Investigation of 5052 Aluminum Melt Cleanliness with High Recycled Content

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The aluminum industry strives to reach net-zero carbon emissions, emphasizing the critical role of recycled scrap. This work examines the melt cleanliness of 5052 aluminum alloy with significant recycled content. New and old scrap aluminum were utilized, including Remelt Secondary Ingots (RSIs) and aluminum cable wires. Findings reveal that recycled scrap contains inclusions such as oxides and grain refiner (GR) particles. Furthermore, the paper discusses the importance of an optimized flux addition rate for impurity removal. In the case of old scrap with grain refiner (GR) particles added, even with a higher flux addition rate, the coexisting oxide films and massive GR particles still compromise the cleanliness of aluminum melts. Therefore, managing the addition of old scrap is a critical issue. Proper flux adjustment and avoiding recycled materials with high grain refiner residues are crucial for maintaining the cleanliness of aluminum melts with recycled content.

Keywords: 5052, Recycle, Scrap, Cleanliness, Inclusion

1. INTRODUCTION

The aluminum industry is facing significant challenges in achieving net-zero carbon emissions. The recyclability of aluminum is crucial for reducing carbon emissions, especially considering the high energy consumption involved in primary aluminum production[1]. Reduce dependence on primary aluminum and use recycled scrap to significantly lower CO_2 and other greenhouse gas (GHG) emissions of aluminum products[1-2].

Aluminum scrap collected from end-of-life products is known as "old scrap" or "post-consumer scrap." The quality of old scrap varies based on the constituent alloy types and the effectiveness of the sorting process. A typical example is used beverage cans (UBCs), usually discarded after a short life cycle, then collected and packaged in bales. The general recycling process for UBCs includes shredding, sorting, decoating, melting, and casting[3]. Another type of scrap is "new scrap," generated during production and fabrication before the final product stage, also known as "pre-consumer scrap." New scrap is typically clean and well-sorted (single alloy), and producers control its quality.

Some studies have explored the production of aluminum alloys by adding various types of scraps, including mixing different alloys[4-5]. However, less emphasis is placed on the impact on the quality of aluminum melts with high recycled content, particularly on the formation of inclusions in the melt. Inclusions have been a longstanding issue in molten aluminum. Various methods, such as fluxing, flotation, sedimentation, chlorination, and filtration, are utilized to remove inclusions, impurities, and dissolved gases[6].

In addition to the Al_4C_3 present in primary aluminum, the oxidation of alloying elements leads to the formation of oxides during the melt of recycled aluminum. Borides (TiB_2), a typical residual of grain refinement from the previous lifecycle of the product, is another example of inclusions commonly found in recycled aluminum. Salt flux is widely used to maintain cleanliness, remove inclusions, and minimize the amount of aluminum metal in the dross.

This study aims to investigate the cleanliness of 5052 aluminum melts containing a high recycled content and explores the optimal fluxing and grain refiner (GR) addition strategy. 5052 is a widely used general-purpose alloy in industrial, transportation, and consumer electronics sectors, particularly for applications requiring anodized surfaces. Inclusions within the alloy can lead to mechanical failures of components during operation and pose challenges during surface treatments such as pickling, polishing, and anodizing.

2. EXPERIMENTAL METHOD

2.1 Materials Preparation

In this study, both new and old scrap materials were utilized. The new scraps were sourced from the scrap yard at the CSAC plant as well as from downstream customers. The chemical composition of the new scrap is provided in Table 1. “The 5XXX-L” primarily consists of 5052 alloys mixed with small amounts of 5005 and 5151. “5XXX-H” includes AA5042 and 5182 alloy. “1XXX” includes AA1050 and 1100 alloy. The old scrap materials were collected from three main sources: UBC, consumer electronics casings, and aluminum electrical cable wires. The collected UBC and consumer electronics (3C) casings underwent sorting, and remelting to produce Remelt Secondary Ingots (RSIs), RSI-A and RSI-B separately. Aluminum cable wires (denoted as Scrap-C) can be directly utilized in the melting processes due to their high purity. The chemical composition of three types of old scrap is detailed in Table 2. The RSI-A and Scrap-C were remelted in a clay graphite crucible at 760-780°C in a 5 kg capacity furnace, respectively, to evaluate the cleanliness of the molten scraps using the Porous Disc Filtration Apparatus (PoDFA) test. Photographs of scraps are shown in Figure 1.

2.2 Melting and Casting

Table 3 summarizes the experimental conditions of five alloys. Set A contains 15% new scrap, and Set B and Set C contain 80% new scrap with different addition rates of flux, $MgCl_2$+KCl. Salt flux like $MgCl_2$+KCl is usually used for dross removal in a typical aluminum cast house. The primary objective is to eliminate impurity elements such as sodium and calcium, which are prone to causing edge cracking during hot rolling. Furthermore, increasing the quantity of flux enhances the opportunity for collisions between inclusions and the flux, thereby purifying the aluminum melt [7]. Set D and Set E contain 60% new scrap and 10% old scrap. In Set D, the additional 10% new scrap is composed of 5%

Table 1 Chemical composition of new scraps (wt%).

New Scrap	Si	Fe	Cu	Mn	Mg	Cr	Zn	Ti	Al
5XXX-L	0.05-0.20	0.15-0.40	0.00-0.02	0.01-0.08	2.20-2.50	0.15-0.20	0.00-0.01	0.01-0.02	bal.
5XXX-H	0.07-0.11	0.20-0.30	0.01-0.03	0.24-0.30	3.00-4.50	0.01-0.06	0.00-0.02	0.01-0.02	bal.
1XXX	0.07-0.14	0.20-0.60	0.01-0.10	0.00-0.01	0.00-0.01	0.00-0.01	0.00-0.01	0.00-0.03	bal.

Table 2 Chemical composition of old scraps (wt%).

Old Scrap	Si	Fe	Cu	Mn	Mg	Cr	Zn	Ti	Al
RSI-A (UBC)	0.28	0.46	0.19	0.70	1.88	0.02	0.2	0.02	bal.
RSI-B (3C)	0.25	0.32	0.06	0.17	1.27	0.08	0.02	0.02	bal.
Scrap-C*	0.04	0.10	0.00	0.00	0.00	0.00	0.00	0.00	bal.

Fig.1. (a) new scraps, (b) UBC bale, (c) RSI-A, and (d) aluminum cable wires.

Table 3 Experimental conditions of five alloys (wt%).

Alloys	5XXX-L	5XXX-H	1XXX	RSI-A	RSI-B	Scrap-C	Flux addition rate
Set A	13	2					0.02
Set B	65	5	10				0.02
Set C	70		10				0.04
Set D	45		15	5		5	0.05
Set E	45		15		10		0.05

RSI-A and 5% scrap-C. Due to the higher manganese content in UBC, aluminum cable wire is used to dilute and reduce the manganese level.

Approximately 60 metric tons of primary aluminum, RSI, and scrap were melted under each set of alloy conditions. Master alloys were used to adjust the alloy composition for magnesium and chromium alloying elements. The molten aluminum was transferred to a holding furnace for fluxing, followed by skimming and sedimentation. Subsequently, the aluminum melt flowed through Spinning Nozzle Inert Flotation (SNIF) and Ceramic Foam Filter (CFF) units to remove gases and impurities. Additionally, an Al-Ti-B GR rod was added to refine the grain structure before the CFF unit. The GR addition rate was 0.04% for all alloys. Samples for the PoDFA test were collected after CFF units.

2.3 Analytical Method

The Porous Disc Filtration Apparatus (PoDFA) test is a semi-quantitative analysis to evaluate the cleanliness of aluminum melt. Approximately 1.5 kg of molten aluminum was sampled using a ladle and poured into a preheated crucible with a filter at the bottom. The aluminum melt was drawn through the fine filter by vacuum, resulting in a residual liquid with a higher concentration of inclusions above the filter. After cooling, the solidified samples with high concentrations of inclusions were sectioned for metallographic examination. The cross-sectional specimens were mounted, ground, and polished. The specimens were analyzed to determine the s total inclusion level of the aluminum melt. The type of inclusions was characterized by scanning electron microscopy (SEM) (Gemini 450) with energy-dispersive X-ray spectroscopy (EDS).

3. RESULTS AND DISCUSSION

3.1 Cleanliness of RSI and Scraps

The main inclusions found in both PoDFA samples were aluminum oxide particles and films. Figure 2(a) shows small clusters of oxide particles. Thin and networked oxides are newly formed and no magnesium-containing inclusion is found in the RSI-A sample. In Figure 2(b), oxide films are thick and long, and associated with massive small inclusions $(Ti,V)B_2$ in the Scrap-C sample. It's essential to remove transition metals like titanium, vanadium, and other solute atoms in aluminum to increase the conductivity for cable wire

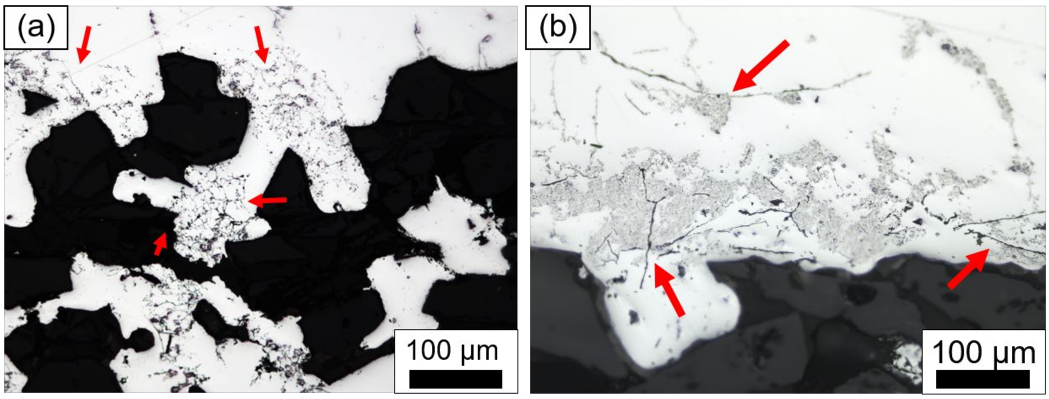

Fig.2. Micrographs of (a) RSI-A and (b) Scrap-C (oxide films are indicated by arrows).

applications. Boron treatment is usually used to precipitate these borides; this explains why there are higher boron concentrations in scrap-C (20 ppm) than in common wrought aluminum alloys. Through PoDFA analysis, one can determine the cleanliness of the RSI or recycled scraps and identify the main source of inclusions.

3.2 Chemical Composition of Alloys

The chemical composition of the as-casted alloys is listed in Table 4. The composition of all alloys is within the specifications of International Alloy Designations and Chemical Composition Limits for Wrought Aluminum and Wrought Aluminum Alloys. In addition to the common alloying and impurity elements, removing sodium and calcium is a crucial issue, with a significantly higher amount of calcium in recycled scraps. Figure 3 shows the removal efficiencies of sodium and calcium. For sodium, the removal efficiencies remain above 90% for all alloys. Set B and C had high calcium content before entering the holding furnace; after fluxing, their values decreased from 6.1 and 5.4 ppm to 2.3 and 2.9 ppm, respectively. The removal efficiency is higher, with only a 0.02% flux addition rate for set A. For sets D and E, removal efficiencies increased with a 0.05% flux addition rate. The calcium content of sets D and E decreased from 6.5 and 5.4 ppm to 0.4 and 0.3 ppm, respectively. A higher flux addition rate is necessary with high recycled content to remove calcium.

3.3 Aluminum Melt Cleanliness

The total inclusion levels are summarized in Table 5. Set A, with minimum recycled content, has the lowest value of 0.002 mm^2/kg. For set B and set C, increasing the flux addition rate from 0.02% to 0.04%, the inclusion levels decreased from 0.024 to 0.009 mm^2/kg. Figure 4 shows micrographs of the PoDFA samples. Clusters of inclusion are frequently observed in set B; further examination confirmed the clusters are composed of oxides

Table 4 Chemical compositions of five alloys (wt%).

Alloys	Si	Fe	Mn	Mg	Cr	Other (each)	Na	Ca	Al
							(ppm)		
Set A	0.06	0.19	0.06	2.3~ 2.4	0.2~ 0.3	<0.05	0.2	0.7	bal.
Set B	0.09	0.27	0.06				0.3	2.3	bal.
Set C	0.09	0.30	0.05				0.5	2.9	bal.
Set D	0.09	0.30	0.07				0.1	0.4	bal.
Set E	0.09	0.30	0.04				0.3	0.3	bal.

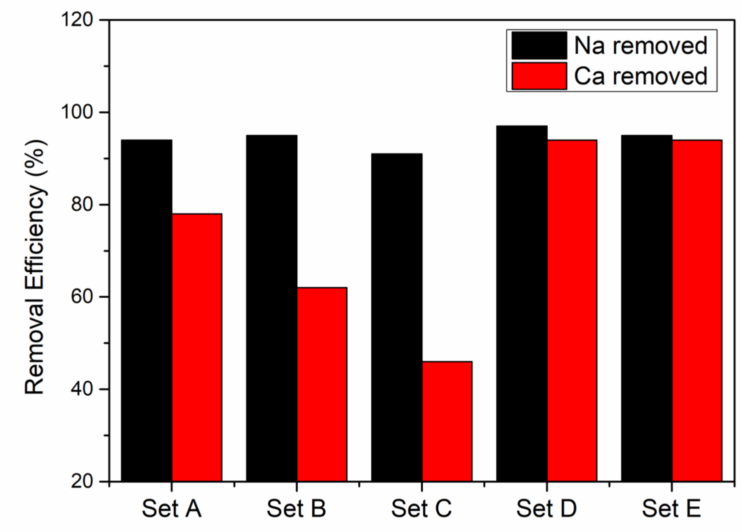

Fig.3. Removal efficiencies of sodium and calcium.

Table 5 The total inclusion levels of five alloys (mm^2/kg).

Alloys	Set A	Set B	Set C	Set D	Set E
Inclusion levels	0.002	0.024	0.009	0.060	0.007

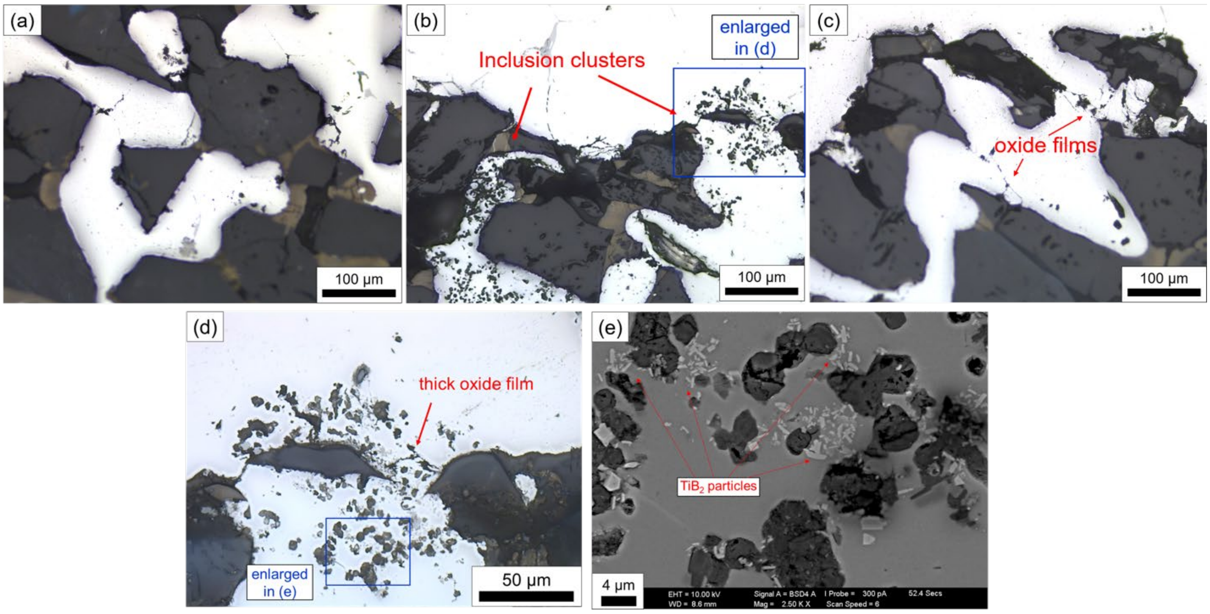

Fig.4. Micrographs of (a) set A, (b) set B and (c) set C. (d) enlarged micrograph of marked area in (b) and (e) enlarged BEI image of marked area in (d).

with irregular shapes in patches and TiB_2, as shown in Figure 4(d). Small TiB_2 particles are spotted in backscattered electron image (BEI) by SEM in Figure 4(e). Since the same GR addition rate is for sets A and B, the one with higher recycled content has relatively low aluminum melt cleanliness, and the filtration efficiency of CFF is weakened mainly due to the interaction between oxide and TiB_2. Studies suggested that at a high inclusion load, the filtration efficiency of CFF reduced significantly. During filtration, bridges composed of oxide film inside CFF may be destroyed by the impact of high-density GR particles(8). The filtration performance is higher in set C because fewer clusters of TiB_2 and oxides are found. The results suggested that higher aluminum melt cleanliness requires the optimum GR addition rate.

For set D and set E, 60% new scraps with different combinations of old scraps, inclusion levels are 0.060 and 0.007 mm^2/kg, respectively. Figure 5 shows the micrograph of the PoDFA sample of set D. Thick oxide films and complex clusters of inclusions are found. Amongst the particles in the cluster, oxide patches and potential chloride (few holes with white spot reflection) existed, and TiB_2 particles agglomerated aside. Few GR particles are found to be $(Ti,V)B_2$, as shown in Figure 5(d); these particles may have originated from scrap-C. Oxide films and the GR particles resulting in the particles with density are assumed to be the weight-averaged densities of both particles. Yet, the morphology remains the same as the film, which reduces the sedimentation of these particles(9). It also leads to a high inclusion load for CFF, decreasing filtration efficiency. On the other hand, set E exhibits higher cleanliness and mostly thin oxide films and fewer TiB_2 particle clusters as shown in Figure 6. In that sense, the inclusions of complex forms like oxide films and GR particles in the aluminum melt are not easily removed, and care must be taken when old scraps are added.

4. CONCLUSIONS

In the present work, the cleanliness of aluminum melt with high recycled content has been studied. The major findings can be summarized as the following:

1. In addition to oxides and oxide films, inclusions in recycled materials may also consist of GR particle types.
2. When a high proportion of recycled materials is added to the melt, the calcium content increases, and more inclusions are present. As a result, additional

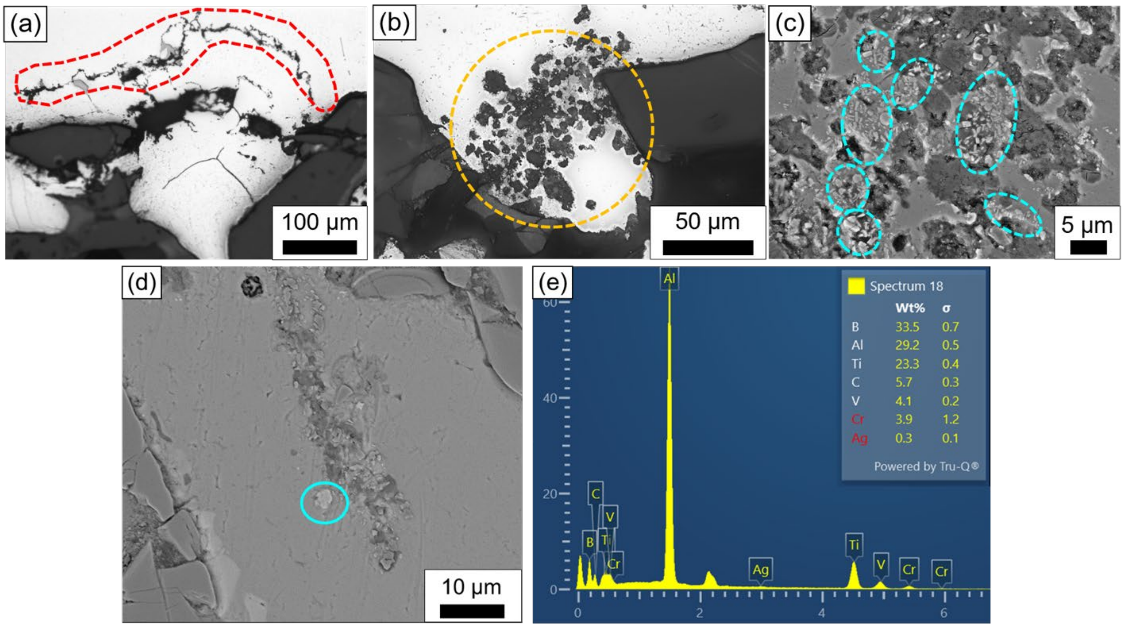

Fig.5. Micrographs of (a) oxide films and (b) inclusion cluster in set D. BEI images of (c) inclusion cluster and (d) (Ti,V)B_2 adhered to oxide film. (e) EDS spectrum of (Ti,V)B_2 in (d).

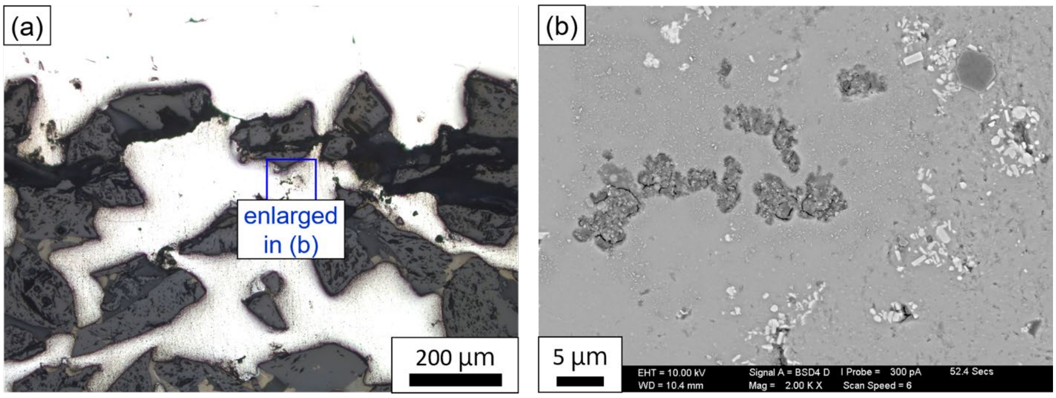

Fig.6. (a) Micrographs of set E and (b) enlarged BEI images of marked area in (a).

flux is required to remove these impurities.

3. When old scrap, like aluminum cable wires, is added, the cleanliness of the melt is degraded, even with a higher flux addition rate. The coexisting oxide films and massive GR particles may diminish the effectiveness of the sedimentation, decrease the filtration efficiency of CFF, and compromise the cleanliness of aluminum melts.
4. When adding recycled materials, special attention must be paid to incorporating old scrap.

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