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THE IMPACT OF LiMCA TECHNOLOGY ON THE OPTIMIZATION OF METAL CLEANLINESS

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SUMMARY

The continuous downgauging of aluminum products and the use of aluminum alloys for critical surface applications make the control of nonmetallic inclusions an essential step in the production process of aluminum alloys. For this purpose, Alcan has developed and used in the last decade the LiMCA technology. It has been widely used to characterize and improve alloy preparation techniques, in-line treatment units and casting practices.

This paper presents examples of application of the LiMCA technique including: furnace preparation and cleaning, efficiency and consistency of in-line filtration units and the control of casting conditions.

INTRODUCTION

The requirement for higher quality aluminum alloys, driven by the continuing downgauging and need for superior performance applications, has governed the development of a large number of molten metal treatment practices and processes (1). Among the properties controlled, the cleanliness of the metal, i.e. its inclusion content, is one of the most important characteristics affecting the performances of the final product. However, the success of these developments can be severely limited by the lack of sensitive, quantitative methods of measuring metal cleanliness.

The very low concentration of inclusions generally present in aluminum alloys is the principal factor explaining the difficulties in developing reliable measurement methods (2,3). This is particularly true for chemical and ultrasonic methods. To overcome this difficulty, the approach of preconcentrating the inclusions has been considered. The PoDFA technique developed by Alcan in the 1960"s (3) and Union Carbide's LAIS technique (4) represent two widely used methods for routine evaluation of molten metal cleanliness. They are based on the filtration of a known quantity of molten metal through a porous disk. After series of preparation and polishing steps, the concentrated inclusions at the disk/metal interface are identified and counted under an optical microscope and the result is expressed in mm²/kg. The quantitative precision of these techniques has been established to be of the order of 30 to 50%. However, they provide unique information on the nature of the inclusions and their relative proportions. These techniques are carried out on spot samples which impair the measurement of transient phenomena. Moreover, the analysis of samples is lengthy and expensive.

Based on the need for a fast, sensitive and on-line technique, Alcan has been developing since 1982, the LiMCA (Liquid Metal Cleanliness Analyzer) (5). This technique used in the stream of flowing metal under casting, allows the continuous measurement of the number density (expressed in thousands of inclusions per kilogram of metal) of inclusions greater than 20 µm in diameter and their size distribution.

Since then, the LiMCA and PoDFA techniques have been intensively used within Alcan for development purposes to understand molten metal treatment practices and processes and improve the quality of molten metal especially for critical products such as can body stock. The complementarity of these techniques, the PoDFA providing routine information on the number and nature of inclusions while LiMCA generates time-sensitive quantitative data, has allowed the achievement of detailed understanding of inclusions behavior. As an example, the detailed study of settling phenomena (6) would have not been possible without these techniques.

While in the past very specific studies involving the LiMCA were presented (6), it is the objective of the present paper to show, through typical examples, how LiMCA can be used to evaluate the effects of preparation, treatment and casting practices on the cleanliness of aluminum alloys.

METHOD AND APPARATUS

The LiMCA technique is based on the resistive pulse principle (5) as shown in Figure 1. The particles to be measured (which have an electrical conductivity different than that of the fluid in which they are suspended) are drawn through an orifice into an electrically insulating vessel. When they pass through the orifice, they displace an equivalent volume of the conducting fluid causing a temporary change in the electrical resistance of the orifice. With a constant current applied through the orifice, this resistance change is detected as a voltage pulse. These pulses are amplified, counted and classified by their amplitude. This provides for each sample a precise knowledge of the number [expressed in thousands of inclusions per kilogram of metal (k/kg)]and size distribution of the particles.

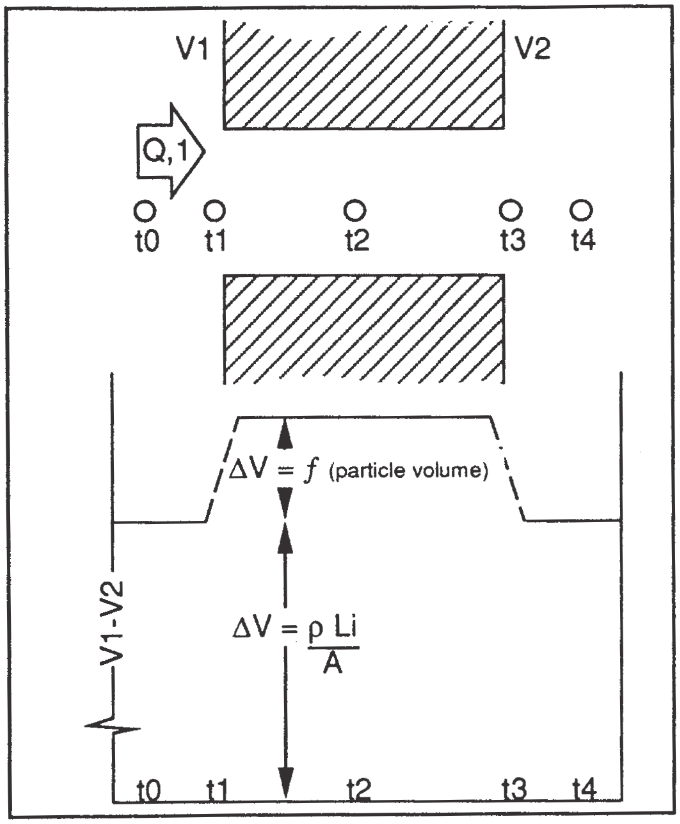

Figure 1: Resistive Pulse Principle of Particle Size Measurement

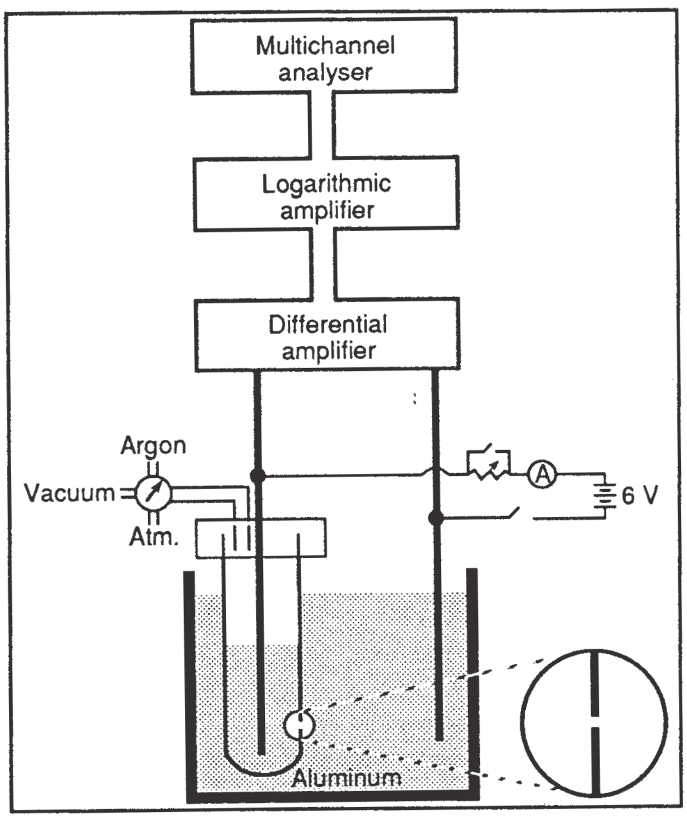

Figure 2: Schematic View of the LiMCA Instrument for the Analysis of Inclusions in Liquid Aluminum

The apparatus used industrially for routine plant evaluations is schematically shown in Figure 2. The sampling tube, which has a small calibrated orifice of 300 μm on its side, is immersed in the liquid metal. By applying negative and positive pressure cycles, the metal can be moved in and out of the tube, with a sampling frequency of once per minute on a routine basis.

APPLICATIONS

1. FURNACE PREPARATION

The molten metal supplied to casting furnaces from melters or pot rooms must be prepared and treated to reach the proper composition and quality. The alloying step is particularly detrimental from a cleanliness point of view (7) while subsequent treatment steps such as fluxing and settling help reduce the inclusion content. Few works have been published regarding the improvement of furnace preparation practices. Most of the efforts have been focused on the development of efficient in-line treatment units capable of restoring the quality of the metal. However, since most in-line treatment units operate in a proportional mode, an improvement in metal quality coming out of the furnace will result in an improvement in the cleanliness of the metal ultimately cast. Moreover, the costs associated with operation and maintenance of these units can be significantly reduced by increasing their life if they are fed with better quality metal.

1.1 Alloying practices

As previously mentioned, the addition of alloying elements to the molten metal has a major influence on the cleanliness of the metal. The choice for a method of addition and a form of the alloying element depends on factors such as the price of the element, its ease of dissolution, its availability etc... A simple method of addition consists in dumping the element in the bath of molten metal and stirring mechanically to complete the dissolution. Another widely used method consists in injecting the alloying elements in the form of powder to maximize the surface of contact and facilitate the dissolution.

The impact of the method of adding alloying elements on metal cleanliness has been evaluated using LiMCA. Table I presents the number of batches evaluated (n), the average settling time and the average LiMCA values measured at the outlet of a furnace for manganese alloying using powder injection and briquets addition. During powder injection, the alloying elements are added under the surface of liquid metal by a pneumatic conveyor using an inert gas while briquets are simply dumped in the bath of metal and mechanically stirred. From these results, it can be concluded that when using powder injection, the metal is 30% cleaner.

Table I Effect of Manganese Form on Metal Cleanliness

Briquets Addition			Powder Injection			Improvement
n	Avg. Settling Time (min.)	Avg. LiMCA Value (k/kg)	n	Avg. Settling Time (min.)	Avg. LiMCA Value (k/kg)	%
55	147	27.3	47	140	19.0	30

Another example of the impact of the alloying practices on the cleanliness of the metal measured using LiMCA concerns the addition of magnesium to the bath of liquid metal.

The first method evaluated was the addition of the magnesium during filling of the furnace. No mechanical or pneumatic stirring of the metal has been performed. This method has been compared with the addition and intensive stirring of magnesium ingots in a furnace full of metal at the proper temperature. Figure 3 shows the LiMCA values monitored at the outlet of the furnace during casting. In the first case, very high levels of inclusions and large variations have been monitored while the other presents a smooth evolution of the inclusion content at a lower level. The extreme sensitivity of the magnesium to oxidation when added to the bath of molten aluminum is the reason for these results. In absence of stirring, magnesium is left to burn at the surface of the bath generating very large quantities of magnesium oxide inclusions.

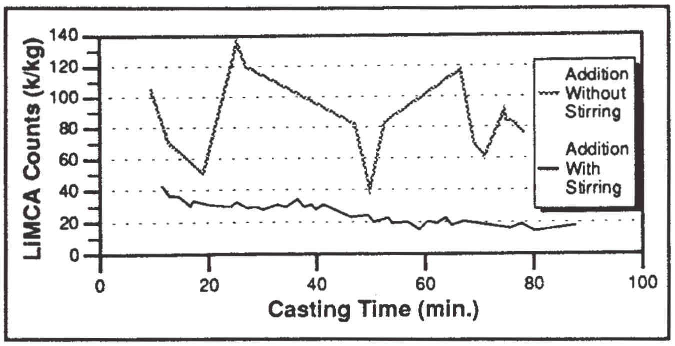

Figure 3: Effect of the Method of Addition of Magnesium on Metal Cleanliness

1.2 Settling

The settling is a natural phenomenon of improving the cleanliness of the metal without using any molten metal treatment device. Depending on the nature of the inclusions present in the metal, sedimentation proceeds more or less rapidly. But in certain instances, particularly when the furnace preparation is the production limiting step, the use of settling to improve metal quality can become very expensive from a productivity point of view. This is why it is important to obtain, for specific plants and alloys, a detailed evaluation of the extent of this phenomenon before proceeding with its application.

As it is a dynamic behavior, the use of an on-line technique with a quick response time such as the LiMCA technique makes possible the precise monitoring of the evolution of inclusions level. As an example, the extent of settling on boron-treated E.C. grade metal is shown on Figure 4. The metal was stirred just prior to the start of the cast and cleanliness was monitored in the launder system at the exit of the furnace. As usual, the inclusion level decreases exponentially with time, very rapidly for the first few minutes and more slowly afterwards. A detailed analysis of that phenomenon was presented by Martin et al (6). In the present case, a settling period of 60 minutes was the proper choice for productivity and quality point of view.

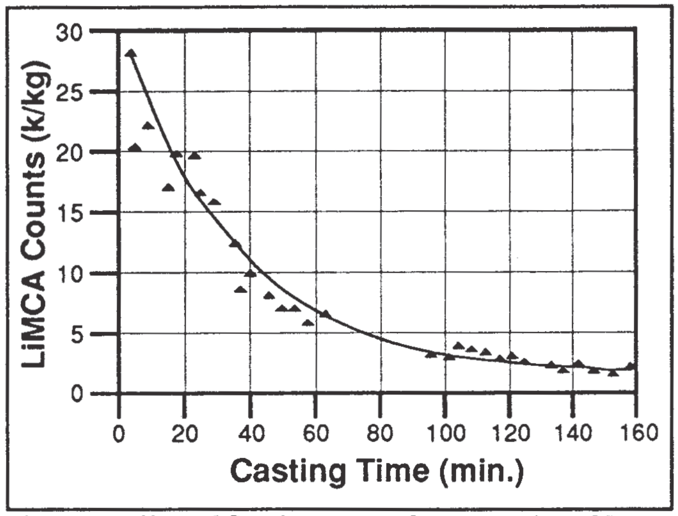

Figure 4: Effect of Settling on the Concentration of Inclusions in the Metal

1.3 Furnace Cleaning Methods

In order to maintain the cleanliness of the metal, it is important in a casting center to periodically clean the walls and the bottom of the furnaces. The tools used in casthouses are rudimentary and the cleaning operation is difficult to accomplish. The dross is difficult to take out of the furnace and in some installations, it is left to float during filling of the furnace and then removed when the furnace is full.

The impact of this practice has been compared with dry cleaning of the furnace, i.e the removal of the dross before the filling operation.

The average LiMCA levels measured for four batches of each practice are presented in Figure 5 and show clearly that when removing the dross before filling, the metal is much more cleaner. Within Alcan, this demonstration of the impact of a good furnace cleaning practice has resulted in the development of a new generation of tools used during the furnace preparation and cleaning steps.

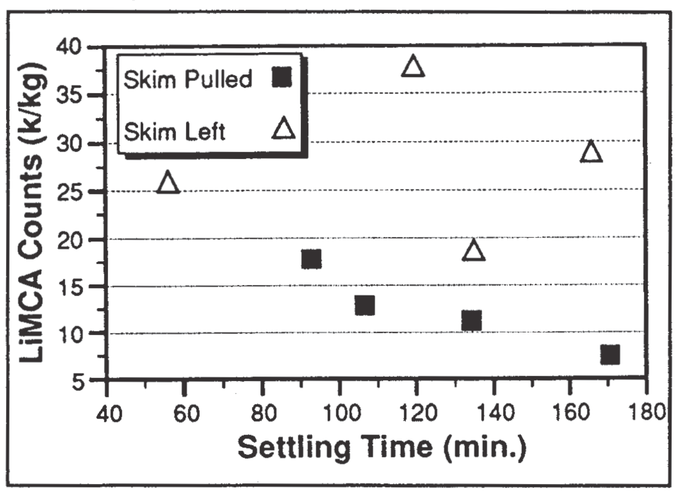

Figure 5: Comparison of Two Furnace Cleaning Methods on the Cleanliness of the Metal

2. IN-LINE TREATMENT

Although the metal is treated in furnace, this may not be enough. In order to reach the proper metal cleanliness levels the metal is further treated during casting using in-line treatment units. While in-line degassers have been developed to remove hydrogen and alkalis, they can provide inclusion removal by flotation. However, their efficiencies are variable (typically between 30 and 80%) (1) and in-line filters are required to reach higher and consistent metal cleanliness levels.

Single-use filters such as ceramic foam filters and multiple-use deep bed filters are the two categories of filters most commonly used. While some studies based on mathematical and physical modelling to understand and predict the performance of these filters have been published (9, 10, 11, 12), few direct studies of the efficiency and consistency of these filters throughout the casting period have been performed. The absence of adequate on-line detection techniques is the main reason for this situation. However, over the last decade within Alcan, extensive use of the LiMCA technique has allowed the monitoring of hundreds of casts to precisely characterize and optimize in-line filtration units.

2.1 Efficiency and consistency of filters

The evaluation of the filtration efficiency from LiMCA data is done using the following equation:

$$\text{Eff}(\%) = \frac{\text{Avg bef. filter} - \text{Avg aft. filter}}{\text{Avg bef. filter}} \times 100$$

LiMCA measurements before and after the filter were done simultaneously by using a two-head system. Detailed evaluation of 30 ppi ceramic foam filters has been done. Deep Bed Filters, namely (Alcan Bed Filter) have also been extensively evaluated.

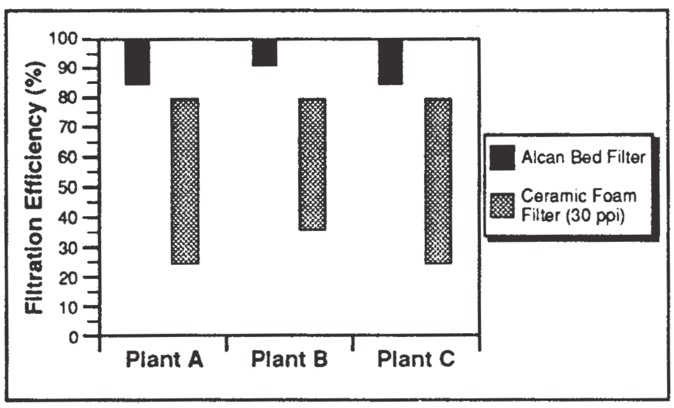

Figure 6: Comparison of Filtration Efficiencies and Range of Variation for Ceramic Foam Filter and Alcan Bed Filter

Figure 6 shows for three different plants using the two types of filters on the same alloy, the average efficiency and the range of variation of filtration efficiencies obtained. Performances of these two types of filters are very similar for the three plants with averages of 53%, 58% and 59% for the CFFs and 94%, 95%, and 95% for ABFs. These performances of the ceramic foam filters do not match the recently published LiMCA data of 80+% removal efficiency for 30 and 40 ppi ceramic filters (13, 14). The difference is even more significant given the very low incoming inclusions level reported (3 k/kg).

The average filtration efficiency obtained for 30 ppi ceramic foam filters demonstrates that it can only be considered as a prefilter for critical products such as can body alloy. The required final level of metal cleanliness cannot in any circumstances be obtained with such filters alone. This situation would not be a limiting problem if foam filters could achieve consistent filtration performances. However, such is not the case, the range of variations of efficiencies is very wide, which is different from Bed Filters (see below).

2.2 Dynamic performance of filters

The average filtration efficiency, based on few sets of PoDFA samples or more precisely, on the average of continuous on-line LiMCA evaluations is a basic information. However, by using the LiMCA, transient phenomena that occur throughout casts can be measured.

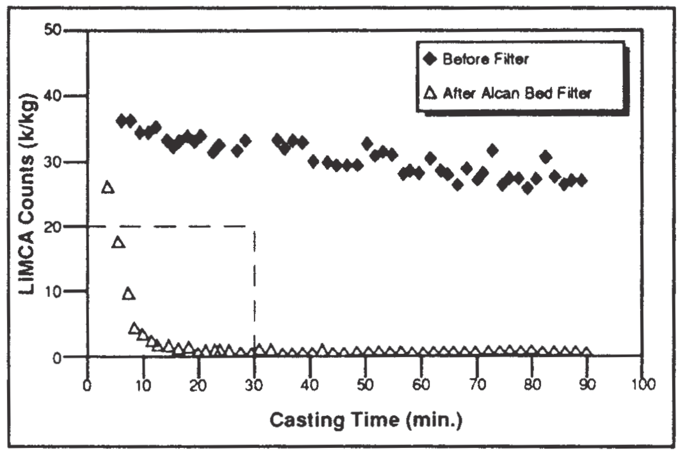

Figure 7: Inclusion Concentrations Measured During Casting Before and After Filtration with Alcan Bed Filter

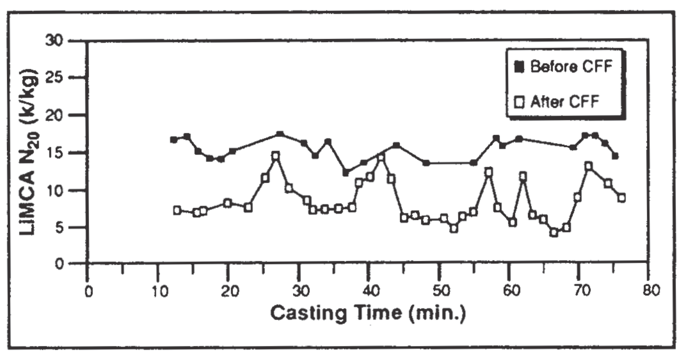

Figure 8: Release of Inclusions from Ceramic Foam Filters (30 ppi) During Casting

While bed filters exhibit inclusion release at start of cast and very stable filtration performance afterwards as shown on Figure 7, ceramic foam filters on the other hand present uncontrolled variations throughout the cast (Figure 8). The sensitivity of foam filters to inclusion releases associated to disturbances that can sometimes happen in the casting system (rapid metal flow change, physical disturbances, etc.) have already been reported (15). However, in the case presented in Figure 8 inclusion releases have occured for no specific reasons. In fact, this unstability of ceramic foam filters appear more and more intensively as the cast proceeds. The majority of casts monitored in plants where foam filters were evaluated have shown unstable and increasing levels of inclusions. After a loading of 10 to 12 kg/cm² [which represent only 35 tons of metal cast through a 58,4 cm x 58,4 cm (23" x 23") CFF] the filter starts releasing the accumulated inclusions. Moreover, the particles size distribution of samples taken before and after the filter during that period shows that it acts as an agglomerator as there are more particles of larger size fractions after the filter than before, as shown in Figure 9.

Deep bed filters that are maintained in operation for several thousands of tons are much more stable due to their larger surface and volume of filtration. Nevertheless, as demonstrated by physical modelling (12) deep bed filters present a release of inclusions at start of casts for a short period of time during the increase of the metal flowrate from zero to the nominal casting flowrate. Using LiMCA, it is possible to precisely measure the extent and the duration of this release (Figure 10).

3. CASTING PRACTICES

The routine control of metal cleanliness is generally performed by taking samples in the launder system at the exit of the furnace and/or after in-line units. At typical linear metal speed (5-10 cm/s), the metal flow in the launder is turbulent and inclusion concentrations are independent of the sampling position. However, even if the metal is close to its final destination, its cleanliness can still be significantly affected if improper flowing conditions are present. In fact, the «true» cleanliness of the metal is obtained only when it is in the mold and when the solidification process takes place.

3.1 Level control

The metal level control in the launder system is done using various devices such as float or capacitance gauges. However, the sensitivity of control of these systems is sometimes deficient and cyclic variations of metal level is observed. Even if these variations seem of low amplitude and smooth, they can affect significantly and continuously the cleanliness of the metal. Figure 11 shows variations of LiMCA values monitored for a poorly adjusted level control device allowing metal level variations of a few centimeters. The point-to-point variation is important and is attributed to the deformation and release of inclusions and oxides accumulated in the dross layer at the surface of the metal in the launders.

3.2 Metal Transfer from launder to ingot

The transfer of the metal from the launder to the mold (the last step before the solidification process starts) may significantly affect the cleanliness of the metal. The level change occuring between the launder and the mold requires an adequate metal distributor system that can ensure a smooth and uniform metal flow into the ingot head, avoiding surface turbulence.

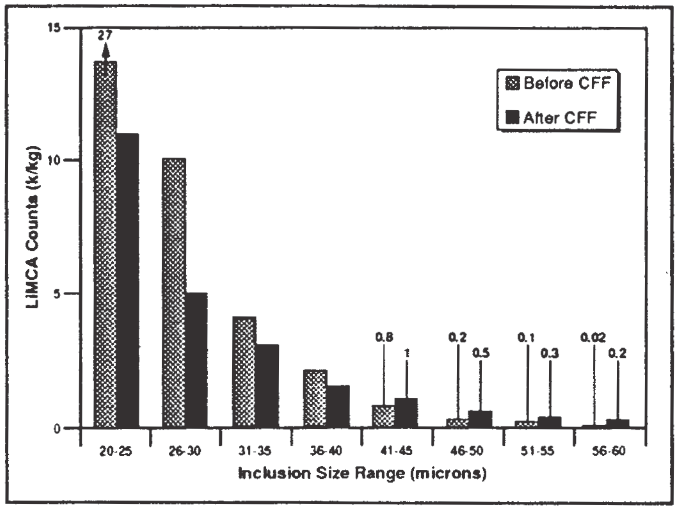

Figure 9: Inclusion Size Distribution for Samples Taken Before and After Ceramic Foam Filter (30 ppi)

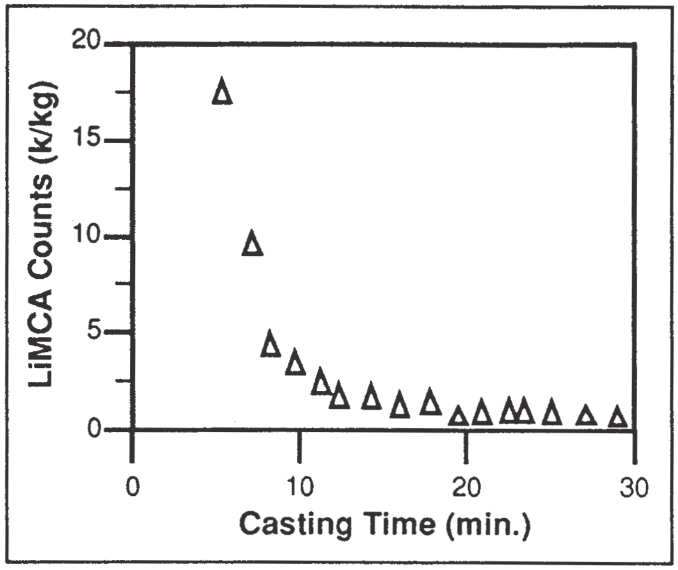

Figure 10: Inclusion Release From Bed Filter at Start of Cast (enlargment of dotted box in Figure 7)

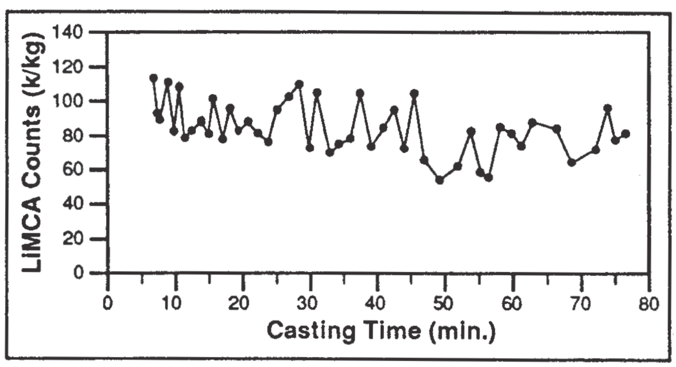

Figure 11: The Effect of Poor Metal Level Control in Launders on Inclusion Concentrations During Casting

The importance of having a good metal distributor design has been demonstrated by performing LiMCA measurements simultaneously in the launder after in-line filtration of the metal and in the sump of an ingot. As shown in Figure 12, a significant deterioration of the cleanliness occurs for some currently used glasscloth or rigid distributors. Only when a proper distribution system has been installed, can the cleanliness of the metal exiting the filter be maintained.

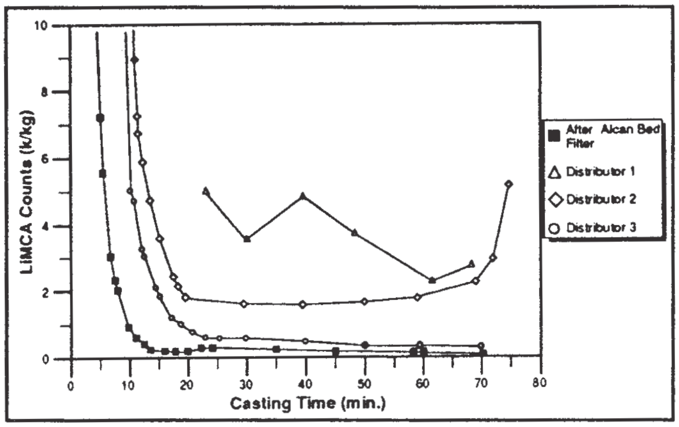

Figure 12: Effect of Ingot Head Feeding Arrangement on Metal Cleanliness

3.3 Heel

In order to maximize productivity, it is important for a casting center to maximize the quantity of metal cast for each batch prepared. However, the continuing settling of inclusions that takes place in the furnace before and during casting causes an accumulation at the bottom of the furnace, generating highly contaminated metal. In no circumstances should this metal be cast. The precise knowledge of the time at which inclusion flushing starts make possible the optimization of the quantity of the metal to cast without producing poor quality metal. To do this, the use of an in-line technique such as LiMCA is essential. Figure 13 illustrates a spectacular situation where very dirty metal was cast but once precisely determined, this situation has been corrected by stopping the cast just prior the start-up of that release.

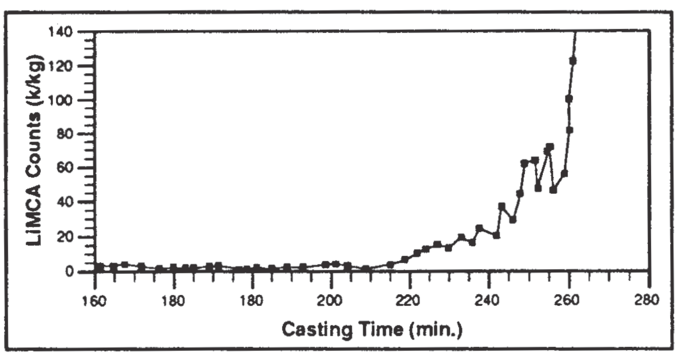

Figure 13: Inclusion Release From Furnace at the End of the Cast Under Dry Hearth Casting Practices

CONCLUSIONS

The use of the LiMCA technique within Alcan over the last decade has allowed a unique comprehension of what happens to inclusions throughout the molten aluminum processing steps. The continuous monitoring capability of LiMCA has allowed optimization of in-line treatment processes and casting operations to reach the highest levels of metal cleanliness.

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