Die Casting Defects:
Identifying the Causes & Determining the Solutions

The Exclusion of Inclusions in High Pressure Die Casting
Defective castings...scrap...Yikes! — the scourge of the high pressure die caster trying to make a good living in a highly competitive marketplace! What’s a body to do? Well for one thing, he can try to avoid making defective castings in the first place! But just what is a “defective” casting? For this article, we wish to consider a defective casting as one which has a defect, right? But there are many ways that a casting can be “defective.” For our purposes, we shall limit this discussion to those defective castings where the cause can be attributed to “inclusion” defects — out of the many other defects and their causes that possibly could exist.

Inclusions in castings are foreign bodies which exist in the finished casting and which are detrimental to the casting’s properties and functionality. Where do they come from? If they are present, how do we get rid of them? More importantly, how can we avoid the “inclusion of the inclusion” into the casting in the first place? So, let’s start at the beginning...

**Inclusion Sources**

“In the beginning” (at least the beginning of the modern high pressure die casting era) there was aluminum — but there also was, and is, oxygen present! Aluminum readily oxidizes at extremely low vapor pressures and concentration of oxygen present. Consequently, since we melt and process our aluminum alloys on planet Earth and not Mars, there is always sufficient oxygen present to create aluminum oxides within the melt. Crystallographically, there are many different forms of aluminum oxide. Other oxides can also be present in aluminum die casting alloys as well. At the melt surface, of course, the oxide layer can build up and create “dross.” In large melting furnaces, particularly reverberatory configurations, the dross layer that develops can grow to significant thicknesses, retarding heat transfer, making skimming and dross removal much more laborious and increasing the chances for dross entrainment and carryover into a transfer ladle or casting furnace. But, in addition to the oxides which can be generated during the melting process itself, one must also consider the charge materials. Specification ingot, remelt sow, alloying agents and foundry returns — trim and gating, flash, machining chips, etc. — will also always contain oxide skins. Then, there is the potential, and often eventual, erosion of the refractory vessel linings themselves, which can add inclusions into the melt. This is especially true even with “best practice” preventive maintenance and cleaning of the furnace vessel, as scraping the refractory and skimming the resultant debris can never be quite complete with total removal.

The use of furnace fluxes to aid in cleaning or melt treatment can also leave behind particulate matter, resulting in entrained inclusions when not sufficiently removed from the melt. Flux inclusions start out as liquid, but as they pick up oxides, they become pasty. Flux inclusions often do not separate readily to the melt surface where they may be skimmed, hence these can be carried over and ultimately into a casting. Subsequent reactions with moisture in the air can result in a corroded surface or a “leaker” casting in operation.

One rather insidious form of refractory erosion results from corundum formation in the melting furnace. Corundum is an extremely dense, hard form of aluminum oxide which forms at high temperatures and can be fairly common with die casting alloys. Excessively high melting temperatures, high oxygen potential with furnaces operating under negative pressure and high free-silica refractories enhance corundum formation. Once formed, corundum adhesions on the refractory vessel walls can only be removed by mechanical means, and there is always the potential for not being able to skim or remove all such debris from a cleaning campaign. These can become inclusions in the finished casting.

One other key source of inclusions pertinent to high pressure die casting alloys is the formation of “sludge.” There are two kinds of sludge which we can define — “heavy metal” sludge (no relation to heavy metal music) and “metallurgical” sludge. Heavy metal sludge develops when the heavier common alloying elements in aluminum die casting alloys — iron, manganese, copper, zinc — fall out of solution and segregate to the bottom of the furnace. This can often occur with metal held for an extended period, or when larger melts are not sufficiently circulated. The second kind of sludge, “metallurgical sludge,” actually forms in-situ in melting and in holding furnaces with the right combination of temperature and composition.

This metallurgical sludge is defined as an aluminum-silicon inter-metallic precipitate complex which also contains iron, manganese and chromium. Metallurgical sludge formation is dependent only on temperature and composition, and not on time. There is a “sludge factor,” usually Fe+2Mn+3Cr, which should be less than or equal to 1.8. This determines the minimum melt holding temperature which must be maintained, often about 1220°F, in order to avoid sludge formation. If the sludge factor based on actual composition within the furnace itself is greater than 1.8, a higher holding temperature must be maintained to avoid sludge formation.

Table 1 summarizes the types of inclusions that can be present in aluminum-silicon die casting melts. Note the spectrum of types, sizes and densities. In general, inclusions in aluminum-silicon alloys also are rarely discreet; they agglomerate and form larger masses, different shapes and a spectrum of bulk densities, which will be noted further in this article.

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Inclusion Defects

It is fair to state that if inclusions are present in a casting, what is truly important is the size of the inclusion(s) and their location(s) within the casting. If the functionality of the casting for its intended purpose is not impaired by the presence of the inclusions, then the casting cannot be considered to be defective. The casting size, shape and solidification conditions often determine where the inclusions end up.

In general, however, inclusions do have a detrimental effect on casting properties. Ductility and fatigue strength are especially sensitive to inclusions. In addition, almost all inclusions are harder than the alpha aluminum/eutectic silicon matrix and will cause tool chatter, tool wear and tool breakage in machining operations. Better known as casting “hardspots,” such inclusions are responsible for considerable scrap and lost production time, and they seriously impact foundry scheduling and profitability when replacement castings are necessary. In addition to creating hardspots, the “right” amount of inclusions in the “wrong” places can nucleate porosity formation during solidification, or blistering during heat treatment. The opening up of such sub-surface porosity during machining can also result in loss of pressure tightness when the casting is subjected to leak-testing. Inclusions which appear on the surface of a casting always create an unacceptable blemish when surface finish operations such as polishing, plating, painting, anodizing or other bright finish processes are employed.

Figure 1 demonstrates several typical types of inclusion defects which may be found in high pressure die castings — oxide stringers, corundum, sludge (hardspots). It is notable that finding such inclusions is almost always the result of needing to analyze a casting problem or defective casting, with corresponding investigation requiring that the casting be destroyed. Using a separately cast test bar can provide some measure of a particular melt lot to generally meet mechanical properties, but that is not the same as using test bars sectioned from an actual casting. Non-destructive testing of a casting for the purpose of detecting inclusions is limited to fluoroscopy and x-ray diffraction, and it is only useful then when inclusions are macroscopic and very dense, such as sludge particles. Consequently, macroscopic and microscopic metallurgical investigation of defective castings is usually required to fully ascertain the nature of the defect, and then all process options must be considered to determine the source and achieve a preventive solution.

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Table 1 – Typical Inclusions in Aluminum-Silicon High Pressure Die Casting Melts and Alloys

Figure 1 – Inclusion defects in die cast alloys: a) oxide inclusion defect; b) corundum; c) refractory inclusions; d) sludge.
“Excluding Inclusions”

While it is absolutely impossible to guarantee any casting to be totally free from the presence of inclusions, there are certainly several means by which the high pressure die caster can achieve good casting success, reduce defective castings and inclusion-related scrap — by minimizing inclusion formation, by removing inclusions with proper melt treatment and by proper molten metal handling.

Careful consideration of all charge materials — purchasing, storage, handling — prior to melting is where it begins. During melting, it is crucial to practice proper furnace operation and maintenance, temperature control, avoid excessive turbulence and melt efficiently without prolonged holding periods at high temperatures to minimize dross formation. Proper furnace fluxing — using the correct flux, correct amount of flux and proper fluxing procedures — are factors necessary to achieve an efficient fluxing operation. Fluxing should be followed by thorough skimming. Any transfer into a transfer ladle for further treatment or delivery to casting cells should be conducted without cascading flowing metal into the transfer vessel, which itself should be reasonably clean and well-maintained.

In a transfer treatment ladle, flux injection — again with the proper flux composition, equipment and techniques — can improve the metal quality as many inclusions can be floated out by the combination of fluxing salts, together with the carrier gas, as they wet the inclusions. However, it is important not to compromise this process afterwards by poor metal handling when filling casting furnaces with this treated metal.

Additional improvements in excluding inclusions can be achieved in the casting furnace itself by proper adherence to good metal practices — minimizing temperatures to the greatest extent possible and good preventive maintenance techniques. Generally speaking, fluxes should never be used in casting furnaces, especially in the actual casting dipwell itself. Maintaining reasonable and minimal metal level variations between fills will reduce the dross and adhesions (“old oxides”) on the sidewalls, which nevertheless should be removed periodically. Occasional and careful skimming of the bath surface itself to remove the “new oxides” formed during constant automatic or manual ladle dipping will also be helpful.

The high pressure die casting process does not lend itself to the use of filters in the die cavity at the absolute last possible moment before casting solidification, as is the case with other slower solidification processes such as sand or permanent mold casting. However, it is still possible to incorporate filtration into the process — in a breakdown furnace or ultimately into the casting furnace itself. Filtering in the dipwell can provide the “last chance” for inclusion removal prior to forming the casting. Inclusions of lower density than the melt itself may have been removed prior to transfer to the casting furnace by drossing and skimming operations in the melting furnace, or by melt treatment in a transfer ladle, and inclusions of heavier density might have segregated and become sedimented in metal transfer vessels. However, it is quite common to have not been able to remove all of these. In a melt treatment ladle, for instance, there is insufficient time for good flotation and settling after a fluxing operation, as the metal must be delivered to the casting cells fairly quickly to avoid excessive temperature loss. In addition, many inclusions and inclusion “complexes” exist in molten aluminum-silicon alloy melts with densities very near to that of the melt itself. Consequently, only “positive” filtration can be counted on to remove these. Typical filtering methods which are well-proven in high pressure casting furnaces include gate or baffle filters, which separate the heating chamber from the dipwell, or three-dimensional filtering vessels, which allow the ladling operation to take fully filtered metal from within, avoiding any entrainment of inclusions from the pouring operations or breakaway of adherent dross and inclusions from the dipwell’s sidewalls. These are shown in Figure 2. Such filters provide good thermal conductivity and long life (often months) and achieve improved properties, better machinability by eliminating or minimizing the presence of hardspots, and thereby, reduce defective and scrap castings.

![Figure 2 – Filtration Methods Options in Dipwells](image)

Summary

All in all, we can easily summarize several key points in the “exclusion of inclusions” in high pressure die casting:

- Proper furnace operation and maintenance procedures
- Proper melt treatment including degassing and flux injection
- Avoiding turbulence in all metal handling procedures
- Application of filtering processes

These are all critical factors in “excluding inclusions,” which allow the high pressure die casters the best capability to optimize productivity, profitability and marketability in a highly competitive casting world.

About the Author

Dave Neff earned his Ph.D. in metallurgy from Case Western Reserve University and has more than 35 years of experience in non-ferrous molten metal treatment technology. Currently, he is director molten metal treatment for Metaluchs Systems Division, Pyrotek Inc. and is a NADCA instructor in metal melting and handling and metallurgy of aluminum die casting alloys. He is also active in the Aluminum Division and Division Council of AFS.

References