12% lower compressive strengths than OPC specimen. However, compressive strengths of FA50RS25 and FA50RS50 specimens are 63% and 60% of that of OPC specimen. It is referred that the specimens replaced with 50% of fly ash showed slow strength development due to pozzolanic reaction of fly ash (Papadakis 1999, Puertas *et al.* 2000). The effect of recycled sand on the compressive strengths of SFRCCs is insignificant compared to the effect of fly ash. Therefore, based on this test results, it can be referred that the limit of the replacement ratio of fly ash should be 25%.

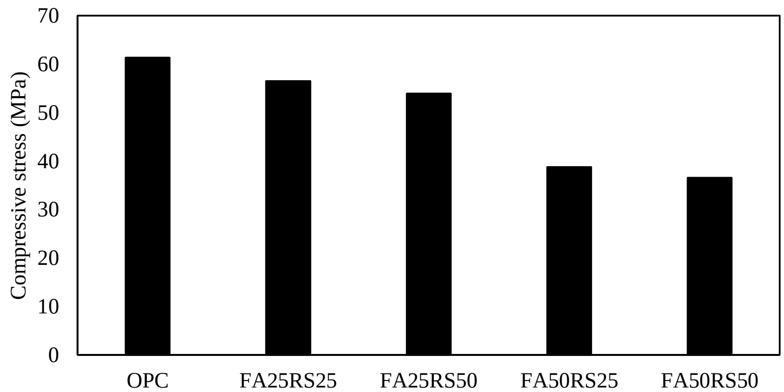


Figure 3. Comparison of compressive strengths.

Figure 4 shows direct tensile strengths of SFRCCs. OPC specimen that has no recycled materials showed a direct tensile strength of 1.50 MPa. FA25RS25 specimen showed 9% higher tensile strength than OPC specimen. It can be thought that the bond behavior of interface between steel fiber and cement matrix is improved due to smaller grain size of fly ash compared to OPC. However, tensile strength of FA25RS50 specimen replaced with 50% recycled sand was 88% of OPC specimen. Tensile strengths of FA50RS25 and FA50RS50 specimens are 96% and 73% of that of OPC specimen.

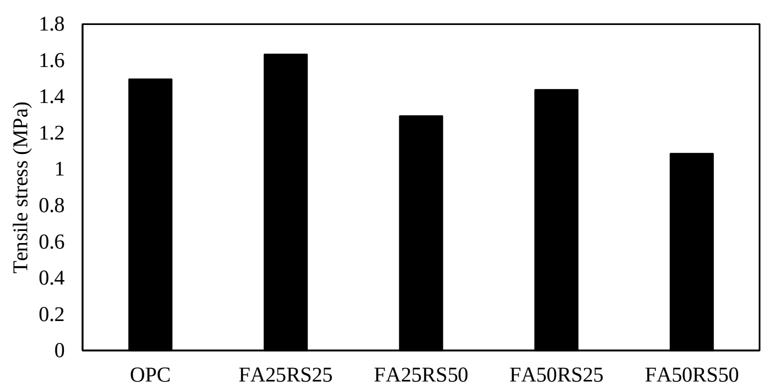


Figure 4. Comparison of direct tensile strengths

Direct tensile strength test results showed that tensile strength of SFRCCs with recycled materials are influenced by recycled sand rather than fly ash. It means that interfacial bond strength between steel fiber and cement matrix depends on quality of old interfacial transition zone (ITZ) of new ITZ (Xiao *et al.* 2013).

5 CONCLUSIONS

Based on the test results, some conclusions are derived as follows:

(1) For compressive strength, FA50RS25 and FA50RS50 specimens showed about 40% lower strength values compared to OPC specimen due to both pozzolanic reaction of fly ash and low strength of recycled aggregate.

(2) As replacement ratio of recycled sand increased, tensile strength of specimen decreased because the interfacial bond strength between fiber and cement matrix is influenced by the quality of ITZ.

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