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20 Years of LiMCA Utilization in the Aluminum Industry: A Review of the Technology Development and Applications

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Abstract

Since its introduction to the aluminum industry at the TMS Conference in 1994, the LiMCA technology has been successfully used by most aluminum producers worldwide for the measurement of inclusions in molten aluminum. The versatility of the LiMCA II instrument has been demonstrated by its ability to be used at various positions in the casting process. It has been very successful from a process understanding, optimization and control point of view. In 2004, a fixed implementation, the LiMCA CM, best suited for process control applications was introduced to the industry.

This paper reviews the development of the LiMCA technology and its successful application for process understanding and optimization through examples of applications presented by numerous contributors at the TMS conference over the past 20 years. The criteria for future generations of LiMCA instruments will be discussed.

Introduction

Materials such as Aluminum are being used in more and more demanding applications where a combination of lightweight, mechanical qualities and perfect surface finish are the norm. In order to meet these increasing stringent requirements the Aluminum industry must tightly control the quality of their product.

For Aluminum products, quality is driven by correct alloy composition, the amount of dissolved hydrogen in the molten metal and the cleanliness of the metal as defined by the number and size of solid inclusions in the metal.

Solid inclusions left in the metal can result in a whole slew of final product defects, examples are small holes and tears in aluminum foil or in aluminum beverage cans, surface defects on polished surfaces and degraded mechanical properties.

To obtain the desired properties improved process knowledge was required in order to understand what was driving each parameter and how to optimize the process to obtain the desired end goal. It is thus that over the course of the last 30 years the aluminum industry has developed good practices and treatment technologies with the aim of reducing metallic and non-metallic impurities in aluminum alloys. In particular a number of different technologies were designed to remove inclusions from the molten aluminum. These technologies include in-line treatment units like degassers and filtration systems.

In order to assess the effectiveness of the processing and to ensure proper quality control the quality parameters need to be monitored preferably in real time. Early metal cleanliness tests were conducted at-line with the Union Carbide LAIS method [1] and the Alcan PoDFA method [2]; e.g. by taking a sample and pulling it through a ceramic filter. The filter is subsequently cooled, cut, mounted and polished which allows the levels of inclusions to be evaluated by microscopic observation. Later, the Prefil-Footprinter Instrument [3] based on the filtration time of the molten aluminum alloy through a calibrated ceramic disc was developed.

In the early 80s, much work was done to develop inline sensors with the ability to provide real time results. There were attempts to measure solid inclusions using ultrasonic sensors [4-6] but this approach was never successfully deployed in industry. This led the researchers at Alcan Research and Development Center and McGill University to develop a new technique that could measure the number and size of non-metallic inclusions based on the coulter principle. The solution, named LiMCA for Liquid Metal Cleanliness Analyzer, was first introduced to the aluminum industry at the 1985 Light Metals TMS conference [2].

In 1985, Alcan (now Rio Tinto Alcan) started a long-term collaboration with Bomem (now ABB) for the development of an industrial version of the instrument capable of being deployed in the severe environment of molten aluminum alloy production.

As a result of this collaboration, multiple generations of the LiMCA instrument were developed and commercialized. This paper will review the main characteristics of the different generations of apparatus developed, highlighting the evolution from an R&D tool to a production grade system for quality assurance, real time process control and process diagnostics.

Principle and limitations

The LiMCA technique is based on the Electrical Sensing Zone (ESZ) technique also known as the Coulter principle. The particles to be measured are suspended in an electrical conductive fluid (the molten aluminum) which is drawn through an orifice into an electrically insulated vessel. At the same time, a constant electric current is maintained through the orifice, completing the circuit between the two electrodes on both sides of the orifice.

The particles to be measured (oxides, borides, carbides) are several orders of magnitude less electrically conductive than the molten aluminum. When a particle enters the orifice, it displaces its volume of the fluid, causing a temporary rise in the electrical resistance of the orifice. This resistance change, in the presence of the current, generates a voltage pulse of duration equal to the transit time of the particle traversing the orifice. The amplitude of the voltage pulse is, as a first approximation, proportional to the volume of the particle.

The magnitude of the voltage pulse is predicted by the following equation:

$$\Delta V = \frac{4I\rho d^3}{\pi D^4} \quad (1)$$

Where:

ΔV is the amplitude of the voltage pulse measured (V)
I is the electric current (60 A)
ρ is the electrical resistivity of the fluid ($25 \times 10^{-8}\,\Omega$-m pure Al)
d is the equivalent spherical particle diameter (m)
D is the standard LiMCA probe orifice diameter (3×10^{-4}m)

The following diagram (Figure 1) illustrates the LiMCA measuring principle

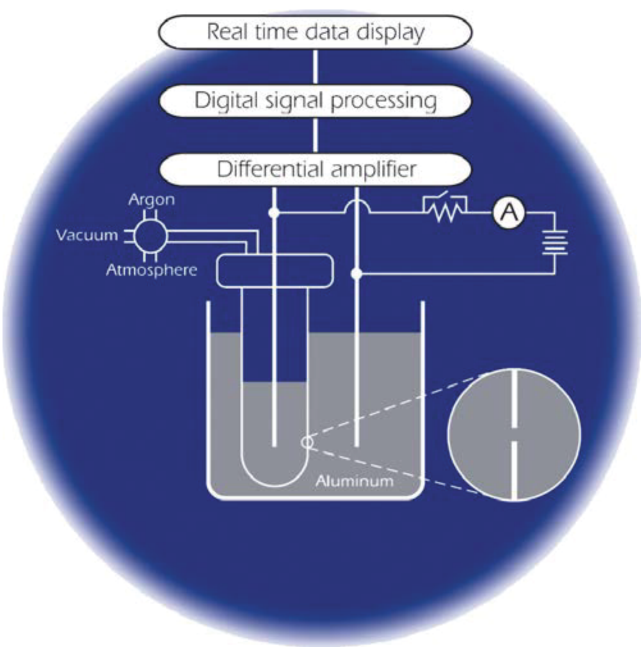

Figure 1: The LiMCA measurement principle

Since the height of the voltage pulse is related to the size of the particle it is possible to count the number of particles of a given size that traverse the orifice over a defined time period. By counting pulses and classifying them by height it is possible to obtain the size distribution of all the particles that traverse the orifice per unit time. This particle size distribution is directly related to the number and size of inclusions present in the bulk molten aluminum alloy into which the LiMCA probe is submerged and can be used as a quality indicator.

The LiMCA detects any particle that is less electrically conductive than the molten aluminum. This includes oxides, carbides, borides, chlorides particles but also the micro-bubbles when measurements are taken at the outlet of an in-line degasser. The number of micro-bubbles present in the flow of metal is so important that they cause a perturbation of the electrical signal that impedes any measurement. Efforts to solve this situation were made by several researchers[10-12] including modified sampling approaches or signal discrimination. The most effective approach remains the utilization of the LiMCA probe with a side extension placed in front of the measuring orifice. This extension allows the separation of a majority of the bubbles before they reach the orifice. However, it may affect the solid inclusions count and therefore should not be compared to measurements taken without a side extension. This specific application of the LIMCA is the only limitation to the LiMCA utilization in a casthouse.

The LiMCA 1

The first generation of LiMCA, the LiMCA I, was thus born in 1987. As illustrated in Figure 2, it was a huge system composed of a measuring head hooked on the side of the trough, a power module to distribute the services (argon, cooling air, and electrical current to the measuring head), and a console where all the electronics needed to control the instrument were located. The console was the user interface.


Figure 2: The LiMCA I, the first industrial LiMCA system

This apparatus was mainly used by the R&D and process engineering teams to develop a basic understanding of factors, affecting the behavior of inclusions during the treatment of molten aluminum alloys [7].

The LiMCA 1 demonstrated that it was possible to draw molten aluminum at a temperature of typically 700 °C through a 300 micron orifice in a borosilicate glass tube and to capture electrical signals of 20 microvolts (corresponding to an inclusion of 20 microns) in an industrial environment where sources of electrical interferences are present. The main LiMCA N20 indicator for the number of 20-micron particles traversing the orifice over a given time period was developed.

The LiMCA II

After the successful application of the LiMCA I, the design of the LiMCA II was undertaken in the 1990's with the primary goal of producing a LiMCA analyzer that would have the flexibility to be easily used at multiple measuring points along the casting process from the furnace outlet to the casting table. The LiMCA II (Figure 3) was introduced and made available to the aluminum industry in 1994 [8].

Figure 3: The LiMCA II instrument

Thanks to new digital technology it was possible to design the LiMCA II into a portable package that now could be moved around on the production floor and inserted at the various metal processing stages of the aluminum casting process. The flexibility of the LiMCA II allowed the technology to make the transition from a research tool to a practical tool for improving process understanding and debugging issues with actual aluminum production lines.

Indeed the LiMCA II can be moved to each process stage and allows users to map out how inclusions are being added and removed from their process at each step of the way.

With the LiMCA II it became possible to measure the level of inclusions at the outlet of the furnace and to assess the effectiveness of the various processing steps designed to remove inclusions from the metal.

The LiMCA II has been used to evaluate the effectiveness of different types of degassers and filters combinations for removing inclusions and the impact of grain refiner on the cleanliness of the metal [9-13].

It was a huge success. The LiMCA technique as implemented in the LiMCA II was adopted by all major aluminum producers and became the standard tool for measuring the quality of liquid metal in the casting process. Indeed some 80 LiMCA II analyzers were sold in the 12 years that it was commercially available.

The main characteristics that contributed to the success of the LiMCA II are:

- The mobile and lightweight design of the analyzer and the cart allowing it to be placed on the walkways around the casting lines of most modern aluminum plants
- The narrow profile of the measuring head and its many degrees of freedom in movement allowing it to sample liquid aluminum anywhere along the casting line and even in the ingot itself
- The use of NiCad batteries to generate an ultra-low noise electrical current in an industrial setting so that the LiMCA readings are not affected by the background electrical noise characteristic of an aluminum plant

The LiMCA II did not remain static over its 12 year lifespan and indeed benefitted from numerous upgrades and improvements in order to keep the design up to date. Despite these efforts the end of life of the LiMCA II was announced by ABB in 2004, just 10 years after its launch due to obsolesce issues with key components of the device.

The LiMCA CM

The success of the LiMCA II as a process control tool and the increasing number of LiMCA II units being used for continuous process control in production led to the development of a new generation of LiMCA instrument called the LiMCA CM (Continuous Monitoring) figure 4.

Figure 4: The LiMCA CM instrument

The LiMCA CM is meant to be permanently mounted in a single location, typically after final filtration of the liquid metal.

To this end the LiMCA CM was designed with a much higher degree of automation then the LiMCA II; e.g.

- the head lowers itself into the molten metal and uses a laser rangefinder to determine the correct position for the probe
- the LiMCA CM features standard networking functionality so that it can be connected to the plant control system

In addition the electronics in the LiMCA CM were modernized to take advantage of the evolution of electronics in the 10 years since the LiMCA II was designed. Amongst the design improvements over the LiMCA II the LiMCA CM uses ultra-capacitors instead of NiCad batteries to provide a stable DC current for the probe and combines the 12 different electronics boards found in the LiMCA II for increased reliability.

The permanently mounted design of the LiMCA CM makes it ideal for process control but very difficult to use for process investigation for example after a process upset because it cannot easily be used to sample different locations along the casting line.

Conclusions

The adoption of LiMCA technology in the form of the LiMCA II or LiMCA CM analyzer systems in the aluminum casting industry has driven the development of a whole new generation of treatment equipment to reduce and control inclusions and allowed the development of consistent high yield specialty materials that would be impossible without tight control over inclusion sizes and quantities.

For example thin materials have revolutionized the food and beverage industries by providing defect free thin walled lightweight aluminum cans for products like energy drinks and beer and the microelectronics industry by providing perfects bodies for smart phones and other commodities.

Also more and more extruded materials made of special hard aluminum alloys are being used in the aeronautics industry to provide lightweight components

A significant amount of wrought alloy cast products produced worldwide is accompanied by LiMCA measurements.

There is clearly still room for evolution and any new generation of the LiMCA instrument should take into account the best qualities of the LiMCA II and LiMCA CM analyzers as summarized in the following list:

- The analyzer should be compact and the measurement head should have a versatile positioning mechanism to allow LiMCA measurements at any point in the casting process
- The analyzer should be lightweight and mobile so that it can easily be moved to different locations
- The analyzer should include a means for fixed unattended operation for continuous process control applications
- The analyzer should have flexible network connectivity so that it can be integrated into plat information systems including the plant control system
- The analyzer should take advantage of the latest advancements in electronics to improve the detection mechanism and overall reliability
- The analyzer should address the question of micro-bubbles in the molten metal

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