Pyrometallurgical Recovery of Aluminium Metal from End-of-Life Beverage Cans

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Abstract

This project was experimentally carried out to recycle these end-of-life beverage cans into premium grade metals production. Ten cans each were taken from a group of cans that were received from the various restaurants and drinking spots in Tarkwa. These groups of cans received are the end-of-life Bavaria drink cans, end-of-life Coca-Cola/Fanta drink cans and end-of-life Malta Guinness drink cans. Their respective masses were taken, with the end-of-life Bavaria drink cans giving 126.70 g, Coca-Cola/ Fanta drink cans giving an average mass of 131.60 g and the end-of-life Malta Guinness drink cans also giving 126.70 g. These cans were then squeezed and placed in fireclay crucibles that were heated by a palm kernel shell fired custom-made furnace. The melts obtained were poured in a bowl of water for quenching to take place after which the solidified metals were recovered. The weight recovered from each end-of-life beverage can was noted and samples of metals so produced were characterised by XRF and SEM/EDS analyses. The results showed the mass of recovered metals as 125.45 g, 122.71 g and 101.80 g for Bavaria cans, Coca-Cola/Fanta cans and Malt cans, representing 99.01%, 93.24% and 80.35%, respectively. XRF and SEM/EDS analyses revealed the recovered materials as being of high purity, up to 92.73 wt% aluminium metal. It was concluded that waste beverage cans are readily available sources of metals, the exploitation of which can conserve naturally occurring ores.

Keywords: End-of-life beverage cans, XRD analysis, SEM/EDS analyses, Pyrometallurgical recovery

1 Introduction

Conventionally, aluminium is produced by the Hall-Heroult process through reactions that are very endothermic and accordingly require consumption of large amounts of costly electrical energy.

$$\frac{1}{2}\, Al_2O_3 + \frac{3}{4}\, C \rightarrow Al + 3/2CO_2 \qquad (1)$$

Two major pre-requisites for the setting up of an electrometallurgical industry for the production of aluminium metal are the availability of large and cheap deposits of bauxite from which alumina can be produced, if it is not to be imported, and the availability of cheap source of electrical energy. For most countries, including Ghana, it is difficult to meet these two requirements, as either the cost of electrical energy is almost always exorbitant or alumina must be imported.

The production of one metric ton of aluminium from bauxite requires about 17000 kWh of electricity while the same amount of recycled aluminium consumes approximately 750 kWh which substitutes primary aluminium with a gain of 95 % energy (Begum, 2013; Totton and Scott, 2003).

It has been estimated that the production of a kilogram of aluminium from end-of-life aluminium metals (Fig. 1) can save up to 95% of the energy, 8 kilograms of bauxite, 4 kilograms of chemical products and 14 kWh of electricity for each kilogram of aluminium extracted for new raw material (AlSaffar and Bdeir, 2008).

Fig. 1 End-of-Life Beverage Cans as a Secondary Source of Aluminium

Globally, aluminium production from bauxite accounts for 1% of anthropological greenhouse gas emissions (Agunsoye *et al*., 2015). Producing aluminium from end-of-life beverage cans is estimated to decrease greenhouse gas emissions by 97% of the amount generated in the primary production process (Agunsoye *et al*., 2015).

Aluminium beverage cans are produced from two different aluminium alloys: 3004 ASTM for the main body and 5182 ASTM for the lids. (AlSaffar and Bdeir, 2008). Typical compositions of the two alloys are illustrated in Table 1 (AlSaffar and Bdeir, 2008).

Table 1 Composition of Aluminium Beverage Can Alloys

Alloy	Composition		
	Al	Mn	Mg
3004	97.8	1.2	1.0
5182	95.2	0.35	4.5

As illustrated in Table 1, end-of-life beverage cans is rich source of aluminium for its potential secondary metallurgical recovery. Although, the mass of a single aluminium can is in the range of 12-14 g a huge number of such cans are produced each year, using a large amount of the metal (Begum, 2013). Since large amounts of electrical energy are required to produce virgin aluminium, recycling the metal or converting it into other useful materials is desirable, both environmentally and economically (Begum, 2013). Several aspects of the recycling process of aluminium cans and drosses have been addressed by many investigators (Gaustad *et al.*, 2012; Murayama *et al.*, 2012; Utigard *et al.*, 1998).

This research is therefore aimed at recovering aluminium from end-of-life beverage cans using a custom made charred palm kernel shell fired furnace.

2 Materials and Method

2.1 Materials

End-of-life beverage cans (Fig. 2) gathered from the various restaurants and drinking spots in Tarkwa were grouped into End-of-life Bavaria drink cans, End-of-life Coca-Cola drink cans, End-of-life Fanta drink cans and End-of-life Malta Guinness drink cans. Ten cans were taken from each group of beverage cans received and their initial masses taken. These cans were then squeezed into smaller bits to allow for their placement into fireclay crucibles for the heating process.

Fig. 2 Samples of End-of-Life Bavaria Cans utilised for the Investigation

2.2 Methods

Fireclay crucibles were placed on a charred palm kernel shell fired furnace with a blower attached in such a way as to blow air continuously into the furnace to enhance the combustion of the charred palm nut shells (Fig. 3). A known mass of the end-of-life Bavaria drink cans that were squeezed into smaller bits were put in one fireclay crucible for melting to take place. After the melting has taken place, the melts obtained were poured in a bowl of water to allow quenching to take place.

Fig. 3 Custom-made Furnace consisting of End-of-life Vehicle Tyre Rim and a Blower Assembly

This process was repeated for the other end-of-life beverage cans (Coca-Cola drink cans, Malta Guinness drink cans and Fanta drink cans but with different masses respectively). The Coca-Cola drink cans and Fanta drink cans were blended together at a known mass while the Malta Guinness drink cans also had a known mass taken before the melting process. After they have all been melted, the melts obtained were poured in a bowl of water for quenching to once again take place. The metals that were recovered from the various end-of-life beverage cans after the quenching had taken place were then weighed to know the weight of the metals recovered after the melting process. Samples from each group were then characterised by XRF analyses (EPSILON ED XRF equipped with OMNIAN Software) and SEM/EDS analyses (Hitachi Tabletop TM 3000 Scanning Electron Machine).

3 Results and Discussion

3.1 Nature of Recovered Metals

Photographs of samples of the recovered metals are illustrated in Figs. 4 to 7 for Malt, Bavaria, Coca Cola and Fanta cans.

Fig. 4 Samples of Metals Recovered from End-of-Life Malt Cans

Fig. 5 Samples of Metals Recovered from End-of-Life Bavaria Cans

Each crucible had a molten material equivalent to ten beverage cans and emptying of the contents of the crucible into the quenching medium was complete and without any residual materials in the crucible. This arrangement allowed for easier weighing of the quenched material after the melting process.

Fig. 6 Samples of Metals Recovered from End-of-Life Coca-Cola

Fig. 7 Samples of Metals Recovered from End-of-Life Fanta

3.2 Characterisation of Recovered Metals by XRF Analyses

Results of analyses by XRF of the recovered metals are shown in Table 2. It is observed from Table 2 that each of the brands of beverage cans displayed aluminium contents of over 92 wt %, with the exception of Malt cans that showed only 66.81 wt %. Other major metals observed in the recovered metals are Mn, Mg and Si. While Mn and Mg could be traced to the raw materials used in manufacturing the cans as shown in compositions Table 1, the presence of Si is usually traced to impurities from the ash from anode material during the Hall-Heroult process.

Table 2 Results of Elemental Analyses (wt %) by XRF

Element	Fanta	Coca-Cola	Malt	Bavaria
Si	3.15	2.25	3.13	2.35
Al	92.25	92.73	66.81	92.44
Fe	0.94	1.23	19.65	1.36
Mn	1.56	1.72	0.30	1.72
Mg	0.30	0.38	ND	0.32
Ca	0.26	0.32	0.30	0.33
K	0.24	0.14	0.32	0.14
Cu	0.32	0.36	0.16	0.41
S	0.24		0.15	
P		0.39	0.11	0.42
Cl	0.40	0.24	0.34	0.26
Cr			5.34	
Ni			3.14	

In addition to the observed major elements other trace elements like Ti, Zn, Cr, Ni and Ga were observed as illustrated in Table 3. These transition metals group of elements are traceable to ash obtained from burning of the anode material in the Hall-Heroult process for aluminium metal production. Other potential sources of these elements are impure alumina and impure cryolite in the Hall-Heroult process.

Table 3 Results of Trace Elemental Analyses (ppm) by XRF

Element	Fanta	Coca-Cola	Malt	Bavaria
Ti	506	388	ND	352
S		165		382
Zn	616	645	73	694
P	611			
Cr	541	323		313
Ni	113	106		138
Ga	258	285	152	**315**

3.1 Characterisation of Recovered Metals by SEM/EDS Analyses

The results of characterisation by SEM/EDS of the recovered metals from the various end-of-life beverage cans are shown in Figs 8 to 11 and Tables 4-7 for marked regions in the SEMs of Fanta, Coca-Cola, Malt and Bavaria cans, respectively. Major elements observed include Al, C and O with minor additions of Fe, Mn, Si and Germanium. The presence of oxygen in almost all of the samples may suggest the presence of an oxidised protective layer on the surface of the cans. This may have arisen when the cans were exposed to the atmosphere or during the quenching process of the molten aluminium in water. The formation of the protective layer of Al_2O_3 is a surface phenomenon and the thickness of such a layer may be a few micrometers, suggesting that this process alone could not have contributed to the compositions of oxygen observed in Tables 4, 6 and 7.

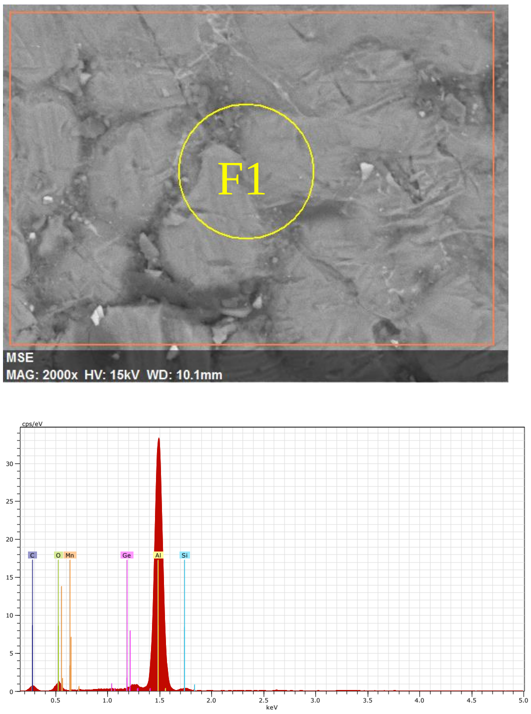

Fig. 8 SEM/EDS of Metal Produced from End-of-Life Fanta Cans

Table 4 Elemental Analyses of Region F1

Element	Atomic No.	Normalized wt %	Atomic %
Aluminium	13	61.54	45.33
Carbon	6	23.43	38.76
Oxygen	8	11.60	14.41
Germanium	32	1.69	0.46
Silicon	14	1.19	0.84
Manganese	25	0.55	0.20
TOTAL:		100	100

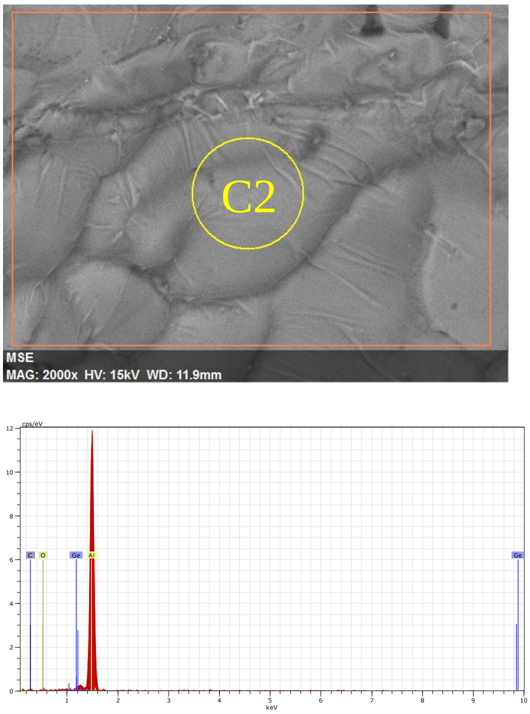

Fig. 9 SEM/EDS of Metal Produced from End-of-Life Coca-Cola Cans

Table 5 Elemental Analyses of Region C2

Element	Atomic No.	Normalized wt %	Atomic %
Aluminium	13	80.48	67.15
Carbon	6	14.28	26.77
Oxygen	8	4.06	5.71
Germanium	32	1.18	0.37
TOTAL:		100	100

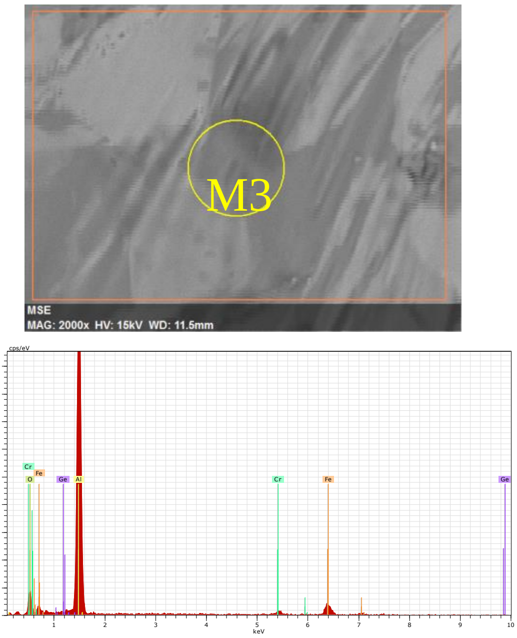

Fig. 10 SEM/EDS of Metal Produced from End-of-Life Malt Cans

Table 6 Elemental Analyses of Region M3

Element	Atomic No.	Normalized wt %	Atomic %
Aluminium	13	68.56	68.05
Oxygen	8	14.12	23.64
Iron	26	13.52	6.49
Chromium	24	2.86	1.47
Germanium	32	0.94	0.35
TOTAL:		100	100

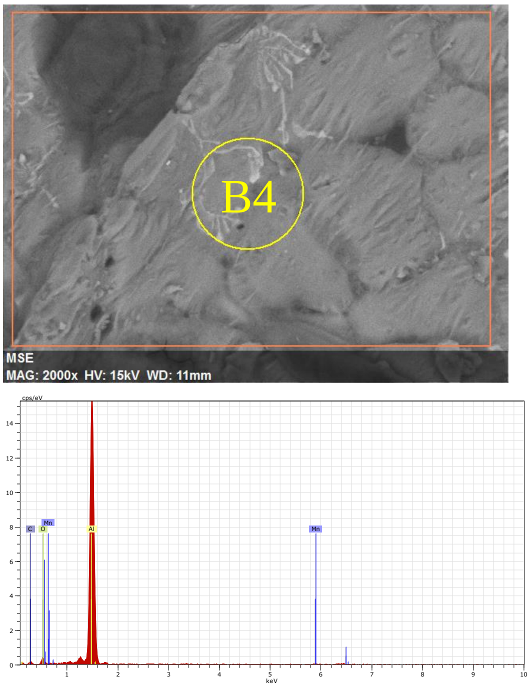

Fig 11 SEM/EDS of Metal Produced from End-of-Life Bavaria Cans

Table 7 Elemental Analyses of Region B4

Element	Atomic No.	Normalized wt %	Atomic %
Aluminium	13	71.82	56.37
Carbon	6	17.36	30.61
Oxygen	8	9.43	12.48
Manganese	25	1.40	0.54
TOTAL		100	100

Carbon is also present, the composition of which suggests aluminium carbide of the form Al_4C_3 evident in the Al/C atomic ratios in Tables 4, 5 and 7. At this stage, it is not clear where the carbon is coming from. However, in this investigation, the lids were not separated from the main body of the can during the melting process. The compositions of the lids and main body as shown in Table 1 exclude either as a source of carbon. It may be speculated at this stage that the aluminium metal used in fabricating these cans may have contained some minor proportions of the oxycarbides of aluminium, typically Al_2OC.

4 Conclusions

From the various experimental works carried out, it can be concluded that it is possible to recycle end-of-life beverage cans into aluminium metal by a simple heating process. The recovered metals are of high purity with aluminium composition in excess of 92 wt%.

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