The XSR Rotor: A new development in FDU degassing technology

Introduction

Aluminium and its alloys are now regarded as indispensable materials for most industrial applications and are used extensively in building, engineering, transport and particularly the automotive sector where it's use has increased rapidly over the last few years.

In the casting sector the products are almost exclusively produced by sand, die or high pressure die-casting methods and as the range of applications has increased so has the quality requirements placed upon them.

The properties and quality of the castings is greatly influenced by the metal treatment of the molten metal including such treatments as fluxing, degassing, grain refinement, etc.

Accordingly as requirements have become more demanding, development work by FOSECO has concentrated in particular areas to produce the products necessary to keep pace with the demands of the end user.

Theoretical principles

Hydrogen has a high solubility in liquid aluminium which increases with melt temperature (figure 1), but the solubility in solid aluminium is very low so as the alloy freezes, hydrogen gas is expelled forming porosity in the casting. [1]

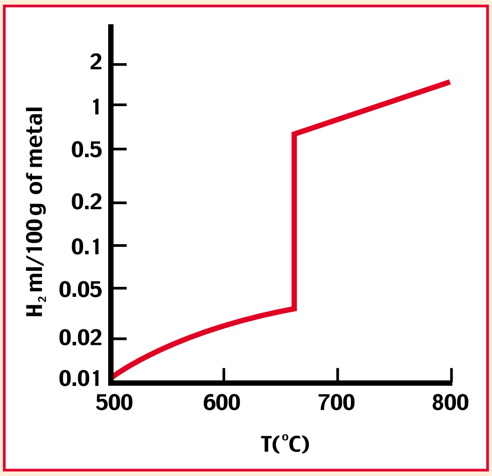

Figure 1: Solubility of hydrogen in aluminium

In aluminium there is a reaction with water vapour as follows;

(a) $2\ Al_{(l)} + 3\ H_2O \leftrightarrow Al_2O_{3\,(s)} + 3\ H_{2\,(g)}$

Molecular hydrogen then dissociates in the molten metal:

(b) $3\ H_{2\,(g)} \leftrightarrow 6\ H_{(dissolved)}$

The molten aluminium also interacts with atmospheric oxygen thus in addition to the oxidation reaction seen in equation (a), the following reaction also occurs;

(c) $4\ Al_{(l)} + 3\ O_{2\,(g)} \leftrightarrow 2\ Al_2O_{3\,(s)}$

This reaction results in oxide skin formation on the surface of the molten metal during the melting process and any subsequent transfer of the molten metal. The oxides produced become trapped in the bulk of the molten material, and are then transferred to the finished cast component. Further non-metallic inclusions such as carbides, nitrides or borides can come from sources such as the crucible material or other refractory materials.

Any inclusions produced can lead to defects in the structure of the casting and therefore can have a detrimental effect on mechanical properties, also they lead to machining difficulties and possible damage to machine tools. It is therefore essential to remove dissolved hydrogen and non-metallic inclusions from the molten metal prior to casting to achieve optimum quality.

The treatment that has been developed to clean the metal is a physical process involving flushing with an inert gas. The hydrogen, which is dissolved in the molten material, diffuses into the rising bubbles of flushing gas and is transported to the surface of the molten material, this process is dependent on two major steps [2]:

- Speed of diffusion of hydrogen through the Nernst diffusion boundary layer into the inert gas bubbles – a diffusion-controlled degassing stage,

- Concentration of hydrogen in the inert gas bubbles – the equilibrium-controlled stage of degassing.

Diffusion is the rate determining stage in degassing therefore the following requirements are necessary for optimum degassing efficiency [3,4]:

- Small size of the inert gas bubbles with long dwell time in the molten metal. This ensures a large surface contact area between the inert gas bubble and the molten metal and therefore a higher coefficient of mass transfer with regard to the diffusion layer
- Consistently broad distribution of inert gas bubbles over the entire cross-section of the molten metal
- Adequate motion of molten material which accelerates the transport of hydrogen to the inert gas bubble,
- A quiescent surface of the molten material bath in order to avoid fresh absorption of hydrogen from reaction with the atmosphere.

Oxides and other non-metallic inclusions are mainly removed by flotation as the small inert gas bubbles attach themselves to the oxides and float them to the surface of the bath. The principles that apply to hydrogen removal also apply to the removal of oxides.

Molten Metal Purification Procedure

Aluminium foundries have long been aware of the need for an effective flushing gas treatment to remove hydrogen and inclusions thus recent development has been to fulfil this requirement and achieve the best possible degassing efficiency.

Previously static lance degassing was used but this has been improved by the application of porous blocks to reduce gas bubble size. Additional movement of the lance has further improved distribution, however, this method is not entirely satisfactory.

The major breakthrough in automated, efficient, cost effective degassing came with the developments in FDU rotary degassing.

The principle of these machines is the patented pumping action rotor that generates very fine bubbles of inert gas that are evenly and consistently distributed throughout the metal bath.

For some considerable time the SPR type Foseco rotors have proved successful in numerous foundries and have become an established technique for effective degassing.

The XSR high-performance rotor

Foseco was prompted to improve the established FDU SPR design by the ever present need to achieve higher-quality castings and also by the desire to reduce the time required for degassing. Intensive investigations with the existing rotor, combined with theoretical studies, simulations, extensive modelling and practical tests have culminated in the development of the new XSR high-performance rotor.

Figure 2: FDU XSR 190 rotor

The FDU XSR high-performance rotor is a new design with an enhanced pumping action (figure 2), where the molten metal is drawn through the rotor more effectively and is therefore mixed more intimately with the treatment gas. The exit speed of the molten material from the rotor increases, thus more consistently distributes the treatment gas over the entire cross-section of the treatment vessel.

Turbo cuts in the upper section of the rotor further reduce the size of the inert gas bubbles thus maximising the surface area of the bubbles for a given volume of treatment gas. Water modelling tests have shown the additional inducement of vortices in the molten metal with extended travel distance (and hence extended dwell time) of the inert gas bubbles in the molten metal leads to greater efficiency (figures 3a and 3b).

Figure 3a: SPR 190 at 500 rpm in water model

Figure 3b: XSR 190 at 500 rpm in water model

The degassing effect has been plotted online using a hydrogen sensor. The rate of degassing under controlled conditions in achieving a target level of 0,08 ppm of hydrogen in the molten material was 0,03 ppm H_2/min with the XSR rotor and 0,02ppm H_2/min with the SPR rotor, i.e. 50% more effective (figure 4).

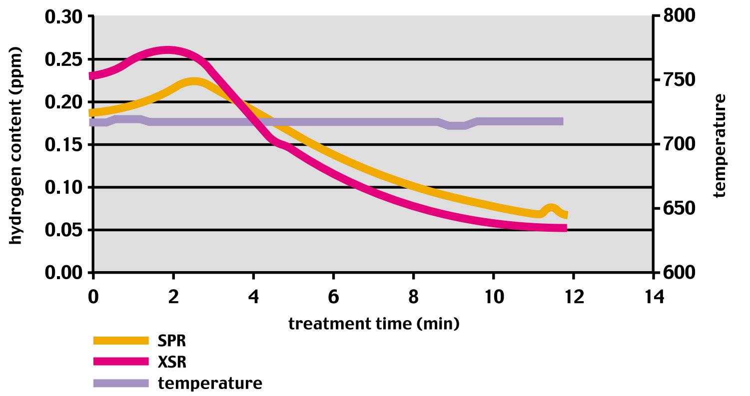

Figure 4: Hydrogen sensor plot of degassing

On the basis of these findings, two different foundry requirements can be both fulfilled by the new XSR high-performance rotor.

- ❑ Quicker degassing of molten metal and hence an increase in the effectiveness of the FDU degassing system and a reduction in temperature loss,

- ❑ Degassing at a reduced rotor speed in order to extend the service life of graphite shaft and rotor because of the reduced abrasion and/or reduction in vortices on the shaft when operating without a baffle plate.

Case Studies

The case studies set out below illustrate various starting conditions, requirements and solutions using the XSR high-performance rotor during foundry trials or in research facilities.

Case study 1 – Reduction in treatment time

Type of casting	Wheel castings
Alloy	AlSi7Mg, AlSi11 (Sr modified)
Quantity of molten material	900 kg
Temperature	760 °C / 750 °C
Rotor speed	500 rpm
Rotor diameter	190 mm
Inert gas	Argon Ar
Inert gas quantity	18 l/min
Quality requirements	Density (AlSi7Mg): 2.58 – 2.60 g/cm³ Density (AlSi11): 2.57 – 2.59 g/cm³

Table 1: Trial conditions case study 1

	SPR 190		XSR 190	
	Result	Time	Result	Time
AlSi7Mg	2.586 g/cm³	8 min	2.590 g/cm³	4 min
AlSi11	2.582 g/cm³	10 min	2.578 g/cm³	7 min

Table 2: Results case study 1

At 100 treatments per working day, the reduction of treatment time by at least three minutes culminated in argon savings of 1200 m³ annually. This corresponded to a saving of more than €8000. It was also possible to reduce the pre-treatment temperature of the molten material by 10 °C.

The shorter processing time increases the client's flexibility when using FDU degassing systems. The peak demand times for the preparation of molten metal were made easier to cover and in the medium term the foundry also found it possible to postpone the purchase of a new FDU degassing system.

Case study 2 – Extension of service life of graphite shaft and rotor by a reduction in rotor speed can be seen in table 3 and table 4.

Type of casting	Sand casting
Alloy	AlSi10Mg (Na modified)
Quantity of molten material	400 kg
Temperature	760 °C
Treatment time	5 min
Rotor diameter	190 mm
Inert gas	Nitrogen N_2
Inert gas quantity	14 l/min
Quality requirements	Density Index (DI) ≤ 2%

Table 3: Trial conditions case study 2

SPR 190			XSR 190		
RPM	Result	Service life	RPM	Result	Service life
500 min^{-1}	DI = 2.0%	100%	350 min^{-1}	DI = 1.3%	160%

Table 4: Results case study 2

Tests were conducted with ten sets of graphite shafts and rotors where abrasion on the graphite was markedly reduced at the lower speed of 350 rpm, such that the average service life was increased by 60%. This direct cost saving for the customer is complimented by the additional benefit of reduced set-up and maintenance times because of the reduced number of shaft and rotor changes.

Case study 3 – Reduction in fine oxide content

Type of casting	Piston casting
Alloy	AlSi12CuNiMg
Quantity of molten material	700 kg
Temperature	770 °C
Treatment time	15 min
Rotor diameter	190 mm
Inert gas	Nitrogen N_2 / Chlorine Cl_2
Inert gas quantity	15 l/min N_2 / 21 l/min $N_2 + Cl_2$

Table 5: Trial conditions case study 3

In tests, the quality of molten metal was examined for oxide content using a PREFIL device.

The SPR and XSR rotors were compared to each other under identical conditions. The results showed that the content of oxide in the molten metal was markedly lower with the XSR compared to the SPR rotor (figure 5).

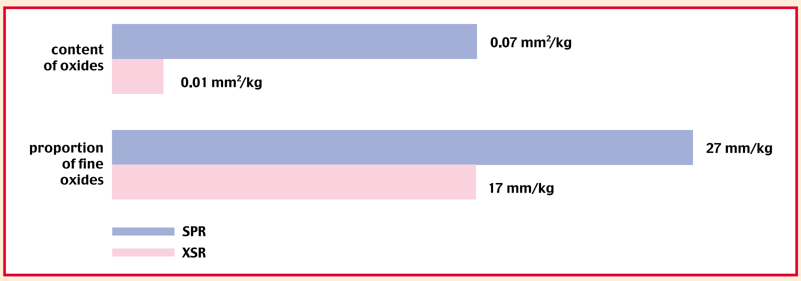

Figure 5: Oxide contents

Surprisingly, following the XSR rotor treatment, the molten metal remains below the stipulated density index for a longer period indicating that hydrogen absorption has been reduced. Accordingly, the customer can get more use from a given crucible before the molten metal has to be re-treated. One reason for this could be the markedly lower content of oxide, since oxides can act as a centre for nucleation for hydrogen followed by dissolution in aluminium.

Summary and prospects

The newly developed XSR high-performance rotor is far more effective than conventional rotors at cleaning and degassing molten aluminium. The reduction in the treatment time to obtain the same or even better levels of metal cleanliness brings about enhanced productivity for the FDU degassing equipment, and reduced temperature loss in the treatment vessel.

The new XSR design can give much lower levels of both hydrogen and oxides in the molten metal compared to conventional rotors. Alternatively, the service life of the graphite shaft and rotor can be increased whilst maintaining metal quality by reducing the rotor speed. The XSR rotor is another demonstration of the development by FOSECO in degassing technology.

References

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