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Preparation and Characterization of Aluminum Ingot Recycled from Beverage Can Scraps

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Abstract: *The use of waste materials (metal scraps, plastic and crop) to produce engineering components is currently attracting so much interest due to their low cost, availability and environmental impact. In this study, aluminium (Al) ingot prepared from beverage can scraps (BCS) was characterized. The composition, density, tensile strength, compression strength, wear rate, thermal conductivity, hardness, storage modulus, loss modulus and microstructure of the recycled Al ingot were determined. The result of the analysis showed the composition of the Al ingots to be 95.62%Al, 1.62%Mg, 1.32%Si, 0.693%Mn, 0.437%Fe, 0.162%Cu, 0.097%Zn, 0.024%Ti, 0.017%V, 0.006Ni, 0.005%Cr and 0.008%Pb. The density, ultimate strength, yield strength, percentage elongation, compression strength, hardness, wear rate, coefficient of friction, thermal conductivity and coefficient of thermal expansion of the Al ingots are* $2.62gcm^{-3}$*,*$138.03Nmm^{-2}$*,* $118.65Nmm^{-2}$*, 0.9%,* $411.15\ Nmm^{-2}$*, 65.67HV,* $0.12\ mm^3n^{-1}m^{-1}$*, 0.56,* $191.58Wm^{-1}K^{-1}$*, and* 0.11^oC^{-1}*. The values of these properties fall within the range of the density and strength properties of standard Al alloys. Also, the peak values of the Loss modulus and damping coefficient obtained through the dynamic mechanical analysis of the recycled Al ingot are* $1118Nmm^{-2}$ *at* 46^oC *and 0.029 at* 45.8^oC *respectively. The lightweight, high thermal conductivity, good wear resistance and good strength properties will make Al ingot good for use in structural application such as brake disc.*

Keywords: *Beverage Can Scraps, Aluminium Ingot, Recycling, Characterization, Mechanical & Thermal Properties*

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I. Introduction

A waste material refer to materials that are abandoned or discarded as refuses or scraps when they reach the end of their life cycle or when their contents are consumed or extracted. Waste materials result from activities in the manufacturing, food processing and agricultural industries (Anyanwu *et al*, 2013; Rosenkranz *et al*, 2011). Municipal solid wastes (MSW) exist in large quantity and their constituents (rubber, plastics, papers, glass, metal scraps (Al scraps, tin & cans), ceramics, wood, textiles, compostables, vegetables, water sachets and cellophane packages, ash, etc.) vary due to increase in food processing, construction and agricultural activities. Nigeria is one of the biggest contributors of solid waste in Africa with an estimated 32 million tons each year; yet only few states provide landfills or dumpsites for the MSW (Obi *et al***,** 2016). In fact, the management of MSW in most developing countries remain a big challenge. Mostly, MSW are dumped in open places and this has been a major source of ecological challenges - blocking water ways and occupying land space. Also, the burning of MSW indiscriminately has resulted to environmental pollution due to emission of gases (Andreas, 2014; Davies, 2015; Adeyi, 2010).

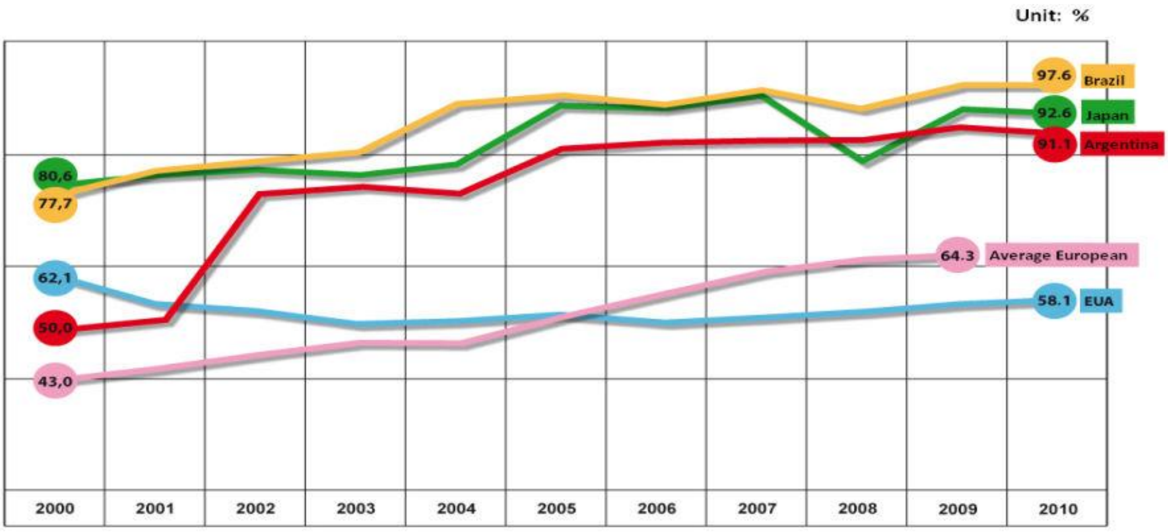
In Nigeria, MSW generated per capita per day in Lagos, Kano, Ado Ekiti and Markudi is 0.63kg, 0.56kg, 0.71 and 0.48kg respectively (Akindayo, 2019; Obi**,** 2016; Babayemi & Dauda, 2009).

Akindayo (2016) wrote on the MSW management and the inland water bodies: Nigerian perspectives listed the components of MSW in Nigeria to include: rubber, paper, plastics, glass, Al scraps, metal scraps, tin and can scraps, food, wood, leaves, etc. The quantity of each of waste's component varies across the different states in Nigeria.

Konya et al (2013) in their study titled 'Characterization of wastes and their recycling potentials; a case study of East-West road, Port Harcourt' discovered some common wastes at the receptacles were cartons, papers , animals bones, plastics , Al plates, nylon bags, ceramic materials, vegetable stems, hospital wastes, old and damaged electronics, old computers, photocopying machines, Al cans, etc. It was observed that: plastics, and Al cans can be recycled into fleece jacket and Al sheet respectively. Bottles, glass and ceramics can be recycled into their original products. Stems of vegetable and garbage can be used to produce compost while animal bones can be used to produce vim. Combustible materials on can be used as fuel.

One of the most valuable wastes in the waste bin is beverage can scraps (BCS). The average can contains between to 92-99% Al with other metals like magnesium (Mg), manganese (Mn), iron (Fe), silicon (Si), and copper (Cu) (http://www.aluminum.org/CanAdvantage). The body of a can is made from 3104 Al alloy and the lid is made from 5182 Al alloy; so a can has a dual design (Jack and Ray, 2013). The use of Al as can to package beverages such as sodas, energy drinks, sparkling waters and craft brew beers was pioneered by Coors, in 1959. Since then, there has been a steady growth in the use of Al cans because of the steady increase in canned beverages and food. For example, 500 craft beer brewers use Al to can more than 1,700 different beers. Consequently, BCS becomes the world's most recycled packaging material, with consistently high recycling rates compare to glass and plastics packaging materials. In the U.S., the average recycled contents of Al, plastic and glass are 73%, 3% and 23% respectively. In 2016, Al industry in U.S. recycled 56.9 billion cans (Shakila, 2013; Jokhio *et al*, 2017; http://www.aluminum.org/CanAdvantage).

Between 2000 and 2010, Brazil recycled 14.7 billion BCS annually to produce 98.2% of its Al and was ranked first in the world followed by Japan that recovered 82.5% of its Al from BCS. Other countries that were involved in recycling of BCS are Argentina, Average European and EUA. It is observed that recycling rate maintained a steady increase as shown in figure 1 below (Shakila, 2013).



Source: (http://www.aluminum.org/CanAdvantage)

Figure 1: *Rate of recycling Al from BCS for some countries between 2000 and 2010*

The use of Al as to package beverages and will continue to increase because the can is light, infinitely recyclable, chill quickly, provide a superior metal canvas to print on, protect the flavour beverages and resistant to corrosion (http://www.aluminum.org/CanAdvantage).

Again, recycling Al scraps requires only 5% of energy used to produce primary Al. E.g., recycling Al scraps requires only 2.8 KWh/Kg of energy and emits 0.6kg of CO_2 as against 45 KWh/Kg of energy and 12Kg of CO_2 (http://www.aluminum.org/CanAdvantage; Jokhio *et al*, 2017).

Shaymaa (2013) investigated the composition and hardness of the ingot recycled from BCS. The ingots were homogenized at 500°C for 2 hours. The chemical composition of the ingot showed that the BCS is Al with Mn as a major alloying element. Micro hardness of the recycled ingot was found to be 50.59 kg/mm^2.

Shakila (2013) investigated the effect of high purity salt flux composition and other additive composition (chlorides and fluorides) on the recovering of Al ingots from BCS. Recycling at a temperature range of 450^{o}C to 950^{o}C and using 5% of flux has led to good yield of the ingots. However, Craters and Dendrites were formed in the ingots when the flux was used in excess. Mg and Al oxides existed in the form of dross due to the oxidation of the internal surfaces and channels.

Stefano and Giulio (2018) reviewed Al recycling process from the scraps' upgrading to the melting process. Innovations and new trends of Al recycling technologies were discussed. Preliminary treatments during recycling process such as sorting, comminution and de-coating are carried out to improve the quality of the ingots. Also, downgrading and dilution are used to reduce impurities.

In Nigeria, though BCS are generated in large across the different city centres because they are considered as trash when the content, limited statistics are available on the physical, mechanical and thermal properties of the Al ingot recycled from BCS.

The aim of this study is to produce and characterize Al ingots recycled from beverage can scraps

II. Materials And Methods

2.1 Materials/Equipments

The materials and equipments used for the study include beverage can scraps. Digital weighing machine; mould (Gidgeon Pins); Ladle; Stirrer; Positive materials identification machine; Crucible furnace, Scanning electron microscope (SEM) with energy dispersive spectrometer (SEM/EDX), Pin-on-disc tribometer; Universal tensile tester; Hardness tester; Dynamic mechanical analyzer and Searle's apparatus.

2.2 Method

The beverage can scraps were sourced from the scrap market in Jos, cleaned and compressed. The compressed BCS were placed in a crucible furnace and heated until it melted. A thermocouple was used to measure the temperature. When a melting temperature of 800^{o}C was attained, slag was removed and then the molten metal poured into a metal mould and allowed to solidify. This work was carried out in a foundry workshop at National Metallurgical Development Centre, Jos and the ingot is shown in Plate V.

(a) (b) (c)

Plate 1 (a) the moulds, (b) molten metal in mould and (c) recycled aluminium ingots

2.2.1 Characterization of the recycled aluminium ingots

The characteristics of the recycled Al ingot that were determined include: chemical composition, density, tensile strength, compression strength, wear rate, thermal conductivity, thermal expansion, storage modulus, loss modulus, damping coefficient and microstructure. The determination of the characteristics of the recycled Al ingot was carried out at different places: Midwal Engineering, Ltd, Lagos; NMDC, Jos; and Metallurgy and Material Processing Laboratory, Dept Metallurgy and Material Engineering, A.B.U., Zaria.

2.2.1.1 Chemical composition

The samples (25mm x 25mm x10mm) shown in Plate II for chemical analysis were produced at the machine shop of NMDC, Jos using a lathe machine. Three (3) specimens were used for the analysis. First, the samples were polished on 60 grit sand paper to remove debris from the machined surface. The positive material identification machine was placed on the polished surfaces and the composition determined. The test was repeated three times on each sample and then the results exported to Excel to determine the average values of the chemical composition of the ingots. The result of the analysis is shown in table 1.

Plate II Specimens for chemical analysis

2.2.1.2 Density

The specimen used to determine the density of the ingot shown in Plate III was produced at the Machine shop of NMDC, Jos.

Plate III Specimen for density test

The density (ρ) of the recycled Al ingots was determined as follows: first, a solid cylindrical shape was produced and its mass (M), diameter and length were measured. The volume (V) of the ingot was determined using the geometry method. The mass of the cylinder was measured using a digital weighing machine while the length (L) and diameter (d) were measured using a vernier caliper.

$$V = \pi x \frac{d2}{4} xl \text{ --- (1)}$$

$$V = 3.142x \frac{(2.54)2}{4} x1.02 = 5.169 \text{ cm}^3$$

$$\rho = \frac{M}{V} \text{ --- (2)}$$

$$\rho = \frac{13.561}{5.169} = 2.624 \text{ g/cm}^3$$

The result of the density analysis of the recycled Al ingot is shown in table 2.

2.4.2.1.3 Thermal conductivity

The thermal conductivity of the recycled Al ingot was determined using Searle's apparatus. The apparatus has four thermometers; stop watch; weighing balance; water base; power pack; heater; ammeter and volt meter; and the schematic diagram of the apparatus setup is as shown in figure 2.

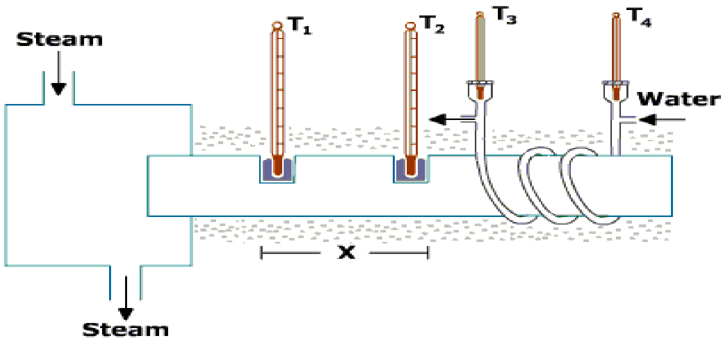


Figure 2: Schematic diagram of the Searle's Apparatus

A stream of water was maintained in the copper tube coiled at one end of rod away from the steam chamber and it leaves at the other end of the rod nearer to the chamber. The temperatures, T_4 and T_3 at inlet and outlet of water were measured with the thermometers inserted at those points. The other end of the apparatus with steam chamber was connected to a power pack which converts AC to DC so that the voltage and current can be monitored effectively. The Al ingot sample, ϕ160mm in diameter and 10mm thick (shown in plate IV) was produced at the Machine shop of NMDC, Jos. The specimen was placed in a specimen holder for 10 minutes, then the temperatures at each end of the specimen were recorded. The voltage, current and cross-sectional are of specimen were determined.

Plate IV: Al ingot specimen

The thermal conductivity, K of the specimen was determined using the following equation:

$$K = \frac{QL}{A(T_2 - T_1)} \text{ --- (3)}$$

Where: Q = heat flow (W); L = length or thinkness of the specimen (m); A = cross-sectional area of the specimen; T_2-T_1= temperature gradient (K)
The result of the test is as presented in table 2

2.2.1.4 Coefficient of thermal expansion(COE)

The specimen used for thermal conductivity test (shown in plate IV) was also used for COE test. The specimen was clamped firmly at one edge in a retort stand. A steel meter rule provided to measure the thermal expansion of the sample was clamped in another retort stand against the sample. The specimen was then heated at centre using a Bunsen burner for 7 minutes. The new length of the sample was then recorded. The thermal expansion was determined from the difference between the new length and the original length of the sample. The coefficient thermal expansion is determined using the equation:

$$\alpha = \frac{\partial L}{L_o(T_1 - T_0)} \text{ --- (4)}$$

where: ∂L = change in length; L_o= original length; $T_1 - T_0$ = temperature gradient (^oC)
The result is as presented table 2

2.2.1.5 Tensile strength

The specimens were produced through casting as presented in Plate V (a) and (b). The specimens shown in Plate V (b) were produced at the Machine shop of NMDC, Jos using a Lathe machine. Each specimen was mounted on a Universal tensile testing machine and an axial load was applied continuously at a rate of 20mm/min until the specimen fractured. The tensile properties: ultimate strength, yield strength, modulus of elasticity and % elongation were determined. The process was repeated for the other specimens and the average value determined as presented in table 2.

(a) (b)

Plate V: (a) As cast tensile specimen and (b) Produced tensile strength test specimens

2.2.1.6 Compression strength

The specimens that were used for the density analysis (shown in Plate II) were also used to determine compression strength of the recycled Al ingot. Two (2) specimens, each of dimension ϕ22mm diameter and 25.4mm length were used for the test. The specimen was placed between two fat anvil surfaces of the Universal tensile tester and then the load was applied continuously by the machine at a uniform rate of 20mm/min and the specimen was compressed until it fractured. The compression strength was monitored on a PC attached to the machine through a stress-strain plot. The process was repeated for the other specimens and the results are as presented in table 2.

2.2.1.7 Wear rate

The specimens (ϕ22mm diameter and 20mm long) for wear rate test are shown in Plate VII. A Pin-on-disc standard tribometer (version: 6.1.19) tester was used for the test. First, the tribometer's software was opened on a computer connected to the tribometer and the track radius (5.00mm), linear speed (10.00 cm/s), number of turns (rpm), distance travel/Lap and applied load (8.00N) were inputted. The specimen was mounted in the jaw chuck of the machine and the arm that applied the load was lowered until it rested on the surface of the specimen. Then, the tribometer was turned on and it continued to run until the set distance was reached and it stopped automatically. The resulting worn track, wear rate, stop condition and frictional force acting between the pin and the disc were recorded. The process was repeated for the other two (2) specimens. The result is as presented in table 2.

Plate VII: Specimens for wear rate test

The schematic diagram of the pin-on-wear test process is as shown below.

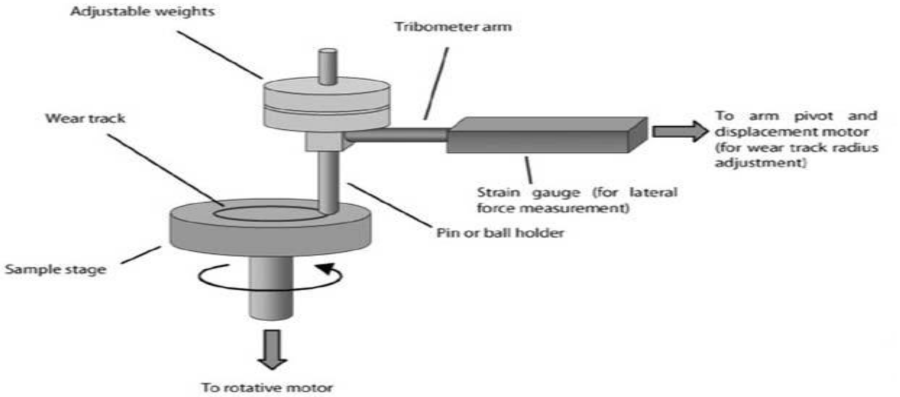


Figure 3 Schematic diagram of the pin-on-wear test process

2.4.2.1.8 Dynamic mechanical properties

The dynamic mechanical properties (Storage modulus, Loss modulus and Damping coefficient) of the recycled Al ingot were determined through dynamic mechanical analysis **(**DMA). The DMA machine used was NETZSCH DMA 242. The specimen was produced through casting and then machined to specification: 40mm x 5mm x 1.4mm (Plate VIII). The selected test parameters: temperature - 30^{o}C to 250^{o}C; frequency – 1Hz and 5Hz; and deformation load – 2.18N; and other information: material name, specimen geometry, starting temperature, heating rate, end temperature, frequencies and deformation amplitude were inputted using the computer system attached to the DMA machine. The specimen was placed in a specimen holder provided in the furnace. The machine was then put on and the test continued; and when the inputted end temperature was reached, the machine stopped automatically. The results: storage modulus, E', loss modulus, E”, damping coefficient, tan d and deformation, dL at the frequencies 1Hz and 5Hz; and temperature ranging from 30^{o}C to 250^{o}C are presented in graphics of figures 4(a, b, c, and d). Also, the peak values of the Loss modulus, damping coefficient and change in line at different temperatures are presented in table 2.

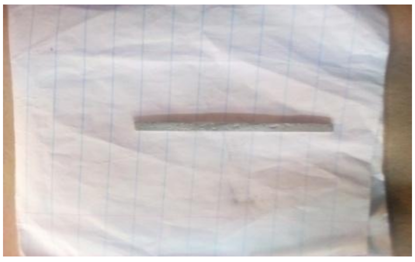


Plate VIII: Specimens for DMA

3.2.1.9 Microstructure analysis

The microstructure analysis was done on a Phenom SEM. The specimens produced at the Machine shop of NMDC, Jos were etched and then placed in the specimen holder using colloidal graphite. The specimen was placed in the SEM and transferred automatically to the optical imaging position. The optical camera was activated and the image was displayed in the main viewing window of the image screen. The brightness and magnification of the images were selected. The results of the SEM analysis and energy dispersive X-ray spectrum are presented in Plate IX.

III. Results And Discussion

3.1 Chemical composition of the recycled Aluminium ingots

The chemical composition of the recycled Al ingots is as presented in table 1.

Table 1 Chemical composition of recycled Al ingots

Al(%)	Cr(%)	Cu(%)	Fe(%)	Mg(%)	Mn(%)	Si(%)	Zn(%)	Ti(%)	V(%)	Ni(%)	Pb(%)
95.62	0.005	0.162	0.437	1.62	0.693	1.32	0.097	0.024	0,017	0.006	0.008

The chemical compositions of the recycled Al ingot contained the following elements: Al, Mg, Si, Fe, Cu, Mn, Cr, Zn, Ti, V, Ni and Pb in different concentrations. The major elements in the ingot are Al (95.62%), Mg (1.62%) and Si (1.32%). This shows that the recycled Al ingot is Al-Mg-Si alloy system. Also, it can be inferred from chemical composition that the recycled ingot is a low alloy system, and as such its properties can be upgraded through the additions of other elements (Das et al, 2006).

3.2 Properties of the recycled aluminium ingot

The density, ρ; ultimate strength, σ_u; yield strength, σ_y; percent elongation, ε(%), compression strength, σ_c; vicker hardness, HVN; thermal conductivity, Tc; coefficient of thermal expansion, COE; wear rate, Wr; and coefficient of friction, μ of the recycled Al ingot are presented in table 1.

ρ (g/cm^3)	σ_u (N/mm^2)	σ_y (N/mm^2)	ε (%)	σ_c (N/mm^2)	VHN	W_r (mm^3/Nm)	μ	T_c (Wk^{-1} m^{-1})	CTE (°C^{-1})
2.62	136.03	118.63	0.9	411.15	65.6 7	0.12	0.56	191.58	0.11

The density of the recycled Al ingots was determined as 2.62 gcm^{-3}. This value falls within the range of densities of 0.016 to 3.5 gcm^{-3} of existing standard Al alloys. This shows that the BCS are light materials, and as such they can be considered suitable for use as structural materials for lightweight applications (http://www.matweb.com).

These tensile strength properties were found to fall within the range of tensile strength properties of the existing standard Al alloys that ranged from 0.7 to1500N/mm^2 – ultimate strength; 1.24 to 730 N/mm^2 – yield strength; 0.138 to 3400 N/mm^2 – compression strength; 0.13 to 50% - percent elongation and 15 to 230 HV - Vicker hardness respectively (http://www.matweb.com).

The recycled Al ingot has high thermal conductivity and as such it is suitable for structural application like brake disc where high thermal conductivity is a basic requirement. The thermal conductivity falls within the range of thermal conductivity standard Al alloys of 1.48-255 Wm^{-1}k^{-1} (http://www.Matweb).

The recycled Al ingot has good wear resistance. The coefficient of friction was found to be 0.56 and it remained constant with increase in the time and distance under constant applied load.

3.1.3 Dynamic mechanical properties of the recycled Aluminium ingots

The dynamic mechanical characteristics – storage modulus, E'; loss modulus, E''; damping coefficient, tan d; and the change in length (dL) of the recycled Al ingots are presented in graphs of figures 4, 5, 6 and 7.

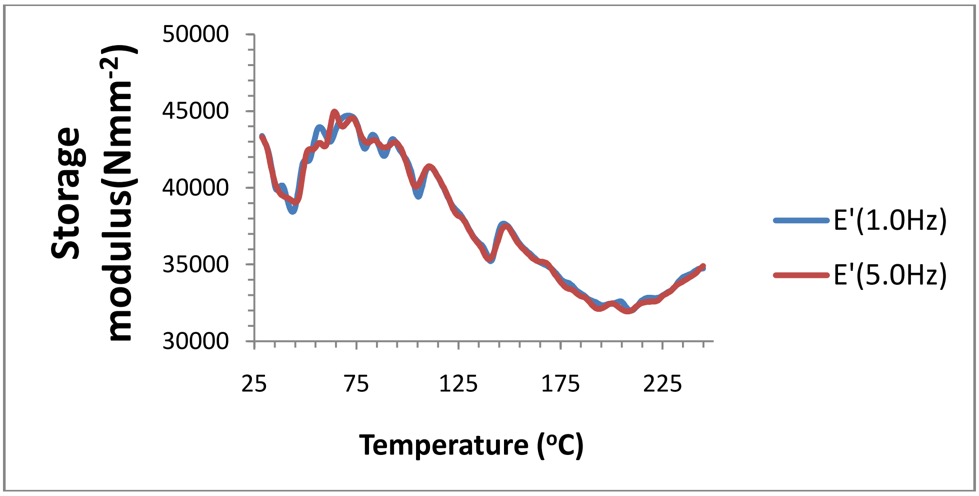


Figure 4: Storage modulus versus temperature at 1Hz and 5Hz

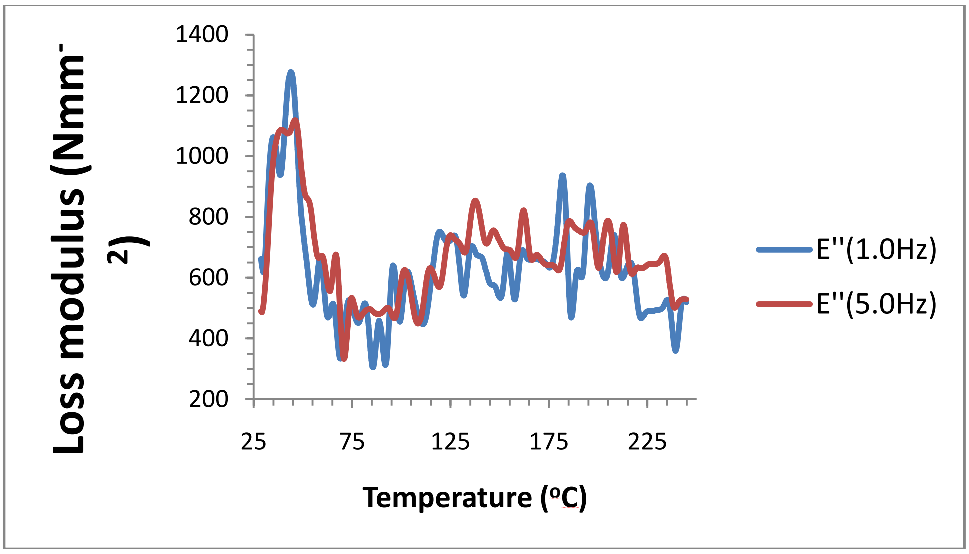


Figure 5: Loss modulus versus temperature at 1Hz and 5Hz

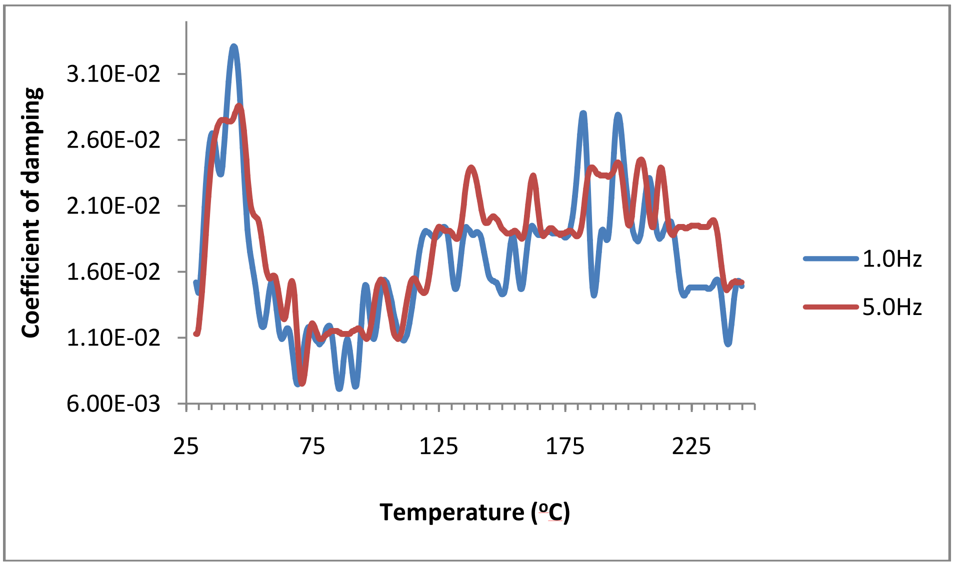


Figure 6: Damping coefficient versus temperature at 1Hz and 5Hz

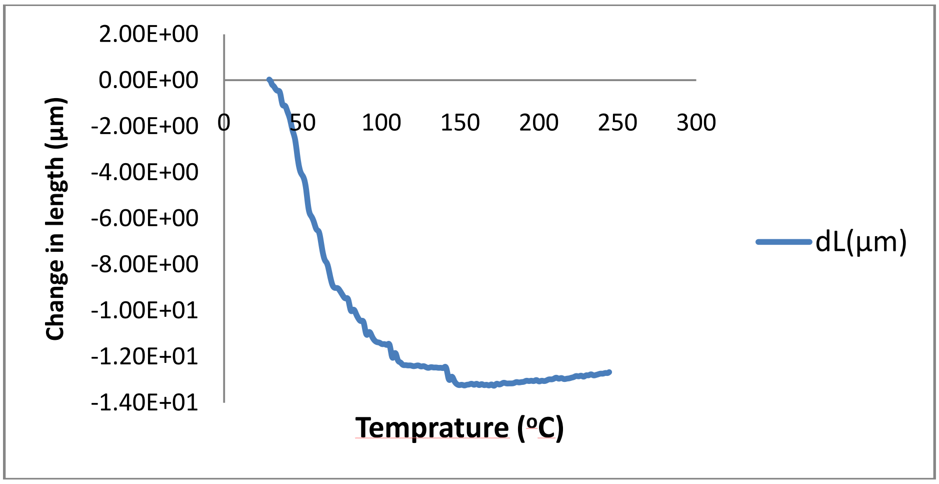


Figure 7: Change in length versus temperature at 1Hz and 5Hz

From the graph of figure 4, it is observed that the storage modulus the recycled ingot recycled ingot is high at low temperature and low at high temperature though failure has not occurred. The ingot attained a peak value of storage modulus of 43000N/mm^2 at 60.8^{o}C. Similar behaviour was observed in the variation of Loss modulus, damping coefficient and change in length with temperature. The peak values of Loss modulus, damping coefficient and change in length were 1118N/mm^2 at 46^{o}C, 0.029 at 45.8^{o}C and -13.3µm at 171.6^{o}C.

3.1.7 Microstructures of the recycled aluminium ingots

The microstructure and energy dispersive spectrograph of the Al ingot recycled from BCS are shown in Plate X below.

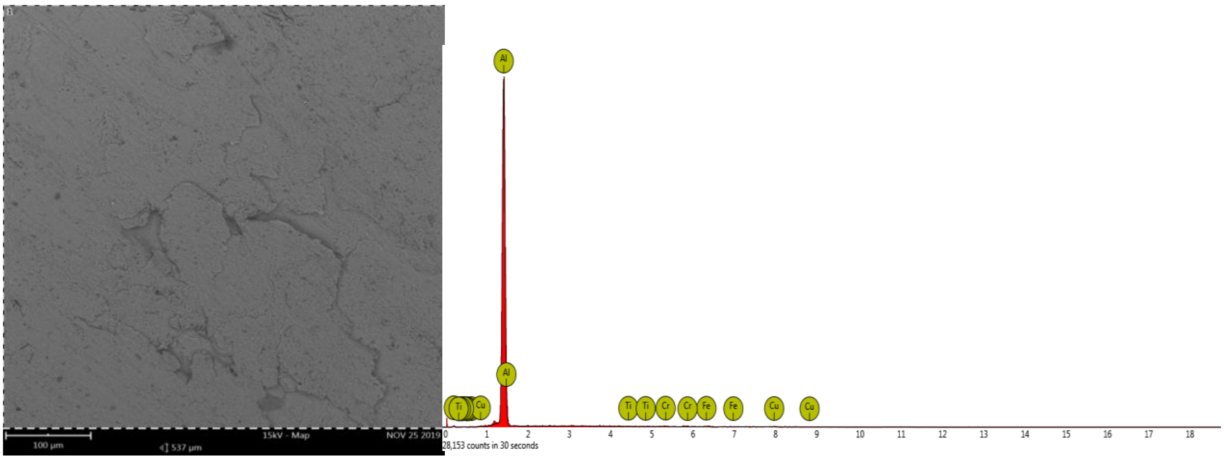


Plate X SEM/EDX of recycled Al ingot

The microstructure is smooth though few traces of inclusions and dendrites are observed. This makes the ingot suitable for use as structural material. This result is similar to the results obtained by Salleh *et al*, 2015, Shouxun et al, 2013 in their respective studies on recycling BCS. Energy dispersive spectrograph (EDS) revealed Al as the major element with. other elements such as carbon, copper, iron, chromium, oxygen and titanium.

IV. Conclusion

The following conclusions were made based on the preparation and characterization of Al ingot from beverage can scraps.

i. The Al ingot was produced from BCS its chemical composition showed Al, Mg and Si as major elements with weight concentration of 95.62%, 1.62% and 1.32% respectively.

ii. The density, ultimate strength, yield strength, percent elongation, hardness, compression strength, wear rate, coefficient of friction, thermal conductivity, coefficient of thermal expansion, storage modulus, loss modulus and damping coefficient were determined as 2.62gcm^{-3}, 138.03 Nmm^{-2}, 118.65 Nmm^{-2}, 0.9%, 65.67HV, 411.15Nmm^{-2}, 0.1236mm^3/Nm, 0.56, 191.58Wm^{-1}k^{-1}, 0.11^{o}C^{-1}, 4300Nmm^{-2}, 1118Nmm^{-2},and 0.029 respectively. The mechanical and thermal properties of the recycled Al ingots were found to fall within the following ranges of the properties of standard Al alloys: vicker hardness: 15–230HV; ultimate strength : 0.7-1500Nmm^{-2}; yield strength: 1.24-730Nmm^{-2}; compression strength: 0.138-3400; percent elongation: 0.13-50%, and thermal conductivity: 1.48-255Wm^{-1}k^{-1} (http://www.Matweb.com; Kaufman & Rooy, 2010;).

iv. The SEM analysis of the recycled Al ingot did not showed the presence of dross in the microstructure. Also, from the EDX analysis, no radioactive elements were detected in the recycled Al ingot.

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