

Evaluating Molten Metal Cleanliness for Producing High Integrity Aluminum Die Castings



David V. Neff, Manager, Molten Metal Treatment
Metaullics Systems
Solon, Ohio

In the production of high integrity castings by a variety of processes — low pressure, high pressure, squeeze casting, precision sand — today's marketplace demands a high quality standard. It is no longer possible to have the casting process by itself “rescue” the quality of the metal and produce a good casting from less-than-desirable molten metal quality. The pressure die casting process has advantages as well as disadvantages in its ability to produce a high integrity casting. However, molten metal quality is a key factor in the overall process. This means that an aluminum die cast alloy melt must be sufficiently free of inclusions and hydrogen gas — which are the principal impurities — to produce the desired casting and quality required by the customer.

Inclusions in the melt arise from oxidation and dross formation, additives, fluxes, returns, and refractory erosion. In addition, other inclusions can be created by metallurgical reaction within the melt. These include sludge formation, heavy metal segregation, and any metallic contaminants whose concentration is in excess of solubility limits, which then form intermetallic precipitates. Dirty furnace tools can be a source of inclusions, principally oxides, and hydrogen as well, through flux and dross residues and minor amounts of water of hydration or adsorbed moisture. The consequences of such inclusions, not removed, can be significant — depending on their size, concentration, and most importantly, their location within the casting, and how they affect the functionality of the casting.

Hydrogen is the only gaseous species that is soluble in aluminum. Hydrogen can be picked up from humidity in the air, from fossil fuel decomposition, returns bearing lubricant residues, and machined scrap castings. If not controlled sufficiently, high amounts of hydrogen in the liquid state can be retained during solidification, resulting in pore formation. Historically, there was little concern for hydrogen in the melt for the production of pressure die castings. The rapid solidification tended to “freeze-in” the hydrogen in a widely dispersed state and in the final regions of the casting to solidify — often in the interior of “beefy” castings which were not subject to significant engineering stress in that area. However, today's more intricate cast structures, and greater demand on engineering properties has meant that hydrogen content can no longer be ignored. For many castings, especially those that must be pressure tight or are to be heat treated, hydrogen porosity cannot be tolerated. But it must be understood that porosity in high integrity pressure die castings can also result from inadequate venting of entrapped air as the metal solidification front displaces the air ahead of it in the

die cavity. Additionally, lubricant decomposition can also generate porosity formation.

To control impurities — inclusions and hydrogen — a variety of melt treatment techniques are commonly employed. These include fluxing in the melter or re-melt furnace, degassing and flux injection in the furnace or in transfer ladles, and filtration in melters and in holding/casting furnaces. Process development studies generally will define the parameters necessary in the application of these technologies to meet internal standards and/or specific customer quality requirements.

But how is melt quality evaluated, other than being “on composition” — and how is the melt suitable for production of a given casting? Correspondingly, how is it known what “buttons to push” — determining which melt treatment(s) to use and to what extent? Fortunately, there are several readily available melt quality determination technologies, including new ones, which the die caster can employ. Fundamentally, the function of these evaluation techniques is to (1) assess quality of the melt and suitability for casting; (2) determine, monitor, confirm, and verify the capabilities and continuing performance of various melt treatment processes which the die caster or foundry may wish to employ.

However, many of these techniques which are currently available to the die caster at reasonable cost provide evaluation of only a small quantity of metal, and not all will provide real-time results. The true measure of consistent melt quality and successful melt treatment process lies in the consistency of producing acceptable quality castings. Nevertheless, these evaluation techniques still provide a good means of evaluation and control of molten metal quality.

The fundamental features and a sampling of results are now herein described for many of the most popular technologies currently available.

Reduced Pressure Test

Arguably one of the most common, quick, simple, and low cost techniques, the reduced pressure test, is a real-time shop floor test method commonly used in virtually all low pressure, permanent mold, and green sand foundries. This test is becoming more commonly used as a quality tool in die casting foundries today. Shown in figure 1, the test consists of a small sample of aluminum which is harvested from the melt and allowed to solidify under controlled reduced pressure conditions, reaching a specified reduced pressure in a given short time. The resultant determination is usually a calculation of specific gravity or density utilizing Archimedes'

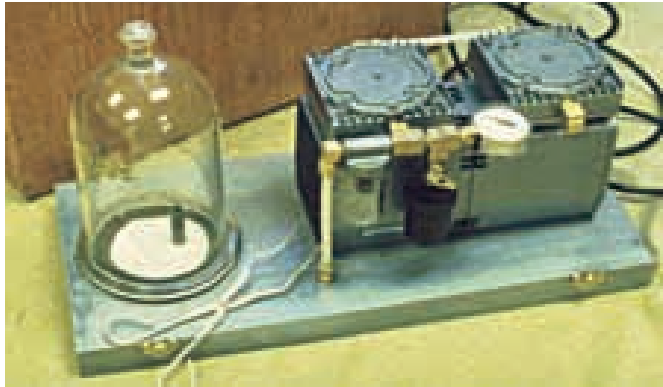


Figure 1: The reduced pressure test apparatus.

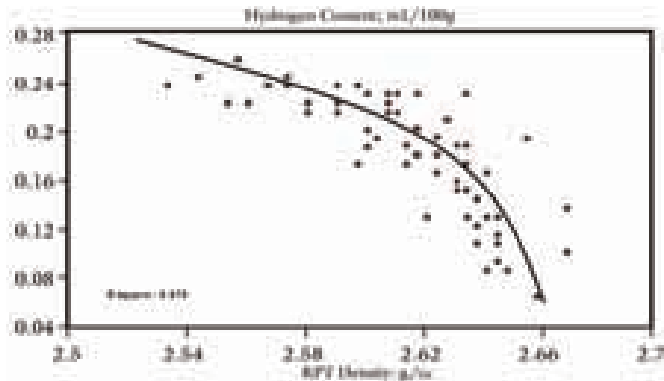


Figure 2: Relationship between reduced pressure test and hydrogen content.^{1,2}

principle and comparing this value with the theoretical value for the alloy in question. Alternatively or additionally, the solidified sample may be sectioned and viewed in comparison with a visual chart which shows different numerically-assigned values based on different amounts of hydrogen-induced porosity resulting from different melt quality levels. The reduced pressure test is quick and many casting customers specify its use as a quality determinant in their casting process purchase specification. However, it must be realized that this is a semi-quantitative test, it is not a true measure of hydrogen content. Inclusions will nucleate pore formation during solidification as hydrogen atoms nucleate as molecules on the internal surfaces represented by inclusions.

Nevertheless, the test is very useful and still allows a correlation to be made between density as measured by reduced pressure test, and actual hydrogen as evaluated by the Alscan technique, whose discussion follows. As shown in figure 2 for unmodified and un-grain refined 356 alloy, a correlation can be determined.^{1,2} Similar correlations can be established for other alloys as well.

Alscan

The Alscan™ (Alcan) and its predecessor, Telegas™ (Alcoa) are two instruments which measure *true* hydrogen content directly, by the principle of closed loop re-circulation. Using an immersion probe containing a small amount of carrier gas (argon or nitrogen), the gas is continuously circulated in a closed loop until equilibrium is reached with the hydrogen gas dissolved in the

melt. The hydrogen concentration in the melt can then be determined as a function of the partial pressure of the hydrogen content in the carrier gas. The results are managed through the electronic circuitry associated with the unit, and a measurement can be made in 15 minutes.

LiMCA

The LiMCA, or Liquid Metal Cleanliness Analyzer, was originally developed (by Alcan) for wrought aluminum cleanliness analysis, but has subsequently been applied in several instances to foundry alloy casting. This is a truly on-line technology, though its cost has limited its usefulness in the foundry industry to mainly process evaluations by large casting concerns. The LiMCA is based on the principle of allowing liquid metal to pass through a small orifice in a tube which measures the voltage potential between two electrodes. When an inclusion enters the orifice, it displaces liquid and creates a rise in electrical resistance. The subsequent voltage change observed can be correlated with the actual inclusion size and concentration. This information can be displayed on a computer screen. The continuous measurement of inclusion size distribution provides a monitoring technique most useful for continuous flow processes. While this technology is predominantly employed in process studies by wrought producers, it is conceivable that greater adaptation will occur in foundry casting in the future.

PodFA and LAIS

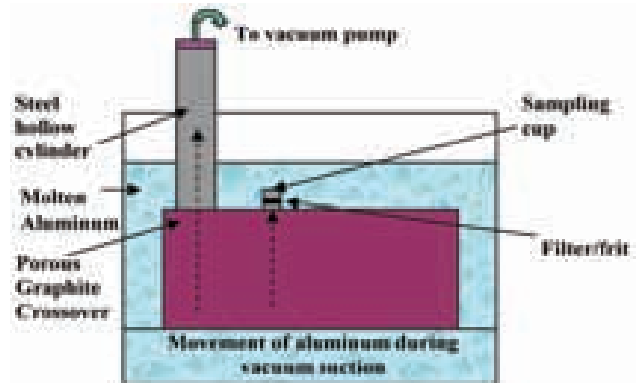


Figure 3a: The LAIS sampling technique.

These techniques are different in their sampling procedure, but both require similar laboratory analysis. Consequently, they are not suitable for online melt quality determinations, but are very useful in establishing process treatment and qualifications. Figure 3a and Figure 3b portray the two techniques, schematic of the LAIS and the apparatus for the PodFA. In the first, the LAIS, or liquid aluminum inclusion sampler, the sampling device is placed directly into the molten metal, which



Figure 3b: PodFA.

is aspirated into a test canister by vacuum. The metal passes through a very fine test filter disc which concentrates inclusions on the surface. The PodFA, or Porous Disc Filtration Apparatus, is an external test which pressurizes liquid metal sampled from the melt through a similar finer filter disc. Both techniques then require metallographic preparation and examination of the inclusion content contained on the surface of the fine filter disc. Results are reported with the evaluation of an experienced technician in terms of areal fraction of the inclusions observed as a function of metal volume passing through the test filter. The standard unit of measure is mm² (area)/kg (volume). Both sampling techniques, however, involve “grab” samples of small melt quantities (only about 1 kg) so care must be taken in proper sampling to be representative of the larger melt.

An example of the usefulness of this technique is shown in figure 4. In figure 4(a), the LAIS method has been employed to evaluate elongation in 319 alloy as a function of several melt treatments.^{2,3} In figure 4(b), a die cast alloy melt has been examined using the PodFA technique before and after flux injection in a transfer ladle, and also after subsequent filtration in a casting/holding furnace.⁴ The validity of both melt processes in improving the melt quality is demonstrated.

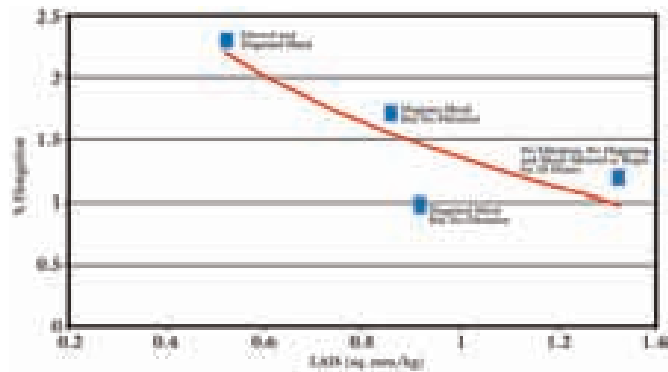


Figure 4a: Evaluating elongation vs. melt treatment condition by LAIS.^{2,3}

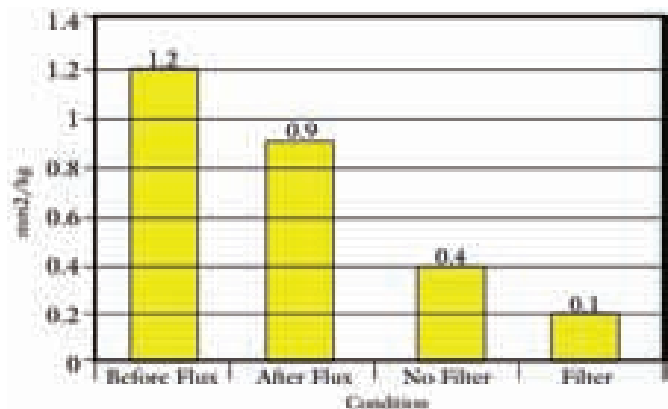


Figure 4b: PodFA results on 380 alloy for flux injection and filtration.

Prefil

The Prefil® Footprinter (N-Tec), figure 5, is a device which provides a real-time indicator of melt quality by measuring the weight of molten aluminum flowing by gravity through a fine test filter as a function of time. This shop floor test can be performed in less than three minutes, and a load cell and electronics weighing the molten aluminum which flows into the collector pan allows online monitoring and quality control. A flow curve is generated which can be compared, i.e. “bench-marked”, against pre-programmed similar curves from a confidential industry-wide database for a given alloy and temperature. Some indication of inclusion types can be garnered from the shape of the curve, but as with the PodFA and LAIS techniques subsequent quantitative inclusion analysis must be determined through metallographic and image analysis techniques on the inclusions concentrated on the test filter disc. Figure 6 portrays a Prefil flow curve with metal evaluated before and after a filter in a die cast holding furnace.⁴ Filtered metal demonstrates a greater volume of metal per unit time flowing through the test system than the unfiltered metal on the inlet side of the filter.



Figure 5: Prefil footprinter.

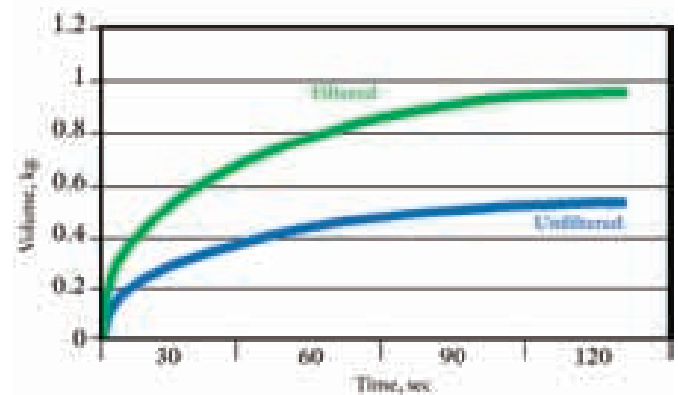


Figure 6: Production result using prefil.⁴

K-Mold

This is a simple shop floor, foundry-friendly test comprising a stepped chill mold with notches to permit easy fracture and examination of the fracture surface. Operators can gain sufficient expertise in just a couple of days experience in looking at the fracture surfaces with the naked eye under good lighting, or with a low power (10X) portable microscope. Only macro inclusions or discontinuities — 60-80 microns or greater, can be discerned easily with this test. Discontinuities on the fracture surface are counted as a function of the

total number of samples investigated — five bars of four fracture surfaces each. An “index” can be determined as the total number of discontinuities (inclusions or pores) observed, or the number of discrepant samples divided by 20. The index number can then be compared to any standard, previously established, which governs the suitability of the metal for making a particular casting. As usual, the technique can be used to establish specific process parameters and any melt treatment necessary. Figure 7 displays several days average results for unfiltered versus filtered metal as one example.⁴

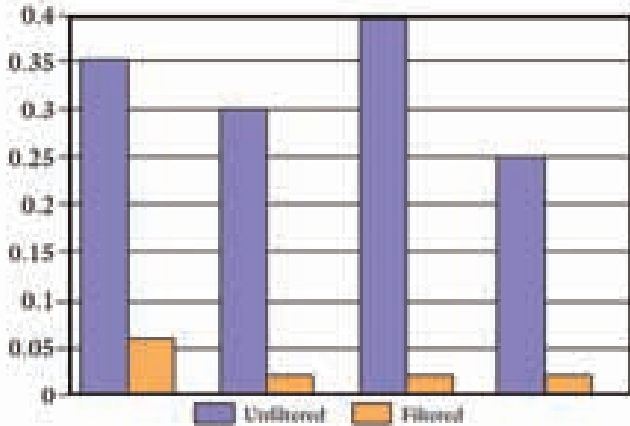


Figure 7: K-Mold results production foundry.

Metal Vision

The Metal Vision system employs ultrasonic technology to detect and measure the size and quantity of inclusions within a melt. While ultrasonic evaluations are routinely employed as quality determinators on solid castings in many instances, this technology has only recently been applied to liquid metal. Based on adaptation of sonar technology which dates back more than 50 years, this technique uses ultrasonic attenuation and reflection of a signal which can be correlated with the particle size distribution and concentration of inclusions within the melt. The system consists of a set of special guide steel rods which introduce high frequency sound waves into the molten aluminum and receive the response signals. The electronic package creates a continuous read-out of the result, enabling the foundry to monitor inclusion level as a function of time, charging condition, or other circumstance. As with the other evaluation techniques, it is possible to assess and/or monitor the progress of a specific melt treatment, as illustrated in figure 8. This chart shows the substantial improvement in reduction of inclusion particles within the melt as rotary degassing is employed in a crucible furnace.⁵ The degassing process though primarily intended for degassing, has also reduced the inclusion level as the gas bubbles evolved during the degas process also provide some degree of inclusion flotation, thus improving the melt cleanliness. The Metal Vision System continues to undergo development and may offer the die casting foundry a very valuable tool.

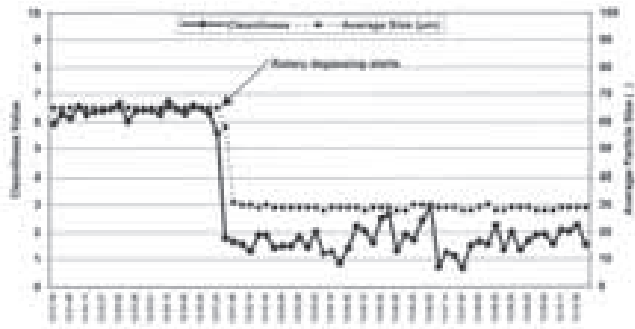


Figure 8: Utilization of metal vision ultrasonic testing to evaluate melt cleanliness.

Metal Health System

The Metal Health[®] System (N-Tec) is comprised of a heated, portable trolley and a series of molds. The unit is depicted in figure 9a. The principal benefit of this testing system, which encompasses several evaluation techniques in a modular package, is to evaluate initial



Figure 9a: Metal Health system.

melt quality and resultant melt treatment parameters in process development and readiness of the melt for casting. Coupled with other technologies such as Prefil or PodFA, the Metal Health System allows diagnosis, spot checking and verification of melt and process for casting suitability.

The several molds, portrayed in figure 9b, include a fluidity finger tree, a “dog-bone” hot tearing mold, a multi-cavity tensile bar mold, the Tatur shrinkage and porosity mold, and a coarse-inclusion mold (i.e. the “K-mold”). The sampling techniques to utilize each mold are fairly straightforward and do not require great sophistication or time on the foundry floor. Evaluation of the results can be made in the die caster’s own



Figure 9b: Metal Health System mold modules.

laboratory. While all test mold modules have application to several casting processes, the fluidity mold may be the most useful for die casters.

Metal fluidity is an important factor in die fill of thin sections, and fluidity in this test is very dependent on melt cleanliness — inclusion as well as hydrogen content. In the fluidity mold, a precise amount of metal is poured at a controlled temperature, into a heated mold. The liquid metal travels through five channels of equal length but varying depth. The distance the melt travels is then measured versus the total length available through the five channels, generating a “fluidity index” numerical result. Because the liquid metal is maintained at a fixed temperature in the heated mold, no solidification is involved, and the only impediment to metal flow is inclusion content and the basic viscosity of the alloy composition being tested. This test thus provides good sensitivity of the melt to specific alloy composition, as well as to cleanliness variations. Figure 10 demonstrates the quantitative capability of this test, generating a fluidity characteristic profile, length of finger the liquid metal travels, for the melt condition under evaluation. Comparisons can be made, of course, with a foundry’s existing database for a given alloy, comparisons between several melt treatments, or with general industry benchmarking ranges available through a separate package.

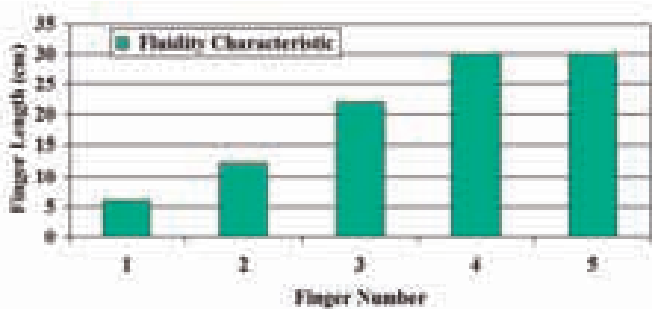


Figure 10: Schematic, melt fluidity using MHS fluidity mold.

Qualiflash

Another fluidity test that has been used by some metalcasters is the Qualiflash. In this technique, a standard volume of metal at a given temperature is permitted to pass through a relatively coarse cellular ceramic filter into a stepped pan below. The more fluid the metal, the greater number of “steps”, 1 through 8, that the metal will occupy, hence generating a Quali-flash fluidity number. Again, distinctions can be made between “cleaner” metal versus “dirtier metal” and process treatment conditions and casting suitability can thus be established relative to specific quality requirement needs.

Other Melt Evaluation Techniques

For the sake of completeness, it should be noted that traditional pressure die castings generally have not required either silicon phase modification or grain refining in the melt stage. The rapid solidification occurring with pressure die casting provides a sufficiently fine alloy microstructure otherwise, although

modification has been shown to enhance die casting nevertheless. However, low pressure, squeeze cast, permanent mold, and precision sand casting processes do require these technologies, especially when producing high integrity castings. Standard grain refining and thermal analysis tests are readily available on a real-time basis to provide predictability of the effectiveness of grain refiner and modifying agent additions.


Summary

A high degree of molten metal cleanliness is paramount in order for the caster to produce high integrity die castings which must meet significant engineering requirements. Not only automotive die castings, but computer and electronic, aerospace, and even today’s consumer castings have exacting quality standards which must be met. Evaluating molten metal cleanliness is a necessary prerequisite to be able to produce a high quality casting. Several existing analytical techniques are available — some real-time, others augmented by further laboratory analysis — which enable the die casting foundry to assess (1) the suitability of metal ready for casting in the instance of real-time tests; and (2) process monitoring and validation of one or more melt treatment processes with evaluation by real-time and/or off-line techniques.

In the final analysis, these measurement techniques must be coupled with actual sustained foundry results — production of acceptable castings with lower scrap rates — which provides the final validation.

Each die caster will have specific needs, resources, and capabilities, as well as economic circumstances, with which to employ these various technologies. However, market necessities and world-wide competition means that ever increasing utilization of several of these melt quality evaluation techniques will be needed by the successful producer of high integrity die castings.

References:

1. B. DasGupta, L. Parmenter and D. Apelian, “Relationship Between the Reduced Pressure Test and Hydrogen Content of the Melt”, *Proceedings, 5th International Conference on Molten Metal Processing, AFS, Orlando, 1998*, p. 285.
2. *High Integrity Aluminum Diecastings*, ed. Apelian and Makhlouf, NADCA, 2004.
3. S. DasGupta, D. Apelian, “Interaction of Initial Melt Cleanliness, Casting Process, and Product Quality: Cleanliness Requirements for a Specific Use”, *Proceedings, 5th International Conference on Molten Aluminum Processing, AFS, Orlando, 1998*, p.234.
4. D. V. Neff, “Using Filters and Evaluating Their Effectiveness in High Pressure Diecasting”, *NADCA Congress, Chicago, September 2002*.
5. R. Gallo, H. Mountford, I. Sommerville, “Ultrasound for On-Line Inclusion Detection in Molten Aluminum Alloys: Technology Assessment” *Proceedings, International Conference on Structural Aluminum Casting, AFS, Orlando, November, 2003*. 

For Further Information Contact:

D. V. Neff
 Metallurgical Systems
 31935 Aurora Road
 Solon, OH 44139
 phone 440-349-8864
 email dvneff@metallurgical.com