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%.

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 cm²/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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creates more compact concrete blocks than the natural aggregate [13,17–19].

3.5. Surface resistance

When there is a corrosion risk in a reinforced concrete structure, the resistivity should be above 20 kΩ cm to prevent corroding the reinforcement [13,17]. Fig. 9 indicates the surface resistance of the SSOS aggregate, which had a resistance between 7 and 13 kΩ could not reach the required value of 20 kΩ cm to prevent corrosion [13,17]. This problem results from the experiment following the ACI method mix design from the literature, rather than the traditional ACI mix design, which use a concrete age of 90 days and a resistance value not exceeding 10 kΩ cm [20]. Although the SSOS aggregate concrete could not meet the reinforcement corrosion prevention requirements, the resistance value was still higher than that of the control.

3.6. Metal dissolution test

Table 3 indicates that no heavy metals were dissolved from the SSOS aggregate material or mixed concrete. This result is consistent with those of previous studies [1,8,9,11–16] and suggests that the slag will not affect the environment and can be safely used in concrete engineering materials.

3.7. Microstructure analysis

Fig. 9 shows the SEM images of the SSOS aggregate mortar. The hydration products for the 0% and 100% SSOS aggregate were similar and produce the same hydration product, C–S–H gels and C–A–H crystals (see Fig. 10). The XRD results shown in Fig. 11 indicate that using the SSOS aggregate to replace the standard sand reduces the CH content of the hydration product relative to the control group after 28 days. Consuming the water-soluble CH content reduces the pH of the hydration product and enhances the durability. Table 4 shows the changes in the interface EDS elemental analysis for the SSOS aggregates and mortars. For the 100% SSOS aggregate after 28 days, 90 days and 120 days, the alkaline elements such as Na and K decreased or disappeared relative to the control group. This result occurred because the SSOS aggregates contained dissolved silicon, calcium and aluminum oxide with pozzolanic properties. These dissolved materials combine with alkaline elements, Na and K, to create a gel and reduce the alkaline content.

Table 4

<table>
<thead>
<tr>
<th>Element</th>
<th>Weight (%)</th>
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<tbody>
<tr>
<td>C</td>
<td>9.95</td>
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<tr>
<td>O</td>
<td>50.88</td>
</tr>
<tr>
<td>Na</td>
<td>0.4</td>
</tr>
<tr>
<td>Mg</td>
<td>–</td>
</tr>
<tr>
<td>Al</td>
<td>1.11</td>
</tr>
<tr>
<td>Si</td>
<td>7.33</td>
</tr>
<tr>
<td>K</td>
<td>0.94</td>
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<tr>
<td>Ca</td>
<td>28.82</td>
</tr>
<tr>
<td>Mn</td>
<td>–</td>
</tr>
<tr>
<td>Ti</td>
<td>–</td>
</tr>
<tr>
<td>Fe</td>
<td>0.6</td>
</tr>
<tr>
<td>Totals</td>
<td>100</td>
</tr>
</tbody>
</table>

4. Conclusions

1. The SSOS aggregate surfaces are rough and multi-angular. Such a shape increases the friction between aggregate particles and reduces the mortar flow and concrete slump. In addition, this shape increases and improves the bonding capacity of the aggregate and cement mortar. Replacing the natural aggregate with 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.

2. The expansion of the 100% SSOS aggregate is 0.05% less than that of the 0.20% requirement, which indicates the material were generally innocuous. These results show that the SSOS aggregate expresses a decreased alkali reactivity potential relative to the natural aggregate.

3. The SSOS aggregate concrete surface resistance values were between 7 and 13 kΩ cm. Although the resistance value for the SSOS aggregate concrete could not meet the 20 kΩ cm required to prevent the corrosion of the reinforcement, the value was still higher than that of the control group.

4. No heavy metals leach from the SSOS aggregate material or mixed concrete occurred. This finding suggests that the slag will not influence the environment and can be used as a concrete engineering material.

5. The SEM microstructure analysis of the 0% and 100% SSOS aggregate mortars are similar. The same hydration products, C–S–H gels and C–A–H crystals, are produced. Furthermore, the durability of the SSOS aggregate concrete is enhanced because the CH content of the hydration products and both the Na and K alkaline contents are lower.

6. This study shows that the optimal aggregate replacement ratio for SSOS is 100%. Therefore, stainless steel oxidizing slag may qualify as an aggregate for green concrete materials. This practice will reduce stainless steel slag wastes, and will contribute to recycling and environmental protection.

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References


