EFFICIENT USE OF ALUMINUM SCRAP IN BATCHING SECONDARY ALLOYS AND POTENTIAL FOR SENSOR-BASED SORTERS TO IMPROVE RECYCLING SYSTEM EFFICIENCY

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Abstract

Aluminum metal production, semi-product fabrication, component manufacture and material recycling systems are surveyed for the quantities of various types of production, fabrication, manufacturing and end-of-life scrap. We then focus on two types of scrap: source-segregated pure scrap that can be used as a diluent, replacing prime Al; and the mixed-alloy scrap that could benefit from upgrading by sensor-based particle sorting. The markets and alloys that can use the various grades of scrap will be explored, and the need for the various types of upgrading by particle sorting demonstrated. A system-efficient use of scrap does not require closed-loop recycling of products or alloys; it only requires minimization of losses to oxidation or landfill. Sensor-based sorters can minimize these system losses. Adding value to scrap is another measure of the efficiency of scrap use. We will show examples of where upgrading of Al scrap by sensor-based sorting provides opportunities for profit in the current system, which includes metal production, fabrication, manufacturing and material recycling.

Introduction

Lifecycle material system efficiency depends on minimizing resource and energy use and undesirable emissions to land, water and air, while satisfying market demand for the material. Recycling is a key component contributing to the efficiency of the material system lifecycle.

Al recycling, which has been practiced since the 1940s, developed without any benefit of sophisticated sensor-based sorting technologies. Development of automated metal separation and sorting technologies dates back to the 1970s, and sensor-based sorters arrived in the 1980s. In the 1990s, there were common predictions that a sustainable Al lifecycle would require sorting of Al by alloy. These led to the development of elemental composition analysis sensors for automated particle sorters. Yet adoption of these light metal scrap sorting technologies by either the scrap or Al industries has been slow.

We explore how the current Al recycling system consumes all available scrap and identify true recycling system needs as well as opportunities for profiting from scrap upgrading.

Markets for Light Metal Scrap

New aluminum scrap generated internally at semi-fabrication rolling and extrusion plants is remelted and generally batched into compatible rolling or extrusion alloy. Prompt Al casting scrap is also closed-loop recycled in the foundry or back at a secondary smelter. New manufacturing scrap is often traded on the international scrap market and comes to the remelt or a secondary smelter with less reliable pedigree. It is usually batched together with post-consumer scrap into secondary alloys, as shown in Table 1.

Table 1. Main markets for secondary Al and the most popular alloys for these markets

Market	Secondary alloy	Compatible scrap sources
Al packaging	3X04 can body sheet	• old cans, can manufacturing scrap • non-can wrought manufacturing scrap • Al- and Mg-based scrap mix from 2 g/cc float fraction of a dense media sink-float plant
Building Al	3105 painted sheet	• old Al siding • Al siding and extrusion construction scrap • mixed wrought manufacturing Al scrap with low copper content • old wrought scrap
Automotive Al	38X.x casting alloys	Some 38X alloys can accept a mixture of the most common old scrap varieties without dilution, providing that the Mg concentration is controlled by chlorination
	319.x casting	Tighter concentration limits on 319 increase the dilution requirement and limit the types of old scrap that can be added to a 319 alloy batch
Steel deoxidants	95% Al	This specification can be met by many mixtures of old wrought alloy scrap

Currently these markets consume all the available post-consumer Al scrap. To satisfy product demand, remelts and secondary smelters have to supplement the old scrap feed by purchasing new manufacturing scrap and even prime-metal-based ingot. As long as prime metal and hardeners have to be purchased to satisfy these markets, the value of these products is set by reference to the prime metal price and there is little price margin between secondary- and primary-sourced alloys. In this case, there is no economical justification to additionally upgrade scrap and divert it to other markets.

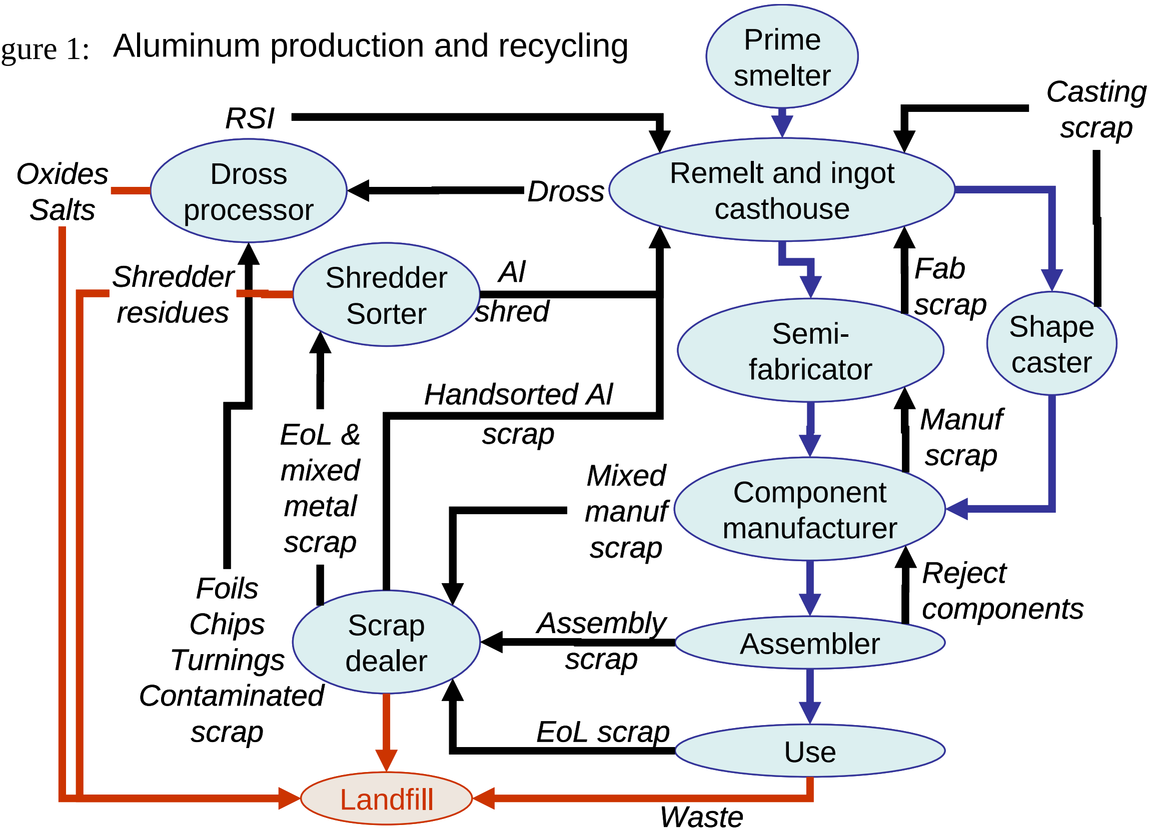
Although wrought Mg alloys exist and their use is expanding, the Mg-alloy market is still dominated by Mg-alloy shape castings for transportation and for consumer electronic equipment housings. Prompt casting scrap is either internally recycled at the foundry or sent back to the specification ingot producers for remelting and re-refining into compatible Mg foundry alloy. Mg metal that is recovered from dross and sludge from remelting and refining is generally granulated for use in steel desulphurization, which consumes virtually all recovered old post-consumer Mg scrap. There are desulphurization granulate grades ranging from 75 to 90 wt% Mg content. Post consumer Mg scrap, when recovered and separated from the light-metal scrap fraction, is currently not recycled into Mg alloys; it is also usually used in steel desulphurization granulate.

In the current expanding market for light metals, there is a continuous need for prime metal production to supply a large portion of the demand. Given the rapid industrialization of the developing world, which is adding billions of additional consumers, the demand for light metals and for light-metal scrap is likely to grow for a long time yet.

System-efficient use of scrap

In a situation where markets are short of scrap, sustainable system-efficient use of scrap does not require closed-loop recycling of products or alloys, but only minimization of losses to oxidation, refining, or landfill. Figure 1 illustrates a simplified lifecycle of Al for Al losses to oxidation and refining that take place during remelting and melt treatment. Metal losses to landfill are in wastes delivered there from consumers, scrap yards, shredders and dross processors. Sensor-based sorters can help minimize these system losses.

Figure 1: Aluminum production and recycling



Recovery of recyclables from landfilled post-consumer waste

By far the largest of these losses is in landfilled post-consumer waste. US EPA figures for 2006 show that US landfills consumed one million tonnes (1,000 kt) of Al cans and another 1,500 kt of other Al items in municipal solid waste (MSW). These Al loss figures account for neither industrial wastes or for construction and demolition wastes (CDW). Sensor-based sorters figure prominently among the technologies required for “dirty” material recovery facilities that can process the landfill-bound MSW. With the Al being dispersed in 140,000 kt of MSW and another 100,000 kt of CDW in the USA, it is clear that these facilities cannot be economic only cherry picking metal scrap, but have to attempt to recover all the recyclable components of the wastes. In municipal recycling facilities (MRFs), sensor-based sorters, pick out the residual metals missed by magnets. They also sort out plastics and sort paper and cardboard by grade for recycling.

Residual metal removal from shredder residue

Primary shredder feed consists of steel containing ~25% nonmetallic and 5-10% nonmagnetic metals. Even a small concentration of nonmagnetic metal in the nonmetallic residue can represent significant loss of recovery of the nonmagnetic metals. Eddy current coil (ECC) sensor sorters inspect and recover the residual metal from nonmetallic residue. The dual energy x-ray transmission (DE-XRT) sensor has the capability to separate light from dense metals, replacing the function of the dense media sink-float plants. Dual sensor ECC and DE-XRT sensors have the resolution and capability to inspect shredder fines residue that still contains small copper wires and small Al particles.

Dross processing

Prior to being remelted in rotary furnaces, Al metal is typically concentrated by crushing dross and eddy current rotor separation (ECS). This mechanical separation is sometimes repeated for the rotary furnace dross or saltcake. The oxide and salt residue still contains metal inclusions too small to be separated by ECS. There are no reliable figures on the quantity of metal lost in this stream as dross processors seldom track and never publish data on the metal content of their oxide/salt residue. USGS data for 2006 reports over 600 kt of metal recovered from dross and skimmings. We estimate that the US residue consists of more than 1,500 kt of nonmetallics containing up to 30 kt of metal.

Dual sensor ECC and DE-XRT sensors have the resolution and capability to inspect crushed oxides for residual metal.

Separation of bare and painted scrap

Decoating of bare scrap is a waste of effort and energy, while melting of painted scrap results in excessive melt losses. The used beverage container (UBC) provides an extreme example. Melting of painted cans in a rotary furnace rarely gives a metal recovery of more than 85%, whereas careful decoating and vortex submergence melting routinely give net metal recoveries of 97%. Al from old post-consumer scrap is a mixture of bare and painted items. USGS data for 2006 gives 215 kt of non-UBC wrought old scrap and 155 kt of cast old scrap consumed by US smelters. Much of it could benefit from bare/painted separation and decoating of the painted fraction.

A particle sorter equipped with a color camera sensor is sufficient to perform this separation after the material is shredded and sized. Reduction in melt losses is more than adequate to offset the additional processing costs.

Separation of nonmetal contaminants and attachments from scrap metal products

As is the case with paint, residual paper, plastic and rubber particles and attachments in Al scrap burn during remelting, leading to oxidation and melt losses. The 190 kt of Al recovered from shredder metal concentrate and consumed in US in 2006 could have been melted with lower melt losses if the residual contaminants were sorted out of the furnace feed. Another 1,000 kt of other Al old scrap consumed in US in 2006 would need to be shredded to permit removal of contaminants and attachments. In 2006 there also were 2,000 kt of new manufacturing trim scrap in US, some of which could have been recycled to applications using alloys closer to the original alloy composition if contaminants were identified in, and removed from, the nominally source-segregated scrap. A particle sorter equipped with a DE-XRT sensor is up to this task.

Separation of Mg-based scrap from Al scrap products

Mg components are still a small fraction of light-metal scrap coming back from the consumers. Some estimates put it as high as 2% of Al coming back in end-of-life automobiles or ~1% of the light metal shredder output. If this material finds a path all the way to secondary foundry Al smelters, it will more than double the amount of chlorination required and associated melt and time losses. The quantity of the Mg-alloy components entering the consumer market is rising steadily and unless Mg-Al separation is implemented, related losses will continue to mount in the future. Without Al-Mg separation, 200 kt of Mg diecastings that have entered the automotive market will contaminate over 5,000 kt of Al automotive castings and will lead to losses of the 200 kt of Mg and similar amounts of Al in refining by chlorination. In the near future, Al-Mg separation will become imperative to maintain the efficiency and sustainability of the light-metal lifecycle.

Options for Al-Mg segregation are either density separation in a dense media plant or sensor-based sorting. Only a few media plants are left in North America and no new ones are being built. This leaves sensor-based particle sorting, where a combination of color and DE-XRT sensors can do the sort.

Separation of Al alloys with high Mg (or Li) content from those with high Si, Cu or Zn in Al scrap

There is much more Mg in Al scrap as alloying elements than as free Mg-alloy particles. The current level of refining by chlorination and the associated losses can be substantially reduced by sorting out Al-alloy particles rich in Mg and batching them into secondary wrought alloys. 3X04 can body sheet and 3105 building sheet are suitable candidate alloys. The second output stream will be high in Si, Cu and Zn and low in Mg, giving it an added value when batching foundry alloys.

Such a sort can be performed by a sorter equipped with an elemental analysis sensor based on laser-induced plasma spectroscopy (LIBS). The first industrial plant based on this technology was commissioned in 2004 by Huron Valley Steel Corp. in Belleville, MI, and has been successfully operating since then on a feed of Al recovered from shredder metal concentrate.

Separation of Mg alloys with Sr, Ca or rare earth alloying element content from those with Mn and Zn in the Mg scrap

Exotic Mg-based alloys containing Ca, Sr or rare earth elements such as Ce, Nd, La, Gd, Eu are being developed for the creep resistance required by automobile power train applications. These are composition incompatible with the common Mg diecasting alloys, which are based on Al, Zn and Mn alloying elements. The first application in BMW engine blocks put 7 kt of such alloys in the 150 kt automotive Mg component market in 2006. Other applications are under development. As mentioned above, virtually all recovered post-consumer Mg scrap is used for steel desulphurization, which results in consumption of the metal and hence permanent loss of the expensive exotic alloying elements. As applications of Mg for automotive components grow, separating the Mg alloys with exotic alloying elements will be mandatory to enable recycling of Mg and its alloying elements as Mg alloys.

Two elemental analysis sensor technologies are technically feasible for this task – x-ray fluorescence and LIBS.

Value-added use of scrap

In the case of light metals, additional recovery of scrap from waste replaces prime with secondary metal whose melting and treating requires only ~5% of the energy required to produce prime metal from ore. This vastly improves the sustainability of the light-metal lifecycle. Once the scrap is upgraded to the point where all of it can be remelted and reused, any additional processing consumes additional energy and resources without further reduction in prime demand and hence is counterproductive from a global material lifecycle perspective.

However, there are regional, national or company strategic considerations that often trump the global sustainability point of view and may justify further scrap upgrading. Europe and the US, having shut down much of their primary light-metal production facilities and having exported much of the low-tech, labor-intensive foundries to Asia, must import prime metal to keep producing beverage cans, building products and automotive sheet in rolling mills that took billions of dollars of capital investment.

Adding value to scrap is another measure of the efficiency of scrap use. Although closed-loop alloy or product recycling is seldom a requirement of a sustainable recycling system, there are opportunities to profit by recovering the value locked up in the scrap composition.

Currently there are small differences between the prices paid by the remelts and the secondary smelters for upgraded Al scrap products or between the prices of various types of remelt ingot that would justify scrap sorting by alloy.

Sensor-based sorting can still uncover additional opportunities for profit. The price of scrap changes as it is recovered and upgraded. Scrap in waste bound for the landfill has a negative value, i.e. the landfill tipping fee. Scrap at the curbside has a zero value to the consumer. In 2007, cans recovered from curbside recyclables at the MRF were sold for ~$1/kg to the scrap dealer, who collected truckload quantities and sold the same UBC at closer to ~$1.75/kg to the UBC remelt. Auto scrap shows a similar story. A customer with a wreck on his or her hands pays for towing it to the dismantler. The dismantler, after scavenging spare parts, sells the flattened hulk for ~$100/t to the shredder. The shredder sells the Al content in the nonmetallic metal concentrate to the sorter or media plant at ~ $1/kg, which in 2007 sold its Al “twitch” product to secondary smelters for ~$1.80/kg. Clearly a remelt operator who installs scrap sorting and upgrading equipment can buy scrap earlier in the value chain and pocket the profit. Such action satisfies regional and company strategic objectives by locally retaining the low-cost raw materials for the benefit of local industry, employment and economy.

Conversely, scrap collectors and shredders at the beginning of the value chain can increase their take by integrating downstream and investing in shredding and scrap sorting. However, they are free to sell the upgraded scrap to the highest bidder – often an Asian scrap importer supplying Asian foundries. The local economy suffers and the global light-metal lifecycle absorbs the energy charge of long-distance transportation and losses associated with refining out the Mg from Al foundry alloys.

Below we offer examples of where upgrading of Al scrap by sensor-based sorting could provide opportunities for profit in the current system.

Contaminant removal from nominally source-segregated manufacturing alloy scrap

A remelt facility equipped with a DE-XRT sensor particle sorter is able to remove contaminants from purchased manufacturing scrap. Such a sensor can also identify particles that differ in thickness, shape, or have significantly different average atomic numbers. This may enable remelt operator to buy back source-segregated manufacturing scrap from its customers or from scrap dealers. Such a sort would be justified by the price difference between prime-based ingot and the cost of manufacturing scrap plus melting and casting.

Sorting of mixed-alloy manufacturing scrap

A remelt facility equipped with a LIBS sensor particle sorter would be able to sort mixtures of manufacturing clips of known composition. This would expand remelt operator's freedom to buy back a lower cost mixed-alloy scrap and use it in batching wrought alloy or alloys in its range of products.

Batching of value-added secondary alloys from post-consumer Al scrap twitch, old sheet and cast

A secondary smelter equipped with a LIBS sensor particle sorting circuit has the freedom to buy post-consumer Al scrap from scrap dealers, which includes shredder product and old sheet, extrusion and cast categories. Through elemental particle analysis, high Mg wrought Al alloy and low Mg, high Cu and Zn foundry Al alloy can then be simultaneously batched at the smelter. Such a sort gives two value-added alloy products from the lowest cost scrap categories available on the scrap market. This not only separates free Mg alloy from free Al alloy particles, but actually batches the target alloy composition on line piece by piece, based on the alloying element concentrations of Mg, Cu, Zn and other major alloying elements.

Such an Al-alloy batching plant has been successfully operated by HVSC, in Belleville, MI since 2004 producing 3105 sheet alloy and 38X foundry alloy sold, respectively, to local US sheet mills and secondary smelters.

Batching of Mg diecasting AZ91 alloy from Mg recovered from shredder nonmagnetic metal concentrate

Since steel desulphurization can still consume all post-consumer Mg scrap, there is little financial incentive to develop a system to efficiently recover this scrap. However, with Al recyclers insisting on elimination of free Mg from Al scrap, and the quickly rising use of Mg diecasting for consumer electronic housings and for automotive applications, this situation is quickly going to change and there will be a need to develop a secondary post-consumer Mg-alloy application. The Mg AZ91 alloy that contains 9% Al, 1% Zn and >0.3% Mn is a good candidate for such a secondary alloy. It is also the most widely used of all Mg alloys. A recently developed secondary Mg alloy AZC1231 that includes 12% Al 3% Zn can accommodate recycling impurities such as Cu and some Ni and Fe without run-away corrosion and with excellent castability.

For most manufacturing scrap sources, it may be possible to melt the available mixture of the incoming Mg scrap and simply add more Al Zn and Mn to reach the AZC1231 and AZ91 composition targets.

For post-consumer scrap that may contain a variety of exotic alloys, a particle-sorting plant equipped with an elemental concentration sensor sorting circuit will likely be required to technically accomplish this AZ91 batching task. There will be also an economic incentive to accumulate and sort the residue stream, which contains exotic Sr, Ca, Ce, La, Nd and other high value alloying elements.

Summary

We have shown that in the current global economic environment which is short of metal scrap, there is little incentive for the scrap collector and processor to do more than separate light metals from other recyclables and waste. Sensor-based sorters can aid in recovering the residual metals from the nonmetallics.

There are global recycling system needs developing for further processing of light metals that first involve separation of free Mg from free Al, and later batching of separate Mg-rich wrought Al alloys and low-Mg foundry alloys. Sensor-based sorters provide an economically viable technical solution to performing these separations.

North American and European remelts and secondary smelters can profit from the freedom to buy lower cost mixed-alloy scrap and batch their current products by upgrading such scrap using sensor-based sorters.

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