The applications of mine tailings to develop low cost UHPC

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Abstract: Nowadays, Ultra High Performance Concrete (UHPC) is being applied in various structural members with its great advantages over conventional cement based materials such as high strength, durability and impact resistance. However, UHPC has some disadvantages including high cost of the materials. In this study, different mine tailings were used in order to reduce material cost and develop eco-friendly UHPC. Four types of mine tailings with different particle sizes were used to substitute silica powder and silica sand. And the effects of the use of tailings on UHPC were evaluated using cost analysis, compressive strength and flowability. The effect of curing procedures, water and air curing, were also investigated. It is revealed from the investigations that different types of mine tailing can be incorporated into UHPC to achieve cost reduction.

Keywords: UHPC, mine tailings, cost reduction, compressive strength, flowability

1. Introduction

Studies on UHPC has been greatly increased due to its high engineering significance on the mechanical and physical properties, for instance, durability, fire, impact, and microstructure (Graybeal et al., 2007; Behloul et al., 2002; Pyo, 2014; Sorelli et al., 2008). However, the resource limitations on silica powder and natural sand in some regions and high prices of constituents depending on regions could hinder broad applications and utilizations of UHPC for construction industry. Many researches have been carried out in different ways to minimize the cost of UHPC. Racky (2004) showed the economic benefits of UHPC by comparing it with normal strength concrete considering the area reduction and life cycle cost. Allena and Newtson (2011) tried to use locally available materials in order to reduce the production cost of UHPC by substituting local sand and eliminating the transportation cost for the row materials to bring. Zhu et al. (2015) used iron ore tailings as fine aggregates by substituting silica sand in UHPC.

In the present study, various types of mine tailings produced in South Korea were utilized as substitutes of silica powder and silica fine-sand in UHPC to reduce the material cost and develop eco-friendly UHPC. The tailing is one of powder-type waste materials from the mining process and their particle sizes are similar to those of silica powder and silica fine-sand (Benzaazoua et al., 2008; Sivakugan et al., 2006). Although it usually depends on locations, the cost of tailings in South Korea are much lower than those of the silica powder and fine-sand for UHPC because additional grinding process is needed to produce silica powder. In addition, the use of the tailings has great environmental and social values. Mine tailings contain various toxic elements including heavy metals, sulfide, and arsenic, which can cause the contamination of soil and ground water (Roussel et al., 2000). Thus, with the solidification/stabilization technique producing an eco-friendly product is possible; this is a technique of reducing the mobility of heavy metals. In this research cementitious solidification/stabilization process is used to reduce the high leaching behavior of the mine tailing in its free state (Fall et al., 2009). In addition the use of mine tailing for the construction industry indirectly reduces the vulnerability of water and soil contamination around the mining site giving a great ecological benefit. Four types of mine tailings with different particle sizes were used to substitute silica powder and silica sand. And the effects of the use of tailings on UHPC were evaluated using cost analysis, compressive strength and flowability. The effect of curing procedures, water and air curing, were also investigated.

2. Background

The UHPC is a type of composite materials composed of cement, silica fume, silica powder, silica sand and fibers. The cost of silica powder and sand is high in addition to the scarcity of the resource which is also another challenge for the applicability. Considering the above drawbacks, this experimental study tries to show effective ways in order to minimize the limitations. The main aim of this experimental study is to develop cost effective UHPC with the appropriate compressive strength and flowability. In order to achieve the goal, four types of locally available mine tailings were used.

3. Experimental Program

3.1. Materials and mix proportions

Four types of locally available mine tailing were used as follows: (i) Sunshin tailing (raw), (ii) Sunshin tailing (microwave treated), (iii) Sangdong tailing (Passing sieve No. 325 mesh) and (iv) Sangdong tailing (Passing sieve No. 100 mesh). The Sunshin tailing was produced from a gold mine in the South Jeolla Province and their particle size was similar to the Sangdong tailing with passing sieve No. 325 mesh. The first two Sunshin tailings were the same in type and size, while the latter one was microwaved to remove arsenic in the raw material. The Sunshin tailings could pass the standard sieve mesh No. 325. The specific gravities of raw and microwaved Sunshin tailings were 2.52 and 2.53, respectively. Both were added in different mixtures by a percentage ratio of 0%, 50% and 100% substituting the silica powder (median size = 3.15μm), and after casting they were given two curing conditions water and air for each mix including the control series. The Sangdong tailing was produced from a tungsten mine in Gangwon province. Two Sangdong tailings were the same in type but have different sieve No. passing: the former one was mesh No. 325 and the latter one mash No. 100. The former and the latter were substituted silica powder and the silica sand smaller than 1mm, respectively. Specific gravity of the Sangdong tailings was 2.61. The mix proportion was listed in Table 1.

Table 1. Weight proportion of mixtures

Materials		Specimen								
		Control	TF1	TF2	TF3	TF4	TF5	TF6	TS1	TS2
Cement		1	1	1	1	1	1	1	1	1
Silica fume (Elkem 940U)		0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25
Silica powder (smaller than 4um)		0.25	0.125		0.125		0.125		0.25	0.25
Sunshin tailing (raw)			0.125	0.25						
Sunshin tailing (microwaved)					0.125	0.25				
Sangdong tailing (Passing sieve No. 325 mesh)							0.125	0.25		
Water		0.23	0.23	0.23	0.23	0.23	0.23	0.23	0.23	0.23
Superplasticizer§		0.008	0.008	0.008	0.008	0.008	0.008	0.008	0.008	0.008
Steel fiber† (19.5 mm length)		1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
Silica sand	0.1 mm	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.15	
	0.3 mm	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7
Sangdong tailing (Passing sieve No. 100 mesh)									0.15	0.3
Curing condition		Water, Air	Water, Air	Water , Air	Water, Air	Water, Air	Air	Air	Air	Air

§Solid Content

†Volume fraction

3.2. Experimental details

The UHPC were prepared by a Hobert type mixer. First silica fume was mixed with all the sand for approximately 5 minutes. Then, cement and silica powder or the equivalents, tailings were added and mixed together for at least another 5 minute before the water and superplasticizer was added. The cementitious mixture becomes fluid after approximately 5minute of adding the liquid ingredients, water and superplasticizer. After the mixture brings adequate texture, fibers were dispersed by hand in the mix. Details of the mix process of UHPC can be found in Pyo (2014).

Flowability were measured in accordance with ASTM C1437 without external vibration or compacting, and flow measurement were taken before and after the fiber added to the mix to check if the flow were affected by the fiber which was totally not affected. Note that the table was not dropped in accordance with the ASTM C1437 as the mixture was able to flowed after removing the flow mold without dropping. 50 mm cubic molds were used to pour the mixture for the 7, 14 and 28 days compressive strength test without any vibration. Initially after the casting it was covered with plastic sheet at room temperatures. After one day demolding were done and each specimen were kept in water and air as shown in table 1.

4. Results and discussion

The results of the experiment are shown on table 2 including the compressive strength, flow and unit price for each series. The cost analysis is made only based on the material cost to fabricate each mix design. It should be noted that it does not consider the labor or equipment cost for the production. From the cost analysis, cost reduction can be achieved by a maximum of 77 USD per one meter cube average volume. In general most of the mix designs show a cost reduction from five to ten percent in comparison with the control mix design. If we consider these values in a big scale of per metric tons of mix, the cost reduction is apparent and noticeable.

Compressive strength and flowability as shown in table 2 have some reduction from the control series but most of them were on the limit and a good early strength were recorded in almost all the specimen either the water or air cured one. Compressive strength at 28 days of curing shows that most of cases have more than 120 MPa. Especially, TF3 case under the water curing shows compressive strength higher than 150 MPa. Flowability was reduced when the tailings were substituted the silica powders. However, the cases of TS1 and TS2, substituting silica sand by the mine tailings, gives even higher flowability.

Table 2. Experimental results

Series		Control	TF1	TF2	TF3	TF4	TF5	TF6	TS1	TS2
Cost (USD/m^3)		792	754	715	754	715	754	715	786	779
Flow (mm)	Before adding fiber	147	115	100	105	100	143	136	194	198
	After adding fiber	163	115	100	105	103	163	145	201	203
Compressive strength [a] (MPa)	7 day	130(W) /97 (A)	107(W) /86 (A)	90(W) /76(A)	102(W) /87(A)	95(W) /75(A)	91 (A)	83 (A)	95 (A)	96 (A)
	14day	147(W)	125(W)	109(W)	129(W)	122(W)	-	-	-	-
	28day	165(W) /132(A)	137(W) /121(A)	118(W) /106(A)	151(W) /114(A)	129(W) /105(A)	120 (A)	115 (A)	133 (A)	133 (A)

[a] (W): Water-cured, (A): Air-cured

5. Conclusions

A series of experiments has been conducted in the effort of producing a low cost and eco-friendly UHPC. Overall, four different types of tailing mixtures were used by replacing silica powder and silica sand. The four mixes were evaluated by their mix design by conducting compressive strength and flowability beside the cost analysis for each mix.

The mixture (TS1 and TS2) containing the Sangdong tailing (Passing sieve No. 100 mesh) as a substituent for silica sand showed a good result on flowability, early strength development, and 28 days compressive strength but the cost reduction on this mixtures was not significant. In the present study, most of the mixtures, substituting silica powder, have shown a satisfactory cost reduction by five to ten percent compared to the control mixture. However, even though most of the samples show compressive strength higher than 120 MPa, a reduction of flowability and 28 day compressive strength were recorded. It can be concluded that there is a capability to safely consume mine tailings on UHPC and reduce cost if further researches on toxicological analysis are carried out.

6. References

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