

ABSTRACT

Over 4 billion tons of cement is produced globally each year, resulting in approximately 0.95 tons of carbon dioxide (CO₂) per ton of cement produced. Over the years pozzolanic waste material has played a significant role in the construction industry as a partial replacement of Portland cement (PC) and other building materials. It seems likely that the greatest CO₂ reduction from the cement industry can be attained by the inclusion of these materials. This study considered the use of incinerated sewage sludge ash (ISSA) as a partial pozzolanic replacement of cement. The aim of this work was to evaluate the pozzolanicity of ISSA and its effect on the hydration and performance of Portland cement products. Dried sewage sludge (DSS) was incinerated at 700°C, 800°C and 900°C to produce ISSA and cooled in the furnace (FISSA), air (A_{ISSA}) and in water (Q_{ISSA}) to study the effect of the incineration temperature and cooling rate on its performance.

Characterization of the ISSA was executed using scanning electron microscopy (SEM) equipped with energy dispersive spectroscopy (EDS), X-Ray Fluorescence (XRF), atomic absorption spectroscopy (AA) and a Malvern Mastersizer for particle size analysis to determine its feasibility as a partial replacement of Portland cement. Cement paste samples were prepared using 30% ISSA to replace PC and compared to a 100% PC mix as the primary reference sample and a mix of 30% coal fly ash and 70% PC as a secondary reference mix. All mixtures were prepared using a water/binder (w/b) ratio of 0.45 and used to study the pozzolanicity of ISSA after 6 hours, 7 days and 28 days of hydration. A SEM was used to study the hydration mechanism of ISSA and thermogravimetric analysis (TGA) to obtain the mass loss rate, calcium hydroxide (Ca(OH)₂) content and chemically combined water (H₂O_{Q.comb}). Mortar samples were also prepared at a PC replacement level of 30% and w/b ratio of 0.50 to study the effect of ISSA on the workability and compressive strength of PC mortar after 3, 7 and 28 days of hydration.

The chemical composition results of DSS/ISSA showed the presence of cementitious compounds and elements (Ca/CaO, Si/SiO₂, Fe/Fe₂O₃, Al/Al₂O₃, etc). These results suggested that ISSA could be used as a partial replacement of PC. The analysis showed that the concentrations of these elements/compounds were increased after incineration. In addition, a majority of the compounds showed an increase in concentration with an increase in incineration

temperature, while the concentrations of elements of the ISSA varied with the different cooling methods.

Particle size analysis showed that ISSA particles were the largest in size compared to the particle sizes of PC and FA. These results were correlated with the SEM micrographs in which an irregular and amorphous morphology of ISSA was observed.

TGA results of cement pastes showed that cement pastes containing ISSA incinerated at 900°C had a considerable reduction in Ca(OH)_2 after 28 days of hydration suggesting that effective pozzolanic reactions took place. The $\text{H}_2\text{O}_{\text{Q,comb}}$ content varied with each sample. Quenched ISSA incinerated at 900°C showed better compatibility in the paste with the highest Ca(OH)_2 content and reduction of Ca(OH)_2 after 28 days of hydration. In general, an increase in the Ca(OH)_2 content was observed with an increase in the incineration temperature of ISSA. An increase of Ca(OH)_2 content in the order $F_{\text{ISSA}} < A_{\text{ISSA}} < Q_{\text{ISSA}}$ of the cooling rate of ISSA's was also observed. SEM analysis also showed that pastes containing ISSA had hydration products such as Ca(OH)_2 , ettringite and calcium silicate hydrates (C-S-H), evidently developed after 6 hours and 7 days of hydration. However, due to the reduced amount of PC in the samples, the hydration was evidently slower compared to the reference sample, meaning that the ISSA pastes developed less heat during their hydration.

A reduction in mortar workability was obtained with the displacement of 30% PC by ISSA. This result was expected due to the irregular morphology of ISSA that reduced the flow of the mortar. A reduction in compressive strength was also obtained with the addition of 30% ISSA in PC mortar. These results were expected due to the reduced reactivity of ISSA compared to PC thus resulting in reduced compressive strength. The compressive strength results showed an increase with an increase in the incineration temperature of ISSA from 700°C to 900°C. The highest compressive strength on the ISSA blended mortars was that of sample MS9Q (70% PC and 30% quenched ISSA incinerated at 900°C) with a compressive strength reduction percentage of 20.1%.

Although FA is generally considered to have higher pozzolanicity than ISSA, the compressive strengths obtained for ISSA blended mortars were comparable to that of MFA30 (FA blended mortar) and even slightly higher for sample MS9Q. The quenched ISSA generally showed better performance, establishing the lowest compressive strength reduction at all ages compared to furnace and air cooled ISSA's. To add to this, the rate of increase in compressive

strength of MS9Q over time was higher than that of MFA30 and also higher than MC100 (reference sample). This result suggests that it is possible to achieve enhanced or even high compressive strength at later stages on mortar samples containing 30% ISSA with reduced PC content. In conclusion the highest cooling rate and the highest incineration temperature of 900°C reduced the weakening effect of ISSA related to its low cementing properties compared to PC, and were regarded as the best methods to be considered when preparing ISSA for partial replacement in cement products.