POZZOLANIC CHARACTERISTICS OF MUNICIPAL SOLID WASTE ASH

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Abstract
Earth as a building material has been used over the years in the construction industry. However its strength characteristics have been inadequate. Therefore, stabilizers are used to enhance its strength. Where conventional stabilizing agents like cement and lime have been used, they have considerably increased the cost of construction. It is with this backdrop that this paper describes the pozzolanic characteristics of municipal solid waste ash (MSWA) and its use as a stabilizing agent. The total elemental concentration in the MSWA was determined by use of Total X-ray Florescence method, while the laser particle analysis method was used to determine the particle size distribution of the ash. X-ray Diffractometer method was used to measure the level of molecular compounds including the oxides of silicon, aluminium and iron. The Total X-Ray Florescence (TXRF) analysis indicated that the ash contained high levels of calcium (220,240 mg/kg) and mercury (23.76 mg/kg). According to the Canadian Public Health guidelines, this concentration of mercury exceeded the acceptable limit of 23 mg/kg. Calcite was the main oxide (57.6%) with its glass halos occurring between 20° to 50° two-theta. The total amounts of SiO_2, Al_2O_3, and Fe_2O_3 were less than 70%, categorising the ash as Class F pozzolana meaning that MSWA was not self-cementing. Laser diffraction particle size analysis showed that the ash was mainly composed of particles finer than 0.002 mm (55.82%), with its probability distribution function depicting a bimodal curve. The municipal solid waste (MSW) had a high loss of ignition (83.49%), an indication that it contained high amounts of un-burnt carbon. Despite the low quartz (SiO_2) content as compared to that of pozzolana cement, MSWA had high calcite ($CaCO_3$) content enabling it to contribute to bonding effect of the ash. From the study, it is recommended that MSWA has to be used as a bonding agent and not as a cementing ash. Also the ash has to be finely ground prior to use as a pozzolanic material in soil stabilization, so as to increase both its filler and bonding effect.

Key words: bonding effect, municipal solid waste ash (MSWA), pozzolana

1.0 Introduction

Construction activities in Kenya consume a large amount of resources and contribute to environmental pollution. Building bricks take a significant proportion of the total construction cost and baking of earth bricks contributes significantly to air pollution. Therefore, development of strategies to reduce the cost of bricks and alleviate the environmental impact of brick production would significantly contribute towards a sustainable construction industry. Waste recycling has potential to contribute towards a cleaner environment and cost reduction. However, waste recycling rates are still too low. In Houston, USA, only 2.6% of solid waste is recycled (Srour *et al*, 2010).

Addition of cement to earth during brick making could enhance stabilization and avoid baking of brick. Among the compounds in Ordinary Portland Cement (OPC) are SiO_2, Al_2O_3, Fe_2O_3, CaO, MgO, SO_3, Na_2O, K_2O, TiO_2, and P_2O_5. Some of these compounds give pozzolanic characteristic, enable cementing effects and help to increase chemical resistance to sulfate attack and reduce thermal expansion. Amin, *et al*. (2012) found that a mixture of 70% OPC and 30% backed clay powder improved the compressive strength of concrete. Pozzolanas are fine silica and alumina rich materials which when mixed with reactive soils produce cementitious materials suitable for stabilization and construction needs. Pozzolana stabilization is not difficult to carry out and it is cheap since the materials can be locally sourced.

The bottom ash obtained after incineration of municipal solid waste has been found to have pozzolanic characteristics which would be beneficial in the stabilization of soils (Berg and Neal, 1998; Lin *et al*, 2003). With increasing population, urbanization and rising standards of living, there has been increased generation of solid wastes from industrial, domestic and agricultural sources (Safiuddin *et al*, 2010). Recycling of these wastes in soil stabilization might potentially reduce construction costs and enhance environmental sustainability.

The per capita rate of solid waste production in Nairobi and Kiambu Counties has been estimated at 1.5 kg/capita/day (Kaluli, *et al*, 2011). In Nairobi County only a third of the generated MSW, approximately 2000 tonnes, is collected for disposal daily and 68% of this waste is from non-industrial sources (UNEP, 2005) and can be recycled without serious environmental impacts. The cost associated with the management and disposal of municipal solid waste is high and should be lowered (Barbieri *et al*, 2002). In Nairobi County, there exists only one dumpsite in the Eastern part of the City and this makes transportation a major expense in solid waste management (Kaluli, *et al*, 2010). Some of the waste disposed of in the dumpsites could be recycled. However, like in the rest of the world, solid waste recycling is not well developed in Kenya.

Incineration significantly reduces the volume of MSW to be disposed. The bottom ash obtained after incineration consists of fine particles of combustible organic matter, unburned municipal solid waste and palletized plastic slag Mohammed (2009). It is referred to as municipal solid waste ash (MSWA) and can be used for partial replacement of cement as a pozzolanic material. The compressive strength of concrete mixture containing 10% MSWA has been found to be higher compared to ordinary concrete (Tay and Cheong, 1991). The predominant chemical constituents of MSWA are lime, silicates and aluminates, all of which are also found in Ordinary Portland Cement. The bottom ash also contains chlorides and sulphates (Berg and Neal, 1998; Lin *et al*, 2003). Prashant (2009) tested the engineering properties of blocks stabilized with screened MSWA and found them to have compressive strength in the range of 3 - 6.2 N/mm^2. Increased strength was associated with the pozzolanic reactions introduced by the ash (Prashant, 2009).

The aim of this paper was to establish the quantities of pozzolanic constituents in the municipal solid waste ash in order to develop an alternative soil stabilizing agent that is cost effective and ecologically sustainable. The use of MSWA as construction and building material will convert the waste into useful products that can alleviate the challenges associated with solid waste disposal.

2.0 Materials and Methods

2.1 Preparation of MSW Ash

A 6 kg sample of municipal solid waste was collected from Jomo Kenyatta University of Agriculture and Technology, dump site. The municipal solid waste was incinerated in a kiln that allowed the generated gases to pass through a water bath and avoid air pollution. MSW experienced loss on ignition of about 83.5% and 0.99 kg of ash was collected at the bottom of the kiln. The ash was then screened through a 0.3 mm sieve to remove un-burnt MSW, ceramics and broken glasses. The ash was further ground using a micro-milling machine to particle sizes less than 0.075 mm.

2.2 Determination of Element Concentration

The Total X-ray Fluorescence (TXRF) spectrometer S2 PICOFOX with a Mo-anode target method was used to determine the concentration of various elements in the MSWA. The sample carrier used had 24 slots. The TXRF spectra were recorded by depositing the samples on quartz sample supports. Some 45 mg samples (in triplicate) were weighed and placed in vials, and 25 ml of 1% concentrated triton was added as a solvent to the samples. An internal standard solution of 40 µl concentrated selenium was also added to aid in standardisation. The samples were thoroughly mixed to acquire homogeneity and break any clods that formed. Ash samples were thoroughly mixed before pippeting while ash-water samples were first centrifuged. For the deposition of the sample, 10 µl volume of the sample solution was put on a flat, highly polished sample carrier to be scanned in the TXRF machine. The concentrations of different elements were measured after evaluating the X-ray intensities at the given wavelengths of the elements in the TXRF machine recorded as electronic signals.

2.3 Particle Size Analysis of MSWA

The particle size distribution analysis for the ash samples was determined using laser diffraction spectrometry method in a laser diffractometer. The analysis was performed in triplicate of each sub-sample with water as a dispersing agent in the wet method and air as a dispersing agent in the dry method. The dried ash samples were placed in the laser diffraction machine and subjected to dispersion energy in presence of a suspension medium. The ash particle sizes were determined from the intensity of the scattered light by the particles in suspension due to their different refractive indices.

2.4 Determination of the Molecular Composition of MSWA

The D2 PHASER portable XRD machine was used in determining the molecular composition of MSWA. The DIFFRAC.EVA computer program was used in phase identification of the samples and in scaling the patterns from the databases to measurable intensities. Ash samples (3 – 4 g) were weighed and ethanol added before grinding them further in a micronizing mill. The suspension was then placed in a vial and centrifuged for 10 minutes. The liquid was decanted and the residue dried in an oven. After drying, the residue was sieved through a 325 μm sieve for scanning in the X-ray diffractometer (XRD) machine. On excitation by the X-rays, the ash produced diffraction peaks of varying frequency as they were scanned in the XRD machine. The X-rays emission spectra peaks were used to identify the different molecules in the samples.

3.0 Results and Discussion

The bottom ash was made up of different types of amorphous particles. In addition to the fine particles of combustible organic matter, unburned municipal solid waste and palletized plastic slag were also present (Figure 1). The colour of the ash ranged from grey to black, depending on the amount of unburned carbon in the ash. The dry lumps possess cohesion, but could be powdered easily in the finger.

Figure 1: Municipal solid waste ash

The mechanical properties of bottom ash are expressed in terms of particle sizes. As shown in Figure 2, the bottom ash was generally well graded, ranging from mostly clay to silt sizes. The finer particles of size less than 0.002 mm represented the largest component (55.8%) of the MSWA (Table 1). The high percentage of fine particles indicates that the ash has a high plasticity index. The particle size distribution followed a bimodal frequency pattern. This kind of particle size distribution was probably due to the varied composition of MSW (Linda *et al*, 2005). Since over 50% the bottom had particle size less than 0.002 mm, there likely was considerable amount of pozzolanic material in the ash. In Indiana, USA, most coal-fired utility plants produce class F fly ash and bottom ash with a typical production ratio of 80% fly ash and 20% bottom ash, and most of them are usually disposed of together as a waste in utility disposal sites (Kim *et al*, 2005).

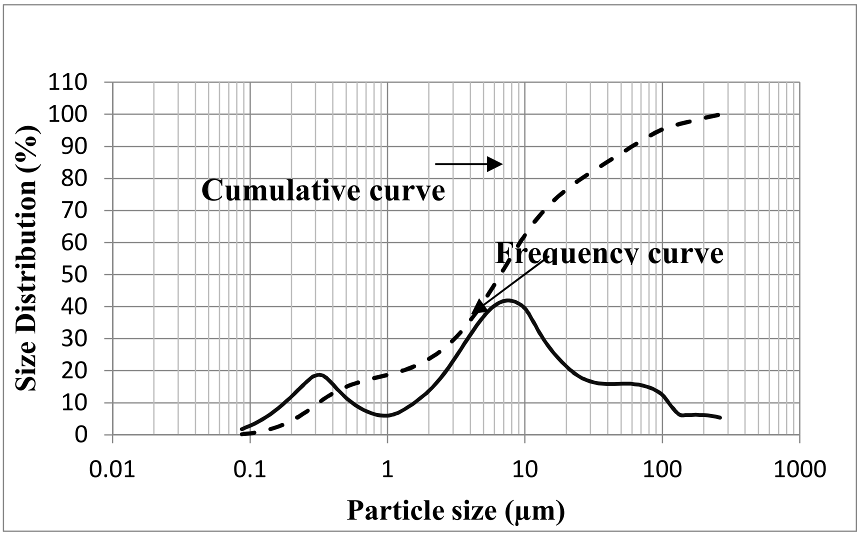

Figure 2: Size distribution MSWA particles

Table 1: Fractions of clay, silt, and sand of MSWA

Particle size (mm)	Quantity (%)
$\leq$ 0.002	55.8
0.002-0.063	32.1
0.063 - 2 mm	12.1

3.1 Chemical characterisation of MSWA

The concentration of sulphur and mercury exceeded the maximum allowable levels in agricultural soil (Table 2). The concentration range of mercury (22.99 – 24.50 mg/kg) slightly exceeded the maximum allowable amount of 23 mg/kg (Table 2) in soil, as prescribed in the Canadian Environmental Guidelines (1999). From the point of view of mercury, the MSWA should not be dumped on agricultural land.

Other elements of environmental concern such as chromium (Cr) and lead (Pb), were significantly within the allowable limits. The source of mercury in JKUAT solid waste could include laboratories, vehicle repair workshops and the paints and other chemicals in construction sites. As shown in Table 2, the ash had a high concentration of calcium (206785.50 - 233695 mg/kg), with lower levels of copper (84.91 – 93.32 mg/kg), zinc (311 – 339.72 mg/kg), and lead (326.59 – 378.65 mg/kg) all of which were within the maximum allowable concentrations in soil (ATSDR, 1992). The maximum allowable concentrations of chemical elements of soils were used to compare with those of the ash since they are classified in the same group.

Table 2: Element concentration of bottom municipal solid waste ash from JKUAT

Mineral element	**Concentration range (mg/kg)**	**Max concentration allowed in soil (mg/kg) (Canadian Environmental Guidelines, 1999)**
Mg	7713.35 – 10579.98	-
Al	10778.23 – 12086.52	-
P	524.24 – 773.52	-
S	222.46 – 500.94	500
Cl	26265.80 – 30381.94	-
K	3131.89 – 3211.82	-
Ca	206785.50 – 233695.00	-
Sc	28.38 – 112.54	-
Ti	4466.00 – 4971.43	-
V	6.52 – 10.93	250
Cr	77.76 – 81.45	500
Mn	309.44 – 340.41	1500
Fe	10309.68 – 11031.71	40000
Co	33.85 – 37.25	100
Ni	60.14 – 68.55	500
Cu	84.91 – 93.32	190
Zn	311.00 – 339.72	600
Ga	0.04 – 0.35	-
Hg	22.99 – 24.50	23
Pb	326.59 – 378.65	400

The ash had its glass halos (peaks) occurring between 20° and 50° two-theta (Figure 3). It contained a large variety of crystalline phases and significant levels of silica. The main components of bottom ash were calcite, quartz and microcline, with minor proportions of feldspar (Figure 3).

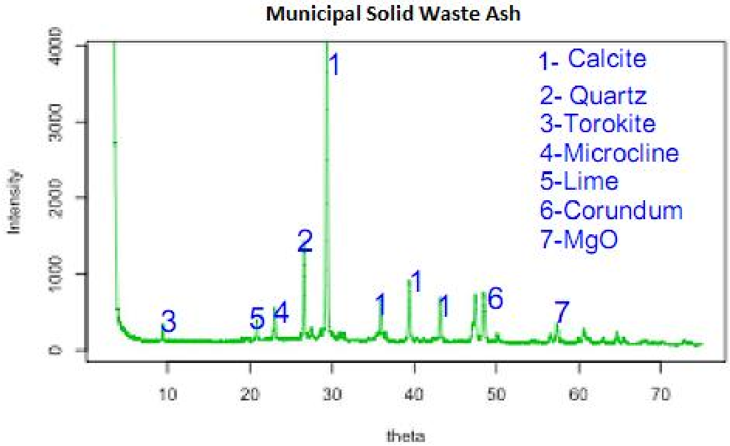

Figure 3: X-ray diffractogram for MSWA

The classification of ash into classes F, C and others is done on the basis of the chemical composition of the ash. The sum total of SiO_2, Al_2O_3, and Fe_2O_3 in MSWA used in this study was less than 70% of the whole sample. Therefore, according to the ASTM C 618, 2003, the ash qualifies for classification as Class F pozzolana. The ash had high amounts of calcite (57.6%) in the form of calcium carbonates and quartz (14.1%) in the form of silicon dioxide. Therefore, when the ash is used in the soil stabilization, the calcium carbonate will initiate bonding of the soil particles thereby increasing the compressive strength of the soil. While Ordinary Portland Cement has about 2.7% sulphates, MSWA did not have any (Table 3). The presence of sulphates in stabilizing agents has been associated with accelerated corrosion of stabilizing bars once present (Neville, 2009). Therefore, the absence of sulphates in MSWA makes it not to contribute to sulphate attack when used in stabilizing soil elements.

Table 3: Chemical composition of Ordinary Portland Cement (OPC) and MSWA

	Chemical composition (%)	
Mineral	**OPC***	**MSWA**
SiO_2	20.9	14.1
Al_2O_3	4.76	2.0
Fe_2O_3	3.41	1.6
CaO	65.41	3.9
MgO	1.25	4.4

$CaCO_3$	-	57.6
$KAlSi_3O_8$	-	13.2
SO_3	2.71	-
$SiO_2 + Al_2O_3 + Fe_2O_3$	-	17.7

Source: Neville, A.M., (2009). Properties of Concrete, 4th edition. Pg 6

The presence of calcium oxide in Ordinary Portland Cement gives it the self-cementing property. In this study it was found out that MSWA had low calcium oxide content (3.9%) as compared to that of OPC. It is therefore expected that MSWA will not initiate self cementing when used as a stabilizer. On the other hand, calcium carbonate creates a high bonding effect in the presence of moisture. Therefore, the high $CaCO_3$ content (57.6%) in MSWA will introduce the bonding effect in the soil. In addition, the physical effect (filler effect) due to the packing characteristics of MSWA (since it is clay) will contribute to the compressive strength if used as a stabilizing agent.

3.2 Loss on Ignition of Municipal Solid Waste (MSW)

The loss on ignition of municipal solid waste (MSW) ranged from 80.02% to 83.49%. This is an indication that, as expected, MSW contains over 80% un-burnt carbon. The ash constituted at most 20% of the weight of MSW. In this study, the LOI of MSWA was not measured. According Eggenberger *et al* (2004) un-burnt carbon in pozzolanic materials can serve as filler in the material being stabilized.

4.0 Conclusions and recommendation

i. The municipal solid waste ash (MSWA) used in this study had over 50% fine particle (less than 2 µm), suggesting that it could have a significant amount of pozzolanic substances. This was confirmed by the fact that the total amounts of SiO_2, Al_2O_3, and Fe_2O_3 was less than 70%, categorising the ash as Class F pozzolana.

ii. The low amount of CaO in MSWA compared to that of pozzolana cement makes it not to be self cementing. However the high content of $CaCO_3$ in MSWA enables it to have a good bonding effect. It is therefore recommended that MSWA be sieved as finely as possible prior to use as a pozzolanic material for stabilizing soil. This would increase both the filler effect (through better packing characteristics of the smaller particles) and the bonding effect introduced by a high content of $CaCO_3$.

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