Foundry Practice 256

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The Authoritative Magazine For Foundry Engineers

PSA - MELT QUALITY AUDIT

ENERTEK* - THE ENERGY EFFICIENT CRUCIBLE

ROTARY DEGASSING

FOSECO

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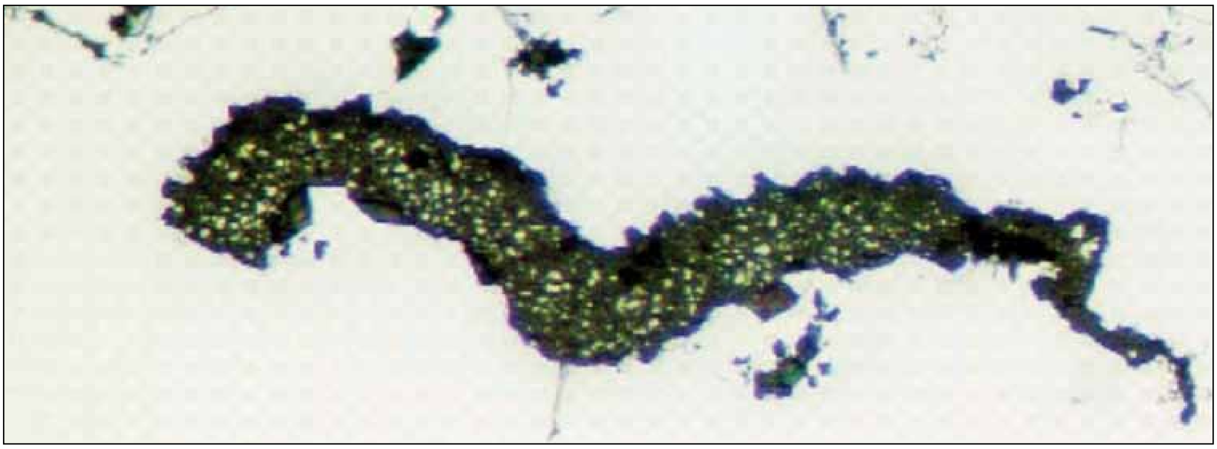
ALSPEK H and ALSPEK MQ: practical in-situ diagnostic tools for the process control of aluminium melts



Synopsis

The types of castings being made today in aluminium foundries are very varied. Thinner and lighter castings are being expected to perform in more arduous conditions than ever before and sophisticated alloys are being developed to raise the potential properties to new heights. With the higher expectancy placed on the foundry there is an increasing need to control the individual processes involved in making the casting.

A number of different issues concern the foundryman, the major ones being:

- the hydrogen content of the aluminium alloy immediately prior to casting
- the cleanliness of the melt and subsequent freedom from inclusions of the casting
- the microstructure of the final casting

Over the last 5 years Foseco has followed a strategy of process control and as part of this has developed a series of tools for measuring these parameters.

To fully understand their processes it is valuable for the foundry to be able to map the melt quality and condition through the various stages of Melting, Holding, Melt Transfer, Metal Treatment, Holding and Casting. With the use of ALSPEK H and ALSPEK MQ it is now possible to rapidly measure the cleanliness level and hydrogen content of the alloy at the different stages of melt preparation, prior to casting.

Metal quality

The quality of aluminium castings has always been important, but today the expectations of the designer and engineer are higher than ever. The casting must be sound, have a good appearance and surface finish, machine easily and fulfil all the various requirements of performance. Pressure tightness is vital in many industrial applications and as the casting must continue to perform for many years in service, fatigue is also critical. In order to achieve optimum mechanical properties from the alloy it is essential that the casting is completely free of any inclusions and open porosity. For many years foundries have made castings and then subjected them to non-destructive testing to ensure they were fit for service. The industry now has to move forward and the melt itself should be tested, prior to casting, to ensure it is of sufficient quality to pour into the die or mould.

In order for this to be possible it is necessary to have fast simple tests, which will not delay the production process, and it is in this field that Foseco has been working.

Hydrogen content of the melt

Hydrogen is readily taken into solution in molten aluminium, but during solidification there is a drastic reduction in its solubility. Therefore, if the hydrogen content in the melt is high, then hydrogen will be liberated during solidification to form very fine porosity throughout the casting. This porosity is not interconnected but will form points of weakness in the casting as well as becoming unsightly on machined surfaces. Alternatively if the hydrogen content is very low then any shrinkage which forms in the casting will tend to be concentrated in the areas of the casting which solidify last. A very low hydrogen content can encourage gross shrinkage porosity if feeding is not 100% effective. It is therefore beneficial to measure the hydrogen content prior to casting; at this point the hydrogen level could be adjusted, if required, against a predefined value for that particular casting and feeding technique.

ALSPEK H

ALSPEK H is a tool for the rapid measurement of hydrogen in the melt. It consists of a sensor that within 90 seconds measures the gaseous hydrogen content. The sensor is an electrochemical device, which comprises a proton conductor containing a solid-state reference material, and when submerged into the melt will generate a voltage from which the hydrogen content can be found. The self contained device measures the melt temperature and, knowing the alloy, the exact hydrogen content can be calculated.

ALSPEK H is unique in its ability to monitor the hydrogen content even during the degassing or regassing processes and so it can be used to truly control the hydrogen content of the melt to the required level.

Figure 1. ALSPEK H unit

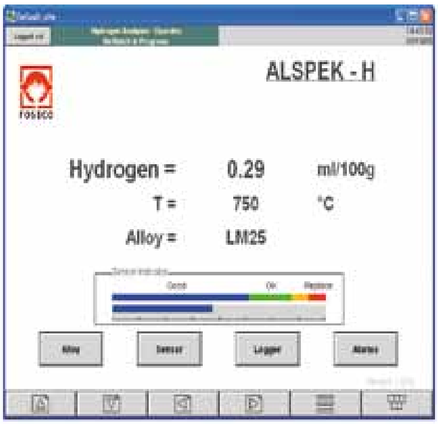


Figure 2. Home screen of ALSPEK H

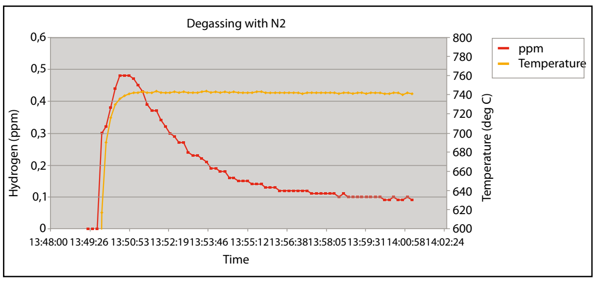


Figure 3. A degassing curve as measured by ALSPEK H during a FDU® treatment

Metal cleanliness

All aluminium alloys oxidise readily, some more than others, and so the formation of non-metallic inclusions will always be a danger. These inclusions can potentially cause stress raisers in a casting, encourage leakage and failure on pressure testing and considerably harm the machinability of the casting. There are many different sources of inclusions but they can be basically separated into two groups:

a) Old oxides, which are dense and very hard inclusions. These have been created some time ago and have probably grown against a refractory wall or been created by heavy elements settling in the melt and reacting with time. Old oxides are often created when metal temperatures are too high, in excess of 800°C for long periods. These inclusions will damage machine tools, resulting in a stoppage in the machining line or create an unsightly mark on the machined surface.

b) New oxides, which have been created during metal transfer and will be most likely a thin film or bi-film. These thin oxide films are created by turbulent flow during melt transfer. They are a few microns in thickness but can be quite long. This type of inclusion can result in pressure test failure as the film can travel from one casting surface to another.

Although they create quite different problems, both types of oxides are equally unwelcome. They can be removed by metal treatment and filtration and so again, if their presence is identified before casting they can be removed.

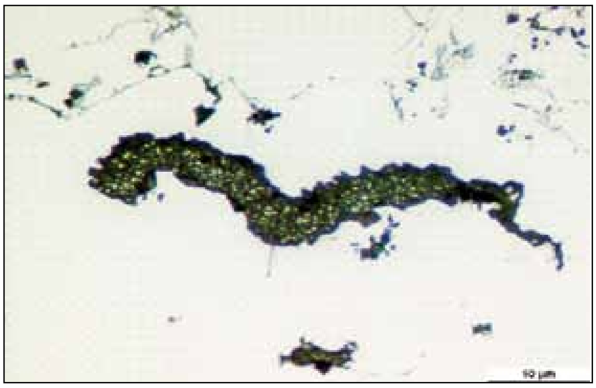


Figure 4. Coarse spinel particle

Figure 5. Oxide swirl created during transfer

Figure 6. An oxide film travelling deep into the casting wall, potentially resulting in pressure test failure

ALSPEK MQ

Foseco has a long history in the manufacture and application of foam filtration and a deep knowledge of the effectiveness of foam in the entrapment of all types of inclusion. It was therefore logical that a test should be developed around this technology. Foam filters are very effective at trapping inclusions and as these inclusions are held in a foam filter so they will restrict the flow of the alloy through that filter. By selecting the correct foam filter structure it is therefore possible to use the flow through the filter to differentiate between different levels of alloy cleanliness. This is achieved by measuring the total transit time while passing a known volume of alloy through the filter.

ALSPEK MQ is a device that, if placed on the surface of the melt, samples 1.5 kg of alloy from below the melt surface and generates a Metal Quality Index to inform the operator whether the melt is clean. The ALSPEK MQ probe, weighing 5 kg, is easily handled by the operator and is connected by wireless technology to the read out unit avoiding the presence of cables. The read out unit can be positioned up to 50 meters away from the probe, making the operation of ALSPEK MQ very flexible. In less than one minute of testing a Metal Quality Index MQI, is generated.

ALSPEK MQ has been tested on melts between 680°C and 780°C. At higher temperatures care must be taken to avoid overheating of the sensor, as highlighted by the warning light on the read-out screen. ALSPEK MQ has also been successfully used on almost every common aluminium alloy, specifically aluminium–silicon hypo-eutectic and hyper-eutectic, aluminium copper and aluminium–magnesium alloys. The MQI result is not affected by metal treatment products, which may be added to refine or grain refine the alloy structure. ALSPEK MQ measures the presence of oxides of over 50 microns in size and particularly the very harmful inclusions of 300 microns, which can be seen on machined faces.

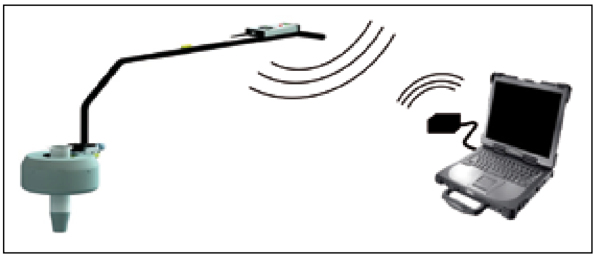


Figure 7. The ALSPEK MQ device communicates by wireless

Figure 8. ALSPEK MQ during a test

The melt quality index generated from ALSPEK MQ can be interpreted as follows:

MQI 1 and MQ 2	very clean and suitable for high quality casting
MQI 3	clean and suitable for commercial castings
MQI 4 and MQI 5	some oxides present, melt needs further treatment with flux and FDU or MTS 1500 rotary degassing process
MQI 6 and MQI 7	melt is contaminated with a fair number of inclusions and must be retreated
MQI 8	heavily contaminated with inclusions
MQI 9	extremely heavily contaminated with inclusions, blocking filter

Melt quality

The use of ALSPEK H and ALSPEK MQ allow the foundry to check the quality of their melts before casting into the mould, but the test can also be used for improving the knowledge of the metal melting, handling and treatment. For instance, by moving around the metal holding and transfer system it is possible to map how the quality of the melt changes with time, transfer and treatment. This can highlight where oxides are being created or hydrogen being picked up into solution and thus is another valuable potential opportunity from having these tools. During the development of these tools Foseco has tested many thousands of melts, many in production foundries and has generated a considerable amount of data.

Development trials

Alloy 356 Al Si7Mg	
Melt condition	Melt Quality Index MQI
As melted	MQI 6
Addition of magnesium	MQI 7
Over vigorous stirring	MQI 8
20 minutes standing	MQI 6
10 minutes MTS 1500 with COVERAL MTS 1524 and 10 minutes standing	MQI 2
Addition of Al - 10% strontium AlSr10	MQI 2
Addition of Al - 5%Ti - 1% B AlTi 5B1	MQI 2

Table 1 Cleanliness of a production melt at different stages of treatment

Table 1 shows the deleterious effects of adding magnesium to the alloy and also over vigorous stirring. After 20 minutes standing, the oxides created begin to settle to the lower part of the melt resulting in the upper parts of the melt becoming cleaner. A treatment for 10 minutes with the COVERAL MTS 1524 flux and MTS 1500 rotary treatment system reduced the inclusion levels considerably. Subsequent additions of Strontium and Titanium Diboride do not affect the cleanliness as seen by ALSPEK MQ.

Melt condition	Melt Quality Index MQI
Casting furnace immediately after filling	MQI 3
After 1 hour standing	MQI 2
Standing over night	MQI 1
After refilling with molten alloy	MQI 3

Table 2. Cleanliness of a casting furnace, heated by roof electric elements

Table 2 shows the changes in cleanliness in a 1 tonne holding furnace as the furnace is filled from a transfer ladle and then allowed to stand. Oxide, which settles to the bottom of the bath, is disturbed when new alloy is poured into the furnace.

PSA Charleville

Built in 1974 in the Ardennes region of France, the foundry of Charleville-Mézières, is the first private employer in the Champagne Ardennes area, and produces cast iron and aluminium alloy castings. Typical applications include power train and suspension parts, all destined for machining or assembly within the PSA Peugeot Citroën group.

Figure 9. The production plant at Charleville - Mezieres

Figure 10. One of the melting shops at Charleville-Mezieres

With 35 years of experience, this site maintains its market leadership thanks to the "know-how" of the 2,500 workers at the plant, all of whom pride themselves on their human and technical capabilities. This foundry produces 250 tons of cast iron parts per day (steering parts, suspension arms, crankshafts, manifolds and differential casings) while also casting 160 tons per day of aluminium (cylinder heads, chassis parts).

PSA achieve the high quality of castings required for their components by the utilisation of Foseco Coveral fluxes and FDU or MTS 1500 rotary treatment technology.

Reflecting the close relationship between the two companies PSA assisted in the early testing and benchmarking of the ALSPEK MQ metal cleanliness test.

PSA Charleville purchase high quality aluminium ingot and their foundry returns of risers and running systems have all been carefully treated prior to melting and thus the as-melted condition of their melt is high. Metal taken from the tower melting furnaces is brought by transfer ladle to the treatment station. In this condition typical ALSPEK MQ results were MQI 3. After a treatment of 12 minutes with a Foseco Metal Treatment Station, MTS 1500, results of MQI 1 were commonly found. The alloy in this condition will be very fluid and free of inclusions, ideal for casting.

All the aluminium castings manufactured in Charleville are machined and up to 10 tonnes per day of machined swarf and chippings are produced. If sent off site, for refining, this swarf would have to be re-melted, cleaned and then cast into ingot before being sent back to PSA for re-melting. This would result in high metal loss as well as extra re-melting, energy consumption and an increased CO_2 footprint. With the implementation of the Foseco Metal Treatment Station, MTS 1500, a highly effective melt cleaning process, the question was asked: could this material be melted in house, cleaned to a high standard and added directly in molten form to the stock of molten metal held every day in the foundry? The availability of ALSPEK H and ALSPEK MQ enabled this exercise to be investigated.

In the extreme case complete melts of chippings and swarf were produced in 1.5 tonne induction furnaces, these melts were tested prior to and after MTS 1500 treatment.

As expected, the metal as melted was high in oxides, due to the large surface area from this fine-machined swarf. Readings of MQI 7 and MQI 8 were found.

After a 20 minute MTS 1500 treatment using Coveral MTS 1524 in the 1000 kg transfer ladle MQI readings of MQI 2 were consistently found, proving that the contaminated melt in the transfer ladle had been effectively cleaned to a very satisfactory quality level suitable for casting.

Figure 11. K- Mould sample taken from swarf melted alloy showing the oxide inclusions. Metal Cleanliness Index of this melt was MQI 8

Figure 12. K-Mould sample from the transfer ladle after treating the swarf material with a MTS 1500 Metal Treatment Station and Coveral MTS 1524. The Metal Cleanliness Index of this melt was MQI 2

To further understand exactly what type of inclusions were involved, a series of Prefil® tests were also carried out. This test generates a residue of metal that can be sectioned and examined under the microscope. The inclusions from the Prefil* sample are therefore concentrated and can be counted, measured and analysed.

Figure 14 shows the presence of alumina needles, magnesium oxide and "others" (mainly sand particles) which are found before and after treatment. This analysis again shows the significant improvements in metal cleanliness seen after MTS 1500 rotary treatment.

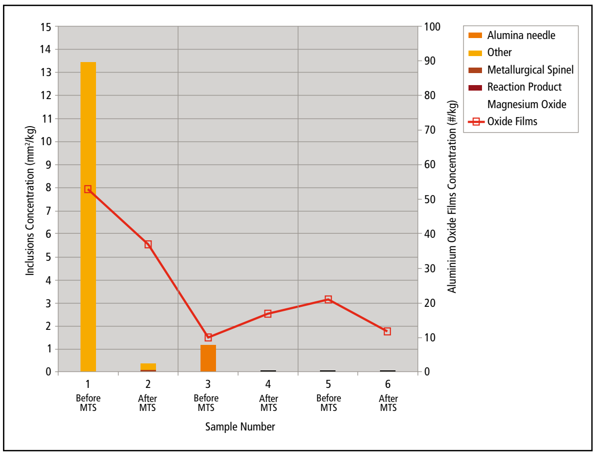


Figure 13.

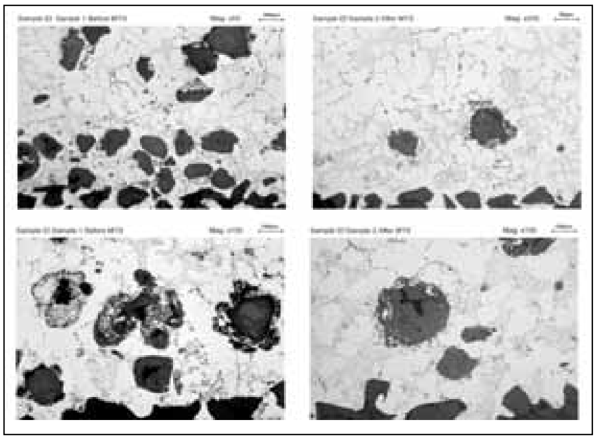


Figure 14. Prefil residue analysis before and after MTS 1500 treatment

MTS 1500 treatment dramatically reduces oxides and sand content.

Date	Trial	Alloy	Condition	MQI	ALSPEK H (mL/100g)
16/02/2010	Ladle 1	AS6 swarf	Before MTS 1500	MQI 7	No
			After 20 minutes treatment with MTS 1500	MQI 2	0.08
	Ladle 2	AS6 swarf	Before MTS 1500	MQI 8	0.21
			After 20 minutes treatment with MTS 1500	MQI 3	No
	Ladle 3	AS6 normal change	Before MTS 1500	MQI 3	0.48
			After 12 minutes treatment with MTS 1500	MQI 1	0.11
	Ladle 4	AS7 normal change	Before MTS 1500	MQI 7	0.58
			After 12 minutes treatment with MTS 1500	MQI 1	0.13
17/02/2010	Ladle 7	AS7 swarf	Before MTS 1500	MQI 7 MQI 8	0.4
			After 20 minutes treatment with MTS 1500	MQI 2 MQI 2	0.14

Hydrogen levels after MTS 1500 treatment are similar for swarf and normal charge melts whatever alloy type.

The MTS 1500 treatment is equally efficient for normal charge and swarf melts in terms of hydrogen removal.

Conclusions

- ALSPEK H gives a fast and accurate reading of the hydrogen content in the melt and enables the foundry to work to a tight tolerance of hydrogen content
- ALSPEK H offers the additional advantage of controlling the rotary degassing process giving the ultimate control. With treatment time optimisation there is a possibility for further savings
- ALSPEK MQ is proving to be a fast and simple check for alloy cleanliness, a combination which no other current cleanliness measurement system is able to offer
- The MTS 1500 Metal Treatment Station using the Foseco XSR rotor successfully reduces the hydrogen content of the alloy whatever the alloy composition, offering the foundry tight hydrogen control regardless of starting hydrogen level or relative humidity in the foundry
- Treatment with the MTS 1500 Metal Treatment station along with Coveral MTS 1524 flux cleans the melt in a 12 minutes treatment cycle for "série" alloys and 20 minutes for swarf, thereby helping to improve the productivity of the foundry
- When melting machining chippings and swarf the melt contains a high degree of oxide skins and inclusions as well as a high hydrogen level.
  This metal can be cleaned to a very good cleanliness level by using MTS 1500 and Coveral MTS 1524. Indeed, often the best MQI results (MQI = 1) are obtained. Moreover, low hydrogen contents (about 0.10 mL/100g) are also achieved
- A reduction of dross percentage from 10.43% to 4.30% in swarf re-melting has been possible by improved metal treatment practice
- Savings per re-melted ton of swarf can be up to 1000 Euros depending on LME prices
- Melting swarf, cleaning and degassing the melt and then using the metal directly, removes one re-melting cycle and thereby saves time, energy and reduces CO_2 formation
- Due to their fast response and portability ALSPEK H and ALSPEK MQ can be used to measure the quality of the melt immediately after treatment and prior to the final pouring stage
- with the development of ALSPEK H and ALSPEK MQ the foundry industry now has the opportunity for regular and systematic checking of melt quality. A valuable database can be accumulated, which, in time, gives the foundry the opportunity to benchmark its quality. When problems occur, as they always will in our complex industry, the foundry can compare its current quality with that from previous times. Large foundry groups can also benchmark the melt quality of each of their foundries by using these standard and repeatable testing methods.

ENERTEK - a new concept in energy efficient melting and holding crucibles for aluminium

Introduction

Refractory crucibles have been used for many years in the non-ferrous foundry industry. Historically, the principal measure of a crucible's performance has been its lifetime; however, with the ever-increasing cost of energy, the thermal performance of a crucible is becoming more and more important.

ENERTEK is a new family of energy efficient crucibles that have been formulated and manufactured to offer the most thermally efficient crucible for melting and holding of aluminium. Apart from long life, ENERTEK crucibles offer significant saving potential in energy costs and the reduction of the CO_2 footprint of a foundry.

Thermal modelling

Melt rate has been one of the primary thermal performance parameters of a crucible. The rate of melting is obviously dependent on the rate of heat transfer through the crucible wall to the metal charge contained within. For a given wall thickness and uniform heat flux, the rate of heat transfer will depend on the thermal conductivity and density of the crucible. The effect of thermal conductivity and density on melt rate can be relatively easily computer modelled using a finite element analysis (FEA) technique.

To measure these parameters, an axis-symmetric model was set up in ABAQUS to simulate a simple heat up and melt event to compare the heat transfer for different crucible products. The model was set up so that the heat was applied on the external crucible surface using a constant heat flux. The amount of heat flux was first determined to obtain a realistic melt rate of about 50 kg/h based on typical furnace manufacturer specifications (Figures 1 and 2).

By entering into the model the thermal conductivity and density measurements obtained from twelve commercially available crucible products, and by keeping all other parameters constant, the difference in melt rate from the slowest to the fastest was predicted. Using this method, a group of crucible products were rated according to the calculated time taken to melt a 180kg metal charge.

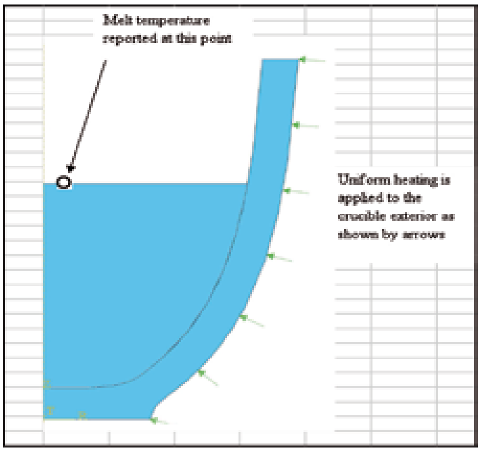


Figure 1. Schematic of FEA model parameters

Test conditions

- charge weight: 180 kg of 356A alloy at ambient temperature
- measure: melt time to achieve 750°C
- gas cost: at 0.012€/ kWh

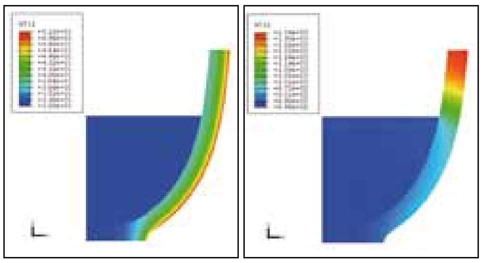


Figure 2. FEA results showing nodal temperatures at the beginning and end of the FEA experiment

This exercise demonstrated a difference of 42 minutes, or just over 20%, from the best to the worst performing crucible (Figure 3).

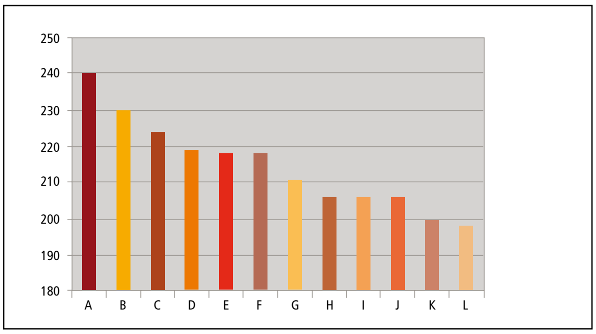


Figure 3. Time taken (minutes) to heat 180kg of metal from ambient to 750°C

This calculated time difference would already be significant in terms of the effect on productivity, potentially allowing for an additional heat in a normal working day. However, if the amount of energy required to perform this same operation is then calculated, a difference in cost is also evident. In this study the difference in performance from worst to best product would equate to 0.16€ to melt and heat 180 kg of aluminium. This may seem inconsequential but if this differential is maintained over a typical crucible life of 4 heats per day for 200 working days then the total difference in running costs between the "best" and the "worst" crucible can be over 175€. Perhaps not so significant by itself but multiplied by the number of furnaces, the potential for energy and cost savings will become significant.

Case studies:

Following on from the thermal modelling, foundry trials confirmed the significant potential for energy saving when using ENERTEK crucibles in comparison with conventionally available crucibles in aluminium melting and holding applications.

Case study 1:

An Aluminium Gravity Die Casting foundry using electric resistance heated 400 kg capacity crucibles to hold liquid aluminium.

A conventional crucible was run side by side with an ENERTEK crucible and the electric energy consumption measured over a 6 month period. Both crucibles were used to feed a single casting cell, therefore the amount of metal put through each crucible was identical over the test period.

Test results per furnace:	Conventional	ENERTEK	Saving
Test period (days)	180	180	
Total energy consumption (kW/h)	90,540	86,940	-3,600
= energy consumption (kWh) per day	503	483	-20
= energy consumption (kWh) per year (300 days)	150,900	144,900	-6,000
Total CO_2 emission per crucible (tonnes)	56.1	53.9	-2.2
Total CO_2 emission per year (tonnes)	112.3	107.8	-4.5
Total cost per crucible (0,08 €/kWh)	7,243€	6,955€	-288€
=Total cost per year	14,486€	13,910€	-576€

Table 1. Energy consumption and CO_2 emission comparison from Case study 1

Table 1 shows that the ENERTEK crucible consumed 3,600 kW/h less energy than the conventional crucible over the test period. This reduced energy consumption equates to both a considerable cost saving and reduction in the amount of CO_2 emissions (Figures 4 and 5).

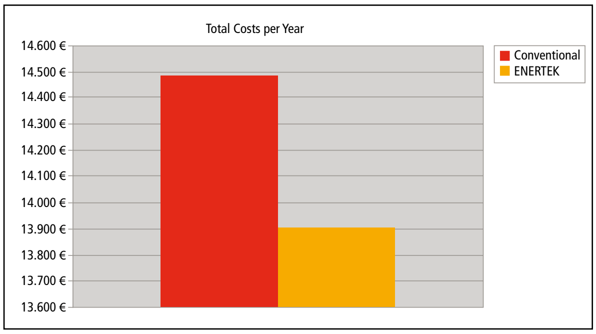


Figure 4. Summary of energy costs ENERTEK v conventional crucible - Case study 1

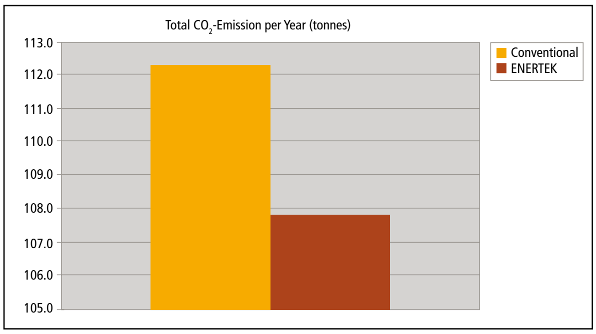


Figure 5. Summary of CO_2 Emissions ENERTEK v Conventional Crucible - Case Study 1

Case study 2:

A High Pressure Die Casting foundry melting aluminium in a tilting gas-fired furnace using a crucible of 800 kg capacity. The total gas consumption over a period of one month was measured for both ENERTEK and a conventional crucible. In addition, the amount of metal melted during each campaign was measured to enable a direct comparison between each crucible to be made.

Test results per furnace:	Conventional	ENERTEK	Saving
Molten metal in test period (tonnes):	169	212	
Total gas consumption (m^3)	34,956	36,795	
= m^3 gas per tonne aluminium:	207	174	-33
= Total gas consumption/month (m^3)	15,720	13,191	-2,529
Total CO^2 emission/month (tonnes):	39.1	32.8	-6.3
Total CO^2 emission per year (tonnes)	469.7	394.1	-75.6
Total cost per month at gas cost of 0,4€/m^3:	6,288€	5,276€	-1,012€
Total cost per year	75,455€	63,315	-12,140€

Table 2. Energy consumption and CO^2 emission comparison from Case study 2

Table 2 shows that the ENERTEK crucible consumed 33 m^3 less gas per tonne of aluminium melted, compared to the conventional crucible. As in the first case study, this reduction in energy consumption equates to significant savings in both cost and CO_2 emissions (Figures 6 and 7).

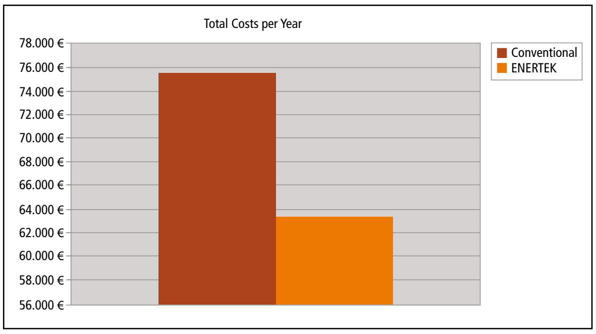


Figure 6. Summary of energy costs ENERTEK v conventional crucible - Case study 2

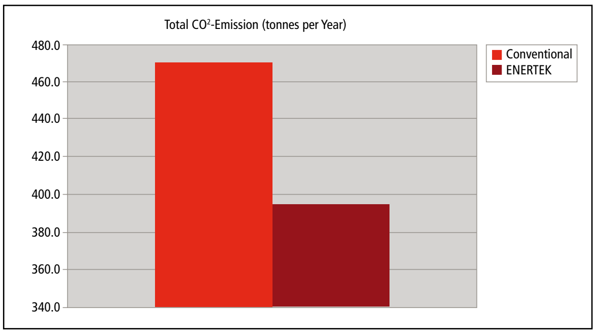


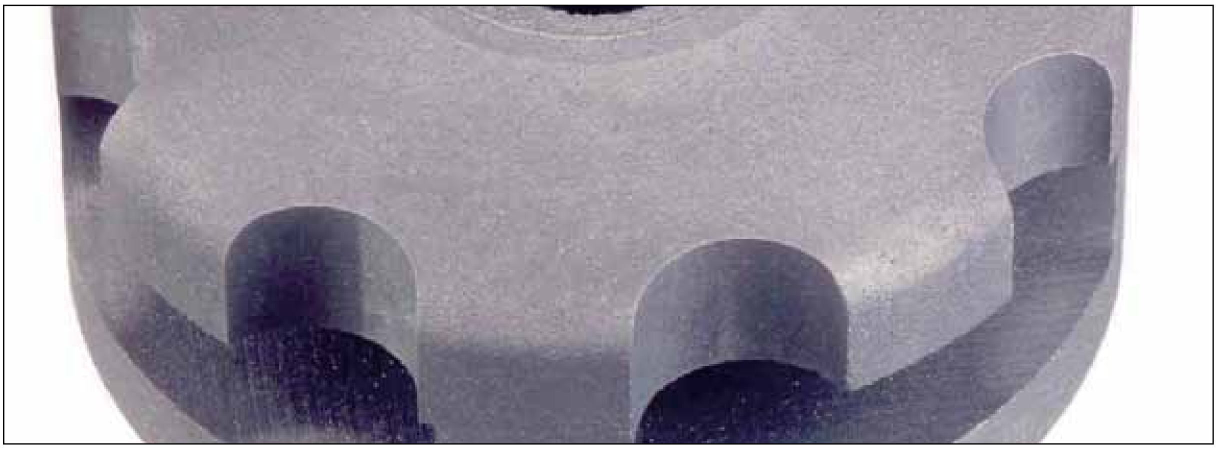
Figure 7. Summary of CO^2 emissions ENERTEK v conventional crucible - Case study 2

Summary

With energy costs continuing to increase, thermal performance is rapidly becoming the most critical operating parameter for crucibles. Computer modelling simulations have been used to demonstrate the large variation in thermal performance that exists in the current range of commercially available crucible products.

The potential for energy and cost savings suggested by the modelling work has been confirmed in foundry trials and show that ENERTEK crucibles offer significant savings and reductions in CO_2 emissions compared to conventional crucibles.

The technology of batch degassing for hydrogen removal from aluminium melts utilising different rotor designs



Introduction

Rotary degassing of liquid aluminium alloys is a widely used commercial process to control levels of hydrogen, alkali metals and inclusions in the melt prior to casting. A comprehensive theoretical understanding of the kinetics of aluminium degassing has been established in the past twenty years. Whilst there have been some published experimental tests of degassing theory in molten aluminium, in many cases key pieces of information are not reported or determined, such that a critical assessment of the underlying theory is compromised. Similarly, practical implementation of such understanding in usable shop-floor process models has met with difficulties owing to lack of knowledge concerning some key parameters. These include the stirring intensity dissipated in the melt, and its relationship to the average gas bubble size, and the mass transfer coefficient at the free surface of the melt.

A selection of different Foseco degassing rotors have been characterised in a comprehensive experimental program. The study resulted in an Internet based simulation software for the degassing processes in foundries; the elements of this simulation are presented in this paper.

Gas porosity and inclusions

The key attribute for early aluminium applications was primarily aesthetic, as surface porosity was unacceptable for ornamental applications. The development of the electrolytic production route and dramatic cost reductions led to an increasing range of engineering applications. Slowly, an empirical understanding emerged that certain practices applied to molten alloys could harm performances. Slow cooling of large castings could also be detrimental, or different alloys varied in their ability to fill the mould.

In foundries today we recognise two major issues of molten metal quality; gas content and inclusions. The presence of porosity became even more problematic when age hardening alloys were developed, because near surface porosity invariably blistered on the surface. Additionally, a significant loss of mechanical properties, such as tensile strength was found with increasing porosity levels.

Figure 1. Surface porosity visible on a casting

Figure 2. Internal porosity visible on a machined face

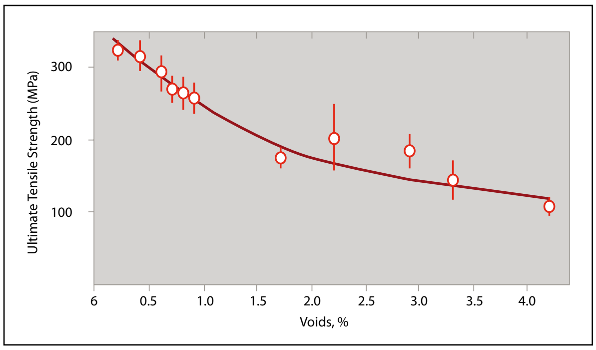


Figure 3. Tensile strength vs. porosity level [1]

Hydrogen solubility and influencing parameters

The aluminium melt is always in interaction with the atmosphere, to a point where an equilibrium is formed between gaseous hydrogen in the air and hydrogen dissolved in molten aluminium. But the partial pressure (i.e. amount) of hydrogen in the atmosphere is almost irrelevant. Therefore, the hydrogen comes from the water vapour in the atmosphere, which readily reacts with liquid aluminium to produce two problematic reaction products, i.e. alumina (inclusions) and hydrogen (gas).

$2\ Al_{(l)} + 3\ H_2O_{(gas)} = Al_2O_{3\ (s)} + 3\ H_{2\ (gas)}$.

Aluminium has problems with hydrogen, not because it is particularly soluble in liquid aluminium, but because it is particularly insoluble in solid aluminium and so it comes out of solution during solidification. Solubility mainly depends on the temperature of the aluminium:

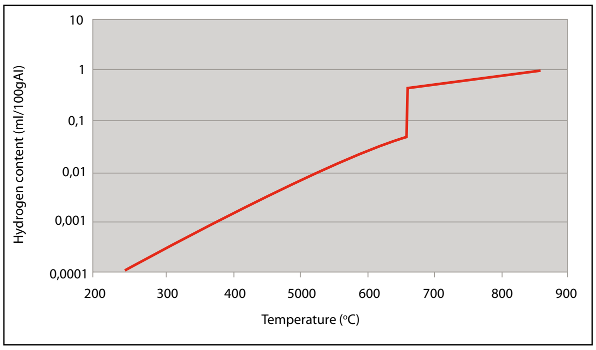


Figure 4. Hydrogen solubility in aluminium [2]

The simple solubility equations for hydrogen in liquid aluminium need to be adapted for the alloy composition. Magnesium increases the hydrogen equilibrium solubility in liquid aluminium, whilst copper, silicon and zinc reduce the solubility levels. Modification elements such as sodium, strontium or titanium boride, at conventional addition rates, do not measurably change the hydrogen solubility. Effects that are reported relating to these elements are caused by other mechanisms; i.e. change of oxide layer thickness and surface strength, or changes in fluidity and feeding properties.

As stated before, the water vapour in air is in interaction with the melt. So the equilibrium level of hydrogen dissolved in molten aluminium should vary significantly with both ambient temperature and humidity. However, the use of gas fired burners in furnaces generates a local atmosphere which can have much higher water vapour pressures.

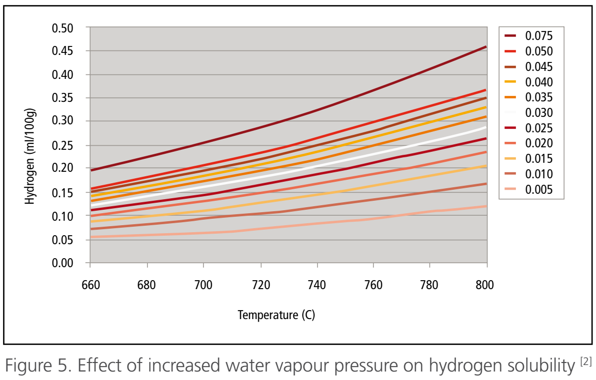


Figure 5. Effect of increased water vapour pressure on hydrogen solubility [2]

Theory and principals of hydrogen removal

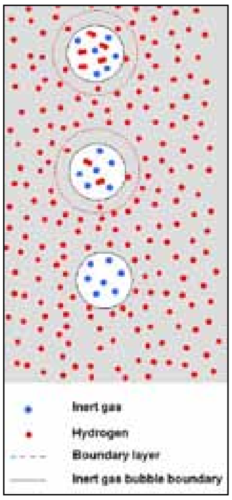


Figure 6. Schematic hydrogen removal

Hydrogen needs to be removed from the melt prior to casting with inert gases, such as argon or nitrogen being used to purge the melt. The understanding of the hydrogen removal mechanism is essential to define and influence factors for the best removal practice.

Atomic hydrogen H is dissolved in liquid aluminium and homogenously distributed. Dry inert gas bubbles are introduced into the melt with a hydrogen partial pressure inside of almost zero. Then a local equilibrium is rapidly established between H concentration in the molten boundary layer and the partial pressure of H_2 in the inert gas bubble. The diffusion of hydrogen from the bulk into the boundary layer is rate limited, whilst the recombination of atomic to molecular hydrogen is very rapid. The hydrogen concentration in the bubble increases as it rises to the melt surface.

The rate of hydrogen transfer depends on both diffusion and the total area of bubble interface. A given inert gas flow rate will have a greater interface area for smaller bubbles. Additionally, each bubble stays longer in the melt as the bubble gets smaller, since the terminal velocity is reduced and allows longer time for hydrogen transport. A deeper reaction zone in a ladle or crucible allows more time for equilibrium because the bubble stays in the melt longer before reaching the surface.

Therefore, the design for a practical degasser needs to create the smallest bubbles low down in the treatment vessel. This is achieved at a high rotor velocity; also mixing the melt at the same time to get a homogenous hydrogen distribution.

Lance treatment was the beginning of industrial degassing, but lances tend to produce rather coarse bubbles between 10 and 50 mm in diameter with a wide bubble size distribution and offered limited melt homogenising. Porous blocks, either attached to the lance outlet or to the bottom of the furnace, create typically finer bubbles of 10 to 20 mm in diameter; but even with them, the homogenising and bubble distribution is not optimal. Eventually, the development of spinning injection systems with rotors attached solved the problem of insufficient gas distribution and delivered bubble sizes in the range of 3 to 10 mm in diameter.

Characterisation of rotor designs

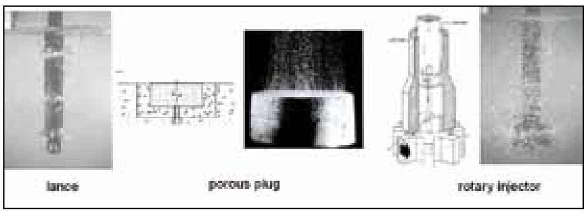


Figure 7. Comparison of inert gas bubble size generated by different systems [3]

Power analysis of degasser rotors

All trials have been carried out in a perspex tank filled with water. A series of rotor designs were selected for these trials, summarised in figure 8, and tested at different diameters. This paper discusses trials with one baffle plate in place and a constant inert gas flow of 10 l/min.

In order to measure the power dissipated in the liquid, the torque in the rotor shaft was measured; it is not possible simply to measure the power drawn by the motor, owing to losses within the transmission system and bearings. This was achieved by coupling a torque sensor DRFL-II-30 from ETH Messtechnik GmbH in series between the motor drive and the graphite shaft and rotor. A read out unit type Value View 291-1 showed the effective torque; the stable reading at different rotor speeds was noted. It is apparent that torques at very high rotational speeds seemed to deviate from the trend at lower speeds; this is indicative that the significant aeration is starting from the free surface.


FDU* SPR


FDU XSR


MTS FDR


Star


Diamond


GBF XHT

Figure 8. Rotors in trial

The torque data as measured was converted into power being delivered into the tank.

Power = 2π r T (T = torque)

The data is well described with a cubic dependency of rotor power on rational speed.

Power = k r^3 (k = trial constant)

Utilising the power, all Foseco rotors can be compared directly with each other. The recently developed FDR and XSR rotors generate higher power than the traditional rotors. Therefore, these rotors create finer bubbles. The GBF XHT, predominantly used in the Asian foundry market, performs similarly to the best-in-class European designs.

Mixing capabilities of degasser rotors

A well designed degassing system will have two key attributes. Firstly, the melt will be rapidly mixed to achieve and maintain chemical and thermal homogeneity throughout the process. It is important that the time required to achieve good mixing is substantially less than the metal treatment time. Secondly, the turbulence generated by the rotor will result in small average size of inert gas bubbles, which the well mixed flow patterns will ensure are well distributed throughout the melt.

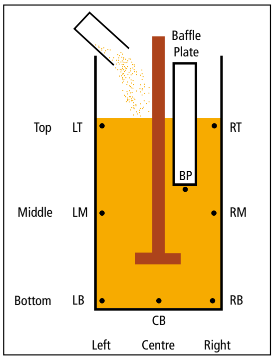


Figure 9. Locations of thermocouples in mixing tank

A further series of experiments have been undertaken to determine the mixing characteristics of each rotor under a range of operating conditions.

The same series of rotors were selected for these trials as shown in figure 8, and tested at different diameters. The trials were conducted with one baffle plate in place, a constant inert gas flow of 10 l/min and 200, 300 and 400rpm for each rotor.

Eight thermocouples type T were located in the tank at the locations indicated in figure 9. For each experiment approximately 7000g of hot water at around 80°C was added to the tank, once steady mixing conditions were established. The temperatures were logged at 100 ms intervals using an 8 channel USB TC-08 Data Logger from Pico Technology.

All plotted data was normalised and a "mixing time" had been defined. Figure 10 shows the results for different 190mm diameter rotor designs at various speeds.

At lower speeds of around 200 rpm, the FDR rotor needs about 40 seconds for effective mixing whilst other types need up to 3 times more. With increasing speed the differences between the rotor types becomes smaller. These observations are almost inline with experiences from foundry trials; FDR rotors start at a lower speed and have a good degassing performance.

The FDR rotor is seen to perform well across the board at all diameters. It generally had a significantly shorter mixing time than the XSR rotor of equivalent diameter, primarily because the FDR rotor delivers more power into the liquid at a given speed.

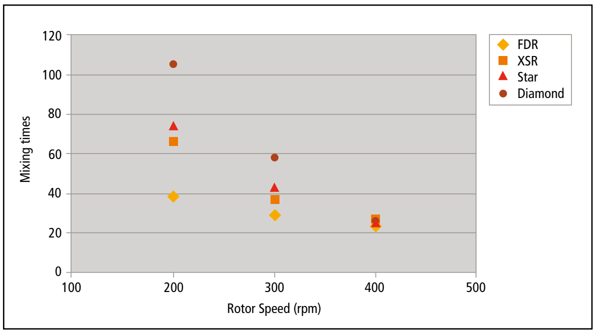


Figure 10. Mixing time comparison for 190 mm rotors

Batch degassing software

Foseco's non-ferrous Marketing and Technology team have worked with Technology Strategy Consultants to develop a web-based batch-degassing model. It has been designed as a tool to quickly analyse foundries' operations, and make suggestions for their improvement.

The mathematical model behind this software is based on the best available published information, concerning the kinetics of hydrogen degassing (e.g. hydrogen solubility, diffusivity, mass transfer rates and stable bubble sizes). An extensive program, which is discussed in this article earlier, was undertaken to provide specific information about individual rotors.

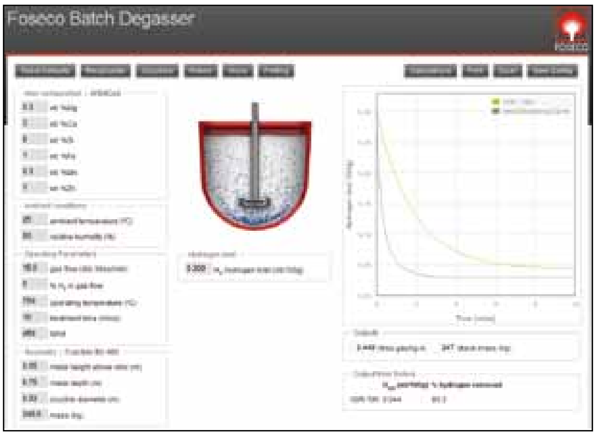


Figure 11. Screenshot of batch degassing software

The starting screen provides sub-menus for input of

- alloy composition
- ambient conditions
- operating parameters
- geometry of the treatment vessels
- hydrogen initial level

The operator can choose alloy compositions and crucible or ladle geometries from a list or input own values. Ambient conditions and operating parameters are foundry specific values, which are known or needed to optimise the degassing process. The initial hydrogen level is often unknown, but 0,3ml/100gAl is a common value and changes in this influence the curves insignificantly.

The rotor menu includes different types of rotors at various diameters. By clicking one or more rotors the degassing curves are drawn in a diagram showing hydrogen level vs. time. The model calculates the degassing performance for each chosen rotor in percentage of hydrogen removed and the average treatment gas consumption.

The input screen offers the option to use a treatment gas containing hydrogen. So there is a way to simulate upgassing processes as well.

A plotting menu enables the user to put in hydrogen levels measured with ALSPEK H electrochemical hydrogen sensor; this data can then be plotted in the diagram to compare predicted degassing curves with real foundry trial results.

Each calculation can be printed and saved for further simulations later.

The following diagrams are created with the batch degasser software version 2.1 and show different influences on degassing efficiency:

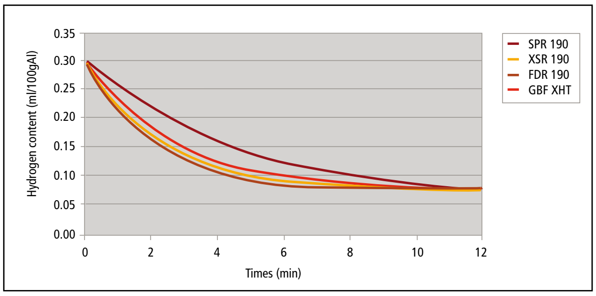


Figure 12. Influence of different rotor designs on degassing efficiency

Simulation variables:

Crucible type: BU 600 with 600 kg of melt
Alloy type: AlSi7Mg
Inert gas flow rate: 20 l/min
Rotor speed: 450 rpm
Rotor design: variable
Rotor diameter: 190 mm

From the parameters defined above the following conclusions can be made:

- initially the FDR rotor degasses more quickly and reached the desired hydrogen level faster
- the XSR and GBF XHT rotors, although quite efficient, reach the desired hydrogen level slightly later
- the traditional SPR rotor takes considerably longer to achieve the specified level on hydrogen

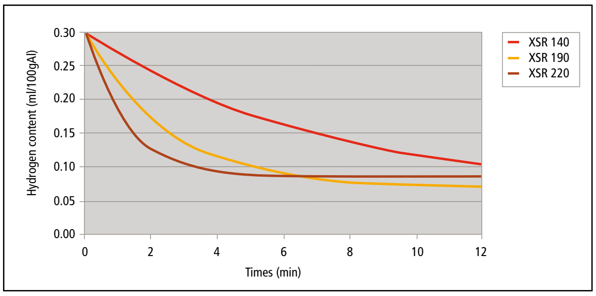


Figure 13. Influence of different rotor diameters on degassing efficiency

Simulation variables:

Crucible type: BU 600 with 600 kg of melt
Alloy type: AlSi7Mg
Inert gas flow rate: 20 l/min
Rotor speed: 450 rpm
Rotor design: XSR
Rotor diameter: variable

From the parameters defined above the following conclusions can be made:

- the larger the diameter, the greater the power generated and the finer the bubbles
- the largest rotor creates considerable turbulence, which increases the regassing when hydrogen level becomes low

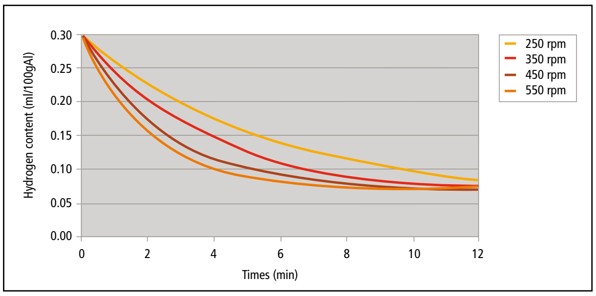


Figure 14. Influence of different rotation speeds on degassing efficiency

Simulation variables:

Crucible type: BU 600 with 600 kg of melt
Alloy type: AlSi7Mg
Inert gas flow rate: 20 l/min
Rotor speed: variable
Rotor design: XSR
Rotor diameter: 190mm

From the parameters defined above the following conclusions can be made:

- by increasing the rotor speed, the power is increased and degassing performance improved
- for every rotor and treatment vessel combination there is a speed above which further increases will not improve degassing efficiency

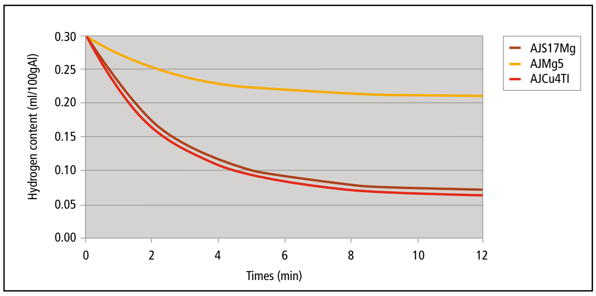


Figure 15. Influence of different alloy compositions on degassing efficiency

Simulation variables:

Crucible type: BU 600 with 600 kg of melt
Alloy type: variable
Inert gas flow rate: 20 l/min
Rotor speed: 450 rpm
Rotor design: XSR
Rotor diameter: 190mm

From the parameters defined above the following conclusions can be made:

- the presence of certain alloying elements increases or decreases the solubility of hydrogen
- magnesium in aluminium alloys has a major deleterious effect on degassing ability

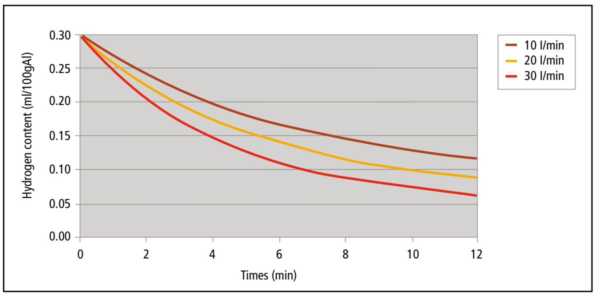


Figure 16. Influence of inert gas flow rate on degassing efficiency

Simulation variables:

Crucible type: BU 600 with 600 kg of melt
Alloy type: AlSi7Mg
Inert gas flow rate: variable
Rotor speed: 450 rpm
Rotor design: XSR
Rotor diameter: 190mm

From the parameters defined above the following conclusions can be made:

- the greater the volume of inert gas introduced into the melt the higher the degassing efficiency
- for every rotor and treatment vessel combination there is a flow rate above which further increase will not improve degassing efficiency

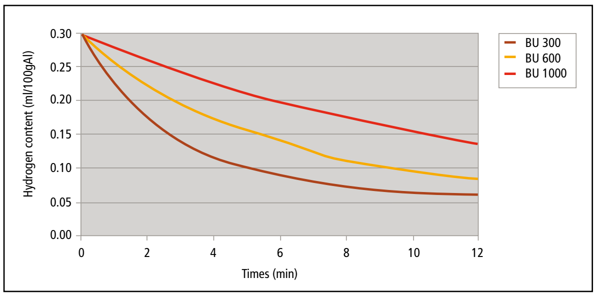


Figure 17. Influence of crucible size and melt amount on degassing efficiency

Simulation variables:

Crucible type: variable
Alloy type: AlSi7Mg
Inert gas flow rate: 20 l/min
Rotor speed: 450 rpm
Rotor design: XSR
Rotor diameter: 190mm

From the parameters defined above the following conclusions can be made:

- for a fixed flow rate, rotor speed and diameter, larger treatment vessels require longer degassing times
- for larger treatment vessels Foseco recommend the use of bigger diameter rotors and higher gas flow rates

Conclusion and outlook

The research work undertaken is proving to be an important contributor to the understanding of hydrogen control in aluminium melts and this will improve the ability to optimise this important part of metal treatment practice.

Foseco is finding the predictions of the degassing model to reflect the reality in production foundries. The degassing model is proving to be an effective tool for analysing and optimising the degassing process.

Each particular metal treatment station requires a particular set of parameters – rotor design, diameter and rotor speed.

The model enables foundries to better understand the degassing process. They can easily compare different strategies:

- shortest degassing time
- increase consumables life
- avoidance of overgassing

By developing the scientific tests described earlier, Foseco has developed more efficient rotor designs which will achieve improved performance for the FDU and MTS degassing machines.

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JG Kaufman and EL Rooy (2005)

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[3] The treatment of Liquid Aluminium Silicon Alloys;
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COMMENT
Editorial policy is to highlight the latest Foseco products and technical developments.
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