THE ALCAN COMPACT DEGASSER: A TROUGH-BASED ALUMINUM TREATMENT PROCESS PART 1: METALLURGICAL PRINCIPLES AND PERFORMANCE

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Abstract

In-line degassing processes, employing rotary gas injectors, are used extensively in the aluminum industry for removing unwanted impurities from the liquid metal just prior to casting.

Although these processes are efficient, and provide the required level of metal treatment, a significant quantity of between one and three tons of metal is retained within the degassing unit between casts. Metal retention is a serious drawback for multi-alloy cast shops, due to the scrap metal produced by draining the degassing unit at alloy changes.

The Alcan compact degasser is a new multi-stage in-line degassing process which treats the metal directly in the trough. Following the initial development period in the laboratory, about two years of process development and optimization in the plant has proven that the Alcan compact degasser provides metal treatment efficiencies equivalent to or better than existing technologies, while eliminating metal retention between casts. The metallurgical principles of this process are described and quantitative plant data are presented which characterize the metallurgical performance with respect to degassing, metal cleanliness, and alkali removal.

Introduction

Aluminum and aluminum alloys must be subjected to a preliminary treatment to remove unwanted impurities that may adversely affect the physical or chemical properties of the resulting cast product. One such impurity is dissolved hydrogen which, upon cooling and solidification of the metal, comes out of solution and forms unwanted porosity in the product. In-line degassing processes are now used throughout the aluminum industry as an efficient means of controlling dissolved hydrogen levels. If the treatment gas in the degasser contains a reactive component such as chlorine, alkali element impurities can be removed. The presence of chlorine also assists the removal of nonmetallic solid particles which are swept to the melt surface by flotation where they accumulate in the dross.

The wide acceptance of in-line degassing processes in the aluminum industry reflects the numerous advantages offered by this metal treatment route, specifically:

- the metal is treated continuously during casting, thus in-line treatment does not adversely affect the productivity of a casting centre as can batch treatments carried out in the furnace;
- there is presently no alternative to in-line degassing as a means to provide consistently low hydrogen levels in the cast metal;
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- chlorine is utilized much more efficiently as compared to furnace fluxing, thus the overall chlorine use can be reduced and is therefore more acceptable environmentally.

Notwithstanding the acceptable metallurgical performance of commercialized in-line degassing processes, there are serious operational limitations to be considered, and for which plant personnel are becoming more attentive, specifically:

- depending on the treatment capacity of the unit in question, between 1000 kg and 3000 kg of molten aluminum is contained within the in-line degassing unit between casts. This results in significant metal loss at alloy changeover, and requires a heating system to maintain the metal in a liquid state;
- the capital costs of these processes are significant: for purchase, as well as installation, and start-up,
- the size and complexity of presently commercialized in-line degassing units have resulted in significant operating costs related to maintenance of electrical heating and hydraulic systems, replacement of rotors, re-lining and replacement of large refractory/graphite vessels, and casting centre downtime;
- the floor space requirement of up to 15 m^2 for conventional inline degassers can make their use impossible in smaller casting centres.

The development of the Alcan compact degasser technology(1) was motivated by the need to eliminate metal hold-up between casts and to significantly reduce the floor space requirements, giving the smaller, multi-alloy casting centres access to in-line metal treatment. At the same time, equivalent metallurgical performance was to be maintained, and, as shown in part 2 of this paper(2), the mechanical design of the compact degasser was to be greatly simplified, resulting in a reduction of the capital and operation costs to a fraction of conventional in-line degassing technology.

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Process description

The Alcan compact degasser is placed in the trough between the holding furnace and the casting machine. It consists of a series of rotary gas injectors arranged within the trough, each separated by a vertical baffle. This effectively divides the trough into a series of treatment chambers or stages, through which liquid aluminum passes sequentially in a "quasi" plug flow regime. Openings of sufficient area in each baffle allow metal flow without generating metallostatic head. This design approach is physically constrained by the low metal depth in the trough available for injection of the treatment gas. A schematic representation of a multi-rotor Alcan compact degassing unit is shown in Figure 1.

Special consideration must be given to the design of the gas injection rotors. For metallurgical reasons, it is desired to generate very small gas bubbles. At the same time, excessive turbulence, or vortex formation at the metal surface is unacceptable since this would lead to increased dross formation rates and the possible entertainment of oxide inclusions into the metal, degrading the quality.

After casting, the liquid metal is drained from the trough, and the compact degassing unit is removed in its entirety from the trough. Post casting trough preparation/cleaning can then be done.

Metallurgical principles

Although in-line degassing processes in general provide efficient removal of hydrogen, inclusions, and alkali/alkaline earth impurities, the principle aspect of metal treatment that is used as a process sizing and selection criterion is hydrogen removal.

Hydrogen removal is effected by introduction of an inert gas, usually argon, beneath the liquid metal surface using one or more high-speed rotary injectors. As the resulting gas bubbles rise through the mass of molten metal, they adsorb the dissolved hydrogen removing it from the melt.

Based on chemical engineering principles, an in-line degasser can be characterized as a continuous flow, well-mixed reactor. Hydrogen removal occurs as a result of diffusional mass transfer between the gas and metal phases. The kinetic factors which influence degassing rates have been documented elsewhere (3), but it is generally accepted that diffusion of the hydrogen through the liquid metal phase is the dominant rate controlling step of the degassing process, and that the hydrogen concentration difference between the gas and the metal is the driving force for diffusion. For the purposes of this discussion, it will be assumed that degassing is a first-order rate process, described by the following relationship for a well-mixed reactor:

$$\frac{H^{in}}{H_{out}} = (1 + \frac{K_1 \bullet A}{V} \bullet t)^n \qquad (1)$$

where :

H_{in} = inlet hydrogen concentration (mL/100g)
H_{out} = outlet hydrogen concentration (mL/100g)
K_l = liquid phase mass transfer coefficient (m/min)
A = total gas-liquid interfacial contact area (m^2)
V = liquid holdup volume per stage of reactor (m^3)
t = liquid phase residence time per stage (min)
n = number of stages in series

The hydrogen removal efficiency of an in-line degasser is therefore dependent upon the metal residence time, the treatment gas surface area, the reactor volume, and the number of stages of the reactor. The group “K1•A/V” is referred to as the first order degassing rate constant, and is a measure of the effectiveness of a gas dispersion device to generate and intimately mix fine gas bubbles into the liquid metal.

The difficulties inherent in the design of a compact, trough-based degassing process are clearly defined: a small reactor volume V, and a short residence time t, combine to reduce hydrogen removal rates. Under these conditions, how can equivalent degassing rates be maintained compared to the conventional degassing technology? A parameter worth further examination is the interfacial gas-metal contact area A.

The total gas- metal interfacial contact area generated by a purge gas is proportional to the gas flow rate and the metal depth above the point of gas injection. In addition, it is inversely proportional to the bubble diameter and the terminal rise velocity of the bubbles through the metal. Assuming spherical gas bubbles, the following relationship can be used to estimate the total interfacial contact area of the gas bubbles:

$$A = \frac{6 \bullet Q \bullet L}{D_b \bullet U_t} \qquad (2)$$

The gas-metal interfacial contact area (A) must be increased to overcome the disadvantages of short residence time and small reactor volume in a compact degassing system. Obviously, the metal depth (L) cannot be increased, and is in fact much lower compared to conventional degassing technology. In addition, the inert gas flow

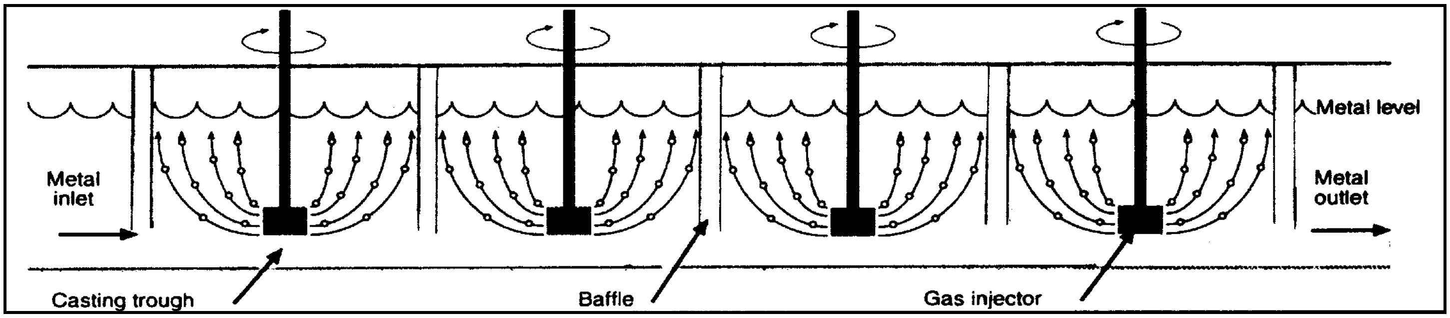

Figure 1: Schemtaic representation of a multi-rotor compact degassing unit.

rate (Q) is to be minimized to allow for a small reactor volume without excessive coalescence of the gas bubbles. This leaves both the gas bubble diameter (D_b) and rise velocity through the melt (U_t) which must be minimized. The gas bubble rise velocity is not a process variable that can be explicitly controlled. The terminal rise velocity decreases with decreasing bubble diameter, therefore, providing a means of gas injection to generate smaller bubbles, will at the same time, reduce the rise velocity of those bubbles through the melt.

It is estimated that in order to achieve degassing performance comparable to conventional in-line degassing processes, the Alcan compact degasser must generate treatment gas bubbles one half to one third of the average diameter compared to those generated by conventional in-line degassers. In this way, a gas-metal interfacial contact area of similar magnitude will be generated, even though the metal depth at the point of gas injection is only a fraction of what is present in conventional degassers.

In order to accomplish this, it was decided that a mechanical device would be necessary to inject and/or break up the treatment gas. In addition, coalescence of the gas bubbles is problematic, especially when the volume of metal contained in the degasser is reduced. A high specific energy input (mechanical) by the gas injector/disperser is also required to help stabilize the relatively high volume holdup of gas bubbles present in the liquid metal. A static injection system such as a porous plug could not accomplish this.

A physical demonstration of how well the treatment gas is dispersed into the liquid metal is the volume fraction gas holdup. During operation. the metal level inside the Alcan compact degasser rises above the metal level in the trough outside the degasser. This level difference is caused by the presence of gas in the metal and is a direct measure of the volume fraction gas holdup. For conventional in-line degassers, the metal level difference is less obvious, and in this case, the volume fraction gas holdup can be determined based on the treatment gas flow rate, the metal depth at the point of gas injection and the rise velocity of the gas bubbles through the metal. The volume fraction gas holdup in the Alcan compact degasser is approximately 10% to 15% compared to typically less than 5% for conventional degassers. Thus the Alcan compact degasser retains gas more effectively than a conventional unit and therefore produces equivalent performance in substantially smaller volumes of metal.

Another aspect of the Alcan compact degasser process design which has a considerable impact on the metallurgical performance is the number of treatment stages. The chemical driving force for hydrogen diffusion during the degassing process is the hydrogen concentration difference between the treatment gas and the molten aluminum. The use of multiple stages for in-line degasser design is advantageous since the hydrogen concentration in the metal reaches its minimum level only in the last treatment stage. This has the effect of increasing the concentration driving force in all previous stages, and as a result, the argon treatment gas is utilized more effectively. In addition. the use of multiple gas injectors physically separates or divides the total treatment gas flow, which helps to limit coalescence of the treatment gas bubbles, especially when the volume of each treatment chamber is relatively small.

The metallurgical advantage of multiple stages is illustrated in figure 2. In this example, the number of stages of an in-line degasser is increased, while maintaining a constant metal volume and residence time in the degassing unit. As well, the inert gas injection rate was held constant. The degassing efficiency increased approximately 14% when eight treatment stages (plug flow regime) were used compared to one stage (mixed flow regime).

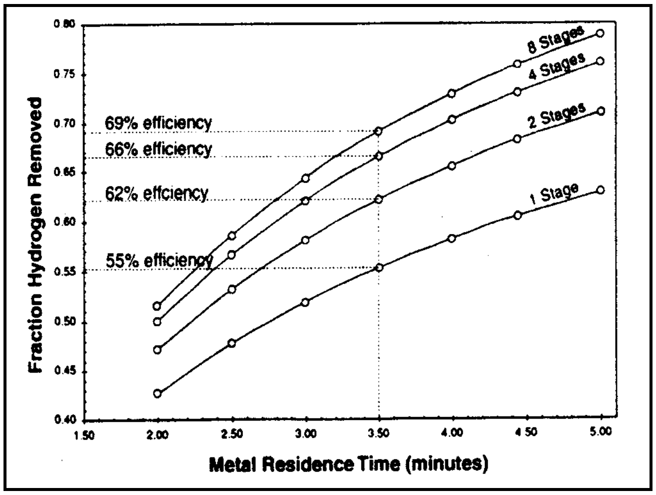

Figure 2 : Effect of increased treatment stages on in-line hydrogen removal.

Although the principles discussed with respect to equation (1) are valid, and clearly demonstrate the important process parameters, this equation is based on the assumption that the hydrogen removal rate is 100% controlled by diffusion, but this is not always true. In practice, especially when very small treatment gas bubbles are generated, the hydrogen degassing rate is controlled by a balance between the speed at which atomic hydrogen can diffuse through the liquid metal, and the extent to which the hydrogen gas approaches its equilibrium (maximum) concentration inside the treatment gas bubbles. A metallurgical model has been described(4) where the approach to equilibrium in the treatment gas bubbles is taken into account when calculating hydrogen mass transfer during degassing. This model was used extensively during the development of the Alcan compact degassing technology in order to quantify various casting parameters which are not included in equation (1), such as alloy composition, hydrogen solubility, ambient humidity, etc.

Plant metal treatment performance

The Alcan compact degasser is modular in nature, and as such, the number of rotors used, depends on the alloy composition and casting rate, the total inert gas flow rate, and to a limited extent, on the trough design. A minimum metal depth of 17 cm must be maintained in the trough during operation. More typically, a metal depth of 20 cm to 25 cm is maintained.

The Alcan compact degassing unit has been operated at Alcan Smelters and Chemicals Ltd.-Grande-Baie Works for over two years. During this period of time, extensive process development and optimization have taken place. Presently, a multi-rotor "industrial" version is in use for regular production, replacing the conventional in-line degasser that was originally used. The following metallurgical data represents typical performance of the Alcan compact degasser with direct comparison to the conventional inline degassing unit. The majority of the comparative data was collected while the Alcan compact degasser and the conventional degasser were both operated each for 1/2 of the same cast. Under these circumstances, both units were operated under identical casting conditions, ideal for direct comparison of the two units.

a) Hydrogen removal

Figure 3 compares the hydrogen removal performance of the ACD to a conventional in-line degasser. Hydrogen levels were measured before and after each degasser using an Alscan™ analyzer. The Alcan compact degasser typically maintains a 55%-60% hydrogen removal efficiency for casting rates of up to 750 kg/minute, which is equivalent to the conventional in-line degasser.

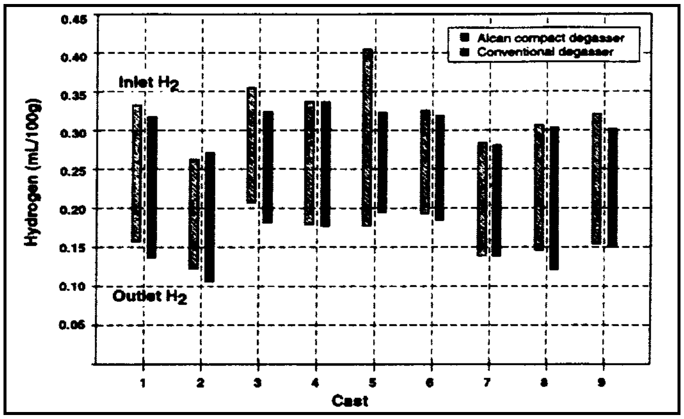

Figure 3 : Hydrogen removal performance of the Alcan compact degasser compared to conventional degassing technology.

b) Metal cleanliness

Metal cleanliness measurements were taken at the inlet and outlet of the Alcan compact degasser at Grande-Baie Works, and for conventional in-line degassing technology at several plants, both for a variety of alloys and casting rates. Figure 4 shows typical results indicating an average inclusion removal efficiency of typically 60%-70%. The variability of these results reflects the different species of inclusions present in the metal as well as changed degasser operating conditions covered by the data, both of which affect the metal cleaning capacity of the degasser.

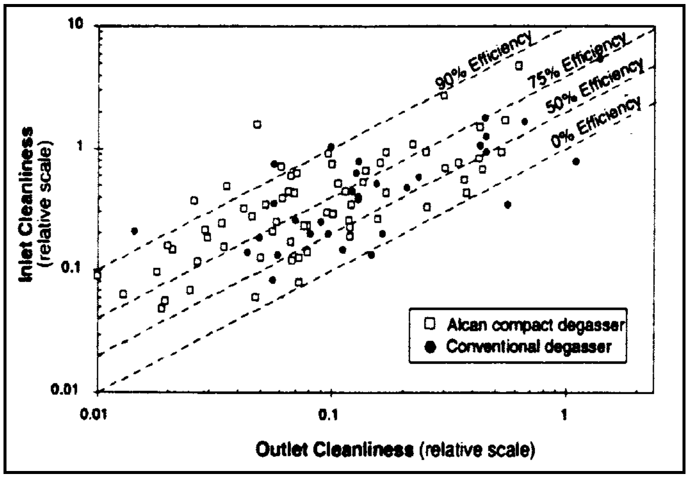

Figure 4 : Global metal cleanliness results for in-line degassing processes compared to the Alcan compact degasser.

For specific cases, direct comparison of the Alcan compact degasser with conventional degassing technology, under identical casting conditions, showed the ACD with an improved inclusion removal efficiency averaging 10% greater than conventional degassing technology.

c) Alkali removal

In an effort to compare the alkali removal efficiency of the Alcan compact degasser to conventional degassing technology, specific tests were performed at the Grande-Baie casting centre during which time approximately 10 ppm of calcium was added to the furnace after alloy preparation and fluxing. In this way, the two degassing technologies could be compared under similar casting conditions.

Figure 5 shows typical calcium removal results. It was concluded that for equal (stoichiometric) chlorine input rates, the Alcan compact degasser provides alkali removal performance equal to conventional in-line technology. In addition, the alkali removal efficiency of the Alcan compact degasser could be further increased with higher chlorine input rates; for example, at twice the stoichiometric addition rate. This latter finding would also be expected for conventional in-line degassers.

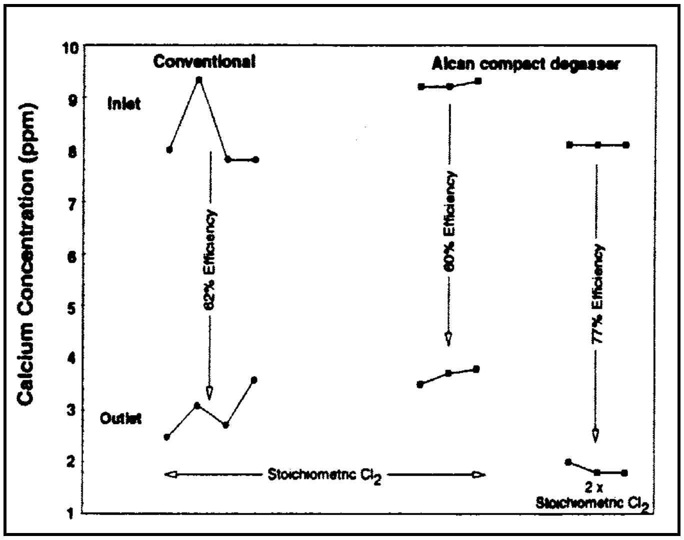

Figure 5 : Comparison of the calcium removal performance of the Alcan compact degasser vs conventional degassing technology.

d) Dross

The liquid surface area inside the Alcan compact degasser is approximately 1/10 that of a conventional in-line degassing unit. In addition, it is operated with a slight over-pressure of argon gas. As a result, there is comparatively less dross formation due to oxidation. The Alcan compact degasser can be operated for casts of several hours in duration without the need to skim off the dross. If it is desired, skimming can be done very easily and rapidly with smaller, lighter tools than required for conventional in-line degassers.

Conclusions

The Alcan compact degasser is a new trough-based in-line treatment process that maintains equivalent or better levels of metallurgical performance as compared to conventional technology, while eliminating metal holdup between casts. This eliminates the scrap metal generation normally associated with in-line degassers, especially in multi-alloy casting centres.

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