Circular economy and recalling of the aluminum beverage cans

Jandrlić, Ivan; Mrkobrada, Lorena; Kozina, Franjo; Mikulić, Mario; Grubišić, Lea

I. JANDRLIĆ[1], L. MRKOBRADA[1], F. KOZINA[1], M. MIKULIĆ[2], L. GRUBIŠIĆ[1],
[1]University of Zagreb Faculty of Metallurgy (CRO), [2] DEPOS d.o.o. (CRO)

CIRCULAR ECONOMY AND RECALLING OF THE ALUMINUM BEVERAGE CANS

ABSTRACT

Modern-day residents enjoy a wide range of widely available food and beverages, resulting in the creation of a large amount of waste. In order to achieve sustainability, the European Commission proposed a new Action Plan for the Circular Economy in March 2020. The main objectives of this plan are to prevent waste and implement better waste management. Besides glass packaging and PET, the most commonly used containers for food and beverages are aluminium containers, which account for a significant share of waste. As aluminium is very suitable for recycling, considerable efforts are being made to increase the share of recycled aluminium in the production of aluminium packaging. In this paper, the recycling process of aluminium beverage cans is illustrated with a good example. In the first part, an overview of the efforts and successes in the recycling of aluminium packaging is given. In the first part, an overview is given of the effects of recycling on the reduction of greenhouse gases as well as on the reduction of energy consumption in relation to the primary production of aluminium. In the second part, the individual stages of the preparation and processing of aluminium waste up to the final product are described. The chemical and mechanical properties of the semi-finished products obtained were tested in various processing stages. The above-mentioned investigations were carried out to determine the basic properties of the secondary aluminium obtained in order to suggest the possibility of expanding its application in other industries.

KEYWORDS: recalling, aluminum, circular economy, tensile testing, AlSi

1. INTRODUCTION

In recent years, people's view of climate change, our role and influence on these changes, etc. has changed. Governments are trying to minimize our impact and create sustainable growth through their action plans [1-3]

Due to economic growth, we enjoy a wide range of widely available food and beverages that, in order to remain fresh and readily available, are packaged differently. This leads to a large amount of waste. Statistics say that in the EU alone, more than 2.2 billion tons of waste are produced each year [1]. Waste itself is not the problem, we are beginning to realize that the bigger problem is our waste management. A famous saying goes: "One man's trash is another man's treasure"

1.1. Understanding the Environmental Impact of the Linear Economy and benefits of transition on circular economy

The linear economy, characterized by a "take-make-dispose" approach, fig. 1., has been the dominant model of production and consumption for decades. However, this linear economic system is not sustainable, as it depletes finite resources and generates immense amounts of waste. The circular economy, on the other hand, aims to avoid waste and use resources for as long as possible. It promotes a regenerative approach that focuses on reducing, reusing, recycling, and recovering materials to create a closed-loop system, Fig. 1, [2,3].

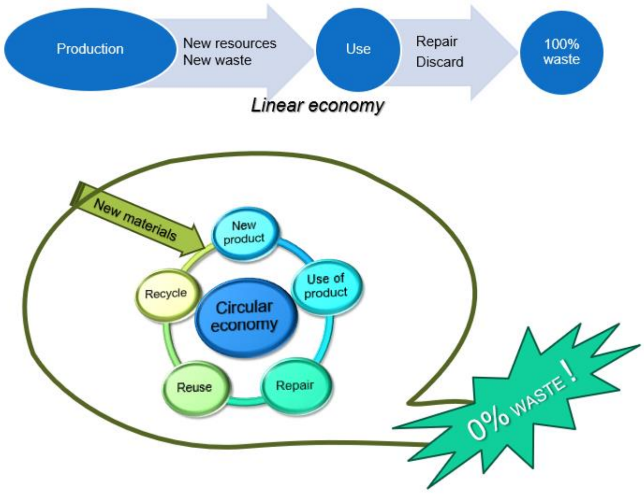


Figure 1. Linear versus Circular approach

In a circular economy, recycling and reuse of materials are therefore the most important strategies. By extending the life of products and materials through repair, refurbishment, and remanufacturing, we minimize the consumption of valuable resources, reduce resource extraction, energy consumption and waste generation. In this way, we can reduce our harmful impact on the Earth. Taking these principles into account, the circular economy strives for environmental sustainability [2,3].

1.2. The roll of aluminum beverage cans recycling in circular economy

Along with plastic, aluminum is certainly the most used material for food and beverage packaging today. The primary aluminum industry, which relies on the extraction of bauxite and the Hall-Héroult process, is less sustainable compared to secondary aluminum production from recycled scraps [4]. The efforts to recover and minimize waste from bauxite mining and the Bayer process are growing to ensure that secondary aluminum raw materials and by-products meet stakeholders' requirements [4]. Statistics show that aluminum is in the top 3 highest emitting materials, with emission of 16 t of CO_2 per ton of produced Al [5]. In addition to the emission of CO_2 and other gases, the biggest problem arises with the large amount of red mud that is separated in the process of primary aluminum production. According to some analyses, up to 4 tons of red mud is produced to produce one ton of aluminum, which makes about 2,7 billion tons worldwide, with increase of over 120 million tons per year [6-9]. Production of aluminum from bauxite uses over 17,000 kWh of electricity.

Remelting aluminum scrap requires only 5% of the energy used in the production of aluminum from raw ore [6,10,11]. With very low energy consumption, recycling Al from scrap reduces CO_2 emissions to 0.5 t/t Al and no formation of red mud [12]. On the other hand, aluminum is a perfect metal for recycling and thus for the circular economy, as it can be recycled infinitely and, compared to the production of aluminum from bauxite, it only requires about 5 % of the energy needed for primary production [13]. In fact, 75 % of the aluminum ever produced is still used today, which underlines the success of aluminum recycling [14].

Since most of the aluminum used in the food industry is for beverage cans, recycling these cans is an important part of the circular economy. Upcycling, i.e., recycling materials into the same material, such as making new beverage cans from old aluminum cans, is an important measure for achieving the circular economy and reducing the extraction of new raw materials [15].

The implementation of circular economy measures in the aluminum industry not only promotes sustainability, but also contributes to the achievement of broader environmental goals, such as the European Green Deal [16]. Recycling aluminum beverage cans is not only beneficial to the environment, but also to the economy. Waste management strategies, including aluminum recycling, contribute to the circular economy by reintroducing scrap materials into the production value chain [17]. This creates economic opportunities and reduces the need to extract and process new raw materials.

1.3. An example of good practice of recycling Al cans in CIAL d.o.o

Since most of the aluminum waste arriving at CIAL consists of reusable packaging (Fig. 2a), which may include non-aluminum cans, large pressed blocks are shredded at CIAL. Large pressed blocks are shredded in the so-called shredders, and iron is separated with a magnetic separator (Fig. 2b).

a) b)

Figure 2. a) Compressed returnable packaging b) Shredder with magnetic separator

The prepared material is then melted in a rotary-tilt furnace (Fig. 3. KTO 10). The unit consists of a rotary tilting furnace, a system for measuring the flue gas composition, a control system for controlling the natural gas and oxygen mixture, and a machine for filling the furnace.

a) b)

Figure 3. a) Tilting rotary furnace, b) Furnace for alloying and maintaining the melt

After melting in the rotary furnace, the molten aluminum is fed through a channel to the melt processing furnace WHO 27 for further processing and alloying. The furnace for alloying and holding the molten metal (WHO 27) consists of the furnace itself for maintaining heat, a device for measuring the exhaust gas composition, a device for metering natural gas and air, and a device for injecting inert gas. The furnace has a capacity of 27 tons of alloy and is equipped with powerful regenerative burners with minimal CO_2 emissions. Filling takes place through the opening at the rear, maintaining the temperature inside the furnace at a minimum of 850 °C. Depending on the requirements, blocks with high aluminum content can be separated during production, which can later be sold as pure Al for further alloying or for use in pure form, e.g. for deoxidation in steelworks. Depending on the production target in the furnace WHO 27, the melt is further prepared by adding fluxes and alloying elements. After preparation of the melt, the chemical composition of the melt is controlled and automatically poured into ingots weighing 6-8 kg. In this research, the recycling process of Al cans was monitored and samples were taken for further testing before and after alloying. The aim was to monitor and confirm the quality of the recycled material and to determine its use.

2. EXPERIMENTAL

The samples to be tested were taken after melting before melt processing and after melt processing by alloying. Chemical analysis of the samples was performed using the SPECTROMAX LMF04 Metal Analyzer for optical emission spectrometry. The specimens for static tensile testing were fabricated on a CNC machine from the cast ingots. The dimensions of the parallel length of the specimens were 57 mm in length and 10 mm in diameter. The dimensions and tests were performed according to the standard HR EN 6892-1 B. Static tensile testing was performed on a Hegewald & Peschke Inspekt table 100 kN machine, and hardness was tested on a Mitutoyo hardness testing machine HV with a load of 10 kg for 10 seconds.
The specimens for the structural tests were cut from the initial grades of ingots in cross-section, cast into a chemically bonded mass, and then prepared manually on the STRUERS Tegramin 30 machine according to the procedure: Grinding on SiC 320 - 2 min, polishing on LARGO DIA DUO 2 9µm for 3 min, polishing on LARGO DIA DUO 2 3µm for 3 min, and finally CHEM OP -U 0.04 µm for 2 min. The prepared samples were etched in Keller solution and then observed using Olympus GX51 metallographic microscope and a DP 27 digital camera.

3. RESULTS AND DISCUSSION

Results of the chemical composition analysis show that the resulting melt after the melting of the scrap Al cans, has a very high aluminum content (above 97.5%), table 1.

Table 1. Results of chemical composition analysis, wt.%:

Material	Si	Fe	Cu	Mn	Mg	Cr	Ni	Zn	Al
$AlSi_9Cu_3(Fe)$	10,45	0,69	2,35	0,5	0,249	0,019	0,025	0,71	<84,9
Recycled Al (Dezox)	0,266	0,57	0,172	0,84	0,465	0,02	0,007	0,06	>97,5

Therefore, it is suitable for further processing by alloying. Further processing required the addition of flux and alloying elements to obtain the alloy AlSi9Cu3(Fe), whose chemical composition corresponds to the standard (Table 1). The results of the static tensile test are shown in diagrams (Fig. 4).

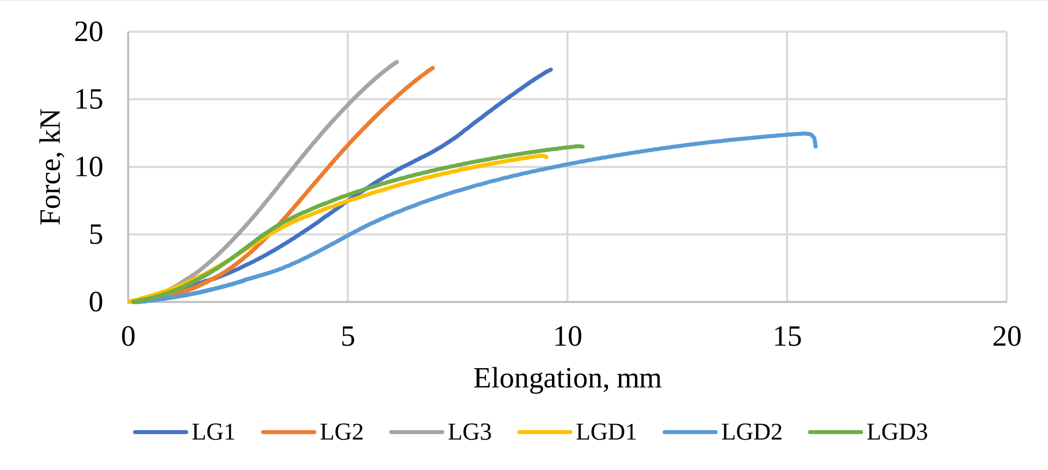
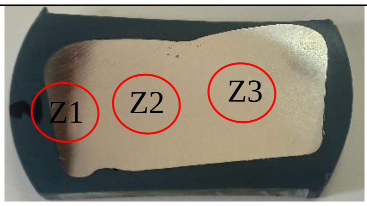


Figure 4. Force-elongation diagrams of unalloyed recycled Al and $AlSi_9Cu_3(Fe)$

(LG1, LG2, LG3 are samples from $AlSi_9Cu_3(Fe)$ alloy, and LGD1, LGD2, LGD3 are samples from recycled Al)

Recycled Al without further processing has pronounced plastic properties, tensile strength 130 - 160 MPa, elongation 5 - 10% and contraction 10 - 15%. After processing of the melt and addition of alloying elements, a decrease in plasticity of the resulting alloy is observed, elongation and contraction are below 2%. On the other hand, tensile strength increases to 220-230 MPa. The same is true for the hardness of the material (Table 2). Hardness was measured at three locations to determine if there was a difference in hardness values per section (see Table 2). It was found that there was no difference in the section. The measured hardness values of the Al alloy increased significantly after the addition of alloying elements. The average value of the measured hardness of plain recycled Al was 51.25 HV, while in the case of $AlSi_9Cu_3(Fe)$ alloy 106.55 HV was measured, which corresponds to an increase of more than 100%.

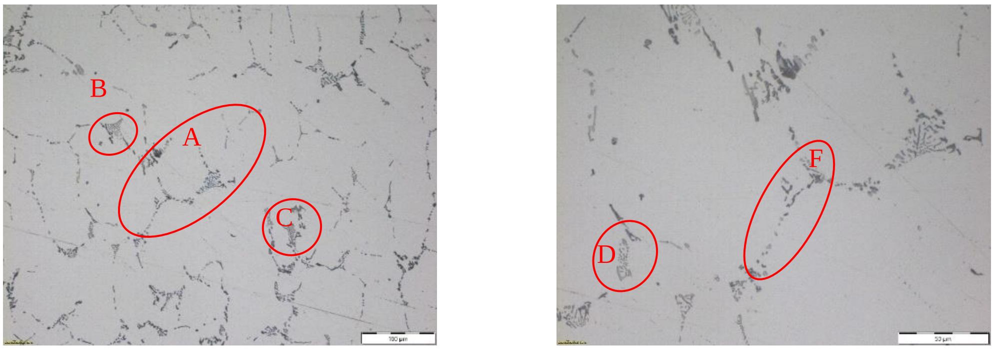
Table 2. The results of hardness measurement:



Positions for hardness measurement HV10

Unalloyed (dezox)		Alloy ($AlSi_9Cu_3(Fe)$)	
Z1	53,7	Z1	110,8
Z2	53,2	Z2	104,7
Z3	53,5	Z3	110,2

The results of metallographic analysis performed on the re-melted secondary aluminum and aluminum after chemical composition correction and melt treatment are shown in Fig. 5.



a) b)

Figure 5. Re-melted secondary Al at magnification 200x

In the microstructure of the re-melted secondary aluminum sample, a dendritic network of primary α_{Al} aluminum with intermetallic phases solidified in interdendritic areas is observed (Fig. 5A). Due to the low amount of alloying elements, the $Al_{15}(Mn,Fe)_3Si_2$ (Fig.5B and Fig. 5C) intermetallic phase are only ones fully-developed and identifiable. Due to the presence of Cu, Mg and Si in chemical composition of re-melted secondary aluminum, it can be assumed that Al_2Cu (Fig. 5 D) and $Al_{15}Mg_8Si_6Cu_2$ (Fig. 5 F) phases are present in interdendritic area.

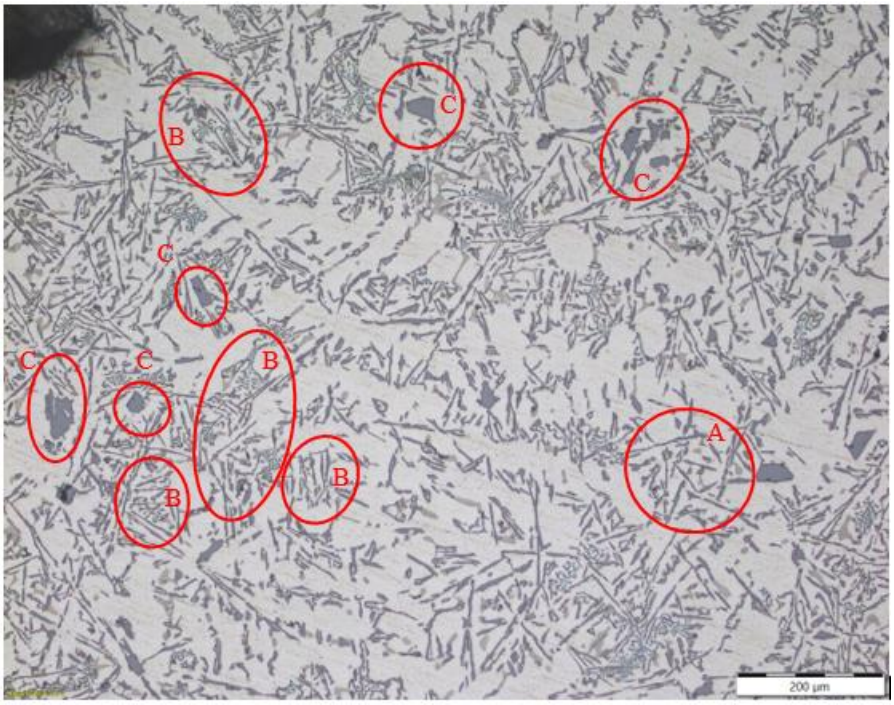


Figure 6. Al alloy $AlSi_9Cu_3(Fe)$ at magnification 200x

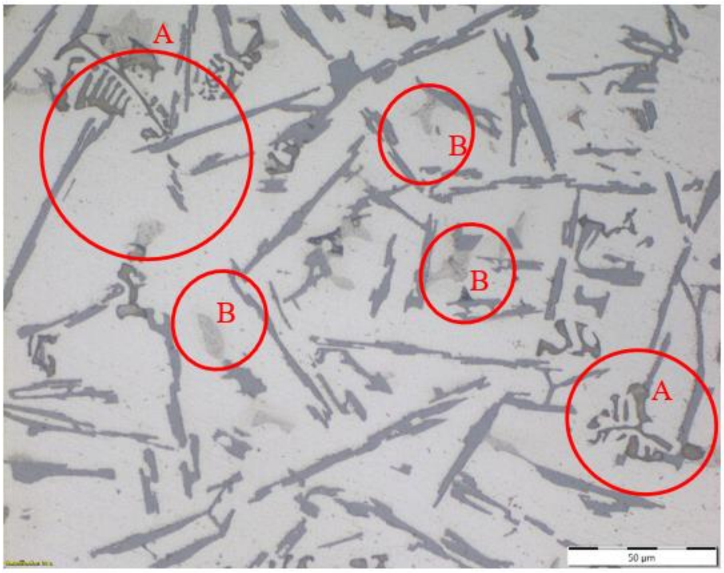


Figure 7. Al alloy $AlSi_9Cu_3(Fe)$ at magnification 500X

The microstructure of the treated sample consists of primary α_{Al} dendritic network with intermetallic phases solidified between the α_{Al} branches. Increase in Si content resulted in the solidification of primary β_{Si} with plate-like morphology as well as eutectic ($\alpha_{Al} + \beta_{Si}$) with un-modified lamellar morphology. The appearance of hard and brittle primary β_{Si} and un-modified eutectic ($\alpha_{Al} + \beta_{Si}$) can explain the lack of plasticity and the increase in hardness measured by static tensile testing and hardness testing of these melts.

In addition to the above, intermetallic phases $Al_{15}(Mn,Fe)_3Si_2$ of the morphology of the Chinese script (Fig. 7A), and Al_2Cu (Fig. 7B) of the cluster morphology can be observed between the dendritic branches of primary α_{Al}.

4. CONCLUSIONS

Aluminum recycling eliminates the need to mine and use primary Al sources such as bauxite. It also avoids the formation of hazardous red mud and reduces overall energy consumption by up to 95% compared to primary production from bauxite.

In addition, recycling aluminum reduces emissions of harmful gasses, especially CO_2, from 16 tons of CO_2 per ton of aluminum produced to only 0.5 tons per ton of aluminum produced.

The tests carried out show that after recycling, a very pure aluminum melt with classical structure and mechanical properties is obtained, suitable for further processing.

In this example, after processing the melt, the alloy $AlSi_9Cu_3(Fe)$ was produced, which corresponds in chemical composition to a known commercial casting alloy. The mechanical properties indicate an increase in strength and hardness of the obtained alloy.

The microstructure shows that the obtained alloy has a primary α_{Al} dendritic network with intermetallic phases solidified between the α_{Al} branches. Due to the Si content, the βSi is present with plate-like morphology as well as eutectic ($\alpha_{Al} + \beta_{Si}$) with unmodified lamellar morphology.

Furthermore, intermetallic phases $Al_{15}(Mn,Fe)_3Si_2$ and Al_2Cu were found to be present in the treated melt.

This brittle primary β_{Si} and the unmodified eutectic ($\alpha_{Al} + \beta_{Si}$) explain the lack of plasticity and the increase in hardness.

Acknowledgments:

Investigations were performed within research project IP-124 University of Zagreb Faculty of Metallurgy, Centre for Foundry Technology—SIMET, KK.01.1.1.02.0020 and VIRTULAB—Integrated laboratory for primary and secondary raw materials, KK.01.1.1.02.0022.

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