Final Report on Refining Technologies of Aluminum

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Report No. 2003-21(CF)

December 2003

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FINAL REPORT ON REFINING TECHNOLOGIES OF ALUMINUM

by

S. Bell*, B. Davis*, A. Javaid** and E. Essadiqi**

EXECUTIVE SUMMARY

There are three processes used for refining aluminum melts of various impurities to meet the current requirements in the cast shop. They are fluxing, floatation, and filtration and are carried out in the pre-treatment crucible and/or casting furnace, the degasser, and the filtration unit respectively.

Alkali metals are removed from aluminum melts by fluxing with either a reactive salt or a gas. Aluminum chloride salt fluxes represent the oldest reagent for removing alkali elements and historically were incorporated into an aluminum melt using a mechanical puddler. Agitation of the melt was very important in this process since physical contact between the salt particles and the alkali elements is necessary for the two species to react and form an alkali chloride.

However, puddling was relatively inefficient, and there were large losses of aluminum because of the massive accumulation of dross on the surface. This led to many improvements in the technique and equipment used in solid flux refining. In Alcan’s Treatment of Aluminum in Crucible (TAC) process, a specially designed rotor replaced the mechanical puddler, and the aluminum chloride salt was replaced with aluminum fluoride salt. The fluorinated compound has been shown to promote the agglomeration of oxide impurities, making their removal considerably easier. Today, the TAC process is commonly used as the first step for purifying aluminum melts with high impurity concentrations, and it is conducted in a pre-treatment crucible. However, its overall removal efficiency of alkali impurities in aluminum melts is not high enough to meet commercial standards, and additional fluxing using a gas treatment is crucial.

Chlorine is the only gaseous species that is used as a flux for removing alkali impurities by reacting directly with the alkali metal to form an alkali chloride, and in alloys containing magnesium, reacting with the magnesium to form magnesium chloride, which then reacts with the alkali metal to form an alkali chloride. In both these cases, the alkali chloride separates out of the melt by floating to the top. Chlorine is added to the aluminum either as a pure gas or mixed with an inert gas such as argon or nitrogen, since 100% chlorine gas is not required to clean the melt effectively. Lance and rotary gas injection (RGI) are the two most common methods for delivering the gas below the melt surface and dispersing it throughout the crucible. Lance fluxing is inefficient in comparison to RGI because the gas bubbles are too large and the

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population is too small for it to be effective. Its stirring capability is also limited and requires
the use of an additional method for stirring the melt. RGI uses only a fraction of the chlorine gas
used for lance fluxing, which helps to reduce emissions and the need for alkaline scrubbers. The
use of chlorine gas also lowers the concentration of hydrogen and oxides in the aluminum melt
by floating these impurities to the surface.

Due to the tighter environmental regulations on the use of chlorine gas, some aluminum cast
shops are moving towards the implementation of a rotary flux injection (RFI) system for fluxing
aluminum melts. RFI uses a reactive salt, either fused magnesium chloride or aluminum
fluoride, and a rotor system designed to inject the solid salt below the melt surface while stirring.
The shear forces of the spinning rotor cause the salt particles to be sheared immediately, which
reduces their size and increases their dispersion in the aluminum. The rotor also adequately stirs
the entire volume of aluminum to ensure the whole melt is treated. This method has the
advantage of almost no chlorine and hydrochloric gas emissions, and its effectiveness for
removing alkali impurities is equal to, or better than, the RGI system. The aluminum fluoride
also works to remove oxides from the melt, since it promotes wetting, agglomeration, and
removal of these impurities.

Lance, RGI, and RFI practices are performed in a casting furnace and are adequate methods for
reducing alkali metal concentrations in aluminum melts. RGI and RFI are the two most widely
used processes in aluminum cast houses because of the resulting increase in metal purity and
reduced chlorine emissions. It is expected that, in the near future, all casting shops will adopt
RFI technology as stricter environment laws are passed. However, none of these fluxing
processes can meet the designated metal cleanliness standards for most commercial purposes,
and additional treatment steps are necessary.

After leaving the casting furnace, the melt is transferred to the degasser where the molten
aluminum is subjected to multiple gas rotors, similar to the ones used in RGI. The degassing
process is designed to reduce the overall hydrogen level in the melt through floatation and is
performed in an enclosed vessel. The gas used is chlorine mixed with either nitrogen or argon.
The presence of chlorine in the gas feed is very important since low hydrogen levels cannot be
achieved in its absence, and it initiates further alkali metal removal. Two major challenges
facing current degassing units are their dependence on chlorine gas, and high melt losses due to
metal being retained in the vessel between castings or alloy changes. Currently, there are no
substitutes for chlorine gas in degassing practices, and when it is used in aluminum-magnesium
alloys, small droplets of magnesium chloride are formed that contaminate the melt. The
development of the Alcan compact degasser (ACD) has helped to solve the large metal retention
issue in normal degassers by performing the process in an enclosed system of casting troughs.
This method is geared towards shops that cast a variety of alloys and products since metal
retention in the ACD is minimal. The generation of magnesium chloride impurities, along with
the presence of small oxide particles or films, has resulted in sporadic changes in impurity levels
in the aluminum after the degassing process. To help guard against these impurities, filtration is
used as the last processing step before the aluminum is cast.

The ceramic foam and the deep bed are the two most commonly used filters in aluminum alloy
processing. Ceramic foam filters use a combination of cake and depth filtration to remove the
small impurities from the melt. This type of filter is meant for single use, and they are removed after every cast. This makes them ideal for companies that cast a number of different alloys. Both their size and their capital cost are small, making them a good fit for small casting operations. On the other hand, their small size does result in notable disadvantages including high metal velocities, low depth filtration, and large pores. These three factors all contribute to a decrease in the effectiveness of the filter. Deep-bed filters are recognized as the most efficient way of eliminating or reducing fine inclusions in aluminum melts. These filters are very large in size and promote slow melt velocities and good depth filtration. However, their size, expense, and single-alloy use make them impractical and uneconomical for applications in most small foundries.
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INTRODUCTION

Over the past three decades, there has been a remarkable increase in aluminum applications because of recent advancements in the automotive market. In 1976, the average North American car contained roughly 40 kg of aluminum while today’s car uses close to 115 kg. This number is expected to continue to grow as wrought-aluminum alloys gain increasing acceptance as an alternative to steel car panels. In order for aluminum manufacturers to meet the increasing product performance requirements of the automotive industry, the molten metal needs to be free of all impurities, including alkali metals (sodium, calcium, and lithium), non-metallic inclusions, and dissolved hydrogen. These impurities have been a major concern for all aluminum cast houses for the last 20 years and have necessitated the development of a variety of new treatments for molten aluminum.

Primary and secondary metal represent the two principal sources of molten aluminum supplied to the cast house for processing. Molten metal from an electrolysis operation is known as primary aluminum, while secondary aluminum is from a recycle/remelt facility. The fundamental difference between these two types of aluminum is the concentration of each type of impurity present in the melt during initial melt cleanliness tests. Primary aluminum contains a higher level of sodium, aluminum carbide, and non-metallic inclusions, which are associated with large additions of alloying agents. Recycled aluminum tends to have increased levels of hydrogen, calcium, and large oxide inclusions that form during exposure to the high temperatures used for melting secondary aluminum. A summary of the impurity levels detected in both primary and secondary aluminum is given in Table 1.

Table 1 - Aluminum impurity levels in both primary and secondary sources.

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<th>Characteristic (PoDFA scale)</th>
<th>Primary</th>
<th>Secondary</th>
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<tr>
<td>Composition</td>
<td>&gt;99.7%</td>
<td>Alloyed or close to compositional specifications</td>
</tr>
<tr>
<td>Hydrogen</td>
<td>0.1-0.3 ppm*</td>
<td>0.2-0.6 ppm</td>
</tr>
<tr>
<td>Alkali metals</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Na</td>
<td>30-150 ppm</td>
<td>&lt; 10 ppm</td>
</tr>
<tr>
<td>Ca</td>
<td>2-5 ppm</td>
<td>5-40 ppm</td>
</tr>
<tr>
<td>Li</td>
<td>0-20 ppm</td>
<td>&lt; 1 ppm</td>
</tr>
<tr>
<td>Inclusions</td>
<td>&gt; 1 mm²/kg Al₄C₃</td>
<td>0.5 &lt; mm²/kg&lt;5.0 Al₂O₃, MgO, MgAl₂O₄ Al₄C₃, TiB₂</td>
</tr>
</tbody>
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* ppm – parts per million

The presence of these impurities in the aluminum causes a drastic reduction in the material properties of the metal, which makes it essential for them to be dramatically reduced if not removed completely to meet commercial requirements.
MOLTEN ALUMINUM REFINING STEPS

In the aluminum industry, there are three or four processing steps used to reduce or eliminate the impurities within the molten aluminum: pre-treatment crucible, casting furnace, degasser, and filter. This sequence of processing steps is shown in Fig. 1. Within these processes, fluxing, floatation, and filtration are the three techniques used to completely refine the aluminum metal in preparation for the final casting stage. All three techniques will be discussed in more detail.

FLUXING

A reactive flux, either salt based or chlorine gas, is used in the pre-treatment crucible and casting furnace to remove alkali elements and other inclusions from the aluminum before it is passed onto the casting furnace. Fluxing of aluminum has been performed since the early 19th century and is well documented. The general purpose of the flux is two-fold: to attach to the inclusions in the melt either by a direct chemical reaction or by wetting; and to separate the inclusions from the molten aluminum through either floatation or settling to the bottom of the furnace. The flux can be a solid, a liquid, or a gas.

Salt Based

The first refinements of aluminum were performed with salt-based fluxes. Zinc chloride and aluminum chloride were cited as the two most popular fluxing agents used in treating molten aluminum. Aluminum-based chlorides were most often used since no foreign elements (i.e., zinc) were introduced into the melt. This type of fluxing was performed in either an iron pot or a special reverberatory furnace. In both systems, a heel of high-purity molten aluminum was produced, which was followed by the charging of the unclean metal, and the addition of the flux. To ensure adequate contact of the fluxing agent with the aluminum melt, a mechanical puddler was used.

Technological improvements in stirring practices and furnace design generated a large number of alternative processes for refining aluminum that used salt-based fluxing agents. In the early 1980s, Alcan International Ltd. demonstrated a new technique for removing alkali metals from
primary aluminum, which is commonly referred to as the TAC (Treatment of Aluminum in Crucible) process. The TAC process is done in an enclosed vessel to avoid the excessive formation of dross. Aluminum fluoride (AlF₃) was sprinkled on the melt surface while a specially designed rotor generated a vortex within the melt that had a unique axial and radial flow component. This ensured a high reaction efficiency of the flux with the metal while minimizing surface turbulence and oxide ingestion. The final concentration of alkali metals, notably calcium and sodium, were lowered to just a couple of ppm while some improvement in the reduction of non-metallic impurities was also achieved. The enclosure of the process allowed skimming practices to be nearly eliminated since dross generation was minimal. The use of fluoride compounds brought about many concerns, especially in regards to refractory erosion and fluorine emissions generated by direct flame impingement on the surface of the dross. In addition, solid fluxes using traditional stirring practices could not meet commercial standards for melt cleanliness, and additional processing was needed.

Lance Fluxing

Hyatt⁷ first realized the potential of chlorine gas as an alternate fluxing agent in 1901. It was not until the late 1920s that a method was put forward to pass chlorine or a chloride-containing gas through the molten metal using a static lance⁸. By using a reactive gas, the alkali and alkaline metals, non-metallic inclusions, and hydrogen concentrations within the melt could be reduced with a single processing operation. The complex mechanisms of furnace fluxing using static lances and chlorine have been reviewed extensively⁹. This led to the quantification of the specific effects that chlorine has on the cleanliness of aluminum for a wide variety of alloys. Unfortunately, this method suffered from inadequate stirring, decreasing the efficiency of impurity removal. By adding more static lances, porous lances¹⁰ or plugs¹¹,¹², slight improvements were made to the lance fluxing system. However, difficulties in lance fabrication and plugging, as well as low lance and plug efficiencies, have prevented industrial acceptance of these approaches. Also, the application of metallurgical modeling¹³ has shown that, assuming a minimal amount of stirring, the rate-limiting step of chlorine fluxing is the gas/liquid surface area generated by the gas injection system. This motivated the search for an alternative fluxing process that focused on enhancing the stirring of aluminum and fluxing kinetics.

Rotary Gas Injection

The rotary gas injection (RGI) system, with high-shear gas dispersers, was the solution to this problem. Its potential in the aluminum industry was realized in the early 1990s, but it was not until recently that it became widely used for fluxing aluminum melts. RGI not only increases the interfacial contact area between the liquid metal and the fluxing agent, but it also improves the stirring of the melt. The overall effect is a dramatic improvement in the alkali removal rate (Fig. 2⁹) that, in addition to reducing the fluxing times and improving productivity, decreases the chlorine consumption by nearly two-thirds².
Fig. 2 – Removal rate of calcium using various fluxing processes.

The reduction in chlorine consumption has also decreased emissions of chlorine and hydrochloric gas, resulting in a positive effect on the environment. Hydrochloric gas emissions are a by-product of the hydrolysed reactions of either AlCl₃ or MgCl₂, which are common impurities of fluxing with chlorine gas in aluminum melts. To further reduce the use of chlorine in the RGI process, a method for using a dilute mixture of chlorine in an inert carrier gas of either nitrogen or argon has been established⁵ and is referred to as the Mixal process. Nitrogen can also be used instead of argon, since the formation of aluminum nitride does not generally occur in a chlorine environment. The typical chlorine content can range from a few percent to 50%⁹. The Mixal process was development by Pechiney Aluminum in France, and it achieves alkali metal reductions of 87% and 95% for sodium and lithium respectively. Initial plant trials using pure argon also showed a reasonable reduction in the alkali metal concentration of the melt, but the overall percentages were lower than those obtained using the chlorine gas mixture. Tests were conducted to determine the extent of the argon reduction and whether it was possible to use a chlorine-free gas to remove alkali metals, however no further information was found.

Rotary Flux Injection

Increased restrictions on environmental emissions have called for the replacement of chlorine during furnace fluxing. The advancement of rotary flux injection (RFI) technologies has enabled the replacement of chlorine gas with a salt-based flux¹⁴,¹⁵,¹⁶. This change has lowered chlorine emissions by 95%² from static lance fluxing operations while maintaining or improving melt cleanliness¹⁵. One type of salt-based flux used in a RFI system is industrial pure MgCl₂ that has been fused together with other compounds. The effectiveness of MgCl₂ in removing alkali species was determined by Celik et al.⁹, who found both the amount removed and the rate of removal to be proportional to the concentration of magnesium in the aluminum melt. The purpose of the additional compounds was to lower the melting point of the flux as well as to enhance the collection and separation of other impurities within the melt. With a lower melting
point, there is a lower surface energy and less liquid-liquid contact between the molten flux and aluminum melt which works to increase the flux’s kinetics. As with the other flux injection processes, the alkali species are removed from the aluminum melt by coming in direct contact with the MgCl₂ and reacting to form alkali chlorides, which rise to the surface where they accumulate in the dross. The rotary system used in RFI is very similar to RGI in the sense that the droplets of salt are sheared directly upon release into the melt, thereby increasing the surface area of reaction. To facilitate the flux travelling through the rotary system, a carrier gas is used (usually nitrogen). Once again the use of nitrogen gas does not promote the formation of aluminum nitride since fused salts do not generate ‘hot’ dross. Hot dross is generated by a large amount of heat, which originates from the exothermic reaction between certain fluxes and aluminum oxide. Another advantage of this system over lance fluxing is that a lower quantity of dross is produced on the melt surface. Lower surface turbulence during RFI has been cited as the primary factor in lowering the accumulation of dross. Other advantages are associated with the elimination of chlorine and include a reduction in corrosion on equipment and building materials where bulk liquid chlorine is stored, and in safety systems required for transporting chlorine gas. According to Beland et al., this particular process has been successfully implemented in six different plants.

Aluminum fluoride (AlF₃) is another example of a salt-based flux used in RFI. The only difference between this type of flux and the MgCl₂-type flux described above is that the AlF₃ remains a solid throughout the entire refining process. The use of AlF₃ has been shown to reduce the concentration of alkali metal and aluminum carbide impurities quite effectively. There was also a noticeable reduction in the amount of dross skimmed from the melt following RFI with the AlF₃ flux. The major drawback of using AlF₃ was a temperature drop of 40°C, which could lead to the precipitation of additional impurities such as aluminum carbide. Also, traces of oxides were still present in the metal after refining. This type of fluxing system is currently in use in one of the Hydro Aluminum plants in Norway.

The TAC process takes place in a pre-treatment crucible, while the RGI and RFI are performed in a casting furnace. The pre-treatment crucible has a relatively large surface-to-volume ratio and is stirred at a rate that enhances the kinetics of the process so that the treatment is quick. The purpose of the pre-treatment crucible is to prepare the aluminum for the casting furnace so that a shorter time is required to further reduce the concentration of impurities. This is becoming increasingly important as the need for cast shops to accept primary metal with higher alkali impurity levels and lower quality aluminum scrap has risen dramatically. Alkali metals are being used as important additives in the electrolyte used for the Hall-Heroult process. Also, the pre-treatment crucible has been cited as a possible location for performing small alloying additions.

The most popular casting furnace used in the aluminum industry is the fossil-fuel heated reverberatory design, which has a relatively shallow melt depth and a high surface-to-volume ratio. This shape is designed to increase the heat transfer and kinetics of the fluxing process. However, poor melt circulation has lead to a large temperature variation between the top and bottom of the furnace, which has been reported to be as high as 200°C. This large temperature gradient will generate a non-homogenous melt, especially in regards to intermetallic impurities, which can either precipitate out or re-dissolve into the melt depending on the temperature in
their position within the melt. To overcome this problem, advanced subsurface stirring technologies have been developed to help stabilize the temperature throughout the casting furnace; these include pneumatic-jet and electromagnetic stirrers. The overall picture is that the casting furnace is not the most efficient design for performing chemical adjustments, even with the improved fluxing technologies of RGI and RFI. In order to generate metal that meets today’s cleanliness requirements, other metal processing steps are still mandatory.

FLOATATION

The first processing step following the casting furnace is referred to as degassing, which uses a mixture of argon and chlorine gases to remove most of the hydrogen through floatation. As the metal comes in contact with the rising gas bubbles, the hydrogen atoms diffuse to the bubble surface where they combine to form hydrogen gas. The hydrogen gas then collects inside the bubble and is transported out of the system as the bubble floats to the surface of the metal. At the surface, the bubbles burst and release the mixture of argon and hydrogen gas. This mechanism for removing hydrogen from aluminum melts is illustrated in Fig. 3.

To prevent the hydrogen gas from re-entering the metal, the off-gas is cleared immediately. Since the removal of hydrogen is done in a step-wise fashion, there are usually two or more rotary degassers used in sequence. The small percentage of chlorine gas used in this process is essential for complete hydrogen removal, but the exact reason for this is still unknown. The chlorine gas also works to remove additional alkali elements contained in the melt, and the presence of small bubbles assists in the removal of non-metallic solid particles by floatation. The uniqueness of this process lies in the design of the furnace and the rotor. This furnace design is a classic multi-stage tank reactor that uses one or more rotary injectors and is shown in Fig. 4. Once again the design of the injector is such that the gas-metal interface is maximized. The process is enclosed to prevent hydrogen pickup from water vapour in the casting plant, and
in recent developments\textsuperscript{19} inert gases have been used above the melt surface to help reduce dross generation and the amount of skimming as well as to lower baghouse collections of particulate matter. Some of the problems associated with the current degassing technique are:

1. Increases in the size of the multi-stage degasser result in a large amount of metal being left inside the unit between casts, and changing the alloy results in substantial metal losses. These losses are estimated between one and three tons of aluminum per batch\textsuperscript{20}.

2. The size of the degasser requires a large area designated in the cast shop\textsuperscript{20} (as much as 15 m\textsuperscript{2}), and the more recent degassing equipment is fairly complex and expensive.

3. The degassing units are complex and expensive to maintain, both in terms of capital expenditure, and in the downtime necessary to make repairs to the electrical heating and hydraulic systems, rotors, and refractory or graphite vessels.

A development by Alcan International Ltd\textsuperscript{20,21,22} based on a trough process has addressed the issue of metal retention at alloy change, which is a problem in the current degassing operations. In this recently patented system, the bubble population is increased by a factor of ten, creating extreme turbulence within the furnace. This combination of excessive bubbles and turbulence results in hydrogen removal rates comparable to those experienced during other spinning nozzle techniques. Since the process is enclosed, the turbulence does not introduce unwanted oxides into the melt. The two biggest advantages of this system over current degassing units are a 75\% reduction in size, and the elimination of substantial aluminum losses during alloy changes. Also, maintenance inside the equipment is much more accessible than in current degassing units. This process is now referred to as the Alcan compact degasser (ACD), which treats molten aluminum in the casting trough and is geared towards multiple-alloy cast shops.

The major concern encountered with the current degassers is that the use of chlorine in the inert gas causes the formation of magnesium chloride in the treatment of aluminum-magnesium alloys. Since the concentration of alkali metals in the degasser is relatively low, the magnesium
chloride droplets become impurities in the aluminum. The additional use of high shear rotary injectors results in very small MgCl₂ inclusions that are difficult to remove by floatation. If these impurities are not eliminated from the melt, they can lead to an increase in surface oxidation on the final cast part. This in turn causes substantial problems for the manufacturers when producing the intended product. The generation of these impurities has lead to the optimization of chlorine levels in the degasser that, if insufficient, can result in poor hydrogen removal. Some experimental work is currently being conducted on ways to eliminate magnesium chloride inclusions from degassing units and is based on impurity coalescence on a perforated block and removal through flotation. Unfortunately, no information on the progress of these techniques was found in the obtainable literature.

While the elimination of chlorine from all degassing units would benefit the environment, improve workplace safety, and increase equipment lifespan as well as reduce maintenance costs and the formation of magnesium chloride impurities, this cannot be done without jeopardizing the metal cleanliness of the aluminum. Currently, there are no chlorine-free processes available for effectively degassing aluminum alloys to a purity required by most applications. Since magnesium chloride impurities form in the degassing process and are not effectively removed, an alternative refining technology is required to achieve the appropriate metal cleanliness. In the aluminum industry, filtration is used as the last processing step to clean the melt before it is cast.

FILTRATION

Filtration Theory

Filtration of particles out of a liquid stream is achieved by two mechanisms: cake and depth filtration. The mechanical removal of impurities by the surface of the filter is referred to as cake filtration. It has been found that inclusions greater than 0.03 cm in diameter are easily removed by cake filtration, and, as the inclusions build up on the surface of the filter over time, they pack together tightly and form a filter cake. This cake formation increases the filtering capabilities of the filter as more metal is pushed through. On the other hand, depth filtration is the most common filtering mechanism used in standard industrial filtration practices. This type of filtration can easily remove inclusions smaller than 0.03 cm. The filtration path is much longer and more rigorous which increases the probability of the inclusions becoming attached to the filter. Particles that come into contact with the sides of the filtering apparatus may adhere to it by one or more of the following five mechanisms:

1. gravity, friction,
2. physical confinement,
3. chemical bonds,
4. Van der Waals forces, and/or
5. electrostatic forces.

The degree of efficiency of a filter depends largely on the properties of the molten metal being refined. These properties include the type, size, shape, number, and distribution of the inclusions throughout the melt. Other factors affecting filtering efficiency include the flow rate of the metal, the surface area of the filter, and the depth of the filter dimensions. Slower flow
rates have greater filtration efficiencies because of the increased probability of entrapment. Larger filter surfaces also increase the probability of particle confinement on the mesh, resulting in better inclusion removal. The longer the path for particle transport, the more likely the particle will come into contact with the filter medium, and be removed from the liquid. Moreover, filters that depend on both cake and depth filtration will produce a better-filtered product than those that depend on a single mechanism. Moreover, relying solely on cake filtration should be avoided since it leads to a dramatic reduction in metal flow. To reduce the amount of cake filtration, the incoming metal should be as clean as possible.

There are many different types of filters used in the nonferrous molten metal processing industry. These are summarised below.

Strainer cores are the basic type of filter used in down spurs in standard sand castings. The purpose of these filters is to control the metal flow by slightly plugging the flow, and in doing so they stop particles from passing by mechanical confinement and a small amount of cake filtration.

Metal or fiberglass screens are used to accurately filter particles greater than 0.1 cm in size. Steel mesh and fiberglass cloth are more often used to filter aluminum melts, while molybdenum mesh is commonly used for copper. These types of filters are planar and are generally single-use filters.

Bed filters are made up of tabular aluminum oxide (Al₂O₃) and are used mostly for large-volume filtration of casting or mill products. These filters are recognized as the most efficient way of reducing or eliminating fine inclusions in metallic melts. However, their size, expense, and single-alloy use make them impractical and uneconomical for large-scale use in most foundry applications. Also, bed filters can lead to turbulent flow, which increases the formation and entrapment of oxides during casting.

Bonded-particle filters are refractory grains of either aluminum oxide or silicon carbide reacted together to produce a rigid structure. This structure gives a long and complex molten metal filtration path, resulting in good depth filtration. Bonded-particle filters contain approximately 38% interconnected porosity of varying sizes. Other advantages include long service lifetime, low temperature gradients, and reusability. These filters are used vertically between melting and holding furnaces, and have been successful in many mill product, foundry and die-casting operations. The average durability of the filter is 500 tonnes.

Cartridge filters are structurally identical to a heat exchanger. They consist of a shell and tube construction and provide a large surface area for physical contact with melt inclusions. The pore size is usually small, resulting in very low flow rates. However, the purity of the resulting melt is high, making cartridge filters a vital method for manufacturing high-quality metal for both the airline and electronics industries. Inclusions smaller than 0.005 cm in size have been removed with an efficiency of 95% or greater using this type of filter.

Ceramic foam filters (CFF) are the most popular filters used in refining nonferrous castings. The filters are manufactured by coating reticulated polyurethane cellular foam with slurry, followed
by drying and firing to eliminate the foam. The final product is a ceramic shell of the original foam. Ceramic materials used for foam filters are alumina, zirconia, mullite, and sometimes chromic oxide. The porosity of the filter is approximately 75%, and pore sizes vary throughout the filter. While the primary mechanism of filtration is believed to be cake, some depth filtration does occur. These filters are used in a singular or multi-layered planar form and are in use in the die-casting and foundry industries.

Filters have been widely used for many years in the processing of aluminum melts to guard against uncontrolled upstream process variations that result in the sudden formation of impurities. The three most prevalent impurities that remain in the aluminum and are removed by filtration are magnesium chloride, aluminum oxide and aluminum carbide. Magnesium chloride inclusions are generally only present in aluminum-magnesium alloys and are a result of reactions with the chlorine gas used in the degassing units. Excessive aluminum oxide formation is a result of surface turbulence and is a major concern in the metal transfer equipment used in the casting shop. Due to the use of refractory materials including graphite in the metal-treatment processes, the aluminum is constantly saturated with carbon, and even a slight drop in the melt temperature will cause aluminum carbide inclusions to precipitate.

Impurity removal in aluminum filters is based on depth filtration and involves the removal of impurities throughout the entire length of the filter. The impurities are eliminated from the melt by being subjected to a long and complex path through the entire depth of the filter. This increases the chance of the impurities coming into contact with, and remaining on, the filter medium. In order to maximize the efficiency of the filter, it must be constructed of a non-reactive material that is easily wetted by the aluminum melt, has a small pore size and a large depth, and promotes a slow metal velocity. It is of interest to note that the factors for improving the effectiveness of a filter tend to increase its size, which is a major concern to the cast house because of the lack of available space. Cake filtration is not intentionally used in the aluminum industry, since there is significant build-up of material on the filter surface and it will eventually clog.

The two most common types of filters used in the aluminum industry are CFF and deep-bed filters. CFF are single-use filters that are generally small in size and can be easily changed after every cast, which is very important when changing alloys. Their small size is advantageous, since they do not occupy much floor space in the cast shop. However, it also results in a fast metal velocity, a limitation of the filter depth, and an increase in the attainable pore size, all of which combine to decrease the overall efficiency of the filter. Cartridge filters are another type of single-use filters used in the aluminum industry.

Deep-bed filters are used over a number of casts and process several hundred tons of aluminum before being replaced. These filters have a large surface area which slows the flow of aluminum and thus increases its filtering efficiency. The large size of the filter is also a major drawback since it results in a high metal holdup, and it occupies a lot of floor space. Also, their poor adaptability to alloy changes is another concern and makes them practical only for cast shops that process a small number of alloys in mass quantities.
The goal in metal filtration process developments has been to find the right balance between the required metal cleanliness and the filtration costs. These two factors are proportional to one another since higher purity melts require the use of larger filters, which in turn are very expensive not only to produce but also to install in a typical refining process. In order to find this balance, more time and money needs to be allocated to research depth filtration to gain a better understanding of the mechanisms at work that affect the filter performance. This knowledge is vital in order to design more efficient filters that will be capable of handling melts with high concentrations of various impurities, thereby reducing the necessity of additional upstream refining processes.

**CONCLUSIONS**

The following conclusions have been made from the survey of the available literature:

1. The aluminum industry uses three different techniques for removing a variety of impurities from their melts: fluxing, floatation, and filtering.

2. Molten aluminum fluxing can be performed by using either a salt or a gas in a number of different processes. Salt fluxes of either fused magnesium chloride or aluminum fluoride are used in the RFI and TAC processes, respectively. The RFI is the most efficient solid-flux method for removing alkali impurities because of its specially designed injection system. Also, chlorine emissions from the RFI are minimal making it the most environmentally friendly fluxing process. While the RFI is performed in the casting furnace, the TAC process can be performed before this stage in a pre-treatment crucible if the starting material is extremely dirty. The TAC process uses an aluminum fluoride addition and a unique rotor to clean the melt of gross alkali and oxide impurities.

3. The only gaseous flux used in aluminum processing is chlorine, which is sometimes diluted with either nitrogen or argon. The gas is transferred to the aluminum melt by a static lance or RGI system, whereby the chlorine interacts with the alkali impurities either directly or indirectly. The RGI is the most effective gas-flux technique because of its ability to generate small bubbles at a much higher population and circulate them around the entire volume of the melt. Also, the chlorine consumptions using RGI are much lower than those in the static-lance processes.

4. The RFI process has the advantage over RGI system in that it eliminates the need for chlorine gas and lowers the emissions of chlorine and chloride-containing gases, while maintaining similar levels of melt cleanliness. Regardless of which process is used, further processing of the melt is still required to increase the metal purity to levels acceptable to consumers.

5. Degassing is used to lower the hydrogen concentration in the melt and is performed by subjecting the melt to a number of sequential gas rotors in an enclosed vessel. The rotors are similar to those used in normal RGI processes, and the gas is chlorine in a nitrogen or an argon carrier. Currently, there are no alternatives to the use of chlorine in aluminum degassing units, which results in high chlorine consumption and the formation of small
magnesium-chloride impurities. Alcan has developed an ACD technique for degassing aluminum in small casting troughs thus reducing the amount of metal retained in the vessel between casts and alloy changes encountered with current degassing processes.

6. Due to the entrapment of small magnesium-chloride inclusions, as well as small oxides in the aluminum after degassing, filtration is the last processing technique required to obtain the required cleanliness value for casting. Deep-bed filters are the most common type of filter used in the aluminum industry and produce the highest quality aluminum product. However, their use is only economical in large-scale casting operations since their size requires a significant amount of space and capital investment. The alternative for small casting shops is the ceramic foam filter (CFF). These filters are much smaller and can be directly introduced into any process. They are well suited for operations that cast a variety of alloys since they are easily changed.

REFERENCES


