Light Metals 2013

CAST SHOP FOR ALUMINUM PRODUCTION

Aluminum Cast Shop II

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Ultrasonic Degassing and Processing of Aluminum

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Abstract

A commercially and industrially viable ultrasonic system has been developed. This system is being used in an industrial environment. The aim of this paper is to present the experimental method used and results obtained from two different processes. The system was tested on a continuous rod, casting and rolling line. This line is used to make wire rod in pure and alloyed aluminum. The system was also tested in a large scale die casting shop. Each process had its own challenges in how to measure the degassing ability of the system, along with product improvements not related to hydrogen gas. We will present various methods used to measure the dissolved hydrogen and the resulting product improvements after ultrasonic degassing. Additionally we will discuss sampling methods for spectrum analysis and inclusion measurement. Sources of contamination will also be discussed.

Introduction

The development of any new process requires extensive testing and evaluation of the final product before it is considered viable for customers. A novel ultrasonic degassing system has been developed for use in molten aluminum on a continuous basis. To qualify this system for use on well-established production lines required extensive analysis of the material in the liquid and solid phases, as well as the full metallurgical analysis of finished product.

The ultrasonic degassing system consists of electrical controls, ultrasonics power supply and, custom designed transducer and ultrasonic stack. The system is lowered into an aluminum melt and is allowed to process the aluminum continuously. Previous work in this area has been confined to laboratory models and small scale proof of concept designs. What sets this apart is its ability to operate continuously in a harsh molten metal production environment.

Two production environments will be discussed. The first environment was a continuous wire rod plant using the Southwire wheel and belt casting system. The second was a large scale die-casting plant using individual electric melting furnaces at each casting machine.

Measurement and Analysis Methods

Hydrogen Measurement

Measuring dissolved hydrogen in molten aluminum is relatively simple. Using the concept of partial pressures the concentration of hydrogen in the molten can be determined. Two systems were used while qualifying the ultrasonic degassing system. The challenge was to determine which method would yield results we could use during the process development.

The first system is the Alscan system by ABB. This system uses a porous refractory block to absorb the hydrogen from the melt. This block has a purge gas flowing through it and the gas transports the absorbed hydrogen to the analyzer where the hydrogen concentration is determined. Each measurement takes about 10 minutes and is displayed in PPM. This system relies heavily on the purge gas being of the highest purity and the porous ceramic being in good condition. Figure 1 is a photograph of the Alscan at work in a launder.

Figure1. Alscan testing H_2 levels

The second method to determine the hydrogen concentration is to use the concept of a partial electrochemical cell and determine the voltage potential across this cell. A solid electrolyte sensor contains a reference material of known hydrogen concentration. This sensor is placed into the melt and hydrogen ions pass into or out of the sensor. The resulting voltage potential is sent to the instrument for conversion to hydrogen concentration. The instrument reads out in ml H_2 per 100g aluminum or mL/100g. This unit will be used throughout this paper.

The instrument used for this process was an Alspek H by Foseco. It also relies heavily on the sensor being in good condition. Additionally the user must pay special attention to the amount of time the sensor has been in use. After some time in the melt the sensor is saturated (or depleted) of hydrogen and must be replaced. The instrument has facilities for alerting the user to the need for a sensor change. Figure 2 shows the Alspek H unit in a launder.

Figure 2. Alspek H unit working in a launder

Both methods are dependent on the alloy mix being tested. Correction factors based on laboratory data are used to make sure that the instrument is reporting correctly. The most aggressive factor in this correction is the magnesium level in the alloy. In the continuous casting system a high magnesium alloy was produced.

Spectrum Analysis

During all of the testing, samples were taken at pre-set intervals. The samples were cast using an industry standard puck mold designed for spectrum analyzers.

All of the samples were tested at Southwire Company's metal lab at the aluminum rod plant.

The spectrum analyzers are Bruker Q8 Magellan models. For the die casting alloy the machines were calibrated using Alcoa SS-380 DD standard. For the 5000 series alloys used at the continuous casting plant, the spectrum analyzers were calibrated using the respective Alcoa 5xxx alloy standard.

Metallurgical Analysis

During all of the trials, selected samples were prepared for metallurgical analysis. Standard procedures were used to prepare the samples. In as-cast parts from the die-casting plant the aim was to look for macro and micro porosity. The continuous casting and rolling plant looked for porosity in the cast bar and a standard microstructure in the rolled rod.

When looking for porosity special attention was paid to the shape of the porosity. Round, spherical pores indicate gas porosity while odd shaped pores are due to shrinkage. Since the aim of the ultrasonic degassing system is to remove the dissolved gasses in the aluminum, reduction of spherical porosity was the goal.

Final Part / Material Evaluation

For the final evaluation of the produced parts and wire rod the respective plant's normal QC procedures were followed and in certain cases expanded upon.

For the continuous cast and rolled rod the standard tests are a tensile test for strength and a twist test for surface flaws. In addition to these two tests an eddy current analyzer is employed before the rod is coiled.

The tensile test delivers a max stress value along with the percent elongation. These figures will indicate whether the rod produced is suitable for its end use. Different wire rod customers require different tensile strengths.

To perform the twist test an operator inserts a sample of rod into a stationary chuck and the other end is connected to a rotating chuck. The rod is twisted 10 times in one direction, the motor reverses and then 10 rotations in the other direction. Using a 10x magnifying glass the operator looks for defects in the rod surface that the twisting will reveal. Typically the defects revealed in a twist test are from either casting problems or problems in the rolling mill.

The eddy current test continuously counts surface flaws in the as rolled rod. Depending on the size of the flaw it will increment small, medium or large counters. Small flaws usually fall within the noise range of the instrument. Medium and large flaws will indicate a problem in casting or in the rolling mill.

In the die casting plant most of the QC checks are visual. A selection of cast parts are sent to the machine shop and machined to the customer's specifications. These are then visually inspected for porosity. All of the produced parts are inspected for surface defects by the machine operator. On critical parts a second visual inspection is carried out by trained personnel to verify that no surface porosity exists.

Expanding on the above testing, ***all*** of the parts produced with ultrasonic degassing were machined to the customer's specifications and visually inspected for porosity. Additionally micrograph analysis was performed to observe any microstructure changes as the degassing system operated.

Continuous Casting System Results

Hydrogen Measurement

In a continuous casting setup the location of the degassing step should be chosen very carefully. As the molten metal leaves the holding furnace and travels down the launder system the metal will lose superheat. As it cools off it will naturally evolve hydrogen to the atmosphere. This fact is well known in the literature and is shown in Figure 3 as hydrogen's maximum solubility in aluminum versus the temperature of the metal.

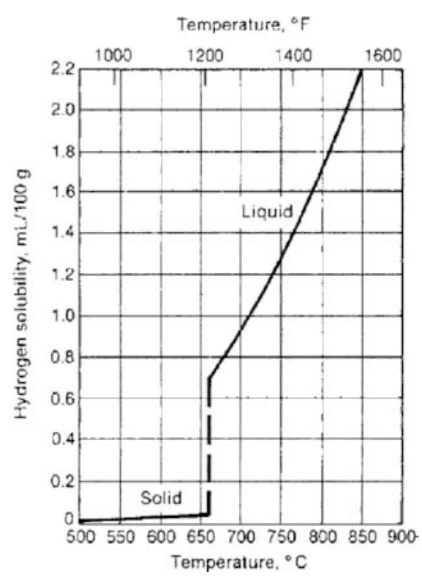

Figure 3. Hydrogen max solubility in aluminum[1]

The ultrasonic degassing system was placed in the launder system in the same location as the traditional rotary degasser. With this choice of location, it is ensured that the comparison results will be valid for the casting line and not be influenced by the location.

If the degassing step is done while the metal is relatively hotter than the desired casting temperature then any hydrogen removed by the degassing step can be reabsorbed by the metal as it is exposed to the atmosphere during the final journey to the casting machine. Figure 4 shows the relationship of hydrogen levels in the launder system as a function of temperature and distance from the holding furnace. It should be noted how the temperature drops during the launder transport and the large drop before and after rotary degassing step.

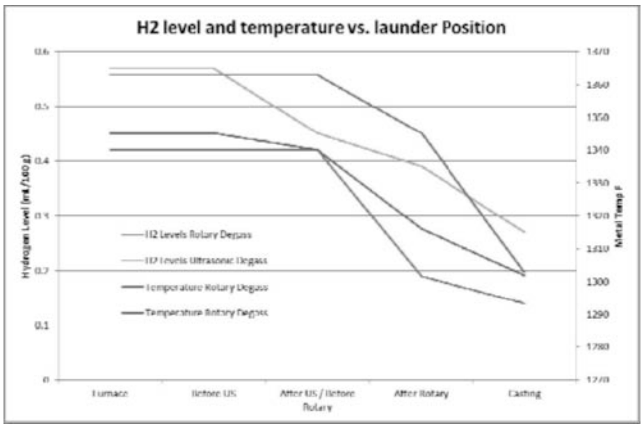

Figure 4. Hydrogen and temperature levels in launder system

The launder system in the above configuration is heated, although it is not automatically controlled. Therefore, the operators will open and close the lids as necessary to obtain the desired casting parameters. During the trials of the new ultrasonic degassing system one of the objectives was to compare the degassing efficiency of the traditional rotary degassing system to that of the ultrasonic system.

To make this comparison, dissolved hydrogen and temperature readings were taken to establish how much hydrogen was being removed due to temperature drop and how much was being actively removed by the degassing step. Figure 5 shows the relationship between temperature drop and the hydrogen removed.

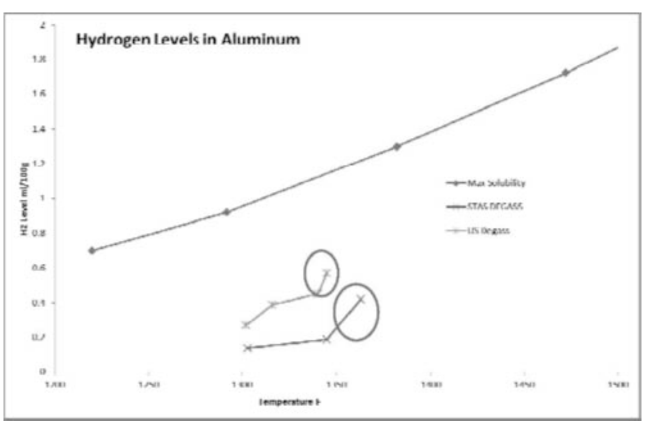

Figure 5. Hydrogen levels in launder WRT temperature, showing effect of active degassing

When the slope of the line in the active degassing step is greater than the slope in the temperature drop only section, then you are creating active degassing in the melt and not hydrogen removal due to the temperature drop. Of special note is the substantial difference in the slope of the ultrasonic degassing step and the rotary degassing step each circled in red in the above figure.

Spectrum Analysis

Spectrum analysis of the molten aluminum was performed at various locations. The most notable locations are before and after the degassing step. The traditional rotary degassing unit uses a mixture of chlorine and argon to remove alkali metals. The ultrasonic system does not use any chlorine.

The objective of the spectrum analysis is to confirm that the ultrasonic degassing system does not alter the chemical make-up of the alloy and to investigate if it is capable of removing unwanted trace elements.

Table 1 shows the concentration of the main constituents of the 5154 magnesium alloy and Table 2 shows the concentration of the trace elements.

5154 Alloy % Wt Max or range							
Main Elements	Si	Fe	Cu	Mn	Cr	Mg	Zn
Standard	**0.25**	**0.4**	**0.1**	**0.1**	**.15-.35**	**3.1-3.9**	**0.2**
Before Degasser	0.033	0.13	0.0009	0.1052	0.0079	3.23	0.0090
After Degasser	0.033	0.14	0.0014	0.1299	0.0077	3.27	0.0126

Table 1. Main element analysis

5154 Alloy % Wt		
Harmful Trace Elements	Na	Li
Before Degasser	0.0018	0.0006
After Degasser	0.0002	0.0003

Table 2. Trace element concentrations

Of special importance to the wire rod product is the Sodium (Na) and the Lithium (Li) levels. If the Na and Li are even slightly high, 5 PPM or higher, it will affect the conductivity, hardness, rollability and drawability of the final product.

Metallurgical Analysis

During the operation of the ultrasonic degasser samples were taken of both the cast bar and the final rolled rod. The cast bar was subjected to sectioning, etching and optical microscopy. Figure 6 and 7 show a micrograph of the polished and etched sections of both rotary degassed and ultrasonic degassed metal.

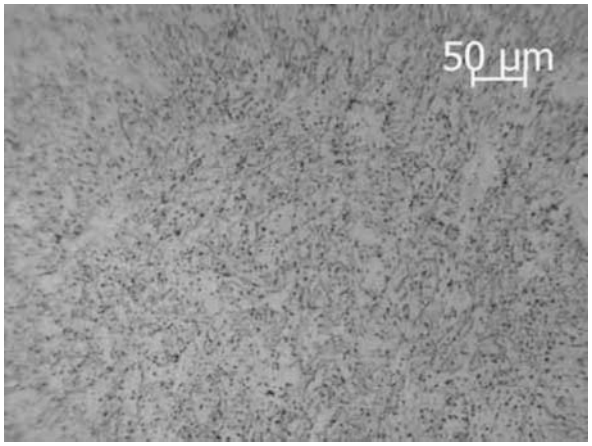

Figure 6. Rotary degassed 5052

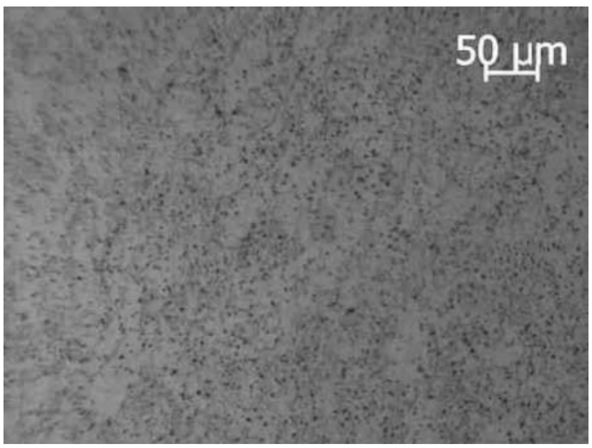

Figure 7. Ultrasonically degassed 5052

In addition to the microstructure evaluation of the cast bar, the same evaluation was carried out on the final rolled rod. In both the cast bar and rolled rod micrographs there were no differences in rotary degassed material and ultrasonically degassed material.

Final Part / Material Evaluation

For final product evaluation the rolled rod is subjected to various tests depending on the particular alloy being made. The 5xxx alloys undergo diameter checking, Eddy Current testing, tensile testing and twist testing while the 13xx and 6xxx series alloys add in electrical conductivity.

Table 3 below summarizes the data for 5xxx alloy rod produced using the ultrasonic degassing process. Standard specifications are provided for reference.

	Surface Flaws				
Coil #	Large	Medium	Small	KSI	Twist
915354	7	4	45	34.4	PASS
915355	3	8	38	34.4	PASS
Standard	< 20	< 50	< 100	35-36	

Table 3. Data excerpt of typical ultrasonically degassed rod coils (Too many produced to report all here)

The final step for rod qualification is customer acceptance. The 5xxx series rod produced using the ultrasonic degassing was used internally by the rod plant to make aluminum strip. The aluminum strip then went to a wire mill where it was used as the exterior cladding for MC cable.

All of the coils produced with the ultrasonic degassing system were accepted by the customer and processed into the final product of MC Cable.

Die Casting System Results

Multiple trials were carried out at a large scale die casting plant using individual electric crucible furnaces. The parts that were the subject of the tests were all porosity sensitive. The parts were two different filter housings and a hydraulic bushing. Figure 8 shows these three parts.

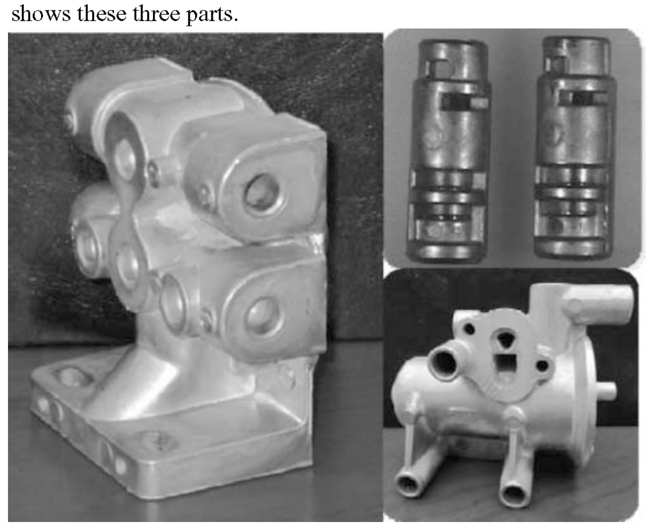
Figure 8. Subject die cast parts

The degassing system was placed into the melt opposite from the ladle, with a ceramic foam filter in between.

Hydrogen Measurement

Compared to the continuous casting system, the die-casting furnace arrangement is less complex to measure the hydrogen due to the homogeneity of the melt. Either method described above could be used, but since the Alspek H unit was readily available it was used for measurement. The hydrogen probe was placed in the furnace opposite the degassing system, but still on the melting side of the filter. The temperature in the furnace remained mostly constant with a recorded temperature change of +/- 15 degrees F. This temperature flux was minimized by feeding the solid ingot into the furnace at a constant rate, rather than in batches.

Figure 9 shows a typical degassing session where the initial high hydrogen was removed and then kept low throughout the casting operation.

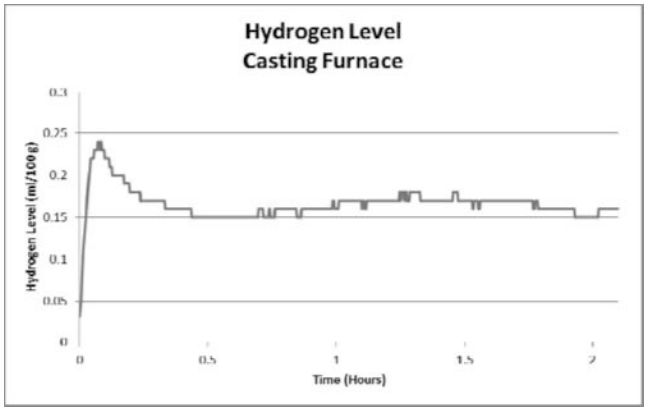

Figure 9. Hydrogen concentration over time in die cast furnace during ultrasonic degassing

During some of the degassing trials the die casting line was shut down overnight and then re-started in the morning. This allowed the furnace to sit and equilibrate the hydrogen in the melt with the atmosphere. Upon re-starting the process the ultrasonic degassing unit and the hydrogen analysis resumed

Spectrum Analysis

Similar to the continuous casting operation, the die casting operation needed to be sure that the alloy composition was not being changed during ultrasonic degassing. During degassing the alloy ingredients did not change as the ultrasonic degassing system was operating.

Also of interest is the trace element analysis. This is purely for double checking the ingot supplier as it is supplied on a certified basis. There were no detectable trace elements in regards to Li and Na, therefore it is not reported.

Metallurgical Analysis

Samples of the castings were taken directly from the production line. At preset intervals the castings were removed, labeled and saved for evaluation. Previous reject castings were also provided by the plant for evaluation and comparison.

A selection of the castings was sectioned and polished. Figure 10 through 12 are photographic results of the die cast parts. Special attention was paid to the shape of the observed porosity as well as the amount of porosity.

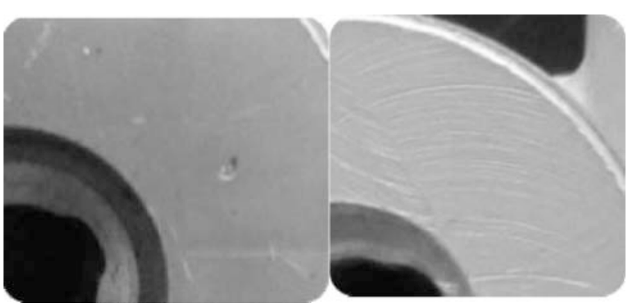

Figure 10. Sealing surface of filter housing before and after ultrasonic degassing

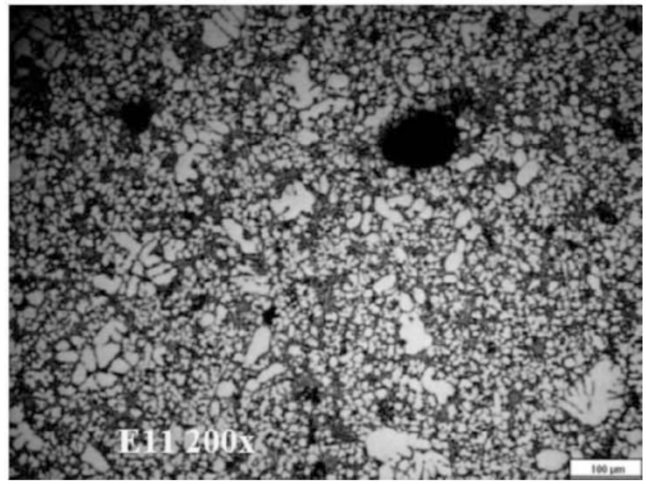

Figure 11. Micrograph of sealing surface w/o degassing

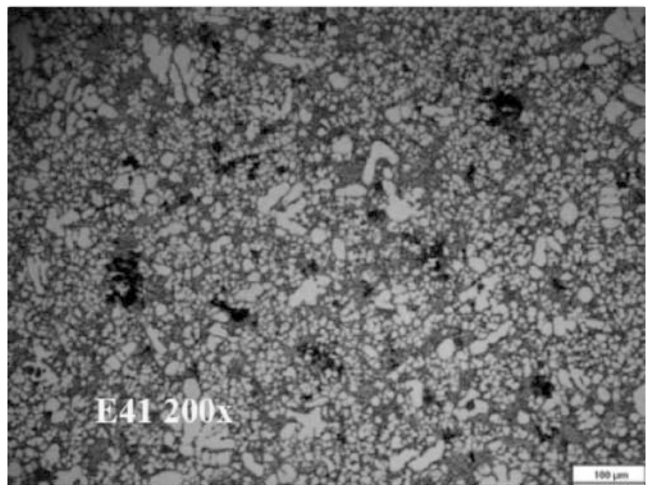

Figure 12. Micrograph of sealing surface after 90 minutes degassing.

As can be seen in the above micrographs, as the degassing system is allowed to run the microstructure is improved through reduced porosity. In addition, any observed porosity becomes non-spherical, suggesting that it is not caused by hydrogen.

Final Part / Material Evaluation

To replicate the standard QC operations at the die casting plant, all of the castings for evaluation were machined according to the final part dimensions. A visual check for macro porosity was carried out using a 10 X magnifying glass. The die casting plant receives customer returns based on visual macro porosity after machining. The only other QC step is a surface quality inspection related to die condition. Figure 13 is a data excerpt showing the number of parts created with visible porosity in each 30 minute period.

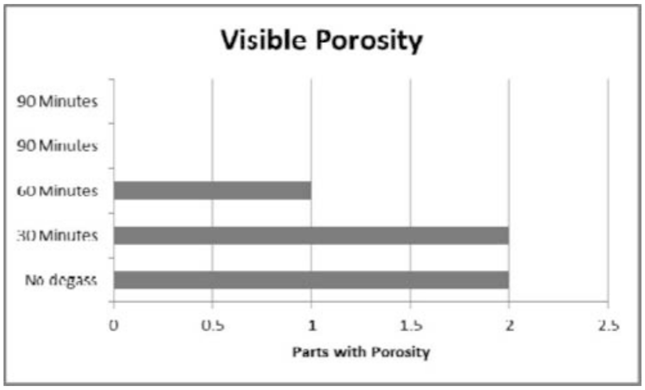

Figure 13. Visible porosity

The final data point for the die-casting trials is customer acceptance of the cast parts. Data provided by the die cast plant stated that there was no customer returns due to porosity for the parts ultrasonically degassed.

Sources of Hydrogen Contamination

Environmental

See Figure 3 above for the maximum solubility of hydrogen in aluminum. This curve will dictate how much hydrogen can be absorbed by the aluminum at a given temperature. The actual amount of hydrogen absorbed will depend on the temperature of the melt and the current environmental conditions. Figure 14 shows the effect of humidity on hydrogen content in the melt.

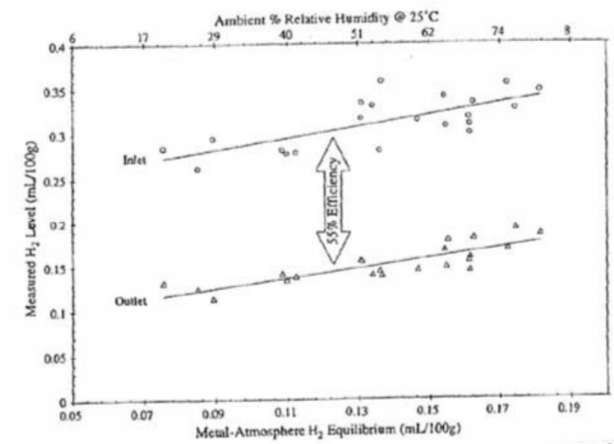

Figure 14. Effect of humidity on a typical rotary degassing unit[2]

From this figure it can be seen that there is a limit to which aluminum can be degassed based on the ambient humidity.

Furnace energy sources

Typically, furnaces use one of two energy sources. Electric furnaces are typically used for smaller applications, while the ubiquitous gas fired reverb furnace is used for larger applications. In an electric furnace there is no external source of hydrogen except for the environment, while the fuel used in a gas furnace is a hydrocarbon.

If the burners on a gas fired furnace are not tuned correctly, either too much air or fuel will enter the reverb chamber. This will result in unnecessary dross in the event of too much air or extra dissolved hydrogen in the event of too much fuel.

In the continuous casting example above there are two holding furnaces feeding the casting operation. It was routinely noted that one of the furnaces exhibited .08 mL/100g to .10 mL/100g of hydrogen higher than its twin counterpart. In a separate investigation it was found that some of the air manifolds were damaged and the burner was not operating correctly. In this furnace there was too much air in the furnace and thus no excess fuel was present. The damaged furnace consistently had lower hydrogen, albeit it also operated at lower efficiencies.

Feedstock

In the large scale continuous casting operation the feedstock was mainly hot metal from a nearby smelter mixed with some internal dry scrap. From this mixture it was not possible to observe the effect of feed material on hydrogen content.

On the other hand, at the die casting facility all of the feed material was ingot from the same supplier. During one of the trials it was observed that every time an ingot was loaded into the furnace the hydrogen level would spike and then return to the steady state level. Figure 15 is a graph of the hydrogen levels versus time for this observation.

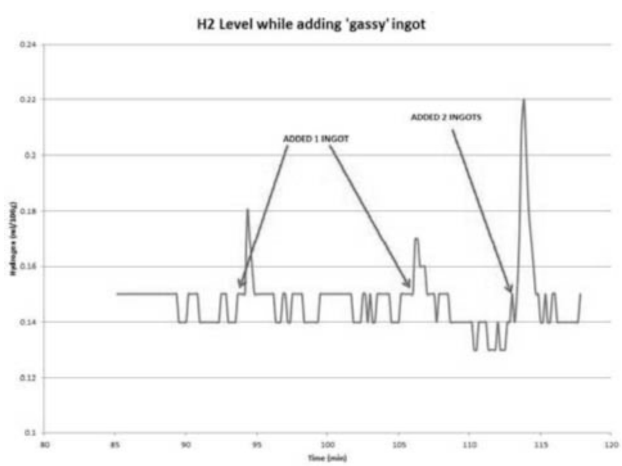

Figure 15. Hydrogen levels while adding ‘gassy’ ingot

A sample of the ingot was sectioned and polished and a large quantity of hydrogen porosity was observed in the ingot. Figure 16 is a photograph of the ‘gassy’ ingot.

Figure 16. Cross section of 'gassy' ingot

A sample of ingot from another day of testing was also sectioned and polished. There were no observations of hydrogen level spiking and very little hydrogen porosity in the related ingot.

Conclusions

In the continuous casting operation it is concluded that the 5xxx alloys can be produced using the ultrasonic degassing system without the use of chlorine. The microstructure of the rotary degassed vs. the ultrasonic degassed is the same. The ultrasonic degassed rod meets all of the same specifications and will be accepted by the customer.

For the die-casting operation, the ultrasonic system provided a continuous assurance that the metal in the furnace had the lowest hydrogen content possible given the environmental conditions. Additionally, it is concluded that the continuous degassing of a die casting furnace is beneficial because of the uncertainty of the feed stock's hydrogen content.

References

1. ASM International, Aluminum Alloy Castings: Properties, Processes, and Applications, Chapter 5, pg. 47

2. Light Metals 1998, TMS, Peter D. Waite, Improved Metallurgical Understanding of the Alcan Compact Degasser After Two Years of Industrial Implementation in Aluminum Casting Plants