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The effect of particle sizes of steel slag as cement replacement in high strength concrete under elevated temperatures

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ABSTRACT

This study investigates the impact of utilizing steel slag (SS) as a partial substitute for cement in high strength concrete (HSC) under high temperatures covering a range from 200 °C to 800 °C over a duration of 2 h. Two particle sizes of SS: 75 μm and 150 μm, were utilized as fine steel slag (FSS) and coarse steel slag (CSS). This study evaluates several physicochemical and compressive strengths of the HSC. After conducting the compressive strength, both residual compressive strength (RCS) and relative residual compressive strength (RRCS) were calculated. Scanning electron microscopy (SEM), Thermogravimetric analysis (TGA), and X-Ray Diffraction (XRD) analysis were carried out to analyze the physicochemical properties of HSC before and after subjected to elevated temperatures. The findings indicate an increase in the RCS of all specimens up to 400 °C. The replacement of FSS for cement enhances the compressive strength of HSC at ambient temperature, and FSS performs better than CSS up to 200 °C. However, beyond 400 °C, CSS exhibits a superior RRCS compared to FSS. XRD analysis confirms mineralogical changes in the HSC after exposure to fire, including the decomposition of C-S-H gel and the conversion of calcium hydroxide into calcium carbonate. The present study suggests that incorporating CSS in HSC has the potential to enhance its performance under high temperature conditions.

1. Introduction

Steel slag (SS) is a byproduct formed in the process of transforming raw iron into crude steel. Approximately 0.2 tons of SS are produced for every ton of crude steel manufactured [1]. The increasing production of crude steel has led to a significant accumulation of SS, posing challenges for its disposal. Conventional methods such as landfilling and incineration have been associated with environmental issues, including the leaching of heavy metals and toxic substances [2–4]. In recent times, there has been an increasing focus on seeking sustainable and environmentally friendly approaches for the management of SS. One of the promising alternatives is to utilize SS as a substitution for cement in concrete [5,6]. Researchers have found that SS possesses chemical and mineralogical properties that contribute to its cementitious nature [7–9]. Specifically, SS is composed of several phases that are similar to cement, including tricalcium silicate (C_3S), dicalcium silicate (C_2S), dodecacalcium hepta-aluminate ($C_{12}A_7$), tetra-calcium aluminoferrite (C_4AF), dicalcium ferrite (C_2F), RO-phase (MgO-FeO-MnO solid solution), Fe_3O_4, and free calcium oxide, which is similar with cement composition to exhibit a common cementitious performance when mixing with water [10–12]. Roslan et al. [13] studied the impact of different SS replacement ratios (5%, 10%, 15%, and 20%) in concrete. The study revealed that compressive strength experienced an initial decline at 5%, followed by an increase at 10%, while a further decrease of strength is observed after 10% as compared to control specimens. The study attributed that the higher value of silica and calcium oxides in SS to its significant pozzolanic activity. Moreover, the hydrated products, specifically the calcium silicate hydrate (C-S-H) gel, derived from SS, improved the density of concrete, thereby increasing its strength. However, the further addition of SS that decreased the compressive strength of concrete is owed to the dilution of C_3S and C_2S in concrete which are primarily responsible for strength [14].

To optimize the performance of concrete that incorporates SS as a cement replacement, researchers have investigated the effect of different SS particle sizes [15–17]. Mechanical grinding of SS has been shown to enhance its performance in concrete [18–20]. Wang et al. [21] conducted a study to examine the influence of particle size of SS on the compressive strength of concrete. The study found that concrete incorporating fine SS particles (particle size <0.1 mm) achieved approximately 19% greater compressive strength than those with coarse SS

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