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The influence of flux type and scrap size on recycling yield of Al drink cans

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Abstract. Aluminium is *widely* used as a beverage can due to its excellence properties, i.e., good deformability; excellent corrosion resistance, high strength to weight ratio and non-toxic. The global consumption of canned drinks in 2017 was estimated at approximately 200 million pieces annually. These aluminium cans should then be recycled to minimize environmental challenges. Challenge, however, exists to optimize the recycling process. In this work, size of recycled cans, flux type, and recycling temperature were investigated to achieve higher recycling and Al yield. After various flux compositions were attempted to increase the recycling and Aluminium yield, the most suitable flux material was a mixture of chloride, fluoride, and SO_4. Meanwhile, when the scrap dimension reduced to 1 cm^2, the recycling and Aluminium yield showed no significant differences with the yield obtained using a scrap dimension of 4 cm^2.

Keywords: recycling yield, Al yield, beverage and drink cans, flux

1. Introduction

Due to its excellent properties, i.e. good corrosion resistance, non-toxic, high strength to weight ratio and good deformability, Aluminium (Al) becomes one of metals which is widely applied in engineering. Exemplary applications of Al in engineering are car rims [1], biomaterials [2], piston for Otto and Diesel engine, bicycle frame, structure and skins of airplane and bullet train. Additionally, Al is also widely applied in daily lives, e.g. cooking and kitchen ware, Al foil for food, as well as beverage and drink cans. Due to its extensive application, Al waste has also become an important environmental issue after its application in engineering and daily lives is ended. Global Al demand is predicted at 70 million tonnes in 2020 [3]. To overcome this challenge, Al recycling is important. Additionally, Al recycling greatly benefits the environment since secondary Al production consumes much lower energy, i.e. only 5%, than its primary Al production from bauxite ore [4].

Many researches have been worked out to increase the recycling yield of Al, e.g. [5-7]. However, many recycling processes still have many challenges. Therefore the mechanism of its process is crucial to be more deeply investigated. Ozer and Burgucu [5] reported that recycle of 7xxx series of Al grade produced lower grade of Al alloy which is monetized in lower economic benefit. Many works also reported high loss of Al as Al_2O_3 [6,7]. Low Gibbs energy of Al oxidation accelerates Al_2O_3 formation. Moreover, some alloying elements present in Al alloy also have low Gibbs energy of their oxidation, particularly Magnesium and Titanium. This circumstance then contributes to low recycling yield and decreasing Al grade of recycling product. Magnesium is added to Al alloy, e.g. in 5xxx alloy, to increase strength, through solid solution strengthening mechanism, and hardness [8]. Magnesium addition also increases corrosion resistance of Al alloy [9]. Meanwhile, Titanium serves as grain refiner to increase its mechanical properties [10].

Of Al waste in 2019, 26 % were from packaging application [11]. Therefore it is great interest for environment if Al waste from used packaging application can be recycled. Due to its short useful life, the amount of Al scrap from drink cans should be easily predicted. Additionally, the recycled product should be maintained in high Al grade from the economic point of view. Previous research reported that use drossing flux containing NaCl and KCl increased the recycling yield of can lid and can body by 4.4 % and 5 %, respectively [7]. Meanwhile, it was also reported that decoating of Al increased the recycling of can body by 4%. Higher recycling and Al yield was due to no oxidation of aluminium, titanium and magnesium from pigment used for coating of can body. Oxygen and its compound contribute to loss of aluminium, magnesium and titanium due to oxidation mechanism. Since this work was focused on the influence of flux type and scrap size, the Al can was not decoated in this work.

2. Material and method

2.1 Crucible for melting

In this work, steel crucible is used (**Figure 1a**). Prior being used, crucible is coated and heated (**Figure 1b**). Coating used prevents ferrous diffusion from crucible to liquid aluminium since this increases iron concentration in recycling product. Higher iron concentration in aluminium alloy is deteriorating circumstance since higher ferrous concentration in aluminium alloy lowers mechanical properties of aluminum alloy. The steel crucible was coated with liquid coating and then heated up. In the early trial of this research, non-coated steel crucible increased iron concentration in aluminium alloy by 5-6 %wt.

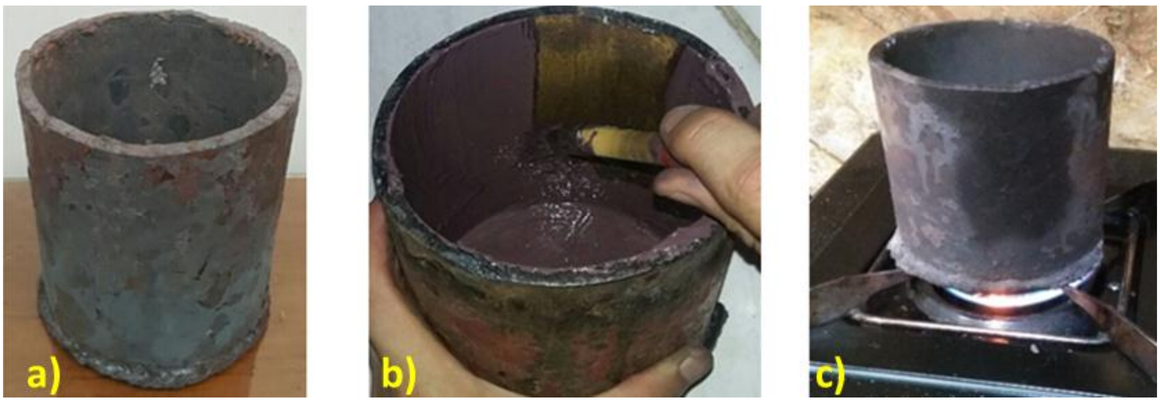

Figure 1. Steel crucible: a)Prior to coating; b)Coating, c)Heating of steel crucible

2.2 Aluminium can

Al scrap from engine and automotive application contains many oil and dirt. Thus additional preparation and cleaning process, e.g. degreasing, are necessary before its recycling. The Al scrap from drinks can is, in contrary, relatively clean. The Al cans used in this work were collected from a particular beverage brand to maintain homogeneity of its chemical composition. They contain other main elements, i.e. magnesium, manganese, titanium and iron (**Table 1**). Can body usually uses AA3xxx series while AA5xxx series are used for can lid [12]. Lower magnesium concentration in can body increases ductility which is an important property in deep drawing process of can production. Due to different chemical composition between can body and its lid and to sustain the Al grade after recycling, the recycling process of each was worked out separately. The can body was separated from the lid and they were cut into two different square sizes of 10 x 10 mm^2 and 20 x 20 mm^2.

Table 1. Main chemical composition of Al can lid and body used in this work

Part	Al	Mg	Ti	Fe	Mn
	[%wt]				
Lid	93.75	4.82	0.017	0.26	0.27
Body	96.46	2.53	0.021	0.32	0.33

2.3 Flux

Use of flux during Al recycling increased recycling yield of can body and can lid by 5 % and 4.4 %, respectively [7]. Al loss during recycling occurs via two mechanisms, i.e. firstly through Al oxidation by oxygen or by the oxides of other elements and secondly Al as free element trapped in the slag layer which reduces the Al content in the melt. In the end of process, this trapped aluminium will be dumped together with slag. In this work, investigation was focused on influence of various flux composition on the recycling and Al yield (**Table 2**). Based on exothermic reaction, this recovers the trapped aluminum. For all experiments, the mass of flux added was 0.5 %wt of recycled Al mass.

Table 2. Chemical composition of 3 fluxes used in this work

Flux type	NaCl	Na_2SiF_6	$CaCO_3$	KCl	$MgCl_2$	Cl	F	SO_4	other
	[%wt]								
A	40	55	5						
B				57	43				
C						45	20	30	5

2.4 Melting and pouring procedure

Electrical resistance furnace was used to melt down the metal at 760 °C (**Figure 2a**). The melting procedure implemented in this work was similar to the previous work [7]. Before pouring the molten recycled Al to the metal die (**Figure 2b**), slag was removed to avoid contamination of the Al melt. This strategy was also worked out to prevent increase of viscosity due to slag presence. In the early experiment of this research, higher viscosity of poured liquid Al extends pouring duration and decreases productivity. Longer pouring duration also increases recycling loss since liquid Al was turn into solid. This is due to heat transfer from Al melt to environment. After pouring, the liquid Al transformed into solid phase. The solid product was then weighed and its chemical composition was then analyzed using an optical emission spectroscopy Thermo ARL 3460 Advantages.

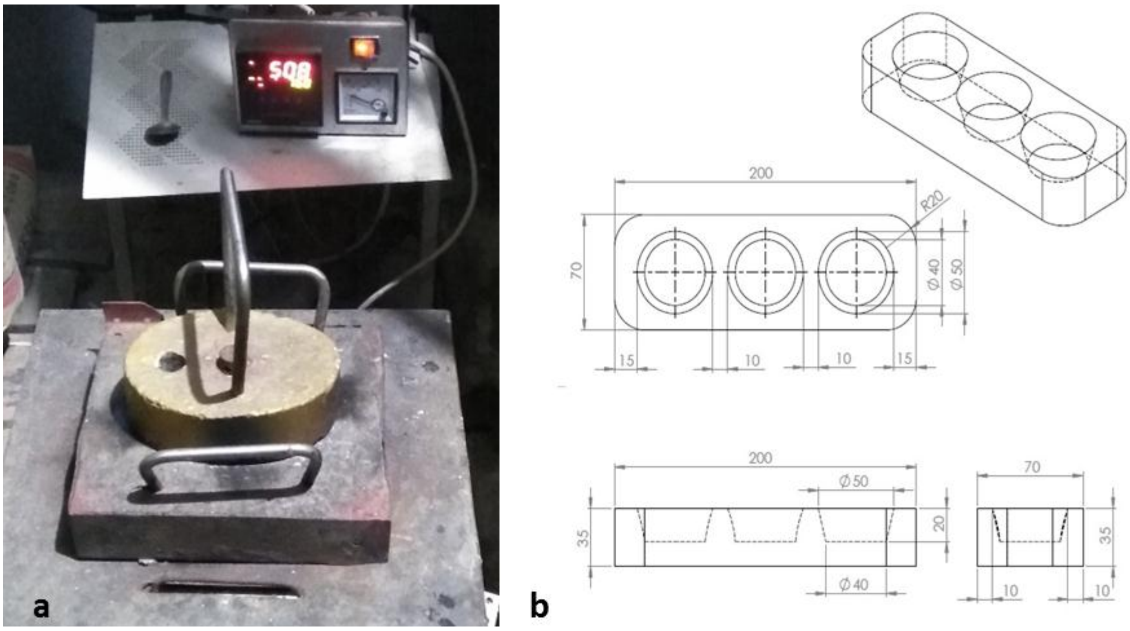

Figure 2. a) Electrical resistance furnace, b) The die

3. Result and discussion

3.1 Recycling yield

Table 3. Experimental set up and its result

Exp.	Can part	Scrap size	Flux Type	Recycling product			
				Mass [gr]	Slag mass [gr]	Slag mass [%]	Recycling yield [%]
1	Body	20 x 20 mm^2	A	232	196	44.5	52.7
2			B	234	193	43.9	53.2
3			C	236	193	43.9	53.6
4		10 x 10 mm^2	A	239	191	43.4	54.3
5	Lid	20 x 20 mm^2	A	292	134	30.5	66.4
6			B	297	125	28.4	67.5
7			C	302	139	31.6	68.6
8		10 x 10 cm^2	A	311	125	28.4	70.7

The experimental conditions and their results are presented in **Table 3**. Recycling yield and aluminium yield were determined with similar procedure from the previous research [7]. For both body and lid recycling, flux C results in the highest recycling yield compared than flux A and flux B. For all flux types, recycling yield of lid, i.e. experiment 5, 6 and 7, is significantly higher than that of can body, i.e. trial 1, 2, and 3 (**Table 3** and **Figure 3**). The difference of recycling yield between body and lid for flux A, flux B and flux C are 13.7 % (53.8% compared to 66.4%), 14.3 % (53.2% compared to 67.5%) and 15% (53.6% compared to 68.6%), respectively. Further investigation was then worked out to explain the above circumstances.

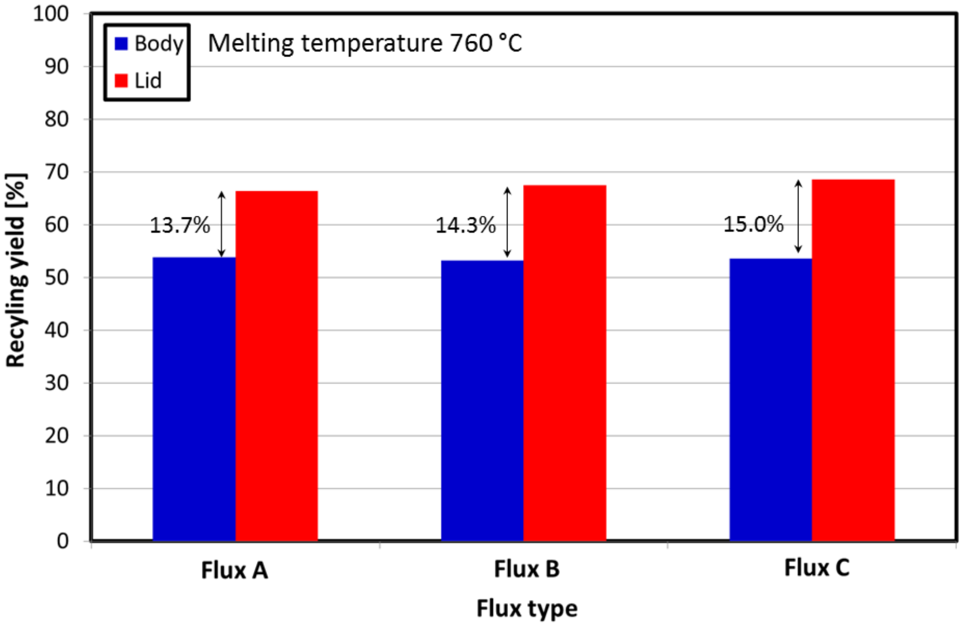

Figure 3. Recycling yield of body and lid with the addition of various flux types

Figure 4. Slag morphology after 10 x 10 mm^2: a) Can body scrap was melted and added with Flux A, b) Recycling of can body added with Flux C, c) Recycling of can lid added with Flux A, d) Recycling of can lid added with Flux C

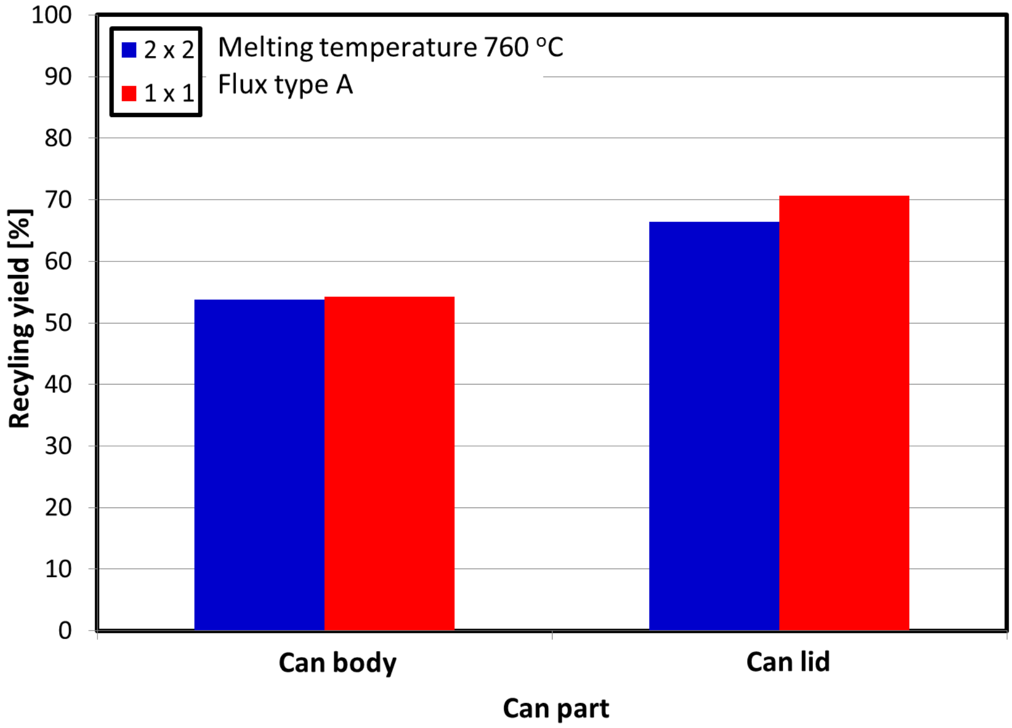

Figure 5. Recycling yield of body and lid for various scrap size

The slag morphology after the recycling process was studied. **Figure 4** shows that the recycling using Fluxes A and C produced more powder-like slag in the lid recycling than in the body recycling. In contrary, observation of the slag chunks (**Figure 4a** and **Figure 4b**) resulted from the body recycling seemed to contain more trapped Al (metallic colour on the slag). This finding confirmed the reason for the lower recycling yield for body recycling. All fluxes used in this work contain Chlorides which is corrosive so that it can destroy oxide layer and turns it to become small fragment [13]. Since slag contains Chlorides and Fluorides, it should however be well managed prior to landfill [14]. Small scrap size increases the recycling yield (**Figure 5**). For can body, the recycling yield increases slightly by 0.5% from 53.8% to 54.3%. Meanwhile, the recycling yield for can lid increases by 4.3% from 66.4% to 70.7%.

3.2 Aluminium yield

Al initial mass of lid ($m_{Al,in, lid}$) and body ($m_{Al,in, body}$) were determined based on the mass of recycled lid and body, which was constant at 440 g for each experiment, and based on the chemical analysis of can lid and body prior to melting (equation 1 and 2). Analysis of chemical composition after recycling both for can body ($\%wt_{i,out,body}$) and can lid ($\%wt_{i,out,lid}$) was performed using spectrometry. Based in that analysis as well as from the data of tapped mass of lid ($m_{out,lid}$) and body ($m_{out,body}$) recycling, mass of main element for both can lid ($m_{i,out,lid}$) and can body ($m_{i,out,lid}$) can be determined (equation 3 and 4) [7]. Using those data, metal yield of Al for lid and body recycling were calculated (equation 5 and 6) [7].

$$M_{Al,in,lid} \text{ [gram]} = \%wt_{Al,in,lid} \times 440 \text{ gram} \quad (1)$$
$$m_{Al,in,body} \text{ [gram]} = \%wt_{Al,in,body} \times 440 \text{ gram} \quad (2)$$
$$m_{Al,out,lid} \text{ [gram]} = \%wt_{Al,out,lid} \times m_{out,lid} \quad (3)$$
$$m_{Al,out,body} \text{ [gram]} = \%wt_{Al,out,body} \times m_{out,body} \quad (4)$$

$$\text{Yield}_{Al,lid}\ [\%] = \frac{m_{Al,in,lid}}{m_{Al,out,lid}} x\ 100\% \quad (5)$$

$$\text{Yield}_{Al,lid}\ [\%] = \frac{m_{Al,in,body}}{m_{Al,out,body}} x\ 100\% \quad (6)$$

Table 4. The Al concentration and its mass after each experiment and Al yield of can body and lid recycling

Trial	Can part	Scrap size	Flux type	Tapped mass [gram]	Al [%wt]	Al [gr]	Al Yield [%]
1	Body	2 x 2 cm^2	A	232	92.89	215.50	50.78
2			B	234	97.23	227.52	53.61
3			C	236	97.09	229.13	53.99
4		1 x 1 cm^2	A	239	97.07	232.00	54.66
5	Lid	2 x 2 cm^2	A	292	95.96	280.20	67.93
6			B	297	96.44	286.43	69.44
7			C	302	96.35	290.98	70.54
8		1 x 1 cm^2	A	311	96.31	299.52	72.61

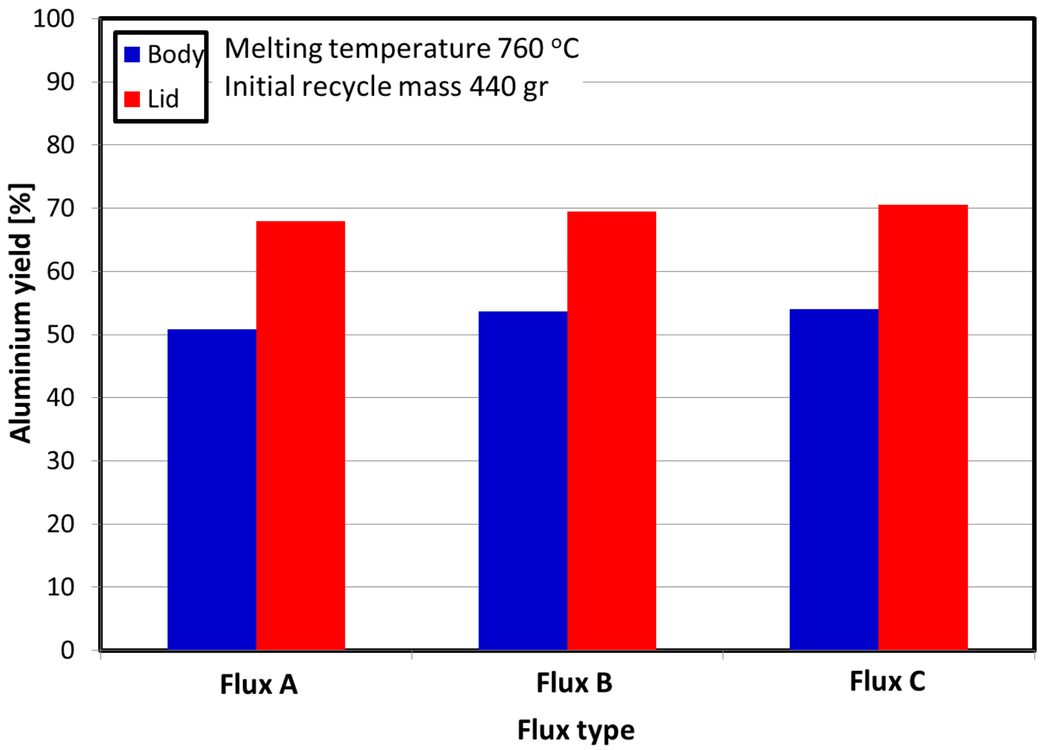

Figure 6. Al yield of body and lid recycling with addition of various flux types

Similar circumstance occurred with recycling yield in which lid recycling resulted in higher Al yield for all flux variation (**Table 4** and **Figure 6**). The difference of Al yield between body and lid recycling for all flux types are close, i.e. 15-17%. This is due to lower tapped mass for recycling of can body compared than recycling of can lid. Meanwhile, reducing the scrap size from 20 x 20 mm^2 to 10 x 10 mm^2 also slightly increased the Al yield, i.e. 3.88 % for recycling of can body and 4.68 %

for recycling of can lid (**Figure 7**). Similar trend was found with the influence of smaller scrap size on recycling yield. In general, Al and recycling yield should be further improved since high slag mass due to low Al and recycling yield requires additional slag processing which leads to additional cost or land dumping. High slag mass also results in low electrical energy efficiency [kWh per ton of product].

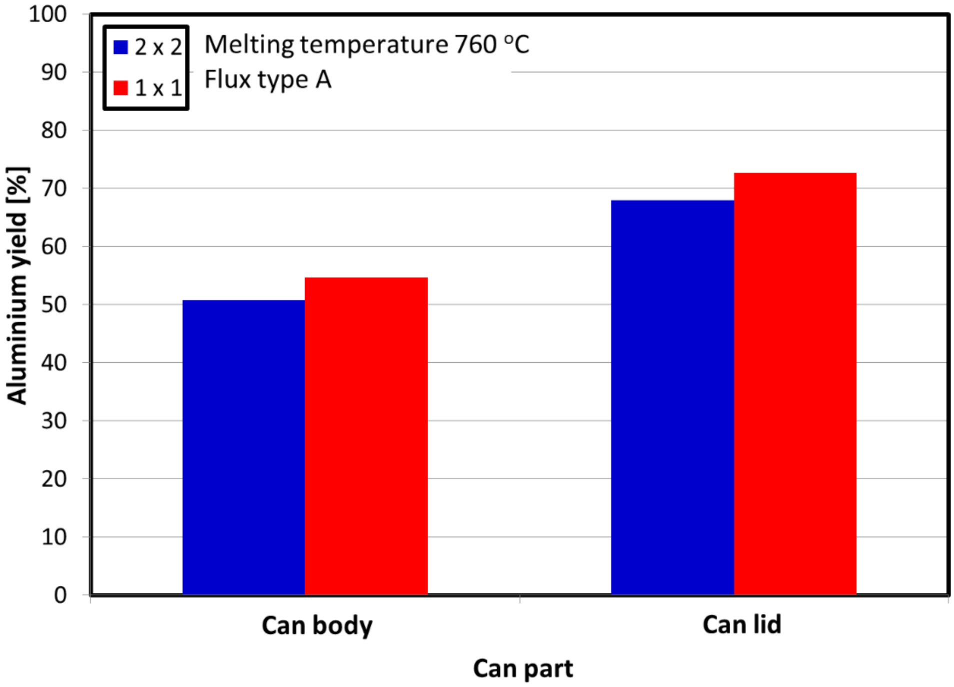

Figure 7. Al yield of body and lid recycling for various scrap size

4. Summary

Al is one of the most used metals, both for engineering and daily application. This in turn delivered additional challenge on how to manage the used Al product. Recycling of Al therefore is significantly important to address this challenge. Some challenges however remain, e.g. low recycling and Al yield. In this work, higher recycling and Al yield was increased by using various types of flux and smaller scrap size. For all varied flux types and scrap sizes, recycling of can lid delivered higher Al and recycling yield compared than recycling of can body.

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