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Solidification and Stabilization of Incinerator Bottom Ash Residue for Construction Applications

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Abstract

Solidification/stabilization (S/S) treatment process is the most economical and popular method to treat ash residues generated from solid waste incinerators. Incinerator bottom ash residue containing different percentages of domestic and hazardous wastes was used to cast monolithic blocks, interlocking bricks, and concrete so as to ascertain their suitability for construction applications. The solidified samples were tested for compressive test and toxicity characteristic leaching procedure (TCLP) after a 28-day curing period. The TCLP test was used to gauge the leaching of heavy metals from the solidified matrixes while compressibility strength was measured to establish the cohesiveness of the materials as well as the effectiveness of the solidification and stabilization of the binder with the waste. The compressive strength increased with increased curing duration while the leaching capability was very low in the solidified samples. However, a comparison between the baseline and the solidified ash samples revealed that the compressive strength increased with a decrease in ash content. The metals (cadmium, zinc, silver, barium) showed low concentrations and the relatively low leaching capability of the metals in the ash residue indicates that the metals were well retained within the solidified matrixes. Thus, the use of the incinerator bottom ash residue for construction applications would not be expected to leach and impact surface or underground water except the pH of the contact water, rainwater or the environment falls below pH 3.

Keywords: incinerator bottom ash; waste utilization; secondary waste management; hazardous waste; solidification, stabilization.

1. Introduction

Today, efforts to use, recycle, or reduce waste streams are ecologically and economically essential. The solid waste management systems in many countries are reinforcing the focus away from land filling and towards waste prevention (zero waste), recycling, composting and energy from waste (incineration) in that order of priority. This hierarchy prioritizes waste prevention and waste management techniques such as reuse, recycling and composting as superior to both the incineration/ash management alternatives and to land filling for a number of reasons such as economics, energy efficiency, and environmental soundness when evaluated from the standpoint of life cycle assessment [1-3].

In an integrated waste management approach, incineration occupies the nest of the last priority, after waste prevention, reuse, recycling, and composting have been undertaken. Nowadays, incineration from waste to energy is gaining wider acceptance in the developed world under strict guidance. Waste generated in developing countries, however usually does not allow for energy recovery, due to its high moisture and organic matter content. The heavy metals present in the ash residue are of concern primarily due to the potential for the leaching of soluble forms of the metals, which could contaminate water resources [4-5]. Most heavy metals can be toxic to biological systems when present in high enough concentrations. The geochemical mobility of these metals accompanied with their toxicity to humans and animals draws attention towards finding suitable remediation technologies for the metals [6-8].

Treatment/disposal approach for managing waste amongst others includes solidification/stabilization (S/S) process which is a cement-based disposal method. The S/S process refers to those processes that use additives or binders to chemically and/or physically immobilize the hazardous content present in waste. In stabilization, the objective is to minimize the solubility and toxicity of contaminates while in solidification, binders like cement are used to encapsulate the waste material in order to immobilize contaminates and reduce leachability. Solidification/stabilization has been identified as Best Demonstrated Available Technology (BDAT) for a wide range of wastes, and Portland cement is the material most widely used for the purpose of S/S [9-14].

Several additives such as cement, sand, granite, and quarry dust mixtures can bind heavy metals and other contaminants [4,15,16]. Fly ash and bottom ash have been used as partial replacement of cement for binding waste into solidified materials [17-19]. However, after being properly tested, ash residues can be used as landfill cover, road base material, and in cinder blocks or concrete mixture [14,18,20,21]. The effect of this technique depends on the affinity of the mixtures to uptake metals as well as their resistance to permeability, leachability, and compressibility [4,22,23].

This study focused on the treatability of incinerator ash residue by solidification/stabilization (S/S). In the process, different percentages of Incinerator Bottom Ash (IBA) residue containing domestic waste (DW) and hazardous waste (HW) was used in making monolithic blocks, interlocking bricks and concrete with a view to preventing metal ions and other toxicants from leaching out into the environment. The ash residue was used as partial replacement of cement to assess the solidified product that best consumes the ash residue and still retains the specified EPA/DPR compressive strength [24-27].

2. Materials and Methods

2.1. Collection of samples

The waste samples were collected from a waste dump site in Udu Local Government Area of Delta State, Nigeria (Latitude 05^0 28^1 49.9" N and longitude $005^0 48^1$42.1" E). The waste types used in this study were hazardous waste ash (HW) from medical and other biological waste and domestic waste ash (DW) containing kitchen, and household waste and rags. The ash waste types were mixed with cement, sand, and other additives to cast monolithic blocks, interlocking bricks, and concrete in three different mix ratios. The baseline (mix A) served as a reference to establish a background for the other mix types. It does not contain any ash waste type. In mix B, part of the cement portion was replaced with 15% ash residue while mix C, contained 30% ash.

2.2. Compressive strength test

This test was carried out according to the American Standard Testing and Material (ASTM), test method for the compressive strength of hydraulic cement mortars C 190/C 109M-95 [28]. The strength of the cubes was measured using a calibrated hydraulic compression apparatus (model ELE) on the 4^{th}, 7^{th} and 28^{th} days of curing. Curing cast properly, leads to increase strength, lower permeability and thus avoids cracking where the surface dries out. The total maximum load was recorded at the point of fracture of the cubes (pressure was applied gradually in form of load continuously at the rate of 140 kg cm^{-2} min^{-1} till the specimen shatters/fails.). The compressive strength for the specimens was determined by dividing the maximum load attained during the test by the cross-sectional area of the tested specimen [12]. The load was calculated using:

Compressive Strength (N/mm^2) = P/A

Where P is the total maximum load (N) and A is the area of the loaded surface (mm^2)

The unconfined compressive strength was measured to establish the cohesiveness of the materials. It also determines the effectiveness of the solidification and stabilization of the binder with the waste [4,14]. The regulatory limit for the unconfined compressive strength for solidified materials must be greater than 1.38 N/mm^2 or 201 lbs/in^2 (psi) [24,27].

2.3. Toxicity Characteristics Leaching Procedure (TCLP)

The TCLP test was conducted using EPA procedure of SW-846 Method 1311 and the DPR (TCLP) protocol to determine the mobility of metals and toxicants in the solidified samples. In this test, the materials that best consume the ash residue and still retained the specified EPA/DPR compressive strength were used. Five grams of each sample (crushed and sieved) in three replicates were agitated with 100 ml (an amount of extraction fluid equal to 20 times the weight of the solid phase) of dilute acetic acid (pH 2.88 ± 0.05) in closed polyethylene containers. The suspension was extracted for 16 hours using a shaker regulated at 25ºC. After 16 h, the liquid extract was separated from the solid phase by filtration through a 0.6 µm glass fiber filter. The leachant concentration for metals was determined using Shimadzu 6701 F atomic absorption spectrophotometer (AAS) [24,27].

3. Results

The results obtained for the analysis of the untreated and solidified incinerator ash residue are presented in tables 1 – 2 and figures 1 – 2.

3.1. Compressive strength

Compressive strength of the different cured specimens were tested at specific curing times of 4, 7, and 28 days. The strength of the specimen increased with increased curing duration. The samples that contained 0% ash (mix A; baseline) showed the best compressive strength, with the concrete having the highest strength of 51.12 N/mm^2 when compared to the interlocking bricks and monolithic blocks of 34.31 N/mm^2 and 15.91 N/mm^2 respectively. Specimens with 15% ash (mix B) had higher compressive strength than those with 30% ash (mix C) (Table 1). The results indicates that the concrete samples have a greater compressive strength than interlocking blocks while all interlocking blocks have a greater compressive strength than monolithic blocks. There was also a direct relationship between the compressive strength and ash content as it was observed that the strength of the solidified matrix decreased with an increase in ash quantity (Fig 1). Using the data recorded, a linear graph of compressive strength (N/mm^2) against % ash was plotted, thus deducing from the slope, the % ash that would be used to produce a desired strength (Fig 2). This would assist in fabricating a new mould/design and deductions could be made as to what % ash is required to produce a particular compressive strength.

3.2. Toxicity characteristics leaching procedure (TCLP)

In this study, mix C was used in the TCLP test since it best consumes the ash residue and still retained the specified EPA/DPR compressive strength. The untreated domestic and hazardous ash showed an alkaline pH range of 9.35 ± 0.01 and 10.4 ± 0.02 respectively. The solidified samples showed a high pH ranged of 11.6 – 11.9 and 12.2 – 12.3 in the order above. There was little variation between the stabilized materials and the baseline material (pH 11.1 ± 0.02). This indicates that the cement material used for the solidification was also highly basic. The base material, domestic and hazardous waste recorded mean concentration for Cd (0.04, 0.04, 0.05 mg/l), Zn (0.05, 0.19, 0.39 mg/l), Ag (0.07, 0.07, 0.06 mg/l) and Ba (1.43, 1.48, 1.85 mg/l) respectively. In the solidified matrix, relatively low concentrations of the metals were leached out (Table 2). The reported concentrations in this study were within the various stipulated EPA/DPR limits. However, total chromium, arsenic, mercury and selenium were not detected in any of the tested samples.

4. Discussion

From the result of the compressive test, all the specimens had values within the EPA/DPR specified minimum compressive strength of 1.38 N/mm^2 or 201 lbs/in^2 (psi) with the strengths varying for the different type of specimen tested. Compressive strength increased with increase curing time. Increasing the curing time for the samples would lead to a better resistance to compression. This is due to the slow formation of hydrated calcium silicates that is produced as a result of reaction of anhydrous silicate constituents of cement with water. This agent crystallizes slowly into an interlocking matrix and increases the sample strength. Longer curing period allows longer time for anhydrous silicate to react and form a strong skeleton structure throughout the material that binds the grains together. The effective binding agent, however, is the one that combines the decrease in leachability of the metals in the solid matrix as well as enhances the strength of the solid matrix to compressive load. Compressive strength is a very useful tool since it determines the weight the bricks or concrete would withstand [13,29,30].

The S/S process is an interesting technology for waste treatment because it can convert the waste into an inert material independent of the solubility of the metal and a majority of metals are soluble at pH below 5. It is also possible to control some physical and chemical parameters such as permeability, compressive strength and metal mobility by proper selection of chemical additive types and ratios. The strength development could be improved by increasing the curing temperatures, lowering the water to cement ratio, or using Portland cement as binder [12,21].

The leaching test (TCLP) has been recognized as the primary and most widely used indicator for evaluating the retention capacity of toxicants in waste / specimens [24,27,31,32]. Leaching is the process by which inorganic, organic contaminants or radionuclides are released from the solid phase into the water phase under the influence of mineral dissolution, desorption, complexation processes as affected by pH, dissolved organic matter and (micro)biological activity. Thus when materials are added to cement, they are effectively controlled. Although the EPA/DPR limit for pH ranged from 6.5 to 9.0, it implies that there would never be pH compliance since the base material (0% ash) was highly basic (pH = 11.1 ± 0.02). The relatively low leaching capability of the metals in the ash residue indicated that the metals would be well retained within the solidified waste form [31,33-36]. Since the mobility / leaching of metals was relatively low in the solidified samples, the binding capacity of substances would be quite high and not expected to leached into underground or surface water except if the pH of the contact water, rainwater or the environment falls below 3 pH units.

Table 1: Mean compressive strengths of domestic and hazardous waste mix designs

Ash Sample	**Mix Designs**	**Compressive Strength N/mm^2**		
		Concrete	Interlocking	Monolithic
Domestic Waste	Mix A	51.12	26.67	15.91
	Mix B	26.67	22.22	6.87
	Mix C	14.46	14.45	4.22
Hazardous Waste	Mix A	51.12	34.31	15.91
	Mix B	32.00	23.56	8.93
	Mix C	16.72	15.56	4.89

Table 2: Mean concentrations of pH and metals in baseline, ash waste and solidified materials

Parameters	**EPA/ DPR Limits**	**Base Material**	**Domestic Waste (DW)**	**Solidified Interlock (DW)**	**Solidified Concrete (DW)**	**Hazardous Waste (HW)**	**Solidified Interlock (HW)**	**Solidified Concrete (HW)**
pH (H_2O) @ 26.0ºC	6.5 – 9.0	11.1	10.4	11.9	11.9	9.35	12.3	12.3
Cadmium, mg/l	1	0.04	0.04	0.04	0.03	0.05	0.04	0.03
Zinc, mg/l	50	0.05	0.19	0.07	0.09	0.39	0.04	0.08
Silver, mg/l	5	0.07	0.07	0.05	0.06	0.06	0.05	0.05
Barium, mg/l	100	1.43	1.48	1.10	1.44	1.85	1.57	1.56

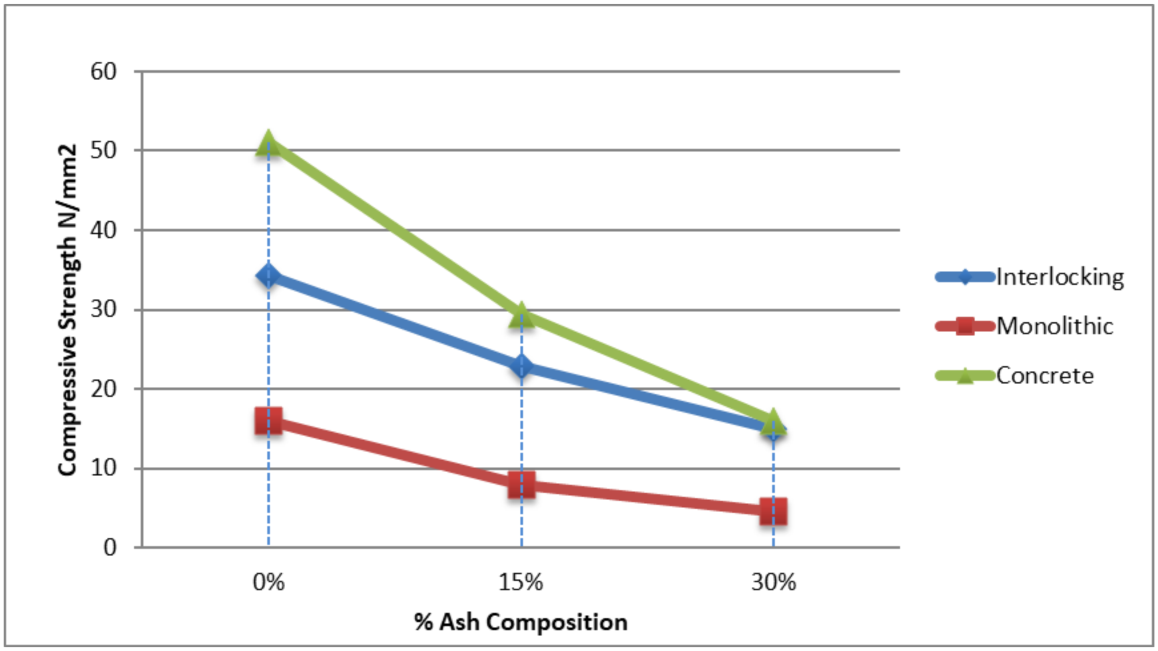

Figure 1: Mean compressive strength of specimen with % ash content

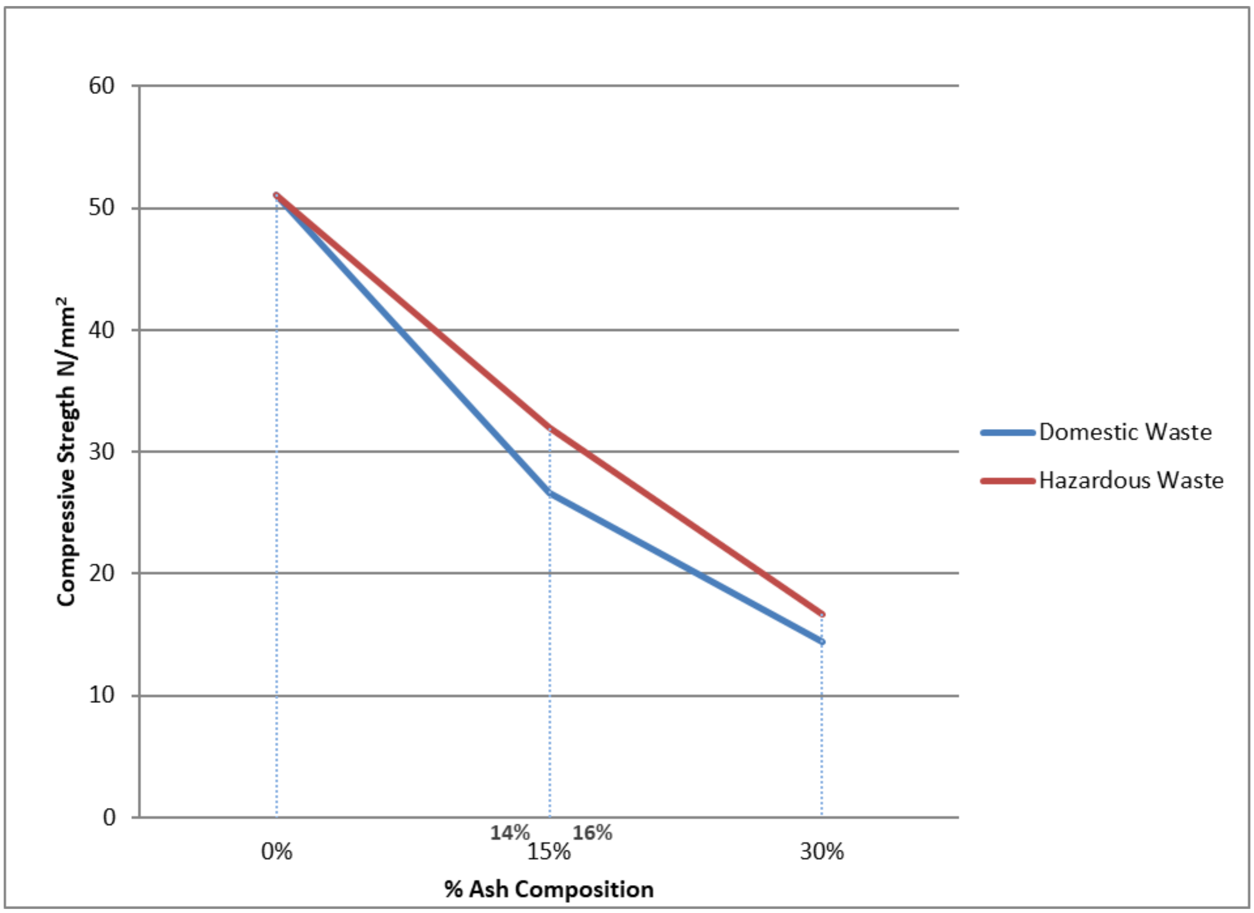

Figure 2: Mean % ash content to produce a desired compressive strength

5. Conclusion

The S/S treatment of incinerator bottom ash (IBA) proved that the method is a good treatment/disposal option as well as a reuse/recycling technology. The advantage of utilizing this solidification/ stabilization process is the low cost of the raw material and the relatively safe treatment process. The use of cement together with other additives (ash residue) effectively binds metals and other toxicants within a solidified matrix. The results from this study showed that the mobility of pollutants in the solidified specimen would be very minimal and may not likely impact underground water or soil. Since metals are bound effectively within a solidified waste matrix, the potential of converting a solidified waste matrix to bricks and tiles for pavement, parking lots and paths or even for road construction should be highly exploited. As such, the solidified matrix does not need to be disposed of in landfill sites but instead can be used to manufacture useful products and thus generate income; waste to wealth.

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