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Engineering Properties of Self-compacting Concrete Containing Stainless Steel Slags

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Abstract

This paper presents the results of an investigation on engineering properties of self-compacting concrete (SCC) containing oxidizing and reducing slag generated from stainless steel making. The oxidizing slag was employed as fine and coarse aggregates substituting to natural materials with various percentages (0%, 50%, and 100%). Meanwhile, the reducing slag partially replaces for Portland cement (0%, 10%, 20%, and 30%). As a result, a total of 12 mixtures with a fixed water-binder ratio (w/b = 0.4) were developed in laboratory and its properties in hardened properties such as compressive strength, ultrasonic pulse velocity and surface resistivity were experimentally examined. The results indicated that 100 % stainless steel oxidizing slag (SSOS) substitutes to aggregates and 30 % stainless steel reducing slag (SSRS) substitutes to Portland cement in SCC, the values of compressive strength, electrical resistivity and the 91 day ultrasonic pulse velocity are within the good quality concrete requirement. It could save 43 % cost of SCC with this substitution. It will contribute to environmental protection and the resource recycling initiative.

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Keywords: self-compacting concrete; stainless steel slag; resource; recycling;

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1. Introduction

Stainless steel slag is a byproduct of manufacturing stainless steel from scrap iron. The characteristics of stainless steel slag differ from those of electric arc furnace carbon steel because of the additional elements of ferrochrome and nickel in stainless steel [1, 2]. Because the content of the stainless steel slag includes chromium, lead, nickel, and cadmium element, these elements create problems of both occupational and environmental health threats [1, 3-4]. Although the chromium found in stainless steel slags have been reported[6], but the toxicity characteristic leaching procedure (TCLP) test results of the stainless steel slags from Italy, China and Taiwan are less than the detection limit [2,5]. Hence, the pollution risks posed by the heavy metals in stainless steel slag are minimal. Moreover, in most areas, stainless steel slag can be simply treated as a common, nonhazardous waste. In general, stainless steel slag could be used as a landfill material in earth engineering [2]. However, the material also has both the cementation and pozzolanic reaction characteristics like Blast Furnace (B.F.) slag and electric arc furnace [7] , it could be the binder of concrete [2, 8].

Self-Compacting Concrete (SCC) is characterized by its ability to be cast and filled into a framework entirely under its own weight and without the need for any type of compaction or external vibration. Additionally, SCC is highly resistant to segregation and flows easily around obstacles, such as reinforcements and hard-to-reach areas [9, 10]. Because the easy-to-pour SCC requires neither additional equipment nor skilled labor to consolidate, it has recently gained popularity [10-12]. However, SCC does contain waste and industrial by-products, such as fly ash, limestone powder, which are generally used as mineral admixtures [2, 8, 13-15].

According to the literature, when the fineness of stainless steel reducing slag (SSRS) is 4400 cm^2/g and cement content that replaces less than 30% by weight, the compressive strength of cement mortar is higher than that specified by ASTM C150 [8]. Moreover, replacing the natural aggregate with stainless steel oxidizing slag (SSOS) improves the compressive strength, with the value for the 100% SSOS aggregate being nearly 1.13~1.14 times the natural aggregate after 28 days [16]. In order to maximize the use of stainless steel slags. The characteristics of test variables and mixture proportions are the high percentage of stainless steel slags. The purpose of the study is aimed at increasing the economic value of stainless steel slag and reducing the cement content in SCC, thereby contributing to the resource recycling initiative.

2. Experimental plan

2.1. Experimental materials

The Portland cement used in this study was produced according to the ASTM C150 type I Portland cement with a specific gravity of 3.15 and a fineness of 3851 cm^2/g (manufactured by Taiwan Cement Corporation, Taiwan, ROC). Class F fly ash was produced by Shin-Ta Thermal Power Plant of the Taiwan Power Company. SSRS were crushed by Fluidized bed opposed jet mill into powders. The fineness of SSRS is 5500 cm^2/g and the specific gravity is 2.85. The tap water was used to mix materials of concrete. The stainless steel slag was obtained from Lihwa Corp. SSOS were by crushing before performing magnetic separation followed by sieving. Fig. 1 shows the Natural and SSOS aggregate particle size distribution curves. The sieve grading of the aggregates used matched the ASTM C33. The material properties are shown in Table 1.

2.2. Experimental variables

According to Hwang’s densified mixture design algorithm (DMDA) [10], the SCC mixture was made with a constant water-to-binder ratio (W/B = 0.40) in which a portion of the aggregate were replaced by SSOS in weight ratios of 0%, 50%, 100% and cement were replaced by SSRS in weight ratios of 0 %, 10 %, 20 %, 30 %. The design compressive strength of 28 days is 280 kgf/cm^2. Table 2 shows the replacement of a weight basis and the mixture proportion.

2.3. Hardened properties

The compressive strength was tested according to ASTM C39. A cylinder specimen of 100 mm diameter and 200 mm height was made, and tested at 1 day, 7 days, 28 days, 56 days and 91 days. Ultrasonic pulse velocity detection was performed according to ASTM C597. An ultrasonic instrument was used to transmit ultrasonic pulse waves to the cylinder specimen, and the signals were returned to the pulse wave receiver. As the concrete test block aged the block became more compact, and the measured ultrasonic pulse velocity increased [10, 17-18]. According to the ASTM C805 standard, the rebound number of the hardened concrete was tested by Rebound Hammer. This test method used to assess the in-place uniformity of concrete, to delineate regions in a structure of poor quality or deteriorated concrete, and to estimate in-place strength development. According to the ASTM C876 standard on surface resistance, the resistivity can be measured by the contact section of concrete. During the test, the specimen was dry on the outside and saturated on the inside. The concrete surface resistance was the degree of concrete density and the index of impermeability [8, 10, 18].

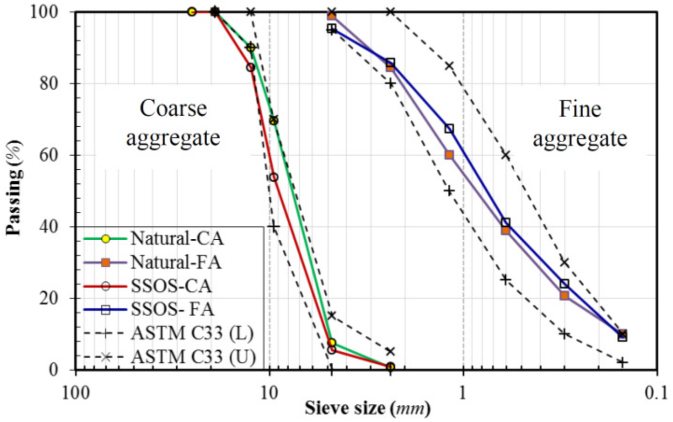

Fig. 1. Particle-size distribution of N.A. and SSOS aggregates.

Table 1. Material properties

Physical Properties					
Items(Aggregate)		SG_{SSD}	Water absorption(%)		Fineness (cm^2/g)
Natural Fine		2.65	2.2		-
Natural Coarse		2.64	1.3		-
Fine SSOS		2.86	2.8		-
Coarse SSOS		2.88	1.9		-
SSRS		2.85	-		5500
Chemical Composition(%)					
		SiO_2	CaO	Al_2O_3	MgO
SSOS		38.61	31.5	2.43	12.8
SSRS		23.5	50.6	4.1	8.2
TCLP(mg/L)					
Cr	Cu	Cd	Pb	Zn	Ni
N.D	N.D	N.D	N.D	N.D	N.D

Note: N.D=Not detect, less than the test detection value

Table 2. Mixture proportion (kg/m^3)

Sample	SSOS %	SSRS %	SSRS	Cement	N.A.		SSOS		F.A.	Water	S.P.
					Fine	Coarse	Fine	Coarse			
A00	0	0	0	448	849	787	0	0	132	232	7.25
A10		10	45	403	849	787	0	0	132	232	7.25
A20		20	90	358	849	787	0	0	132	232	7.25
A30		30	134	314	849	787	0	0	132	232	7.25
B00	50	0	0	448	425	394	424	393	132	232	7.25
B10		10	45	403	425	394	424	393	132	232	7.25
B20		20	90	358	425	394	424	393	132	232	7.25
B30		30	134	314	425	394	424	393	132	232	7.25
C00	100	0	0	448	0	0	849	787	132	232	7.25
C10		10	45	403	0	0	849	787	132	232	7.25
C20		20	90	358	0	0	849	787	132	232	7.25
C30		30	134	314	0	0	849	787	132	232	7.25

3. Results and analysis

3.1. Compressive strength

As shown in Figure 2, the compressive strength of stainless steel slag SCC (SS-SCC) tends to increase when the SSRS replacement ratio of the cement decreases, and the compressive strength tends to decrease when the SSOS replacement ratio of the aggregate decreases. The compressive strengths of 28 days are 348-580 kgf/cm^2 higher than the design compressive strength 280 kgf/cm^2. The compressive strength of C10 (100 % SSOS and 10 % SSRS substitution) is higher than the control group A00 after 28 days. However, after 56 days, the compressive strength of C30 (100 % SSOS and 30 % SSRS substitution) is higher than the control group. The results indicate that SSOS and SSRS replace aggregate and cement material of SCC is acceptable. The maximum substitution is 100 % SSOS and 30 % SSRS.

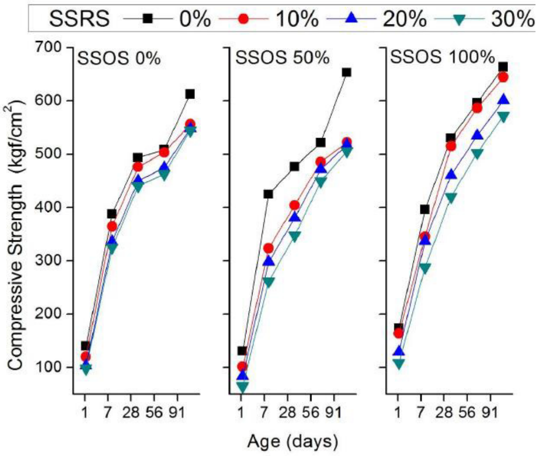

Fig. 2. Compressive Strength of SS-SCC.

3.2. Ultrasonic pulse velocity

Fig. 3. shows that the ultrasonic pulse velocity for the SS-SCC after 1 day, 7 days, 28 days, 56 days and 91 days. Ultrasonic pulse velocity tended to increase with the SSOS aggregate proportions and age. The ultrasonic pulse velocity is in range of 4028-4393 m/s after 28 days. The measured values are within 3660-4575 m/s, it meant that the quality of SS-SCC are "good" in density [19]. The results indicate that SS-SCC density is the same with the control group. Meanwhile, the ultrasonic pulse velocity of C30 (4230 m/s) is higher than A00 (4212 m/s) after 28 days.

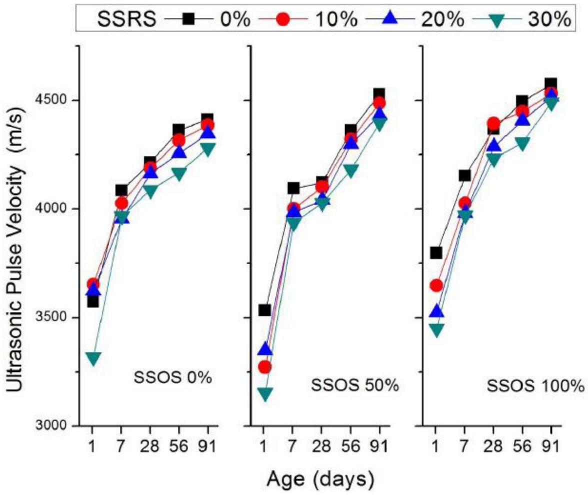

Fig. 3. Ultrasonic pulse velocity of SS-SCC

3.3. Rebound Hammer test

Although the rebound hammer test can not be used in accordance with the strength of concrete, but applied to detect the concrete quality is uniformity or not. Fig. 4 shows that the Rebound Hammer test for the SS-SCC after 1 day, 7 days, 28 days, 56 days and 91 days. The Rebound Hammer test Q values are 38-53 higher than the design compressive strength 280 kgf/cm^2 (Q=26). The results indicate that SS-SCC quality is the same with the control group.

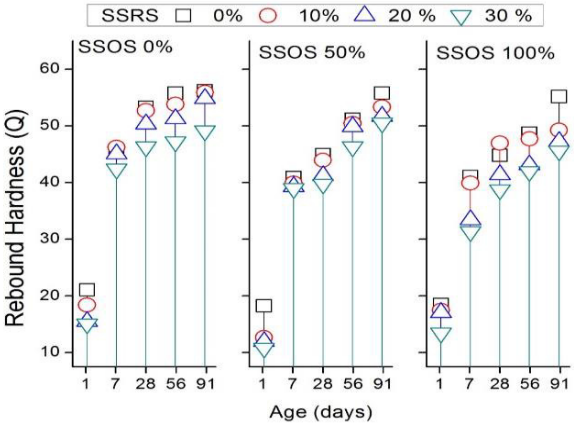

Fig. 4. Rebound Hammer test of SS-SCC

3.4. Surface resistance

When there is a corrosion risk in a reinforced concrete structure, the resistivity after 56 days should be above 20 kΩ-cm to prevent corroding the reinforcement (Hwang 2010). Figure 5 indicates the surface resistance of the SS-SCC, which had a resistance between 20 and 50 kΩ-cm after 56 days could reach the required value of 20 kΩ-cm to prevent corrosion. The results indicate that SS-SCC can prevent the corrosion risk in a reinforced concrete structure is the same as the control group. The surface resistance of C30 (35.3 kΩ-cm) is higher than A00 (34.4 kΩ-cm) after 56 days.

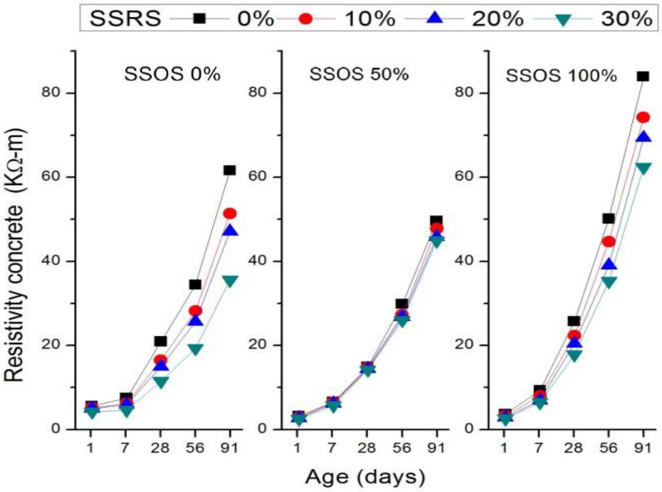

Fig. 5. Surface resistance of SS-SCC

3.5. Economic benefits

The testing results show that 100% SSOS substitutes to aggregates and 30% SSRS substitutes to Portland cement within the good quality concrete requirement of SCC. The optimized substitution is 100 % SSOS and 30 % SSRS（C30）. Table 3 shows the economic benefits analysis of the mixture proportion. The price of A00 is 1763.7 NT$/m^3 and C30 is 997.4 NT$/m^3. The cost of C30 is 57 % of A00. Therefore, when SS-SCC contains 100 % SSOS for aggregates and 30 % SSRS for Portland cement, it can save about 43% of the cost.

Table 3. Economic benefits (NT$/m^3)

Sample	SSRS	Cement	N.A.		SSOS		F.A.	Water	S.P.
			Fine	Coarse	Fine	Coarse			
A00	0	448	849	787	0	0	132	232	7.26
Unit price	0	2.3	0.28	0.28	0	0	0.6	0	27
summary	0	1030.4	237.7	220.4	0	0	79.2	0	196
Total									**1763.7**
C30	134	314	0	0	849	787	132	232	7.26
Unit price	0	2.3	0	0	0	0	0.6	0	27

summary	0	772.3	0	0	0	0	79.2	0	196
Total									**997.4**

4. Conclusions

- The SS-SCC compressive strength tends to increase when the SSRS replacement ratio of the cement decreases, and the compressive strength tends to decrease when the SSOS replacement ratio of the aggregate decreases. Due to the characteristic, the compressive strength of SS-SCC is similar the control group.
- The ultrasonic pulse velocity measured values show that SS-SCC density is the same with the control group.
- The Rebound Hammer test values are higher than the design compressive strength. The results indicate that SS-SCC quality is the same with the control group.
- The SS-SCC surface resistance values are over 20 kΩ-cm. The results indicate that SS-SCC can prevent the corrosion risk in a reinforced concrete structure.
- The testing results show that 100% SSOS substitutes to aggregates and 30% SSRS substitutes to Portland cement within the good quality concrete requirement of SCC. It could save 43% cost of SCC with this substitution.
- The results will reduce stainless steel slag wastes and increase the economic value of stainless steel slag. Additional, it will contribute to environmental protection and the resource recycling initiative.

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