Consolidating Stress into Shrinkage

We have found significant shrinkage arrests in both aluminum and in iron thermal analysis curves. Now we are looking closely at the actual shape of these curves and noticing considerable differences in them. Some curves show a single massive shrinkage arrest, and others show multiple small shrinkage arrests. What could this mean in our efforts to reduce or prevent shrinkage in castings[i]?

Although iron and aluminum are quite different from each other, there are many common physical reactions that can teach us something about the physics that is driving shrinkage. Here is what we now understand about the relationship of stress and shrinkage:

1. Stress can be thought of as a low pressure area of the castings tending toward a partial vacuum.
2. Shrinkage/stress cannot occur until the casting is rigid enough that metal cannot easily flow to the higher stressed areas.
3. Stress at an atomic level is when the atomic bonds between atoms are elastically stretched without actually breaking.
4. Internal shrinkage occurs on an atomic level when the atomic bonds between atoms are broken thus forming an interior surface within the casting.
5. External shrinkage occurs when an external wall of the casting is pulled in (suck-in) by the pushing of atmospheric pressure outside the casting while the partial vacuum inside the casting is strong enough to bend the casting wall inward.
6. Both stress and shrinkage absorb energy and so are endothermic reactions on the cooling curve of thermal analysis.
7. A shrinkage occurrence reduces the residual stresses in the casting. This reduced residual stress can be used to discover the degree of shrinkage – at least in iron. We are still looking at this for aluminum.
8. Consolidating the shrinkage into one major shrinkage hole is clearly undesirable and degrades the physical properties of the metal, i.e. tensile, yield, and elongation.

Given this knowledge of the interplay of stress and shrinkage, the question we are raising is what causes some shrinkage to be dispersed and fine, and causes other shrinkage to be concentrated and large? And since concentrated or consolidated shrinkage is of course undesirable, can anything be done to reduce its occurrence?

Catalysts of Shrink

The key is in identifying catalysts for nucleation of shrink. A catalyst is something that reduces the energy needed for a reaction to occur. The reaction we are trying to prevent is the stretching of the atomic bonds to the point of them breaking apart and forming a void. Once a void forms, it can easily grow from the surrounding stress energy until that energy is consumed. If that void is not catalytically induced then we can get micro-porosity with thousands of tiny voids removing the stress energy. But if a catalyst exists, then the early formation of a void is created at a lower level of stress, followed by much of the evolving stress acting to grow a large void.

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A simple answer to what that catalyst would be is a preexisting void in the metal. A void is an area where the atoms are not bound together in what we metallurgists call a “metallurgical bond”—where electrons are shared. From basic chemistry we have ionic bonds, covalent bonds, and metallurgical bonds. If there is something within the metal that does not bond to the atoms of the metal, then we have a readymade interior surface—a catalyst for the growth of stress caused shrinkage.

Aluminum has a natural catalyst in that of aluminum oxide. While great care is taken to remove the ever present oxide film before and during pouring, tiny particles of Al_2O_3 are always present to some degree. Since aluminum does not strongly adhere to aluminum oxide, Al_2O_3 could be a source of nucleation. Good melting practices and possibly last second filtering in the gating systems could possibly improve casting soundness.

Iron also has oxide problems. Dr. John Campbell has for several years been demonstrating the presence of oxide films in cast iron. Ductile iron does not have oxide films but can have magnesium oxide particles (MgO) as well as other rare earth particles.

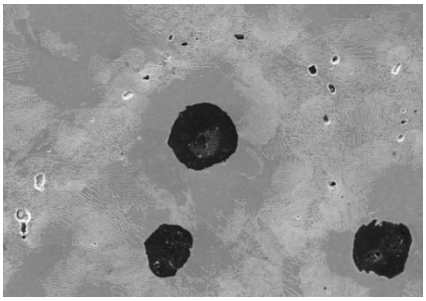
Detecting Shrink using Thermal Analysis

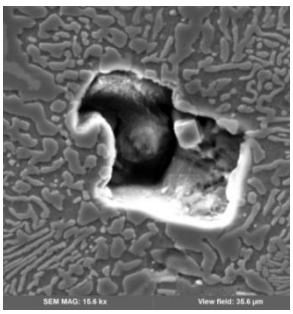
What can we do to help foundries monitor their metals for shrink potential? We have pioneered methods in iron for measuring stress, and examining shrink on a microscopic level through the use of the taking the 2nd derivative of the cooling curve which is 100 times magnification of the cooling curve. In Aluminum we can observe typical shrinkage from the 1st derivative because it is a larger problem in that metal.

What we are looking into now is applying the microscopic iron shrink detection methods to aluminum to pick up the cleanliness of the metal. By looking at the arrests in the second and third derivatives we can see events at 1,000 magnification and higher. From these events we hope to be able to produce a “cleanliness” value for aluminum. For iron we will focus on the type and amount of shrinkage occurring, even if it is miniscule.

Images

Oxide nucleated shrinkage in iron





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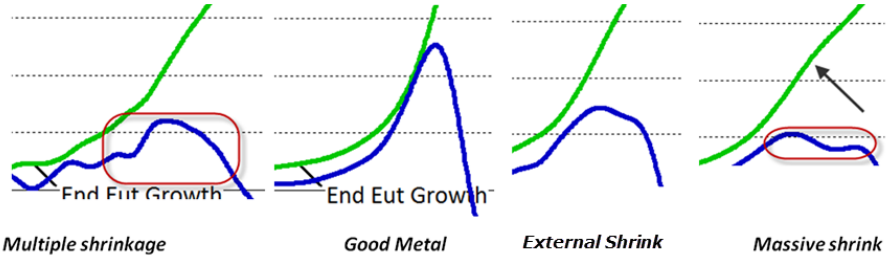
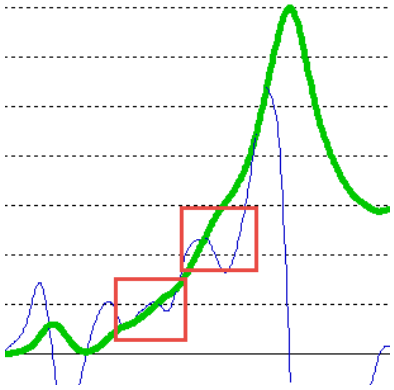
Iron Shrinkage revealed in 2nd derivative

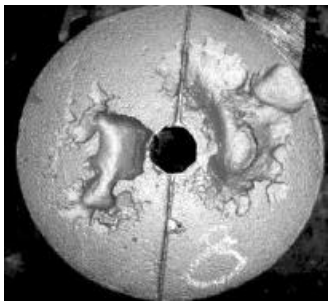


Shrinkage types in Iron

Looking at the graph to the right, the "dips" in the blue curve (red boxes) indicate endothermic or heat absorbing events in the sample. What is happening at these moments is the formation of an interior surface – something we associate with shrinkage.[ii]



Note: the fact that these arrests begin very low on the green curve indicates little stress energy was required to initiate stress reducing voids. This suggests that catalysts existed in the melt.



Massive shrink in a trial of gray iron with chrome and moly added from the AFS paper 15-043 by L. Stuewe, A.P. Tschiptschin, W.L Guesser, and R. Fuoco San Paulo University, Brazil. Comment: this seems to be a surface shrinkage effect. The large shrinks only occur with high levels of chromium and molybdenum as a late addition. Graphite formation is considerably lower leading to high stress in the casting, and molybdenum oxide has been shown to be a nucleate for shrink[iii]. The paper is interesting, but only reflects a college student's knowledge of metallurgy. It is available through the AFS library.

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The Future

We are adding this new knowledge to the next version (6) of MeltLab under Metal types Aluminum Microstructure, Grey Microstructure and Ductile Microstructure. Because this form of analysis requires the absence of Tellurium, it does not apply to Iron Chemistry. This upgrade will be available free of charge to service contract holders as we remain years ahead of the competition in technology. The continued support of our customers is what makes this progress possible and we appreciate that support.

David Sparkman
February 4th 2016

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[i] It should be clear that we are discussing metallurgical shrinkage effects. Shrinkage due to poorly designed casting, gating and risering is outside of this discussion. But it can be said that good metallurgical shrink reduction can make the job of pattern design easier.

[ii] Shrinkage by Tearing, David Sparkman, October 12th 2014 MeltLab News Letter

[iii] Thermal Analysis of Ductile Iron Microstructure by David Sparkman, October 12th 2015 paper for DIS

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