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Recovery of Sewage Sludge Incinerator Ash by Geopolymerization

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Abstract

Purpose
Incineration is a common disposal method for sludge management. Sludge ash is an unavoidable by-product of the incineration process that needs to be managed in an environmentally friendly way. The purpose of this study was to investigate the recovery potential of sludge ash, which is generated from the incineration of sewage sludge in a fluidized bed type reactor under 850^{o}C.

Methods
Geopolymerization technology was applied to this aim. Sludge ash was combined with cement, fly ash, and marble sludge in different combinations to prepare paste samples without aggregate. NaSilNaOH solution was used as an alkaline activator for geopolymerization. Samples were analyzed for unconfined compressive strength (UCS) after 28 days of air cure.

Results
UCS results of the samples showed that sludge incinerator fly ashes have the potential to be used as supplementary cementitious material in geopolymerization towards obtaining construction materials. An optimum formulation can be obtained for the intended use. Sludge ash was also found to show non-hazardous waste character after being analyzed for the leaching of heavy metals with eluate (EN 12457) solution, which confirms a potential to be safely used in terms of heavy metals.

Conclusions
The UCS and leaching results were found to be promising by the authors for the possible usage of sludge ash after geopolymerization.

Keywords

Keywords: construction material, stabilization, solidification, TCLP, eluate, compressive strength

Introduction

The amount of wastewater treatment plant (WWTP) sludge increases every year due to increasing populations. Incineration has gained as a common disposal method in sludge management, recently. Although the volume of the sludge decreases considerably during incineration, large volumes of ashes are generated as a result.

The sludge originated from the municipal wastewater treatment plants of Bursa city are incinerated at a fluidized bed reactor type plant. The plant can incinerate a sludge rate of 400 tons/day and produces 15-20 tons/day fly ash. The sludge ash generated is landfilled at the municipal landfill site of the city. However, this is not a sustainable solution to the everyday increasing sludge ash problem, which decreases the life of the landfill site that should be dedicated to the unavoidable municipal waste only. There is a need to find a sustainable management strategy for the ashes generated by the incinerator plant. This study is an attempt to offer a recovery strategy for the sewage sludge incinerator ashes.

Geopolymerization is an emerging technology for the recovery of several by-products such as fly ash and the immobilization of toxic metals in waste [1,2]. The reaction of a solid aluminosilicate with a concentrated alkali hydroxide or silicate solution produces a synthetic alkali-aluminosilicate material called geopolymer [3,4]. Geopolymers exhibit several physical and chemical properties that can lead them to perform comparably to traditional cementitious binders [5,6]. Generally, fly ashes from coal-fired power plants are used as precursors of geopolymerization [7]. Sludge incinerator fly ash was used as geopolymer precursor in this study.

Several researchers investigated the feasibility of sludge ash use in cement mortar and showed that it has the potential to be used as supplementary cementitious material [8-16]. However, none of the studies reported on the geopolymerization of sludge ash to the best of our knowledge. This study aims to investigate the potential of the sludge ash as a precursor for geopolymers and its use as a construction material.

Materials & Methods

Sludge ash was obtained from the multi-cyclone outlet of the incinerator plant. Sludge ash was combined with cement, fly ash, and marble sludge in different combinations to prepare paste samples without aggregate. Chemical compositions of the sludge ash and the materials used are given in Table 1.

Table 1 Chemical compositions of the materials and wastes used in the experiments

Component	Unit	Cement	Fly Ash	Marble Sludge	Sludge Ash (multi-cyclone outlet)
SiO_2	%	33.75	54.99	0.7	28.53
Al_2O_3	%	9.47	19.06	0.22	7.34
Fe_2O_3	%	4.86	11.69	0.13	4.71
CaO	%	40.35	2.06	45.6	27.48
MgO	%	1.62	2.68	6.82	4.52
SO_3	%	2.72	0.75	0.12	5.47
Na_2O	%	0.79	0.99	0.1	1.1
K_2O	%	1.22	2.13	0.03	2.76

Sludge ash was also analyzed for the leaching of heavy metals with eluate (EN 12457) solution to determine if it has hazardous nature. Heavy metal leaching results after the leaching test EN12457 are given in Table 2. NaSilNaOH solution was used as an alkaline activator for geopolymerization. Stabilization/solidification products, which relied upon cement hydration reactions, were also prepared by using water instead of NaSilNaOH solution. Samples were analyzed for unconfined compressive strength (UCS) after 28 days of air cure. The contents of the samples are given in Table 3.

Table 2 Heavy metal leaching from the sludge ash used after leaching test EN12457

Parameter	Level measured in sludge ash from the multi-cyclone outlet, mg/L
Silver (Ag)	<0.003
Aluminum (Al)	0.053
Arsenic (As)	<0.012
Boron (B)	0.030
Cadmium (Cd)	<0.003
Total Chromium (Cr)	1.629
Copper (Cu)	<0.003
Total Ferrous (Fe)	<0.004
Manganese (Mn)	<0.005
Nickel (Ni)	<0.005
Lead (Pb)	<0.012
Antimony (Sb)	0.018
Tin (Sn)	<0.009
Zinc (Zn)	0.052
Selenium (Se)	0.026
Total Phosphorus (TP)	<0.012

Table 3 The content of the samples prepared

Cement	Fly ash	Sludge Ash	Marble Sludge	Activator
100%				Water
10%	30%	30%	30%	Water
40%		30%	30%	Water
40%	30%		30%	Water
70%			30%	Water
40%	30%	30%		Water
70%		30%		Water
70%	30%			Water
100%				NaSilNaOH
10%	30%	30%	30%	NaSilNaOH
40%		30%	30%	NaSilNaOH
40%	30%		30%	NaSilNaOH
70%			30%	NaSilNaOH
40%	30%	30%		NaSilNaOH
70%		30%		NaSilNaOH
70%	30%			NaSilNaOH

Results & Discussion

Fig. 1 shows the influence of the components on the unconfined compressive strength (UCS) of the paste samples prepared by using sludge ash, marble sludge, fly ash from the coal-fired power plant and Portland cement. It can be inferred from the figure that combined influence of the parameters (components of the matrix) was significant. For example, UCS level decreased when fly ash was combined with sludge ash. However, when this combination was united with marble sludge, the UCS was positively affected. It is clear that the existence of the activator solution NaSilNaOH increased the UCS level.

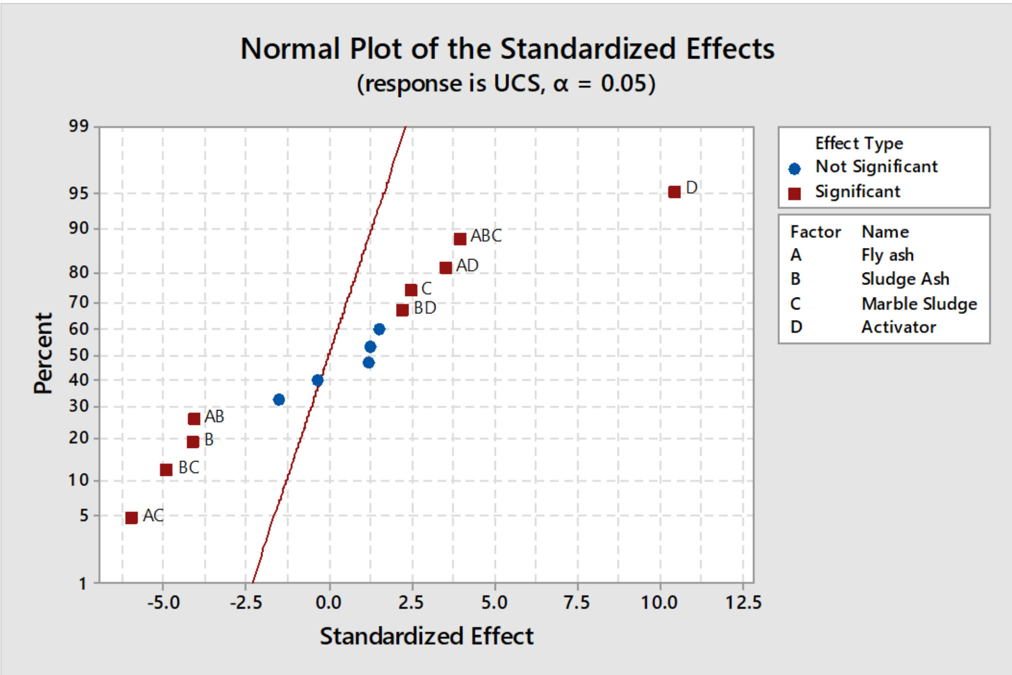

Fig. 1 Normal plot for the effects on unconfined compressive strength (UCS) levels of the samples

Synergistic and antagonistic effects of two components are given in the interaction plots in Fig. 2. The interaction effect in Fig. 2 indicates that the relationship between sludge ash and UCS depends on the existence of marble sludge or fly ash. For example, if sludge ash was used with marble sludge, the UCS decreases. Similarly, if fly ash was used with sludge ash, the UCS decreases. Interaction occurs between the pairs fly ash & sludge ash, fly ash & marble sludge, sludge ash & marble sludge.

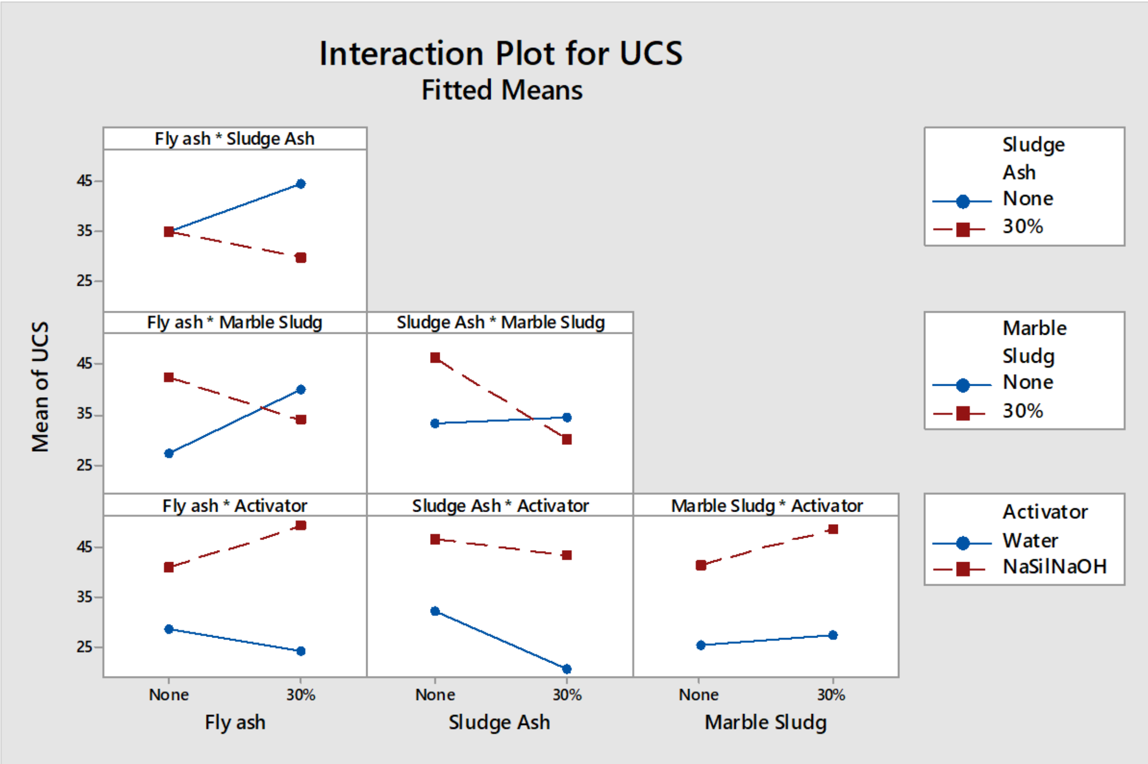

Fig. 2 Interaction plot for the waste types introduced to the samples for unconfined compressive strength (UCS) levels

Fig. 3 shows the main effects on the UCS levels. It can be inferred from the figures that fly ash, and marble sludge had a positive; sludge ash had a negative influence over the UCS of the samples. Geopolymer samples that were prepared by using NaSilNaOH solution (activator) had a higher UCS value than the stabilization/solidification samples prepared with water.

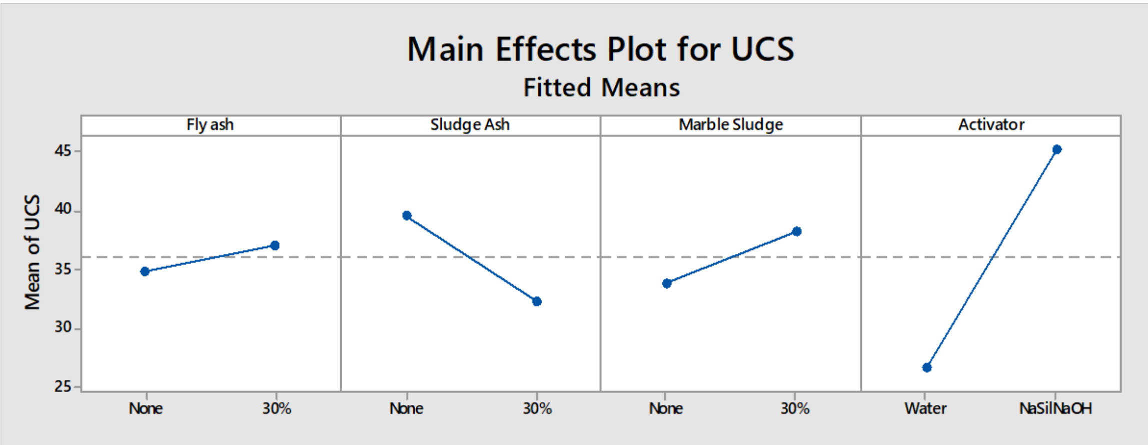

Fig. 3 Main effects plot for the effects on unconfined compressive strength (UCS) levels of the samples

Fig. 4 compares the UCS levels of the S/S and geopolymer samples prepared. It is clear from the figure that all the geopolymer samples yielded higher UCS results than that of S/S samples. In Geopolymer samples, highest results were obtained with the combinations of CEM+FA, followed by CEM+MS, CEM+FA+MS, CEM+FA+SA, and CEM+SA+MS, UCS levels varying between 58.60 MPa and 45.45 MPa. It can be seen that although sludge ash negatively affects the UCS, it still can yield a high level of UCS such as 46.70 MPa for the sample containing CEM+FA+SA, and UCS level of 45.45 MPa for the sample containing CEM+SA+MS. The negative influence of sludge ash content can be balanced by using other wastes such as fly ash or marble sludge.

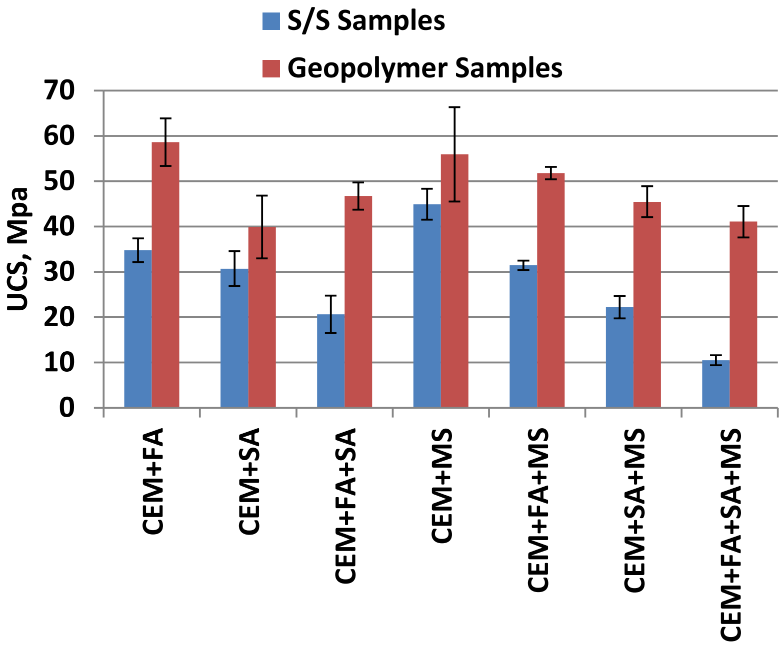

Fig. 4 UCS levels of the S/S and geopolymer samples prepared (CEM: Portland cement, SA: sludge ash, FA: fly ash, MS: marble sludge)

A comparison of the UCS levels of the geopolymer samples prepared with or without cement is shown in Fig. 5. It is clear from the figure that the geopolymer samples prepared by using cement as a component resulted in higher UCS levels than those prepared without using cement. When the UCS levels of sludge ash containing samples which were prepared without cement were compared, it can be seen that the highest results were obtained when sludge ash was combined with fly ash and marble sludge. The UCS level of this sample was 40.56 MPa. The UCS level of this sample, which does not contain cement, implies that it is possible to obtain high UCS levels without using cement that has a high carbon footprint. The components of this sample were only the waste materials that should be managed individually. Therefore, this initial study shows promising results to use sludge ash as a construction material.

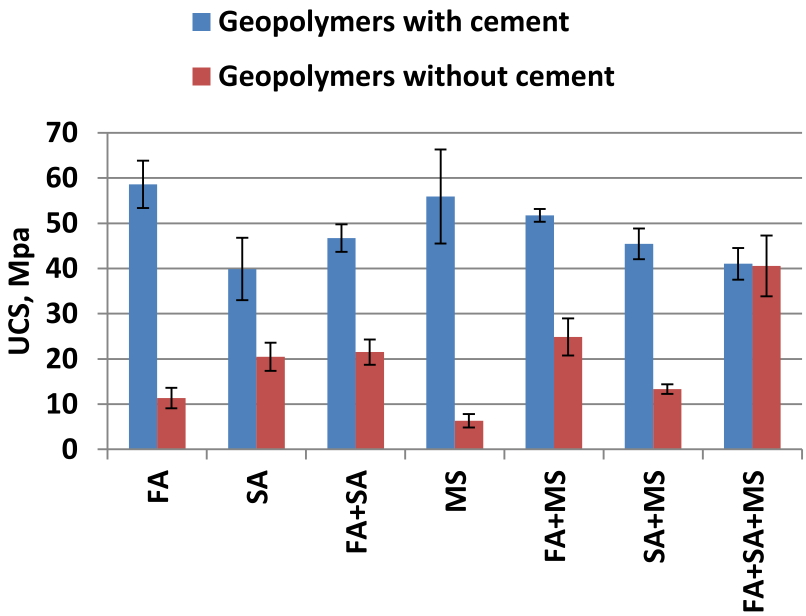

Fig. 5 UCS levels of the geopolymer samples prepared with or without cement (CEM: Portland cement, SA: sludge ash, FA: fly ash, MS: marble sludge)

Conclusions

Geopolymer and S/S samples were prepared with incinerator sludge ash by combining it with cement, fly ash and marble sludge in different combinations. Following conclusions can be drawn from the study:

- Fly ash and marble sludge had a positive; sludge ash had a negative influence over the UCS of the samples. However, the combined influences of the components of the matrix were found to be significant on the UCS levels. For example combined influence of sludge ash, fly ash, and marble sludge was found to be positive although the influence of sludge ash alone was negative.
- Geopolymer samples that were prepared by using NaSilNaOH solution (activator) had a higher UCS value than the S/S samples prepared with water.
- High UCS levels were obtained when sludge ash was combined with other components, such as 46.70 MPa for the sample containing CEM+FA+SA, and 45.45 MPa for the sample containing CEM+SA+MS.
- Among the sludge ash containing samples which were prepared without cement, highest results were obtained when sludge ash was combined with fly ash and marble sludge. The UCS level of this sample without cement was 40.56 MPa. The components of this sample were only the waste materials that should be managed individually and have a lower carbon footprint than that of cement.
- The results of this study showed that sludge incinerator fly ashes have the potential to be used as a supplementary cementitious material in geopolymerization towards obtaining construction materials. An optimum formulation can be obtained for the intended use.
- Heavy metals leaching results also confirmed that sludge ash does not possess any problem in terms of toxicity characteristics leaching.

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