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Properties of green concrete containing stainless steel oxidizing slag resource materials

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HIGHLIGHTS

- Replacing the natural aggregate with SSOS improves the compressive strength.
- The expansion of the 100% SSOS aggregate is less than the requirement.
- The durability of the SSOS aggregate concrete is enhanced.
- No heavy metals leach from the SSOS aggregate material or mixed concrete occurred.
- This study shows that the optimal aggregate replacement ratio for SSOS is 100%.

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ABSTRACT

This study aims to investigate the engineering properties of green concrete containing stainless steel oxidizing slag (SSOS). The goal of this study is to determine the best substitution proportion of the SSOS for fine and coarse aggregates. The results indicated that a 100% substitution of SSOS for the natural fine aggregate creates a mortar with better compressive strength. A 100% SSOS substitution also produces better hardened concrete properties, such as the compressive strength, surface resistance and ultrasonic pulse velocity, than the natural coarse aggregate. Furthermore, X-ray diffractometer (XRD) and energy dispersive spectrometer (EDS) microstructure analyses show that the CH content tend to decrease with increasing SSOS aggregate substitution, and the alkaline elements sodium (Na) and potassium (K) dissolve into the mortar and coarse aggregate interfaces. These alkaline reducing agents help improve the concrete durability. Additionally, heavy metals do not leach from the SSOS concrete. Thereby, the SSOS could be considered a green concrete material as it is a recycled resource.

1. Introduction

Stainless steel slag is a byproduct of manufacturing stainless steel from scrap iron. Approximately one ton of stainless steel waste is generated to produce three tons of stainless steel [1]. Stainless steel slag is different from carbon steel electric arc furnace slag [1,2] because the process of making stainless steel requires the addition of ferrochrome and nickel. This waste creates problems not only because of its quantity but also its toxic ingredients, such as chromium, lead, nickel, and cadmium, which pose both occupational and environmental health threats [1,3–8]. Chromium has been reported as the most harmful element in stainless steel waste [9]. The toxicity characteristic leaching procedure (TCLP) [10] results for stainless steel slag from Italy, China and Taiwan concluded that the amount of almost all of the heavy metals recovered via leaching were below the detection limits [1,8,9,11–16]. Therefore, the pollution risks posed by heavy metals from stainless steel slag are very low. 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 [1].

In 2010, stainless steel production reached 1.5 million tons in Taiwan, which created stainless steel slag and the other wastes nearly 0.5 million tons. Therefore, determining how to recycle this slag is very important. This research aims to investigate the use of SSOS as the aggregate in concrete and the engineering properties of this green concrete. This use of SSOS would reduce stainless steel wastes and enhance the economic value of stainless steel slag.

2. Experimental plan

2.1. Experimental material

This study used ASTM C150 type I Portland cement (manufactured by Taiwan Cement Corporation, Taiwan) with a fineness of 3800 cm^2/g and a gravity of 3.15. The mixing water was normal tap water. Stainless steel oxidizing slag (SSOS) was obtained from Lihwa Corp. by crushing before performing magnetic separation followed by sieving which had been placed for more than 6 month in normal weather outdoor. Figs. 1 and 2 show the sieve analysis grading of the SSOS fine aggregate and SSOS coarse aggregate matched ASTM C33. The fineness modulus (F.M.) of the SSOS fine aggregate is 3.00. The gravity of the SSOS aggregate is 2.9.

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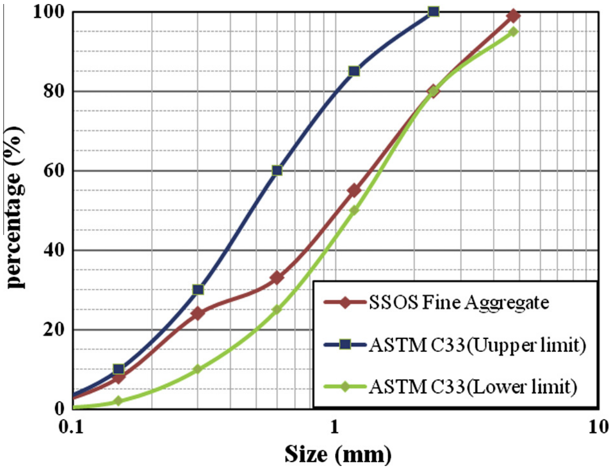

Fig. 1. The sieve analysis grading curve of the SSOS fine aggregate.

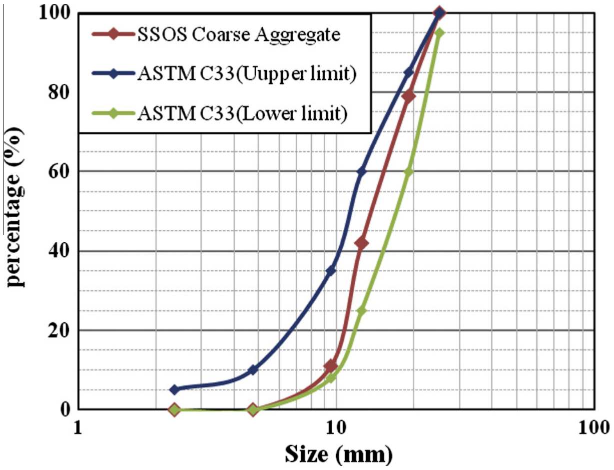

Fig. 2. The sieve analysis grading curve of the SSOS coarse aggregate.

Table 1
Mix design proportion of the SSOS aggregate mortar.

Material		Stainless steel oxidizing slag (SSOS) (9 specimens unit: g)				
		0%	25%	50%	75%	100%
Water-to-binder ratio		0.485	0.485	0.485	0.485	0.485
Cement		740	740	740	740	740
Water		359	359	359	359	359
Fine aggregate	Standard sand	2035	1526	1018	509	0
	SSOS	0	509	1017	1526	2035

2.2. Test variables and mixture proportion

This study was divided into two parts. The first part of the study involved studying the cement mortars according to ASTM C109, with the proportions of cement : fine aggregate = 1:2.75, and a water-to-binder ratio of 0.485 after replacing 0% (control group), 25%, 50%, 75% and 100% by weight of the standard sand with SSOS fine aggregate (Table 1). These specimens were aged 3 days, 7 days and 28 days. The second part of the study studied the concrete compression specimens according to ASTM C192, C39, C617 and ACI method mix design [13,17]. The natural coarse aggregate was replaced with 0% (control group), 25%, 50%, 75% and 100% of the SSOS aggregate by weight (Table 2). These specimens were aged 3 days, 7 days, 28 days, 56 days, 90 days, 120 days, 180 days and 240 days.

2.3. Test items and methods

The compressive strength of the SSOS fine aggregate was tested according to ASTM C109 compressive strength of hydraulic cement mortars, using 50 mm cube specimens, and tested after 3 days, 7 days and 28 days. The compressive strength of the SSOS coarse aggregates was tested according to ASTM C39 compressive strength of cylindrical concrete specimens. A cylinder specimen 100 mm in diameter and 200 mm high was created and tested after 3 days, 7 days, 28 days, 56 days, 90 days, 120 days, 180 days and 240 days. The ASTM C1260 standard was used to detect potential deleterious alkali-silica reactions from the SSOS aggregate in the mortar bars. Ultrasonic detection was performed according to ASTM C597. An ultrasonic instrument was used to transmit ultrasonic pulse waves through the cylinder specimen, and the signals then returned to the pulse wave receiver. As the concrete test blocks aged, they became more compact, and the measured ultrasonic pulse velocity increased [13,17–19]. According to the ASTM C876 standard for surface resistance, the resistivity can be measured using the contact section of the concrete. During this test, the specimen was dry on the outside but saturated on the inside. The concrete surface resistance was based on the concrete density and index of impermeability [13,17,20]. The metal dissolution value for the SSOS was measured using the TCLP test [10]. A scanning electron microscope (SEM) was to analyze the micro crystalline phase of SSOS mortar for different replacements and different ages, and the composition was analyzed by XRD. Furthermore, EDS was used to explore the changes in the interface element analysis of SSOS aggregate and mortar [13,17,21–24].

Table 2
Mix design proportion of the SSOS aggregate cylindrical concrete specimens.

Material		Stainless steel oxidizing slag (SSOS) (unit: g/m^3)				
		0%	25%	50%	75%	100%
Water-to-binder ratio		0.5	0.5	0.5	0.5	0.5
Cement		386	386	386	386	386
Water		193	193	193	193	193
Coarse aggregate	Natural aggregate	1051	788	525	263	0
	SSOS	0	278	556	835	1113
Natural fine aggregate		718	736	754	770	785
Total		2348	2382	2414	2446	2477

3. Results and analysis

3.1. Workability

Fig. 3 shows the flow value of SSOS fine aggregate mortar and Fig. 4 shows the slump of SSOS coarse aggregate concrete. The flow value and slump for the groups of different SSOS aggregate proportions tended to decrease with substitution. This workability reduction is because the surface of the SSOS aggregate is rough and multi-angular; therefore, this shape will increase the friction between the particles of mortar or concrete.

3.2. Compressive strength

As shown in Fig. 5, the SSOS fine aggregate mortars possessed better compressive strengths than the control group after 3 days, 7 days and 28 days. The compressive strength for the different SSOS fine aggregate proportions tended to increase with both the

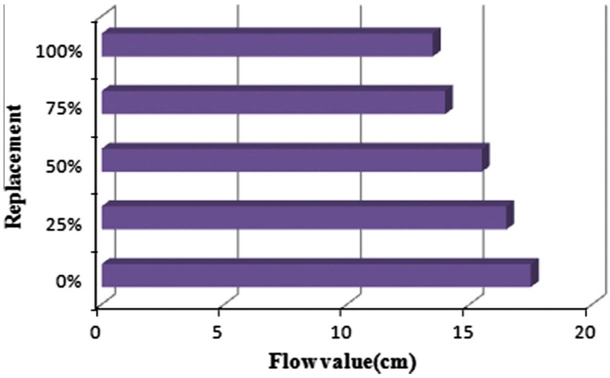

Fig. 3. Flow value of the SSOS fine aggregate mortar.