Aluminum Dross Recycling by Melting: Effect of Particle Size and Flux Salt Quantity on Recorvered Aluminum Yield

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In recent years, aluminum recycling has significantly increased, particularly in Brazil, where the recycling rate of aluminum cans exceeds 95%. Aluminum dross is generated as a byproduct during the melting and recycling processes. The composition and morphology of this dross vary according to its metallic aluminum content. This study analyzed the recovery of aluminum from secondary dross, focusing on particle size and the amount of flux salt used. The results showed that particles larger than 7.5 mm yielded an aluminum recovery rate of 73.99% with 15% salt. The melting of larger particles improved aluminum recovery, suggesting greater process efficiency when targeting particles above 3.0 mm.
Keywords: Aluminum Dross. Recycling. Melting.

Aluminum is widely used due to its advantageous properties, such as low density and high corrosion resistance. Its production can be either primary, using bauxite as the raw material, or secondary, based on recycling scrap. Primary production involves bauxite extraction and processing and is highly energy-intensive, generating dross that can cause environmental harm. In contrast, secondary production uses aluminum scrap and consumes significantly less energy [1,2]. As a result, secondary aluminum production has gained prominence due to its economic benefits and alignment with sustainable development goals [3].

However, it is estimated that approximately 8–15% of the total mass of raw material used in the melting process is converted into solid waste considered environmentally hazardous. A significant portion of this waste is disposed of in landfills without proper treatment, contributing to severe environmental impacts [2].

Aluminum recycling has grown substantially, increasing its share in global aluminum production. Brazil has emerged as a global leader in secondary production, with a recycling rate for aluminum cans exceeding 95%. As production increases, hazardous waste generation is also expected to rise [4].

According to Mahinroosta and Allahverdi (2018) [5], the main wastes generated in the aluminum industry include red mud, produced during bauxite beneficiation; primary dross, generated during the electrolysis of alumina; secondary dross, produced during scrap melting; skimming, produced during the remelting of aluminum ingots without coatings and salts; and salt dross, generated during the melting of secondary dross using large quantities of salts for metallic aluminum recovery.

Secondary Aluminum Dross and Treatment Techniques

Secondary aluminum dross is an unavoidable byproduct of aluminum melting and recycling and is formed through multiple sequential processes. Oxidation occurs at the molten bath surface, where oxide particles decompose, sink, or float due to the bath's agitation. These particles coalesce, forming voids later filled with metallic aluminum. As these oxidized particles are removed from the bath surface, dross forms. Contact of hot dross with the atmosphere triggers chemical reactions that produce hazardous waste, including reactive compounds such as aluminum nitride, aluminum carbide, and leachable salts [5].

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Treatment of secondary dross can be performed using pyrometallurgical or hydrometallurgical methods, depending on the aluminum content. Dross with high metallic aluminum content is typically processed pyrometallurgically, while low-content dross is treated hydrometallurgically [1]. Salt fluxes are commonly used to aid the recovery of aluminum trapped in the dross; however, their use generates salt dross waste, which must be appropriately managed to prevent environmental contamination. Improper disposal can lead to soil and groundwater pollution and the emission of toxic gases such as ammonia and methane caused by the reactions of aluminum nitride and aluminum carbide with moisture [3].

Conventional methods for extracting metallic content from dross involve using salt flux and melting in reverberatory furnaces. Emerging technologies include plasma arc rotary furnaces [6] and rotary furnaces with salt flux. Plasma arc furnaces eliminate the need for flux salts, thus reducing waste generation. Rotary furnaces using salt flux can use up to 50% of the dross weight in flux to enhance aluminum recovery efficiency [7]. The rotational dynamics of these furnaces improve the interaction between the flux and oxides in the dross, promoting aluminum droplet coalescence.

Another critical factor influencing recovery efficiency is the viscosity of the dross, which increases with higher non-metallic content, complicating the separation of high-purity aluminum. Hazar and colleagues (2005) recommend melting high-aluminum-content dross, particularly with particle sizes above 125 µm, at temperatures between 800 and 850°C to maximize recovery efficiency. In non-rotary furnaces, increased melting temperatures lower the molten metal's viscosity, enhancing droplet coalescence.

The literature indicates that dross composition and morphology vary with metallic aluminum content. Dross with high aluminum content exhibits a compact, granular morphology, while dross with lower content—composed mainly of salts and oxides—results in finer particles. Particle size significantly affects process efficiency, with larger particles typically containing more metallic aluminum [2,7,8]. This study aimed to evaluate the aluminum recovery yield from secondary dross generated during the melting process. It also examined the effects of particle size and the quantity of flux salt used on the recovery rate.

Materials and Methods

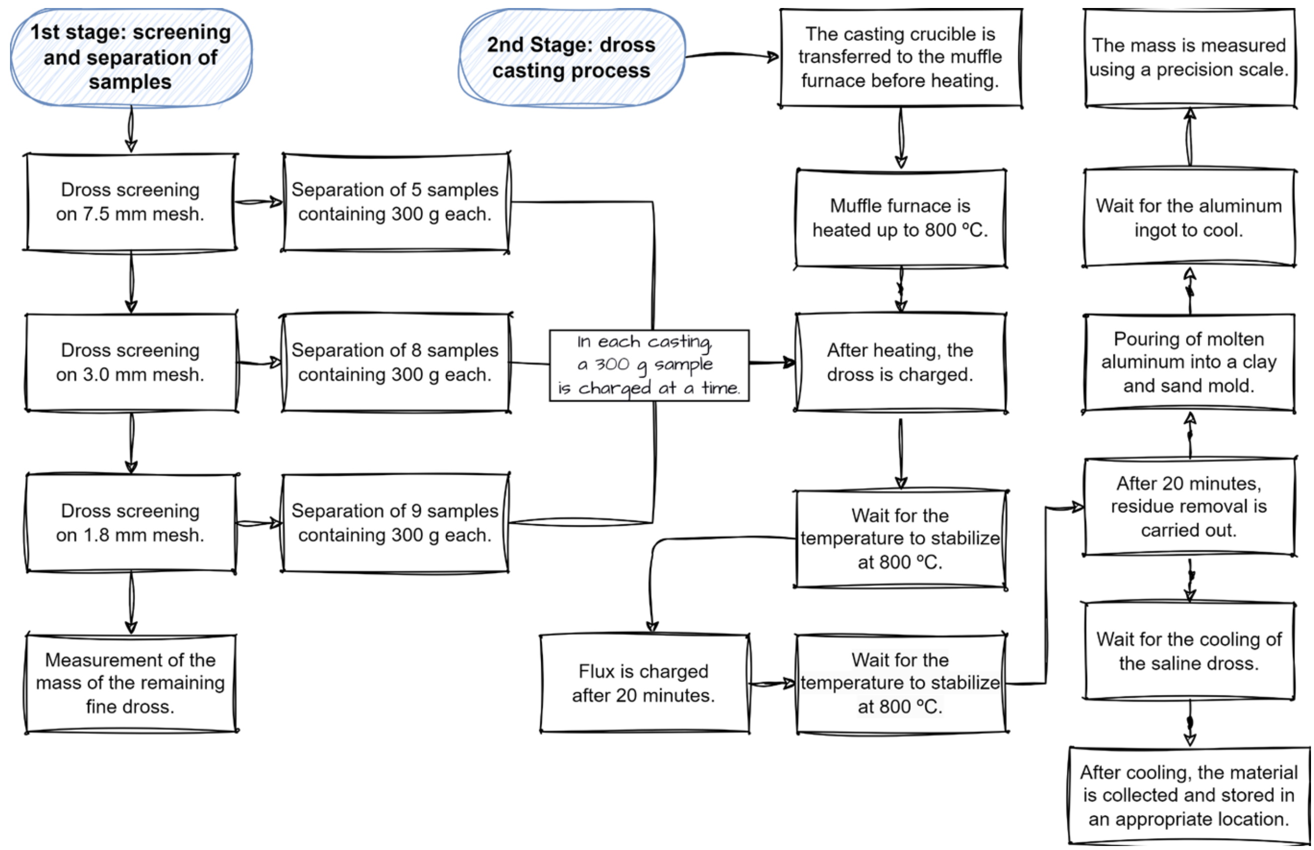
The materials used in this study included secondary aluminum dross supplied by RSA Fundições de Alumínio LTDA, located in Feira de Santana, Bahia, Brazil. Approximately 10 kg of dross was provided and used in its original state without pretreatment. The flux employed was ESCORIMIL AL LP/20, supplied by COMIL COVER SAND Produtos. This flux was selected for its cleaning, deoxidizing, and refining grain structure properties during melting.

A cordierite crucible manufactured by Up Brasil was used in the melting operations. The crucible had a capacity of 600 mL and could withstand temperatures up to 2000°C. Its external dimensions were 128 mm in depth, 130 mm in height, and 115 mm in width. An EVEN precision balance, model BL-4200AS-BI, with a maximum capacity of 4200 g, was used to record the mass of the recovered aluminum ingots.

The melting processes were carried out in a muffle furnace (model LF7013) manufactured by Fornos Jung LTDA. This equipment has a power rating of 6.8 kW and a maximum operating temperature of 1300°C. It is installed at the Advanced Manufacturing Laboratory (LAMAv-CETENS), part of the Center for Science and Technology in Energy and Sustainability (CETENS), Federal University of Recôncavo da Bahia (UFRB).

Figure 1 presents a flowchart of the experimental procedure, which was divided into two stages. The first stage involved screening the aluminum dross by particle size, followed by dividing the screened

Figure 1. Experimental procedure.



material into 300 g samples. A total of 22 samples were prepared: 9 samples with particle sizes between 1.8 mm and 3.0 mm, 8 samples between 3.0 mm and 7.5 mm, and 5 samples larger than 7.5 mm.

The fraction with particles smaller than 1.8 mm was excluded from the melting stage and weighed separately using the precision balance. The mass of this excluded fraction was recorded as 3,341.33 g to quantify the proportion of material not used in the experimental trials. The second stage involved melting the prepared samples, varying the particle size and percentage of added flux salt. All experiments were conducted at a fixed temperature of 800°C. The data collected from these experiments are presented in Table 1.

The aluminum recovery yield (ρ) from the melting process was calculated using Equation (1), where m_{Al} represents the mass of recovered aluminum and m is the initial mass of the dross sample:

Equation (1):

$$\rho = \frac{m_{Al}}{m} \times 100\% \quad (1)$$

The average recovery yield (η) for each condition was determined using Equation (2), where n is the number of replicates under the same experimental parameters:

Equation (2):

$$\eta = \frac{\sum \rho}{n} \quad (2)$$

Results and Discussion

As described in the experimental procedure, the first stage involved screening the dross by particle size. In Figure 2.C, particles larger than 7.5 mm contain large aluminum sheets resembling skimmings formed by oxidation of the metallic surface. These skimmings are typically removed

Table 1. Data obtained from the experiments.

ID	Replicates	Particle size (mm)	m(g)	Q_{flux} (wt%)
S1.10	3	1,8 < d < 3,0	300	10
S1.20	3	1,8 < d < 3,0	300	20
S1.30	3	1,8 < d < 3,0	300	30
S2.05	3	3,0 < d < 7,5	300	5
S2.15	3	3,0 < d < 7,5	300	15
S2.30	2	3,0 < d < 7,5	300	30
S3.05	2	d > 7,5	300	5
S3.15	2	d > 7,5	300	15
S3.30	1	d > 7,5	300	30

ID = experimental test identifier, coded based on particle size range and flux salt concentration; replicates = independent repetitions performed under each experimental condition; particle size (mm) = the range of aluminum dross particle diameters in millimeters (m (g) denotes the total mass of the sample subjected to the melting process, expressed in grams); Q_{flux} (wt%) = the percentage by weight of fluxing salt added during the melting process.

during the extraction of dross from molten metal, resulting in metal loss due to partial removal of the metallic phase and the dross [5].

In Figures 2.A and 2.B, the presence of non-metallic compounds dispersed among metallic aluminum grains is evident. These darker, non-metallic regions are attributed to impurities in the recycled scrap, such as coatings and aluminum pot handles.

Table 2 presents the experimental data. The results indicate a clear dependence of aluminum yield (η) on particle size and the quantity of flux salts used. For the tiniest particles (1.8 < 3.0 mm), the aluminum yield ranged from 41.39% to 47.12% as the flux salt content increased from 10% to 30%. The associated standard deviation (σ) was relatively low, indicating moderate variability among replicates.

For intermediate-sized particles (3.0 < 7.5 mm), aluminum yield increased substantially, ranging from 58.24% to 72.42%, as flux salt content increased from 5% to 30%. The standard deviation was higher for lower salt percentages. However, it decreased as the salt content increased, suggesting that greater amounts of flux improve the process's recovery and consistency. The maximum aluminum yield achieved for particles larger than 7.5 mm was 73.99% with 15% flux salt. This group also exhibited the lowest standard deviation, especially at the 15% flux level, indicating highly consistent results. Due to the limited number of experiments with 30% salts in this particle size range, no definitive conclusion could be drawn for that specific condition. Figure 3 illustrates the yield behavior as a function of particle size and flux salt content (Q_{Flux}).

The results show that the quantity of flux salt considerably impacts yield across all particle sizes. At 5% flux salt, aluminum yield is comparatively low but increases notably with higher flux quantities. An intermediate flux concentration (15%) significantly boosts yield, especially for larger particles, while reducing variability.

At 30% flux, yields continue to increase but show signs of saturation, implying that further increases in flux salt content do not proportionally enhance recovery. Excess salt may diminish returns, increasing operational costs without additional benefits.

Figure 2. Aluminum dross (A) particle size 1.8 - 3.0 mm; (B) particle size 3.0 - 7.5 mm; (C) particle size greater than 7.5 mm.

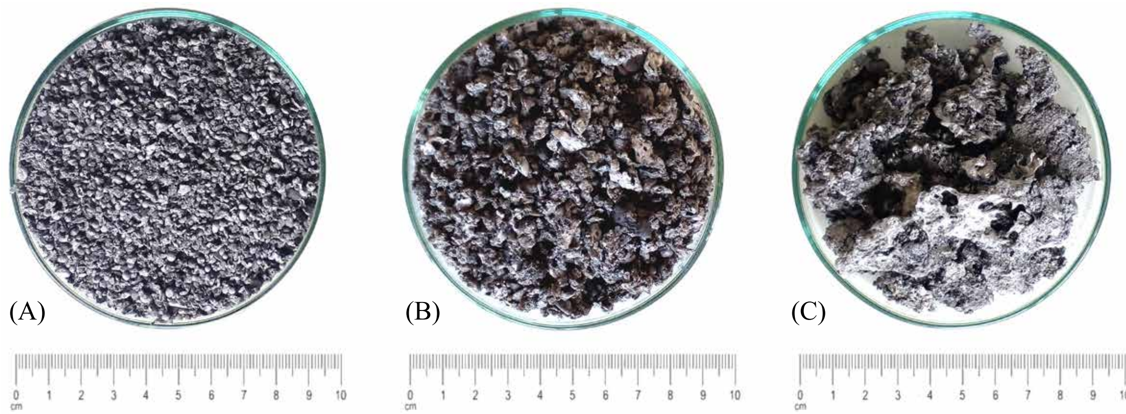


Table 2. Average yield (η) of aluminum recovered.

ID	$\bar{m}Al(g)$	η $(wt\%)$	σ
S1.10	125.90	41.39	2.66
S1.20	141.35	47.12	6.05
S1.30	133.64	43.37	5.35
S2.05	174.72	58.24	7.09
S2.15	191.82	63.94	4.63
S2.30	217.25	72.42	2.66
S3.05	192.67	64.22	2.20
S3.15	221.97	73.99	0.58
S3.30	216.98	72.33	-

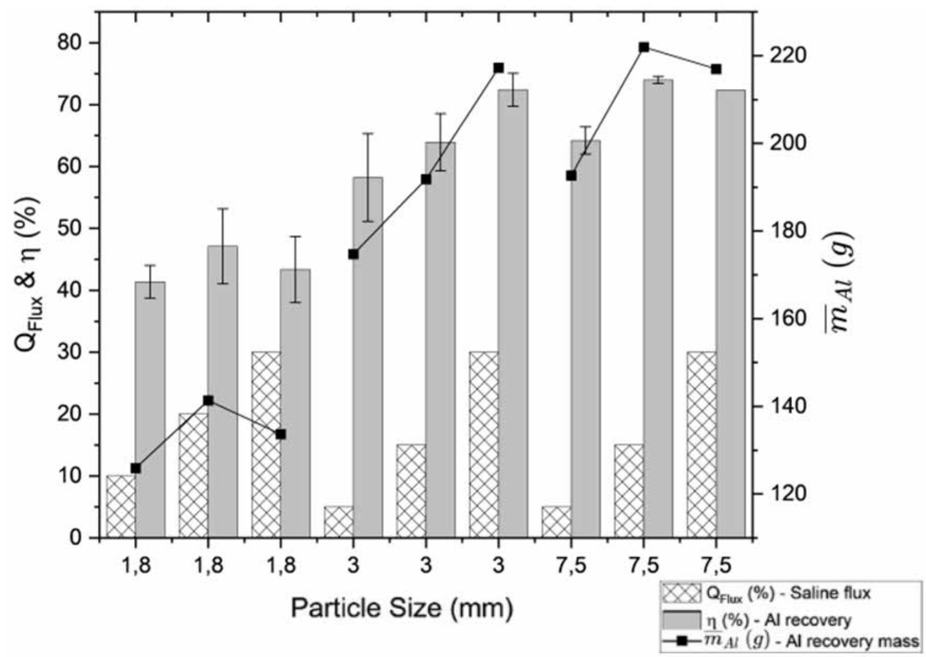
Overall, the data in Table 2 indicate that the highest recovery yields were associated with particles larger than 7.5 mm (average yield of 69.75%), followed by particles between 3.0 and 7.5 mm (average yield of 63.92%). The lowest yields were observed for the smallest particle group (1.8 < 3.0 mm), with an average yield of 44.54%.

Conclusion

This study evaluated the aluminum recovery yield from dross melting, focusing on varying flux salt concentrations and implementing particle size-based separation to optimize metal recovery. The results demonstrated that particle size and flux salt quantity significantly influence the yield of metallic aluminum. Particles larger than 7.5 mm achieved the highest yield, reaching 73.99% when treated with 15% flux salts. This high performance is attributed to the greater presence of metallic aluminum in these skimmings, which are primarily composed of metal and whose efficient recovery is crucial for minimizing losses.

The findings suggest maximizing aluminum yield is best achieved by targeting the recovery of particles larger than 3.0 mm. This approach

Figure 3. Aluminum recovery yield (η) as a function of dross particle size and flux salt content (Q_{Flux}).



results in more efficient extraction processes and enhances the overall recovery rate, contributing to more sustainable and cost-effective aluminum recycling operations.

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