Aluminum Degassing Methods & Measurements

To produce quality aluminum castings, metalcasters must remove excessive hydrogen in the molten metal, while conducting tests to be sure they did.

A MODERN CASTING Staff Report

(More here to see the story as it appears in the August issue of MODERN CASTING.)

Molten aluminum is extremely reactive, so when it comes in contact with moist air or wet tools, the water decomposes to release hydrogen in the melt. Excessive quantities of this dissolved gas have a well-documented detrimental effect on the mechanical properties of the final aluminum castings. What is also well known to anyone making castings is that dissolved gas has an overriding effect on the distribution and amount of porosity and shrinkage. Dissolved hydrogen levels must be controlled to minimize scrap. To control gas in aluminum, metalcasters must accomplish two things:

1. Prevent and minimize introduction of hydrogen in the melt.
2. Measure and remove the hydrogen prior to pouring.

This article will focus on measurement and removal.

Gas Removal

The ability to degas molten aluminum is generally accomplished by using a purge gas, typically introduced into the melt by a rotary degassing unit. This degassing process is limited by thermodynamic laws; when purge gas bubbles are introduced to the melt, they collect hydrogen as they float toward the surface. The best possible situation is these hydrogen-saturated bubbles leave the melt and reduce hydrogen levels. In this case, the process efficiency is 100% from the thermodynamic point of view. But as the gas content in the melt drops, so does the equilibrium pressure of hydrogen in the bubbles, so the amount of purge gas required to remove the remaining hydrogen must increase.

The equilibrium gas removal ratio is shown in Fig. 1 for pure aluminum above 1,400°F (760°C). A gas removal ratio of 200, for example, means it will take 200 liters of inert gas to remove one liter of hydrogen. This behavior limits a metalcaster’s ability to degas to a very low level of hydrogen. The solubility also increases exponentially with temperature, meaning an increase of 200°F (111°C) doubles the solubility. All things being equal, a higher temperature of an aluminum melt will increase the necessary degassing time.

Alloying elements also can have an effect on hydrogen solubility. The effect of alloying elements is characterized by changes in the alloy correction factor, with some common casting alloys show in Table 1. Alloys having greater values are more difficult to degas, so, for example, aluminum 535 will take four times longer to degas than pure aluminum. Fortunately, these factors can be controlled and the gas content and process required to eliminate excessive porosity in aluminum castings can be achieved without undue difficulty in most cases.

Practical Degassing Procedures

Degassing is usually accomplished in one of three areas of the metalcasting facility:

1. In the transfer ladle, used to convey metal between melting and holding furnaces.
2. In crucible furnaces, usually just before the molten aluminum is cast.
3. In an in-line system, when the metal is conveyed to holding furnaces through a launderer.

The first two options are most common and the degassing operation for both is typically accomplished using a rotary impeller degasser (RID). In practical terms, all rotary degasers are not created equal. It is important to have an optimum head design to produce highly efficient, small bubbles. Significant cost savings may be
realized from shorter treatment times and reduced gas usage. In the past, the metal-casting industry has gravitated toward simple head designs, which are less costly to machine but produce larger bubbles. This path presents a false economy due to reduced efficiency.

Adjusting Process Parameters

Once the RID unit is fully lowered into the liquid metal with the shaft in place, the degassing operation can begin. The shaft location is slightly off the centerline of the crucible or ladle to help avoid vortex formation with its circular rotation in the liquid metal. An offset distance of 2.4 in. from the centerline is usually sufficient. The use of a baffle plate also is a good idea, because the baffle opposes the circulation movement of metal and reduces vortex formation.

With the RID in the proper location, the unit should be turned on and the shaft speed should be set to 300 RPM. The inert gas flow also should be on and operators should then adjust the gas flow rate and shaft speed. Gas flow should be increased until gas bubbles are visible as they float to the surface of the liquid metal. As the gas flow increases, the size of the bubbles should increase.

The desired result is a good dispersion of small bubbles while maintaining a relatively quiet surface. When an optimum combination of flow rate and shaft rotation speed is found, note the parameters for future use. Also note the total degassing time, which normally falls somewhere between four and eight minutes, unless the temperatures are very high or the amount of gas needed is low.

Gas Measurement

There are two primary methods of gas analysis, sampling techniques and in situ methods. Sampling techniques may be further divided into two classes. In the first, a liquid sample is withdrawn and introduced directly into the measuring instrument before solidification takes place. In the second, a sample of liquid is poured into a specially designed mold and the solid sample is analyzed. The methods of analysis are shown in Table 2.

All three methods of analyzing a liquid sample somewhat depend on the inclusion content of the melt, because these inclusions nucleate gas bubbles. Fig. 2 shows a pore in an A356 casting that has nucleated on oxide films. In spite of this problem, the Reduced Pressure Test (RPT), a procedure of examining a solid sample, is a commonly used and effective tool. The procedure is easily understood and followed. The equipment is simple, rugged and inexpensive and the results usually correlate to casting quality. However, pressure must be controlled during solidification.

Either the solidified RPT test sample is cut and polished to yield a qualitative or semi-quantitative measure of gas content or the sample density is determined by measuring the sample weight when it’s dry and then suspended in water. As long as there is no shrinkage in the sample, measuring the density is the preferred method as it eliminates the subjectivity associated with visual examination of the cut surface.

With in situ techniques, the sampling process causes no errors, so these measurements have the potential to be the most accurate and reliable. The majority of in situ methods feature a system that involves recirculating inert gas introduced into the melt by a sample probe. The inert gas is recirculated through the melt, collected and passed over a differential thermal conductivity sensor to determine the hydrogen content of the gas. This recirculation continues until the hydrogen content reaches a value in equilibrium with the melt.

The new method for measuring hydrogen is promising. The latest version of the electrochemical sensor is nearly equivalent to a thermocouple. This would be the holy grail of gas measurement, allowing us to measure gas like we measure temperature with handheld devices.

Practical Considerations on RPT

At least 90% of aluminum metalcasters in North America use the RPT to determine metal quality. A few practical approaches can improve performance.

The necessary equipment for a vacuum evaluation of an aluminum melt consists of a pump, a gauge to monitor the vacuum level inside the test chamber and a control system to regulate the pressure (Fig. 3). In practice, the molten sample is placed on the pedestal, a chamber with a viewing port is placed over the sample, the chamber is evacuated to the desired pressure, and the sample is allowed to solidify under the reduced pressure. The reduced pressure in the chamber causes dissolved hydrogen to come out of the solution in the melt and either escape from the sample through the molten surface or form bubbles inside the solidifying sample.

It is important that the operator view the sample during solidification to see if bubbles form on the surface. In practice, the reduced pressure test is conducted two ways:

1. Low Gas Contents: Sometimes low gas metal may be required, such as needed for high-end aerospace castings or safety critical components. In these cases, the best procedure is to use a low test pressure (high vacuum) and to count bubbles forming on the surface. When less than two or three bubbles appear on the surface of the casting, gas content is low.

2. Medium to High Gas Contents: Sometimes higher gas levels are beneficial, such as in permanent mold castings, where higher gas level can help avoid shrinkage. In this case, a higher test pressure (lower vacuum) is used so that the gas remains inside the solidifying sample. The test result is usually measured by determining the density or specific gravity of the RPT sample.

http://www.afsinc.org/multimedia/contentMC.cfm?ItemNumber=18281
In either case, it's a good idea to train operators to look at the surface of the samples, both during the test and afterward. Two RPT samples are shown in Fig. 3. The sample on the right is of better metal quality, having fewer oxides and presumably lower gas content.

It's important to choose the correct test pressure for the RPT test. To do this, one needs to know a little more about how pressures are measured and how pressure determines when porosity is found during solidification. Most of the gauges used on RPT testers are differential, measuring the difference in pressure between the vacuum test chamber and ambient air. At sea level, the average atmospheric pressure will support a column of mercury 29.92 in. (760 mm), or 30 in. for simplicity's sake. Most metalcasters will use a gauge pressure of 26-28 in., which is called vacuum level or pressure.

A356 alloy can be chosen as an example to show what happens during solidification. The metal contains a hydrogen gas content of 0.12cc/100g, a fairly low gas content. When a sample of this metal is taken from the crucible and placed in a RPT, the pressure of hydrogen increases because of two factors:

1. The sample cools to a lower temperature.
2. As freezing progresses, hydrogen and silicon segregate and accumulate in the remaining liquid.

The gas pressure continues to grow during solidification until it reaches the equal of the average atmospheric pressure when 70% of the sample had solidified.

For a casting of this metal freezing on your shop floor, porosity cannot form until 70% of the material is frozen solid. However, when a vacuum is applied, the situation is different. First consider the case where a gauge pressure of 28 in. is applied to the solidifying sample. The gauge pressure of 28 in. corresponds to an absolute pressure of 30 Torr. This is slightly below the equilibrium gas pressure in this sample at the start of solidification, so gas bubbles may form on the surface of this sample before it starts to freeze.

Receiving accurate readings from reduced pressure tests is essential to creating quality castings. Here are a few of the many ways of ensuring proper RPT procedures:

- Use a thin-walled cup for sample collection.
- Skim oxides from the melt.
- Surface.
- Preheat the cup in an adjacent surface area.
- Transport sample rapidly to a vacuum unit with proper seals and pump capacity.
- Cover the chamber that allows visual observation.
- Control vacuum to target level.
- Adjust cycle time to allow for full solidification of the sample.
- Measure specific gravity of the sample and compare to process specifications (or count bubbles on the surface).