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Aluminum Dross: Cost-Efficient Aluminum Waste for Production of High Grade Potash Alum

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Abstract

The disposal and recycling of aluminum dross residue has been a global challenge for a long time. Aluminum residue is one of the major wastes produced during aluminum smelting in chemical industries. The dross generated in Nigeria is approximately 120000 tons/year and little has been done on the large amount of the dross residue in terms of conversion to other useful products. About 98 % of the dross residue generated is land-filled due to the unavailability of advanced technology for recycling. The results of the studies in this work indicated that aluminum dross has a potential to be a cost-efficient source for aluminum-based materials. The potash alum, a commercially important chemical, produced through this technique can be used in water treatment.

Keywords: Aluminum/ALD, alum, dross, preparation, residue/filtrae

1.0 Introduction

The era of roofing buildings and designing windows, doors and so on with corrugated metal sheets are almost over because of the advent of aluminum (Al) materials. A survey of most buildings in most cities and local areas in Nigerian major cities and rural areas showed that Al roofing sheets were used for roofing purposes. A look at most of the construction sites agree to the change in building trends in the last few years. Corrugated metal and asbestos sheet, have been replaced with Al by builders and homeowners alike resulting in increased production of Al roofing materials. Consequently, this has led to increased amount of Al Dross (ALD) generated annually in Al industries globally. ALD is one of the residues that is generated in the process of refining Al. Mohammed in his publication in 2003 gave analysis of Al utilization, production and consumption as a major index of industrialization. With the rise in Al waste, there is no doubt that the dross residue has risen to a point of concern and may lead to environmental degradation if urgent action is not taken.

The dross residue contains a lot of toxic substances such as nitrides, fluorides, and in some cases, cyanide causing local flora and fauna. Treatment of the dross for producing valuable products is non-negotiable due to environmental laws and restrictions, and the increasing demand for aluminum products and chemicals used in various applications. Apart from various grades of alum, other chemicals that can be obtained from the dross include aluminum chloride, alumina trihydrate, alumina and poly aluminum chloride.

The ALD is grouped as Black ALD (BALD) or White ALD (WALD) type depending on the metal content in the dross. The BALD has low amount of metal content with high quantity of salts, and oxides (Samson *et al.*, 2014). The WALD contains a high concentration of metal content with small amounts of salts and oxides compared the BALD. ALD is a product of melting of Al scraps such as used Al siding, castings, beverage containers and so on. The salt flux accumulates on top of the melt and forms dross or skim which contains Al and elements such as magnesium (Mg), silicon (Si), carbon (C) and so on in trace or very small amount. Approximately, four million tons of WALD and more than a million tons of BALD are reported throughout the world each year, and around 95% of this material is land-filled (Brough, 2002). Survey studies have shown that the industries dispose almost all tons of WALD and BALD generated in most countries. The quantities of dross land filled nowadays are expected to be drastically reduced with the invention of technology, as a large amount of it can be reprocessed to produce alum and other chemical both for environmental remediation and industrial purposes. The conversion of ALD to useful materials adds value to the dross and helps to convert waste to wealth. According to Chen 2012, recycling results in significant cost savings over the production of primary new aluminum even when the cost of collection, separation and recycling are taken into account. The economic impact for recycling ALD is significant as it mitigates metal losses, alleviates the use of salts, and eliminates the need to landfill salt cakes (Chen, 2012). Part of the economic targets of dross are; aluminum oxides from dross recycling comprised of alternative source to many materials that are primary in nature, and by channeling dross towards a useful product, aluminum smelters or government can also gain by charging a gate fee for handing and processing waste dross.

Studies have shown that ALD can be processed into varieties of materials through different careful approaches in systematic steps. Singh *et al.* (2016) on their studies have described the development of process, optimization of parameters, and characterization of value added products extracted from waste dross. They concluded that ALD has become an area of interest to the Al producers and secondary processors due to large production of ALD and recovery of Al metal. The report also showed that recovery of metal from dross is carried out by conventional metallurgical process all over the world. Kenichi *et al. (*2007) in their material flow analysis of ALD explained that the dross and the residue, which have high concentration of metallic Al are mostly used as an Al resource for production of Al. On the other hand, the lower grade residue with the Al content less than 20 % is difficult to be recycled and is therefore land filled. The hydrometallurgical route utilizes ALD for leaching in acidic and alkaline media to generate various valuable products. Das *et al.* (2007) had used sulphuric acid for leaching nearly 84 % Al_2O_3 into the liquor in 3 hr from WALD at 363 K. Similarly, Tsakiridis *et al*. (2013) have used sodium hydroxide solution to leach around 57 % aluminum into the basic liquor in 2 hr from BALD at the temperature range of 433 - 533 K. Various new methods for recycling of aluminum dross have been developed recently. These include the generation of valuable products like layered double hydrates, zeolites, ion exchangers and using ALD as the raw material (Hiraki *et al*, 2009). The utilization of metallic aluminum entrapped in the matrix of alumina is achieved by using these methods (Meshram *et al.*, 2019). Using ALD as a raw material, the authors have produced a relatively rare mineral, tamarugite, which has good coagulant properties (Meshram *et al.*, 2017 and Meshram *et al.*, 2019). The leaching of ALD has been carried out using sodium hydroxide, and subsequent addition of sulphuric acid led to the crystallization of tamarugite, $NaAl(SO_4)_2.6H_2O$.

This research article focuses on the recycling of WALD and the simultaneous production of potash alum. Potash alum is a very important inorganic compound that has many commercial applications. It is mainly used in wastewater treatment plants as a chemical flocculants to remove the suspended colloids present in the turbid water (Mukherjee *et al.*, 2014). The other beneficial applications of potash alum are leather tanning and fabric dyeing, apart from being a necessary ingredient in medicines and cosmetic products (Alzomor *et al.*, 2014).

2.0 Materials and Methods

2.1 Chemicals and Equipment

The WALD, with range of properties in Table 1, was obtained from aluminum rolling mill (Tower Aluminum) industrial layout Ota, Ogun state, Nigeria.

Table 1: Range of physical and chemical properties of ALD

Property	Granular	Compact dross
Alloy content (%)		
Melt	2.44 – 11.77	1.34 – 10.03
Recoverable metal	1.03 – 5.51	0.33 – 6.80
Distribution (q)(mm^{-1})	0.08 (coarse) – 0.452 (fine)	-
Density (t/m3)	0.828 – 1.118 (bulk)	2.396 – 2.528 (apparent)
Metal content (%)	46.9 – 69.1	71 – 93
pH	9.52 – 10.14	9.03 – 9.48
Salt content (%)	0.18 – 6.21	0.01 – 0.03
Gas evolution (1/kg dross)	0.25 – 1.17	-

Adapted from Chen, 2012

Analytical reagent grade chemicals obtained from MERCK for the laboratory research work were sulphuric acid; H_2SO_4, hydrochloric ;HCl, sodium hydroxide; NaOH and sodium carbonate; Na_2CO_3. Determination of elemental composition were conducted on inductively coupled Plasma (ICP) spectrometter. Distilled water was used during all the dilution purpose while de-ionized water was used for preparing standard solutions for ICP experiment. The ALD samples were characterized using scanning Electron Microscopy (SEM) to determine the morphology, while the Elemental Diffraction X-ray (EDX) was used for elemental analysis.

2.2 Experimental

A 100 g of the small size ALD was weighed and crushed in a mortal and sieved to obtain fine particles. The recovery of metal was carried out by leaching using HCl and H_2SO_4 acids. Fig. 1 shows the method and procedures for the production of potash alum from the ALD. A 50 g amount of sieved ALD was added to 250 mL of 5 M potassium hydroxide solution at 45 ^oC for about 120 min. After the reaction time, the supernatant was filtered to separate the residue, and a filtrate containing the complex oxide product was obtained. A 5 M H_2SO_4 solution was prepared for the addition of sulphate ions to the complex oxide product formed to produce potash alum. A 100 mL of H_2SO_4 was added to the filtrate with continuous stirring using a glass rod throughout the process. A white gelatinous precipitate of aluminum hydroxide, $Al(OH)_3$, was formed just as the drops of H_2SO_4 were mixed with the filtrate solution. The beaker was left undisturbed for nearly 20 hr after the reaction. After the crystallization of potash alum at the bottom of the beaker, the liquor was decanted to separate the crystals from the solution and placed in the chilled water bath again. This led to crystallization of alum after primary crop. The total crop of alum crystals was collected and stored in a desiccator. The overall amount of alum was measured using a digital balance (OHAUS, USA). The alum

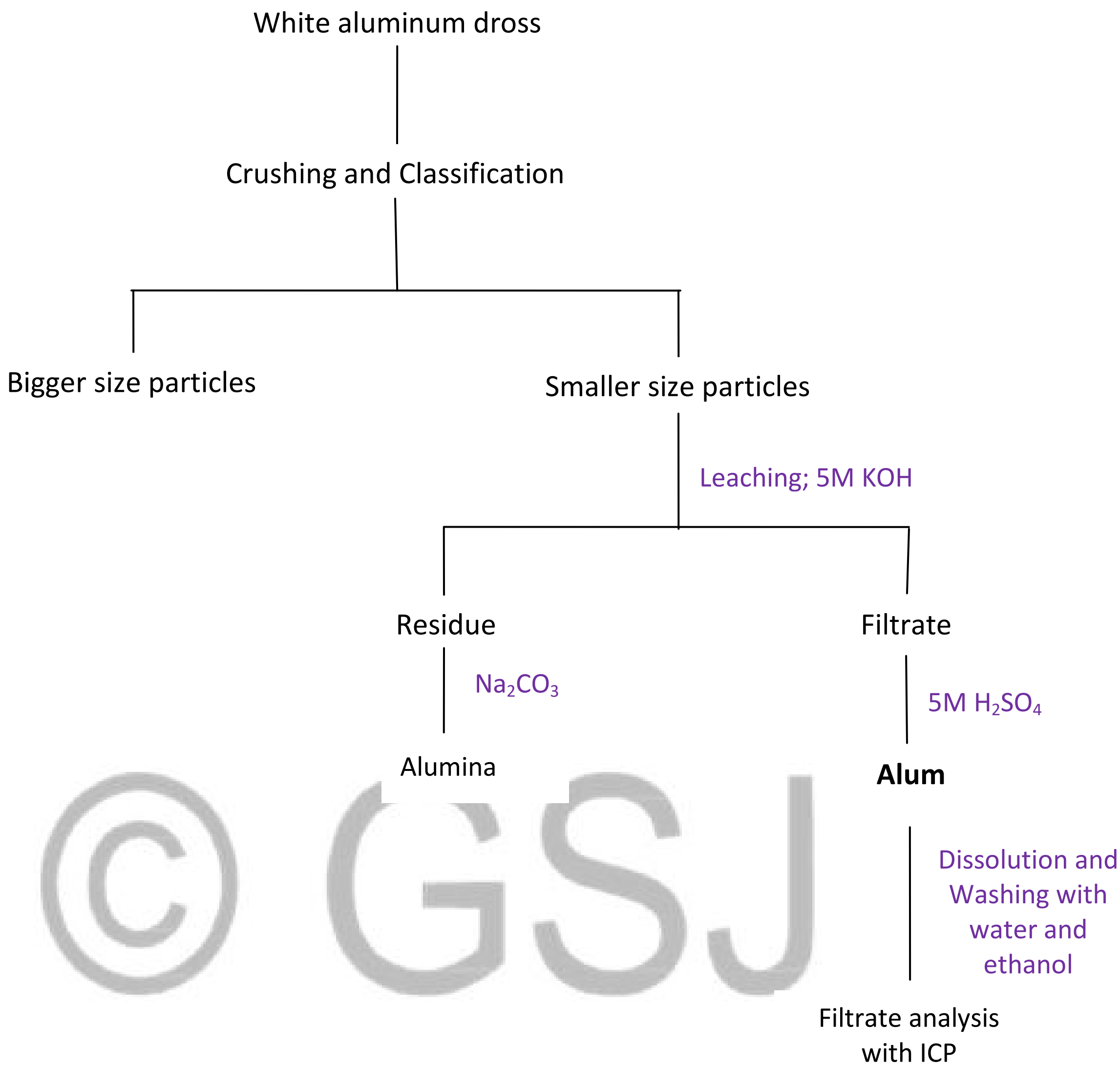

Fig. 1: Procedure for preparation of alum from ALD

crystals were dissolved in distilled water, recrystallized and washed with 10% v/v ethanol solution to remove any impurity associated with it and protect the final crop from contamination. Finally, the residual liquor obtained after the production of potash alum crystals was analyzed. The ICP analysis of potash alum has been carried out to examine the elemental composition of the resultant product and the result is shown in Table 3. The residue portion was fused with sodium carbonate to obtain sodium aluminate liquor which further processed to recover pure alumina by precipitation and calcinations at 950 ^{o}C.

The ALD and alum obtained after digestion were characterized using SEM to determine the sample morphology in the samples, while the EDX analysis after recovery of alum was taken after washing with water to remove adsorbed impurities.

3.0 Results and discussion

The Tables 2 and 3 give the physicochemical analysis and composition of the ALD used for preparation of alum. The morphologies of the ALD sample as represented in Fig. 1a showed no definite shape with white images signifying presence of metals, while the alum prepared appeared lumpy (Fig. 2b), which consisted of dense aggregates of lumpy amorphous macro-crystallites. The macro-crystallites were small without crystal sizes indicated on the SEM images obtained. The sample showed spherical shapes. The EDX spectra shown in the Fig. 2c clearly indicated absence of peaks due to Al which means complete recovery of Al metal from dross to form alum. The metallic aluminum reacted with sulfuric acid in the reaction medium to produce alum according to equation 1;

$$2Al + 3H_2SO_4 \rightarrow Al_2(SO_4)_3.nH_2O + 3H_2 \qquad 1$$

Table 2: Analysis of commercial alum and as-prepared alum from ALD

Parameter	Commercial alum	Alum as-prepared
Colour	White	White
pH	2.92	4.05
Al_2O_3 (%)	64.26	76.77
Insoluble matter (%)	0.41	0.87

The Alum obtained was characterized as $Al_2(SO_4)_3.nH_2O$ with some impurities such as iron. Chemical characterization was done using ICP and the analysis reveals the close resemblance with commercially available alum in the market. The chemical analysis data furnished for the alum is presented in Table 2.

4.0 Conclusion

The results above indicate that aluminum dross has a potential to be a cost-efficient source for aluminum-based materials. Production of valuable products from such waste substances is an exciting aspect of industrial waste management, which can further result in avoidance or reduction of environmental pollution. Potash alum, a commercially important chemical, produced through this technique can be used in water treatment.

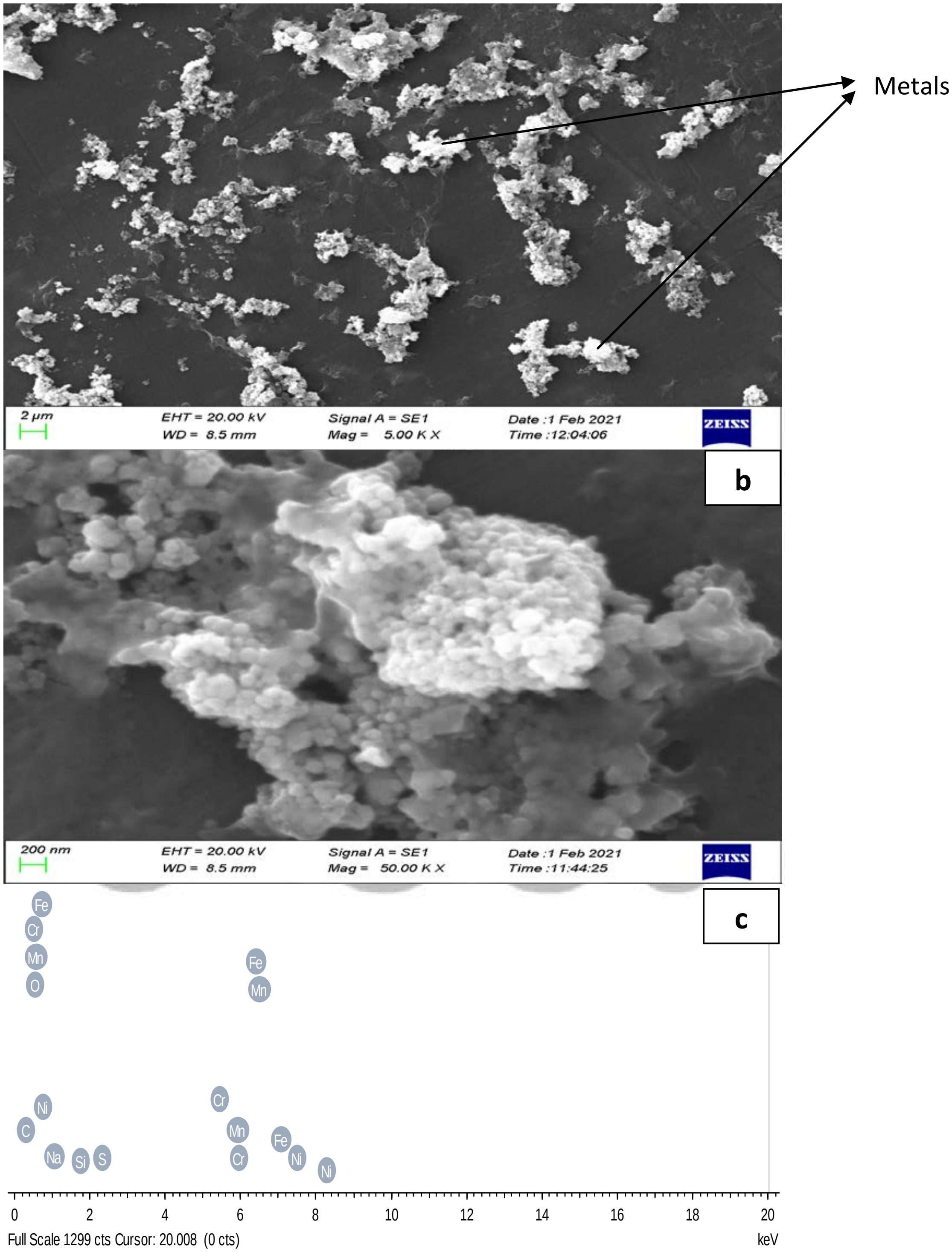

Fig. 2: SEM for ALD (a) and as-prepared alum (b), and EDX (c) for residual filtrate after alum preparation

Table 3: Comparison between as-received and treated ALD

Composition	As-received (w/w)	After purification
Al_2O_3	69.88	92,91
SiO_2	1.49	1.67
Fe_2O_3	1.67	1.23

Na_2O	5.99	0.04
CaO	0.51	0.03
TiO_2	0.14	0.12
MgO	1.87	0.04
K_2O	1.55	0.03
Zn	0.06	0.07
Cu	0.61	0.58
Fe	1.69	1.32
Al	6.72	0.36
C	1.12	0.02
Ca	1.75	0.03
Na	0.93	0.04
Mn	0.02	0.02
Cr	0.06	0.05

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