A TECHNICAL PERSPECTIVE ON MOLTEN ALUMINUM PROCESSING

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Abstract
In today's context of global competitiveness, all factors related to molten metal treatment which directly or indirectly affect product quality, the environment and processing costs must be optimized. In this regard, technology and innovation play a decisive role for the development and implementation of the most appropriate molten metal treatment processes and practices. The following discussion will review the most recent significant developments in the field of molten aluminum processing and outline potential areas for improvement.

Introduction
In order to meet the continually increasing product performance requirements of the world marketplace, molten metal quality is a major preoccupation of the cast house. In the context of this discussion, metal quality refers to the degree to which an aluminum alloy is free of the following contaminants: alkalies (sodium, calcium, and lithium), non-metallic inclusions, and dissolved hydrogen. Improvements in metal quality have been achieved with the development and implementation of molten metal treatment technologies during the last 20 years. Advances, particularly during the last decade, are significant and reflect an improved comprehension of the underlying principles governing molten metal treatment.

However, notwithstanding recent advances in metal quality, the cast house metallurgist still faces significant challenges. Metal processing and monitoring costs are significant - available resources must be used judiciously. Pressure to increase productivity and metal throughput are incessant, while at the same time, metal quality variation is unacceptable. Environment issues must be taken seriously and can limit the metal processing options that are available.

Recent progress made in the field of molten metal treatment technologies is summarized and future challenges are suggested.

Overview of Metal Processing Steps
Many different metal treatment technologies and practices are available to the cast house metallurgist. The successful implementation and use of these technologies is accomplished only when an appropriate balance is achieved between metal quality, productivity, cost and the environment. The general sequence of molten metal processing steps is shown in Figure 1 and consists of crucible pre-treatment upstream of the furnace, furnace processing, and in-line treatment — degassing and filtration. Additionally, the transfer of the liquid metal between each processing step must be given particular attention. It is generally recognized that as the liquid metal advances towards the ingot, metal treatment operations become increasingly "critical".
In the past, process development and optimization efforts focused on individual metal treatment steps. Semi-empirical methods, requiring little knowledge of the underlying metal treatment mechanisms, were used to relate process changes to final product performance. This situation was complicated by the low impurity concentrations that had to be accurately measured and because the available metal quality measurement techniques, at the time, were costly and often laboratory-based - leading to limited acceptance or use by the industry.

Molten Metal Analysis and Control

Impurities

The types and sources of impurities present in liquid aluminum, as well as their detrimental effects on specific products, have been reviewed in detail elsewhere(1). It is pertinent to note that the molten aluminum supplied to the cast house comes from two distinctly different sources: smelter electrolysis and remelt/recycle operations. The impurities present in the metal supplied from these sources are also different and can affect the metal treatment strategy that is used. Remelted metal is normally associated with higher levels of hydrogen, calcium, and hard oxide inclusions that are formed during high temperature scrap melting processes. On the other hand, smelter metal is associated with higher levels of sodium, aluminum carbide inclusions, as well as non-metallic inclusions generated from the addition of large quantities of alloying elements. Table I summarizes the impurity levels present in the metal supplied to the cast house.

Table I Typical Impurity Levels in Metal from Smelter and Remelt Sources

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Smelter</th>
<th>Remelt</th>
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<tbody>
<tr>
<td>Composition</td>
<td>≥ 99.7% Al</td>
<td>Alloyed or close to final composition</td>
</tr>
<tr>
<td>Hydrogen</td>
<td>0.1 – 0.3 ppm</td>
<td>0.2 – 0.6 ppm</td>
</tr>
<tr>
<td>Alkali Na</td>
<td>30 – 150 ppm</td>
<td>≤ 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 (PoDFA scale)</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>
</table>

Motivated by cost reduction or simply by a sometimes limited availability of good quality clean scrap metal, today's aluminum recycling plants must have increased flexibility to accept variable scrap quality, and as such, the molten metal treatment system must be increasingly robust to handle a higher and fluctuating impurity load. Similarly, present trends in aluminum smelter operation include efforts to improve current efficiency and to reduce environmental emissions. This has led to increasingly high sodium and/or lithium levels in the primary metal produced. Consequently, improved molten metal treatment performance in the cast house is necessary.

Control Technologies

Quantitative instrumental techniques capable of accurately measuring the extremely low concentrations of the various contaminants are presently used throughout the aluminum industry.

Inclusions - Metal Cleanliness Considered industry standards, the LiMCA and PoDFA metal cleanliness assessment techniques, developed by Alcan, have been previously described in detail(2, 3, 4). Briefly, LiMCA is based on the resistive pulse principle and generates both an inclusion concentration value and a complete size distribution. PoDFA is based on the filtration of 1–2 kg of metal through a well-calibrated small filtration disk with subsequent metallographic examination of the inclusion concentrate. Information on inclusion species and sizes, as well as a semi-quantitative total inclusion level expressed in mm²/kg are obtained. LiMCA and PoDFA are complementary technologies in as much as their respective quantitative and qualitative capabilities combine to give essential data required for an informed judgment of metal cleanliness.

However, significant challenges remain to be overcome. The LiMCA instrument is on-line, but complex to operate, and PoDFA analysis requires metallographic expertise/facilities and is thus off-line. An inherent weakness of the LiMCA technique is the inability to distinguish the physical state of the inclusion. Consequently, and unless a deep bed filter is used, reliable LiMCA measurements are difficult to obtain immediately downstream of an in-line degasser(5) due to the complex interactions between the gas/liquid/solid inclusions present. Exploratory development work on an alternative inclusion detection technology focuses on the use of ultra-sound(6). It remains that a simple, low cost yet quantitatively accurate on-line metal cleanliness assessment tool is needed by the industry.

Figure 1: Sequence of Molten Metal Processing Steps.