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An Investigation into the Mechanical and Structural Properties of Alloys Obtained from the Recycling of Beverage Cans

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ABSTRACT

Aluminum is currently in greater demand in the transportation sector. This is the result of efforts to make the car more lightweight and reduction in production cost. The main forces behind the continued development of less expensive, unique, and imaginative materials are the dynamics and competition in the transportation sector. In this study, investigated the mechanical and structural properties of aluminium alloys produced from recycled beverage cans. According to the type of alloy, three different alloys were produced by recycling beverage cans. Both the first alloy and the second alloy were produced by recycling the alloy used to produce the can lid (CCO) and the can body (CBO), respectively. the third alloy, were produced by combined the can body and cover (CCM) alloys together. At 300 oC, the alloys were treated for one hour. The ratios of the alloys in atomic percentage were calculated using the EDS data from multiple points for each alloy. It was found that these alloys contain the highest percentage of aluminum of other metals. By analysis the X-ray diffractogram of alloys, it's found the (α- Al) is high peak in all alloys were produced in thes work. Besides that, The secondary peaks of these alloys are Al2Mg and Al2Mn. In addition to primary and secondary peaks, the alloys also contain other peaks. CCO and CBO alloys have the low hardness values, whereas the CCM alloy had the highest hardness values.

Keywords: Recycling of beverage cans, Beverage cans, Mechanical properties, Structure properties, Al alloys

I. INTRODUCTION

Green economics is a key area of the most important orientation for developing an environmentally friendly society [1]. A method for decrease climate change is to increase recycling. Less raw materials are required to deliver the same social benefits with greater material recovery. Aluminum offers excellent significant environmental benefits due to its infinite recycling ability.

Aluminum is widely used nowadays. It can be found in a variety of areas, including beverage cans, food packaging, chips, and automobile components[2]. Aluminum and its alloys have unique properties that make them one of the most adaptable, cost-effective, and appealing metallic materials for a wide range of applications, from very durable soft laminates to the most demanding engineering ones. These are a few of aluminum special characteristics[2]. The most important properties of aluminum are its excellent mechanical properties, low density when compared with steel, as well as its ability to be cycled repeatedly without loss of quality products and with minimum material loss due to oxidation (1-2%). Moreover, compared to original materials, recycling saves nearly 95% in energy and emissions, an important factor in a carbon-constrained world. Thus, there is a growing need for aluminum and aluminum alloys on the international market.

Recycled aluminum in particular is being used in auto parts, which is crucial since it lowers vehicle mass, stabilizes fuel efficiency, and lowers pollutants. Ultimately, this application is expected to have a beneficial impact on the carbon footprint of the aluminum industry. Aluminum is resistant to the kind of gradual oxidation that makes steel rust. The exposed surface of aluminum reacts with oxygen to form an inert layer of aluminum oxide that is only a few ten- millionths of a cm thick and prevents further oxidation. In contrast to iron rust, the aluminum oxide film does not flake off to expose a fresh surface to subsequent oxidation. If aluminum is scratched, its protective layer will rapidly reseal. The thin oxide layer is transparent, without color, and firmly adheres to the metal. Moreover, it is invisible to human sight. Unlike iron and steel, aluminum does not corrode, flake, or change color.

The density of aluminum is approximately 2.7 g, cm3, Around a third as much as steel (7.83 g, cm3) [3]. Because of this lightweight and the high strength of some aluminum alloys (some of which are stronger than structural steel), it is possible to design and build sturdy, lightweight structures that are especially useful for moving objects like aircraft, spacecraft, and all kinds of land- and water-based vehicles.

Aluminum stands out for its amazing ability to be recycled without losing any of its physical or chemical properties, which makes the metal a fantastic option, particularly for the preparation, storage, and protection of food and drinks. Aluminum has the ability to be formed into extremely thin foils. These thin, strong, and very effective aluminum foils protect food and beverages from Uv light and bacteria. Packaging made of aluminum is safe, tamper-proof, hygienic, simple to open, and recyclable during its useful life; almost all commercially made aluminum products can be recycled without losing their metal characteristics or quality. Due to the rising usage of recycled aluminum in numerous applications, aluminum metal is also known as green metal[4].

The goal of this research is to create alloys from recycled beverage cans, study their mechanical and structural properties, and determine whether they can be used in industrial fields with environmentally polluting emissions. As a result, they can be applied to a variety of vehicles.

Beverage cans are usually made of three different alloys. The lid is made of ASTM 5182 and the main can body is made of ASTM3004. In addition, the third alloy that makes up the seal is ASTM 5082. Its composition is shown in Table1 [5].

Table 1. Stander chemical compositions of alloys used in the manufacture of aluminum cans [5].

Components	Si (%)	Fe (%)	Cu (%)	Mn (%)	Mg (%)	Zn (%)	Cr (%)	Ti (%)
Body (ASTM3004)	0.3	0.7	0.25	1.0	1.5	0.8	1.3	0.25
Lid (ASTM5182)	0.2	0.35	0.15	0.2-0.5	4.0-5.0	0.25	0.1	0.1
Seal (ASTM5082)	0.2	0.35	0.15	0.25-0.4	3.3-4.0	0.25	0.15	0.10

II. Experimental Procedures

2.1. Alloys preparation

We began this research by assembling and cleaning beverage cans. Usually, the cover of the can is made from a different alloy than the one used for the can body, so we have split the can into the alloys it is composed of to use them to make new alloys. Then we melted them as batches in a gas-fuel furnace and poured them into a steel mould to form the alloys. Thus, we have three types of alloys that we obtained from recycling beverage cans. As shown in Fig 1 and Table 2 we produce three groups of alloys. The first group of alloy (CCO) was produced by melting the alloy of the can's body; the second group of alloy (CBO) were produced by using the alloy of the can's lid only, and the third group is the alloy (CCM) were produced by mixing the alloy of the body and lid(the alloys of the first and second group)were combined to produce the third alloy (CCM).

Table 2. The alloys were produced using beverage cans that had been recycled

Code of alloy	The alloy made by
CCM No. 1	different cans
CBO No.4	Beverage cans body
CCO No.5	Beverage cans lids

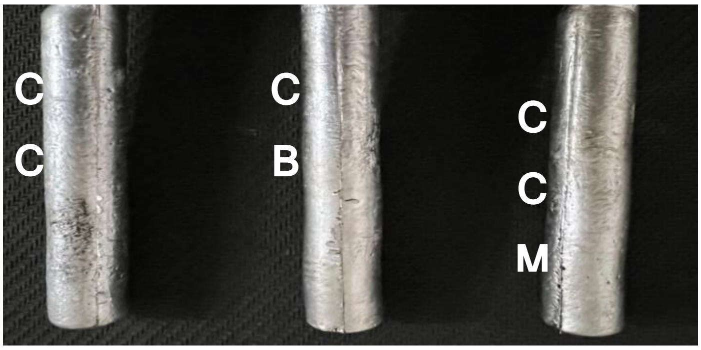


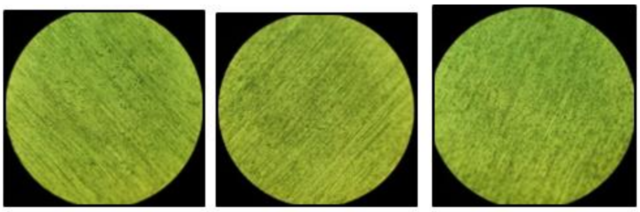
Fig. (1) Three types of product alloys

2.2. Alloys treating

Heat treatment processes were carried out for the manufactured alloys, where an electric furnace was used to heat the alloys. The alloys were introduced into the furnace and were heated to 300 °C for one hour, after which the alloys were removed from the furnace and the alloys were left in the laboratory for 24 hours at room temperature. The alloys are cut into different thicknesses using a CNC machine to produce high-quality surfaces.

2.3. Mechanical Test (Hardness Test)

In the beginning, each alloy surface is treated with a liquid for five seconds to appear more transparent (Etching). This solution contains 2 ml of hydrochloric acid (HCl), 96 ml of ethyl alcohol, and 5 grams of ferric chloride ($FeCl3$). The surfaces of the alloys were then photographed with an optical microscope and a mobile phone camera. Pictures captured on the surfaces of the alloys are shown in Figure 2.



CCM No.1 CCB No.4 CCO No.5

Fig.(2) The surfaces of (CCM, CCB and CCM) alloys

The material's resistance to localized plastic deformation, such as a minor dent or scratch, is measured by its hardness [6]. Initial hardness tests used natural minerals, and a level built purely on how easily one substance could scratch a softer material. Before performing the hardness test on the samples, appropriate smoothing and polishing processes were carried out. Vickers method was employed in this work to determine the hardness value. The HV was assessed using the WOLPERT gadget of type (V-Testor 2) as shown in Figure 3. with P =1kg and Equation 2. A square-base diamond pyramid is used as the indenter in the Vickers hardness[HV] test as in Fig 4.

$HV=2\,P\,sin(\emptyset, 2), (D^{2}_{mean})$ 1

$HV=1.854\,P, (D^{2}_{mean})$ 2

where:

HV: measurement of Hardness Vickers,

P : is the load in (kg),

$\emptyset=136^{\circ}$, $sin(\emptyset, 2)$=0.927

D^{2} : is the squared average between the length and width of pressured diamond head .

Fig. (3) WOLPERT gadget of type (V-Testor 2)

Fig. (4) The indenter of hardness test.

2.4. Investigations of alloy structure

In this study, Several examinations were made for the structure of the manufactured alloys using the EDS-SEM and XRD. The alloys were treated with heat at 500°C for one hour before being analyzed using an X-ray diffractometer that was computer-controlled. A steady scanning speed of 2o, min was used for measurements between 2 = 0° and 80º. The alloys' lattice properties were established using an X-ray diffractometer. The Energy Distribution Spectroscopy (EDX) method was used to calculate the alloy ratios. Scanning electron microscopy (SEM) was used for microstructural analyses. Using the EDX system, compositional analyses, SEM analyses, and mapping analyses of alloys were performed.

III.Results and decision

3.1. EDS Analysis

The samples were cut using a CNC device for SEM-EDS measurement after the heat treatment of the alloys was completed. The small cut pieces were embedded in polyester resin, one side of the implanted piece was polished using a polishing device. A 75ml HCl, 75ml ethanol, 15g $CuSO_4$, and 10ml distilled water etching solution was used to etch the polished surface. Following etching, optical micrographs and SEM images were taken. SEM photos were collected from the complete alloy surface and its different regions. The different regions were selected, EDS spectra were obtained, and the results of these four regions were averaged to determine the weight and atomic per cent ratio of the alloys. Based on the EDS spectrum results, the electron concentration (e, a) was determined for each alloy.

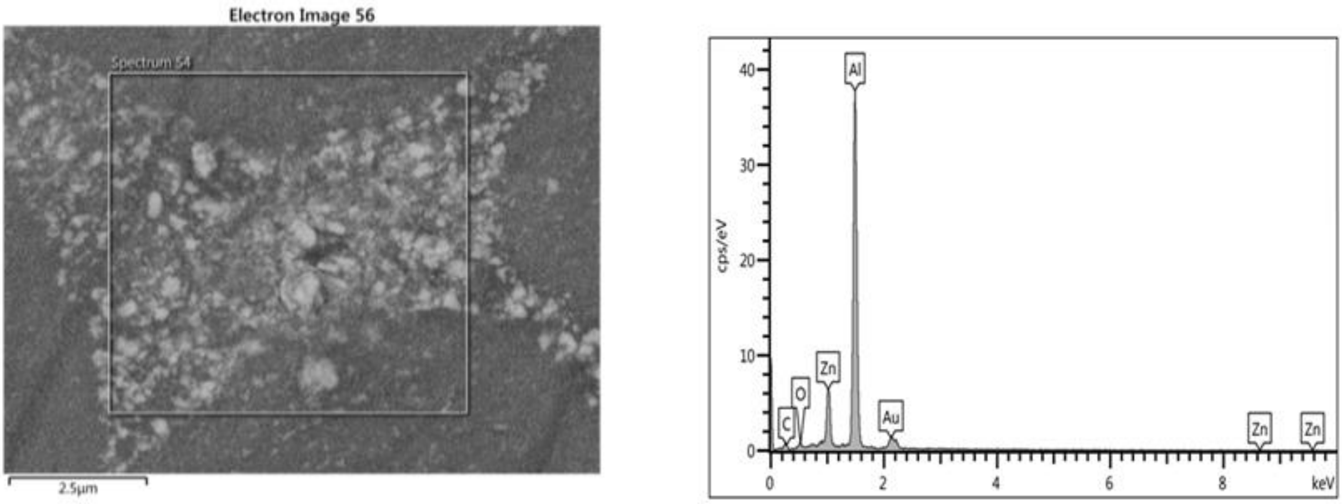
When the EDS spectrum results of the alloys are compared with the ratios determined before casting, it is seen that the percent weight and percent atomic values are different. Although the samples were kept far away from the oxidation, oxidation occurred when the elements were melting into powder form. The ratios before casting and the ratios after casting differed because some slag was produced as a result of oxidation. The EDS spectra show the presence of Al, Zn, and carbon in significant amounts. The oxygen content is present in both the recycling alloys and EDS spectra further showed that the Mn is present in oxides form.

By detailed investigations of the sample morphology and the nature of the precipitates were carried out using EDS. Al, Mg, Zn, C, O, Mn, and Au are all found in the alloys were made in beverage cans according to the EDS analysis in general. On the surface of the alloys, precipitates also form. Two different types of precipitation were seen. The investigation showed that the black precipitates contained a substantial amount of C and O, whereas the white precipitates revealed an unexpected amount of Mg and Zn. In these analyses, the element Au was also noted as shown in fig. (5) and percentages of elements that found in these alloys shown in table (2).

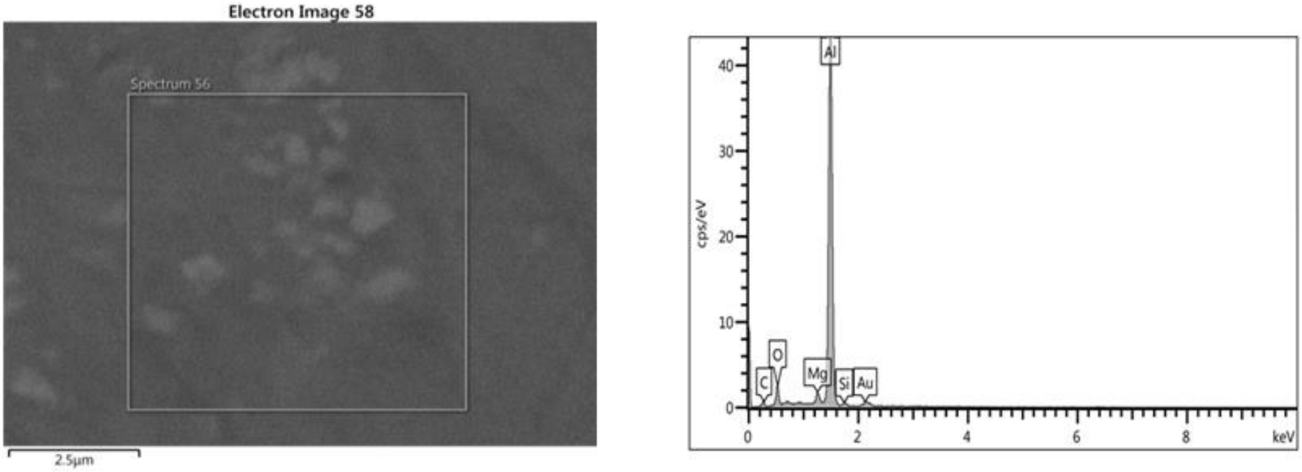
Table (2) Element ratios obtained by EDS analysis results of alloys were produced using beverage cans that had been recycled

Table (2) Element ratios obtained by EDS analysis results of alloys were produced using beverage cans that had been recycled

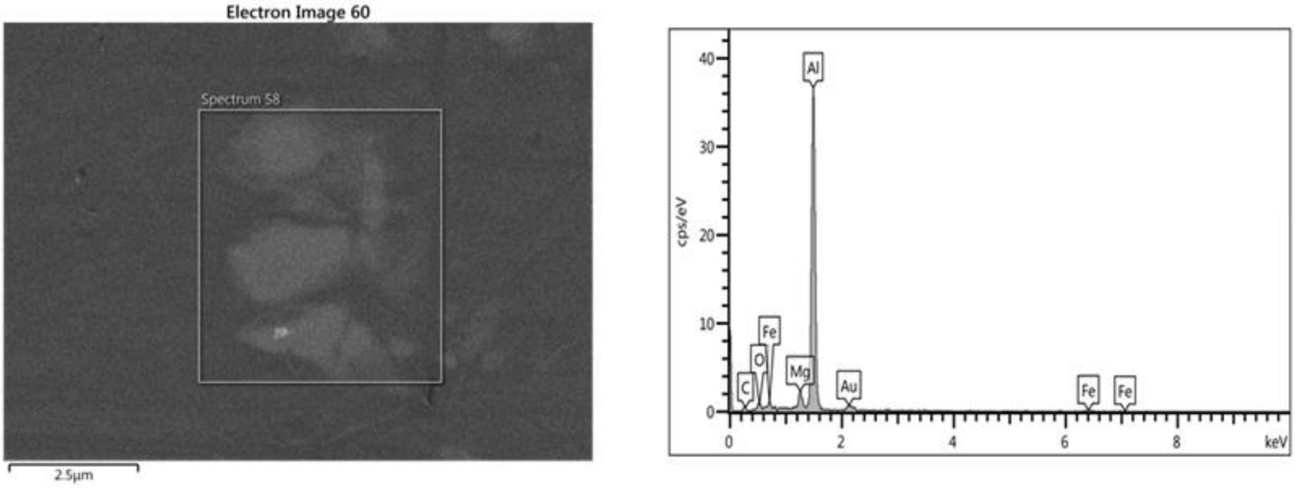
Code of alloy	The alloy made by	Alloying Elements				
		Al	Mn	Zn	Mg	Other
CCM No. 1	**different cans**	**78.2**	**-**	**18.1**	**-**	**3.7**
CBO No.4	**Beverage cans body**	**89.6**	**-**	**-**	**2.0**	**8.4**
CCO No.5	**Beverage cans lids**	**86.3**	**-**	**-**	**3.6**	**10.1**



CCM No. 1



CCSO No. 3



CCO No. 5

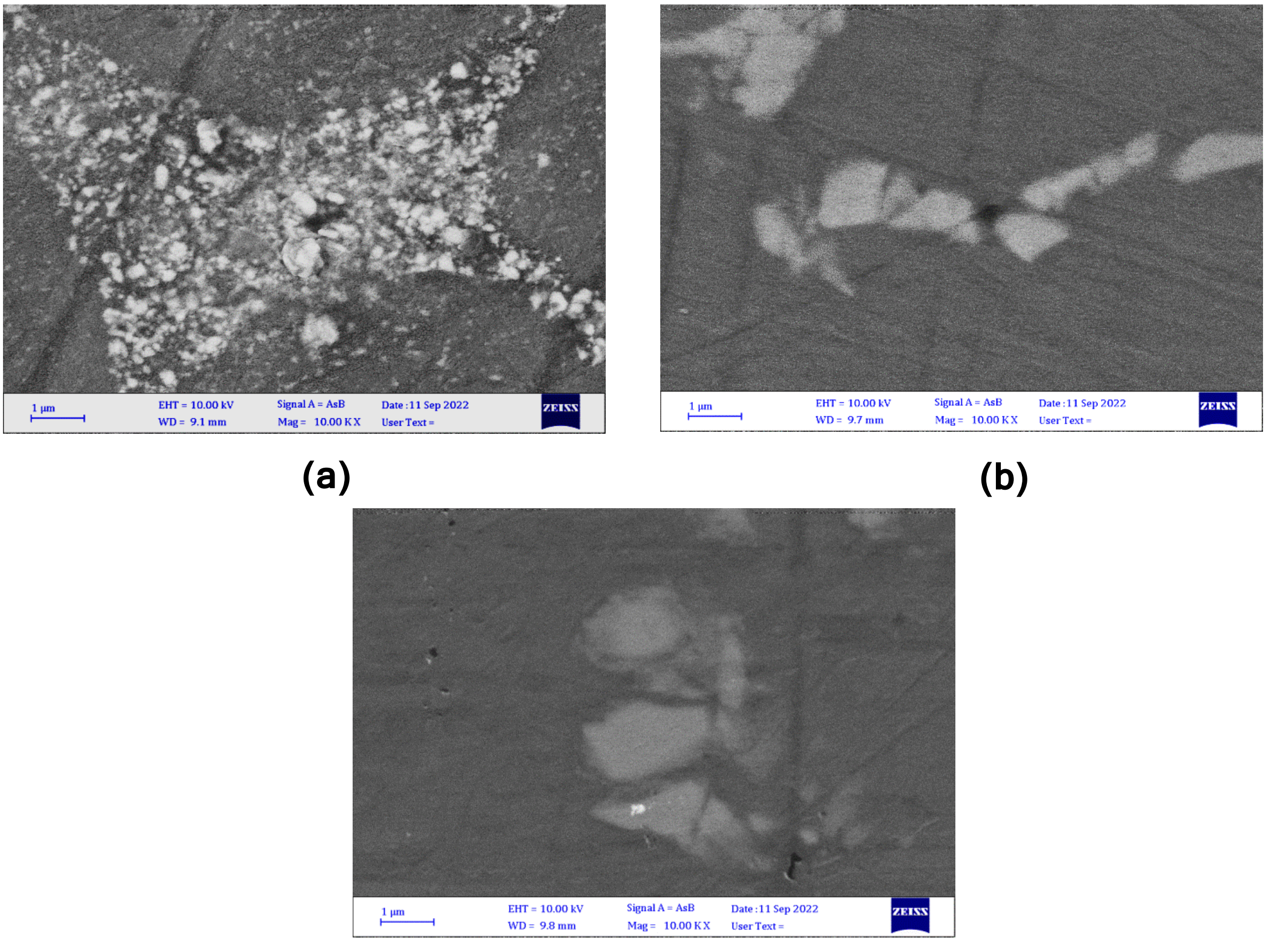
Fig. (5) EDS results of alloys were produced using beverage cans that had been recycle

3.2. SEM analysis of alloys

SEM images of the samples' surfaces were taken after they had been etched. SEM images of the samples' surfaces were taken after they had been etched. For each sample, the images were captured from the same area at various magnifications. These images were used for evaluating the alloys' surface morphology.

The materials' morphology revealed the presence of elements Al, Mn, Mg, and Zn. In addition to these, the alloys have the oxygen and carbon element product by combustion on the gas oven, as revealed by the scanning electron microscope (SEM) and shown in Fig. (6). The alloys were made from recycled beverage cans. These borders and phases of an amorphous structure show the extrusive nature of the particle reinforcement[7]. In the samples of established cast alloys shown in Figure 6, the phases of the alloys are investigated using the SEM test, and the results show the phases.

On the other hand, the area fraction of particles increases continuously with the Mn and Al content. Furthermore, different regions of content and shape of these alloys can be seen. According to Figure (6), the single-phase and two-phase zones are indicated by grey and black areas, respectively. It was observed that the Al and Mn element ratios in the black regions were high [8]. It was seen that the values found from SEM images and EDX measurements were in agreement. Phase peaks are also seen in the X-ray diffractogram.



(a) **(b)**

(c)

Fig. (6) Scanning electron microscope (SEM)-Image from the longitudinal section in 1000× magnification of Al-Zn-Mn alloys; (a) CCM No. 1 sample , (b) CBO No.4 sample, (c) CCO No.5 sample.

3.2. X-ray analyses

X-ray analyses of samples using CuKα (λ = 1.5405 Å) radiation with Rigaku RadB-DMAX II computer-controlled X-ray diffractometer, measurements 2θ = It was taken at room temperature at a constant scanning rate of 2°/min between (20°-80°). The structure can be determined based on the element ratios of the samples obtained. The secondary phases of Al_2Mg phase, as well as Al (with a dominant hcp base structure), are recognized as the matching peaks [9].

X-ray measurement of beverage cans alloys were produced at room temperature 2°/min. The X-ray diffractogram of the alloys is given in Figure (4.10). The corresponding peaks are identified as α-Al and Al_2Zn phases. The highest intense reflection of the α-Al phases in the plane of this alloys was found at $2\theta = 42.5^{\circ}$. The α-Al peak in these alloys confirms that the beverage cans contain a high percentage of the element aluminum [10]. The dispersed phases in the figures show that the beverage cans contain other elements in addition to the fundamental elements, these agree with the EDS analysis. The mass ratio of Al to Zn and Mg was approximately 0.75, as shown in Table (3). As a result, Fig. (6) clearly shows the diffraction peaks for Al_2Mg and Al_2Zn [11].

Table (3) XRD Analysis for alloys were produced using beverage cans that had been recycled

Code of alloy	The alloy made by	Alloying Elements					The X-Ray diffractogram information	
		Al	Mn	Zn	Mg	Other	Phases	2θ degree
CCM No. 1	Different cans	78.2	-	18.1	-	3.7	α-Al	38°, 45°, 66°, 78°
							Al_2Zn	20°, 62°
CBO No.4	Beverage cans body	89.6	-	-	2.0	8.4	α-Al	38°, 45°, 65°, 78°
							Al_2Mg	25°, 48°
							Mg	16°, 44°
CCO No.5	Beverage cans lids	86.3	-	-	3.6	10.1	α-Al	39°, 45°, 66°, 78°
							Al_2Mg	-
							Mg	20°

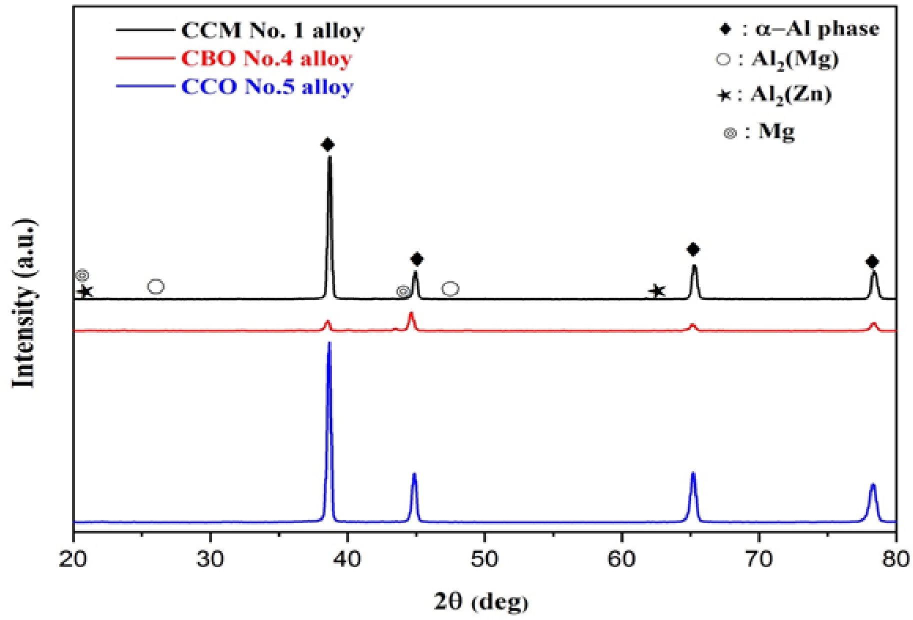


Fig. (6) X-ray diffractogram of the (CCM No. 1, CBO No.4 and CCO No.5) alloys sequentially

3.3. Hardness

For each of the identified cast alloys, the hardness has been measured. More specifically, HV, HB, and TS hardness determine have been used. The hardness of the three alloys was initially determined using a WOLPERT device of the type (V-Testor 2) with P = 1 kg. Calculations for hardness also were carried out using Equation (2). The results of the hardness tests for the alloys made from recycled aluminum cans are shown in Tab. 3 From the table, we can see that the alloy prepared by using only can body alloy had the lowest hardness values, whereas the alloy produced by mixing can body alloy with can cover alloy had the highest hardness values.

Table (4.5) Element ratios obtained by EDS analysis results of alloys were produced using beverage cans that had been recycled

Code of alloy	The alloy made by	Measurements	
		HV(Kg/mm²)	HB(Kg/mm²)
CCM No. 1	**different cans**	**77**	---
CBO No.4	**Beverage cans body**	**49**	---
CCO No.5	**Beverage cans lids**	**60**	---

IV. CONCLUSION

In this study, the alloys were produced by beverage cans as recycling method. The alloys underwent heat treatment for one hour at 300 o C. in the EDS analysis were taken from different regions for each alloy, the ratios of the alloys in atomic percent were calculated as shown in table 2. When compared to some metals, it was found that the element aluminium had the highest percentage. As can be seen from the X-ray diffractogram (Figure 6), the high peak at α- Al. The secondary peaks of these alloys is Al2Mg and Al2Mn. The alloys produced using different cans contain additional peaks in addition to the apparent main peaks. the alloy formed by blending can body alloy with can cover alloy had the highest hardness values, whereas the alloy produced by using just can body alloy had the lowest hardness values.

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