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A NEW VACUUM DEGASSING PROCESS FOR MOLTEN ALUMINUM

Jianmin Zeng, Bolin Wu, Zhiiu Hu, Linjiang Wang, Deguang Cao
Key laboratory of Nonferrous metals and Processing, Guangxi University, Nanning, Guangxi, 530004, P.R.China

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Abstract

Molten aluminum reacts with the water vapor to form hydrogen which can dissolve in the aluminum melt and be released during the solidification of casting as a harmful gas, resulting in porosity in the casting. There have been quite a few methods of degassing molten aluminum in industry. However, the hydrogen content will increase with the increasing of the time even if the effective degassing has been carried out carefully. In order to keep a low hydrogen content all the time during the continual pouring (such as the case in low pressure die casting, high pressure casting and permanent gravity casting), a patented degassing method is investigated. A porous refractory absorber that is connected with a vacuum system is immersed in the molten aluminum. The vacuum is started inside the porous absorber and the dissolved hydrogen atom will diffuse towards the absorber. In this way, the hydrogen in the melt is removed through the vacuum system. The absorber is made of mullite and of porous structure. It is permeable with gas but can't be penetrated by the molten aluminum. RPT experiment (Reduced Pressure Test) and density test were conducted to evaluate effectiveness of the new method. The experiments indicate that use of the absorber can improve the metallurgical quality of the melt

Introduction

Hydrogen is the only gas that dissolves appreciably in molten aluminum [1]. It9. Dissolved hydrogen in molten aluminum adversely influences the physical, chemical and mechanical properties of aluminum cast products because hydrogen precipitates as porosity during the solidification of aluminum alloys. The molten aluminum should therefore be subjected to degassing before casting. The traditional methods include floatation in which some reactive solids such as Hexachloroethane and Zinc chloride are put within the melt to react with molten aluminum to form dispersed aluminum chloride bubbles carrying hydrogen and inclusions floating up to the surface of the melt. However, the use of chloride creates environment problem and are seldom employed by industry. So far, quite a few degassing techniques have been put into industrial use, such as SNIF, ALPHUR, MINT, etc. There have been other degassing methods that mainly depends on some physical principle to change the balance of the aluminum melt-gas system so as to separate hydrogen and inclusions from aluminum melt. [4,5]. However, reducing porosity during casting is still a challenging problem in the aluminum industry. In the present work, a new and simple degassing method that is based on vacuum metallurgy principle is investigated. The application of this method in aluminum industry is under way.

New principle of the vacuum degassing

The solution of hydrogen in the aluminum melt originates from the following chemical reaction:

$$2Al(1)+3H2O(g) = Al2O3(S)+6[H] \quad (1)$$

where, the subscript (l), (g) and (s) stand for liquid, gas and solid, respectively. The hydrogen generated from the reaction will dissolve in molten aluminum. The solubility of hydrogen in molten aluminum can be expressed by the following:

$$S = m\sqrt{P_{H_2O}}\exp\left(-\frac{E_s}{2RT}\right) \quad (2)$$

where, S is solubility of hydrogen in molten aluminum; m is a constant; T is the temperature of molten alloy; R is gas constant and Es is dissolving heat for hydrogen.
It can be seen from Eq. 2, Solubility of hydrogen will increase dramatically with the increasing of partial pressure of H2O.
If the molten aluminum is in the vacuum environment, the partial pressure of H2O will reduced dramatically close to zero. In this case, the hydrogen dissolved in aluminum will escape from the melt and hydrogen will diffuse out through the surface. The current vacuum degassing method is shown in Fig.1 where (1) is the crucible, (2) is the molten aluminum and (3) is the valve that connecte the vacuum system.

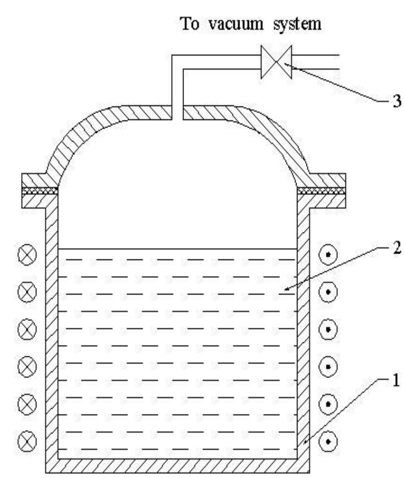

Fig.1. schematic of the conventional vacuum degassing

However, vacuum degassing, is used primarily in the steel industry and seldom used in the aluminum industry. S J Hellier and G H J Bennett suggested Vacuum stream degas sing of molten aluminum [z]. An aluminum melt may be successfully degassed by passing it through a vacuum in the form of a thin continuous cylindrical stream. Zeng described a counter gravity casting process that used vacuum degassing [zeng]. However, because the system is closed, the pouring operations cannot be carried out during degassing, and diffusion of hydrogen is also restrained by the oxide film covered in the surface of the melt. To overcome these shortcomings, an innovative hydrogen removal process has been proposed [6]. The schematic of the process is shown in Fig. 2. where, (1) is the vacuum pump; (2) is the controlling valve; (3) is the vacuum meter; (4) is the pipe connecting the absorber and vacuum system; (5) is the tie-in; (6)

is the furnace body; (7) is the heating element; (8) is the porous absorber; (9) is the aluminum melt and (10) is the crucible. Porous absorber (8) is immersed in the molten aluminum (9). Switch the valve (2) on to connect the vacuum system. In this way, within the porous head, the hydrogen partial pressure is always maintained at zero. Thus large hydrogen concentration gradient creates at the interface between the melt and the porous absorber. By diffusion, the hydrogen will transfer from the aluminum melt to the absorber that is connected with the vacuum system through the pipe.

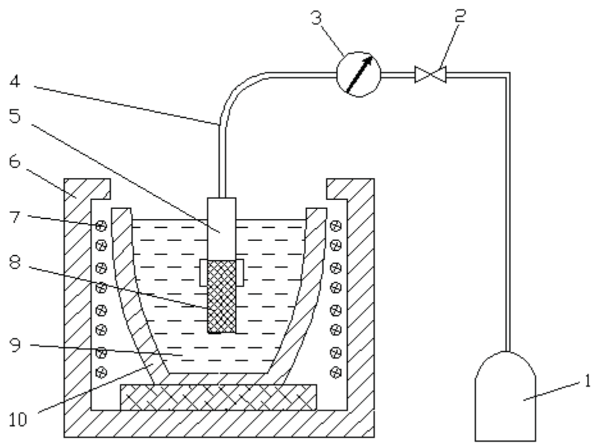

Fig. 2. schematic of the degassing the melt with porous absorber

Experimental methods

The commercial alloy ZL114A was melted in a graphite crucible in an electric furnace. When smelting was finished, the floating dross was skimed with a perforated spoon. Magnesium was added into the melt through an immersion bell at the temperature of 710^{o}C. After that, the melt was respectively transferred into two small preheated graphite crucibles with capacity of 40 Kg aluminum for hydrogen-adding treatment which was based on the Sivert principle. The crucibles were covered with a soaked firebrick during holding time. In this way, the water vapor covered over the aluminum melt, which results in drastic reaction between the aluminum melt and water. Hydrogen will diffuse into the melt as one of the products of chemical reaction. In the present experiment, the hydrogen concentration in the molten aluminum could get to a level of about 0.3ml/100gAl .

The analysis of hydrogen content. The hydrogen contents in the melt were test by RPT principle that is dependent on the fact hydrogen dissolved in the melt will released rapidly during solidification under vacuum or negative pressure, as shown in Fig. 3. The test was of rapidity, simplicity, and economy A constant mass of the melt (approximately 100g) is placed in a chamber and the pressure is decreased rapidly to a predetermined value by a vacuum pump. The chamber and associated vacuum system are then isolated from the pump and the sample allowed to solidify. As the melt cools hydrogen is released and its partial pressure is measured by a calibrated Pirani gauge whose output is converted continuously to a digital display of hydrogen content. It will take about 5 minutes to finish one whole testing procedure.

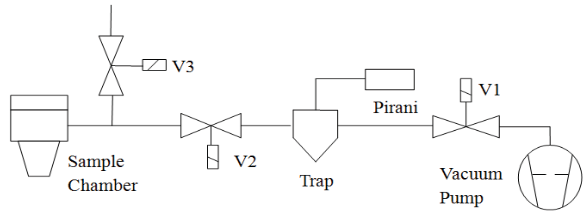

Fig. 3. Schematic of Hydrogen in aluminium analyzer.

The reduced solidification or vacuum solidification test was done in VT613ST VAC-TEST system. Using the ladle take approximately 200g of molten aluminum and poured into a testing crucible about 75% full and rapidly put the crucible into the vacuum chamber. Start the vacuum pump, the pressure within the chamber rapidly reduced to about 80 mbar. The solidification of sample was finished in 4 min. The samples were weighed in air and in water, respectively. The density, D, of the sample is given by the following equation:

$$D = \frac{W_a}{W_a - W_w} \tag{3}$$

where, *Wa* and *Ww* are the weights of the sample measured in air and water, respectively.

The density index *DI,* a parameter reflecting porosity degree of a sample, can be defined as:

$$DI = \frac{\rho_a - \rho_V}{\rho_a} \times 100 \tag{4}$$

where, ρ_a and ρ_V are the density of the sample solidified in air and in vaccum, respectively.

Results and Analysis

Two groups of test were done to compare the contents of hydrogen in the aluminum melt under two conditions. One was that the melt was open to air (the relative humidity was about 70% on site); the other was that the porous absorber was immersed in the aluminum melt so that degassing could be conducted uninterrupted during casting, as shown in Fig.3.


Fig.3 Vacuum degassing with a porous absorber immersed in the melt

The relationship between hydrogen contents and temperature holding time was shown in Fig.4. It can be seen that there is a significant difference between the two conditions. When the melt was exposed to air without being covered with a protective agent (usually a mixture of salts of chloride and fluoride), the hydrogen contents increased gradually with the increasing of the holding time.

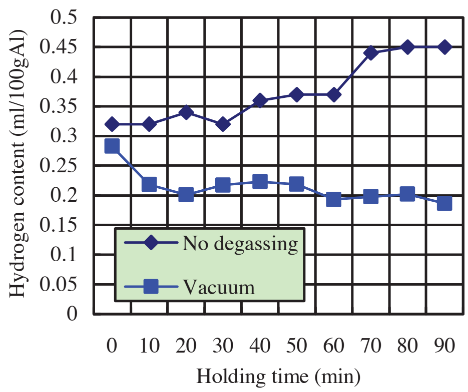

Fig.4 Relationship between hydrogen contents and temperature holding time

At 90 minutes, the samples were taken respectively from the two crucibles and solidified under negative pressure. The Morphology of samples solidified under reduced pressure was compared between Fig.5. and Fig.6. It could be seen that the sample for no vacuum degassing after 90 min's holding time (Fig.5.) looked like a honeycomb on the cross section and protruded out on the surface, which indicated a higher hydrogen content duo to the release of hydrogen during solidification of the sample. On the contrast, the sample degassed with porous absorber (Fig.6) showed the concaved surface and denser cross section, which indicated lower hydrogen content in the sample.

Fig.5 Morphology of samples without degassing solidified under reduced pressure (time = 90s)

Fig.6 Morphology of samples degassed with absorber solidified under reduced pressure (time = 90s)

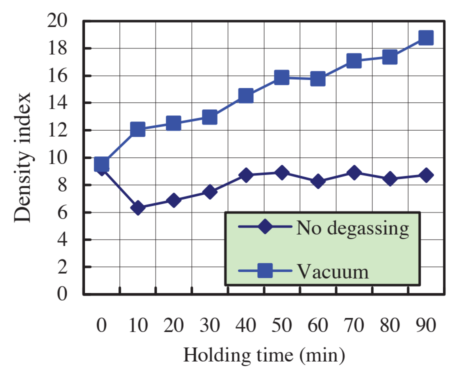

Fig.7 Relationship between density index and temperature holding time

Density index, another parameter for reflecting the porosity formation tendency, is shown in Fig.7. A higher density index means more hydrogen will precipitate from the molten aluminum during solidification and form porosity inside the casting and a lower index stands for more integral casting

It is indicated that "porous absorber" was a successful innovative degassing method. The advantages can be summarized as follows:

(1). The degassing operation is very simple, no special facilities are needed other than a vacuum pump system.

(2). The process is of low cost and environment friendly.

(3). The degassing can be carried out continuously, maintaining the low level of hydrogen concentration during the whole working operations.

Summary and conclusion

Degassing of molten aluminum can be done with a porous sprayer that is immersed in the aluminum melt at one end and is connected with vacuum system at another end through a pipe. The process is an effective, simple, low cost and environment friendly way to removal of hydrogen from aluminum melt. No special facilities other than a vacuum pump are needed. The degassing can be carried out continuously without stopping the pouring operation, maintaining the low level of hydrogen concentration during the whole working operations (this is of significance for low pressure die casting and for continuous permanent casting). Under normal circumstances, the hydrogen contents in the molten aluminum can be maintained as low as 0.1ml/100gAl.

Acknowledgements

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