Castability Control in Metal Casting via Fluidity Measures: *Application of Error Analysis to Variations in Fluidity Testing*

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Introduction

At the surface, the question "what is fluidity" (to a metallurgist) is a relatively simple question. Having said that, the necessary caveat 'to a metallurgist' has already revealed one problem. Physicists define fluidity to be one over the viscosity. Metallurgists, on the other hand, refer to the ability of a molten metal to flow and fill a channel or cavity as fluidity. This is most often measured by the length metal can flow through a given mold before freezing.

The answer to the question 'why is fluidity important' is highly dependent on who is asking. There are at least three scenarios:

- To a foundry worker, the answer is: "because it is useful". Fluidity refers to a very important property of cast alloys. The more fluid an alloy is, the more easily it should be able to fill a given cavity. As the response of fluidity with increasing superheat is known to be linear, fluidity directly relates to the amount of superheat needed to fill a given cavity

- Theorists express interest in fluidity as it relates to the study of solidification and interdendritic metal flow. The majority of fluidity investigations in the last 25 years have focused on maximizing fluidity with respect to precise alloy chemistry. The influence of minor alloy additions, however, is often slight when compared with that of superheat, head pressure, or melt cleanliness

- A third answer, one which might satisfy an ambitious experimentalist, is that there are believed to be significant problems with the repeatability and precision of fluidity measurements. Surmounting these challenges so that more accurate and repeatable measurements of fluidity can be conducted would be an important contribution in the area of experimentation, and given the interest in fluidity by both theorists and industrialists, these accomplishments would receive praise beyond the scope of just the experimentalist community

All answers are equally correct, but each touches on a different aspect of the ways fluidity measurements are conducted and used. Our definition of fluidity shall be: **Fluidity is a material's ability to flow into and fill a given cavity, as measured by the dimensions of that cavity under specified experimental conditions.** As will be detailed this work, fluidity is heavily dependent on heat flow during solidification.

The likely benefits of this work are threefold: A robust and reliable testing apparatus and methodology will allow for comparisons between groups working in different parts of the world, confidence in fluidity testing will improve, and metal casters will be able to use the derived theoretical error equations and testing methodologies to more closely fine-tune their processes to optimize scrap rates, superheat, and alloy chemistry. More consistent fluidity should lead to more consistent castings.

Objectives

As inspired by Ragone's [1] elegant statement of purpose, the purpose of this investigation is to quantitatively relate variations in fluidity to fundamental properties of metals, mold materials and test equipment design. Fluidity is a material's ability to flow into and fill a given cavity, as measured by the dimensions of that cavity under specified experimental conditions. As will be detailed in future work, fluidity is heavily dependent on heat flow during solidification. Specifically, the plan is to derive analytical equations relating the variation of fluidity of metals to the above-mentioned properties and to conduct controlled experiments to validate these relationships.

Project Overview

Work in this project falls into four categories, but in each phase of work the dependent variable was fluidity and its variation.

Phase 1: Preliminary experiments

Independent variables included:

- Superheat
- Tube diameter
- Depth of tube
- Crucible/mold temperature
- Testing method (permanent mold versus vertical vacuum)
- Operator variation

Phase 2: Confirmation of a reliable test

Independent variables included:

- Superheat
- Date of experiment

Phase 3: Demonstration on variables of interest

Independent variables included:

- Silicon content
- Iron and Manganese content
- Alloy system (binary hypereutectic Al/Si, pure Al, A356.2)
- Grain refinement
- Eutectic modification
- Oxide level
- Degassing level

Phase 4: Computer modeling

Independent variables included **Phase 2** variables and, if the models matched with experimental data, **Phase 3** variables as well.

Outcome / Impact

1. An improved testing apparatus and procedure capable of producing precise, accurate, and consistent results has been developed and tested.
2. Certain existing tools to evaluate fluidity have been demonstrated to have limitations, and an alternative method has been described in detail. Through MSV testing, multi-fingered permanent mold tests designed for qualitative testing have been shown to be unsuitable for adaptation as robust quantitative tests, though their use in this capacity is not unknown.
3. Work has been done demonstrating a capability of measuring fluidity changes within an alloy's specified chemistry range as that chemistry is changed, which has only previously been achieved in eutectic alloys.
4. The introduction of oxides has been shown to impact both the mean and the range of fluidity, though A356 remained quite fluid at intermediate levels of oxide addition.
5. Compounds more common in secondary alloys, iron and manganese, were found not to negatively impact the fluidity of this alloy.
6. Degassing also had very little impact on fluidity.

7. Similarly, high levels of strontium and grain refiner addition had relatively little impact on fluidity. This is particularly noteworthy, as strontium is known to have a major influence on melt viscosity; thus fluidity is shown to be relatively invariant to changes in melt viscosity.
8. As modeling improves, comparing simple models such as the filling of a thin glass tube by vacuum and subsequent flow choking will remain a valuable check to see if improvements have been made in determining the conditions under which flow stops. These improvements are quite important given the popularity of modeling techniques in industrial practice. Consequently, recommendations are given for how these research data might be incorporated into solidification models.
9. Superheat remains the dominant factor in fluidity.
10. Accurate analysis of necessary superheat temperatures will allow for a reduction either of cycle time or scrap rate. This quantitative capability will help to meet productivity goals.
11. Now that the variations are understood and equations are available to estimate the fraction of samples, which have a lower fluidity as compared to the mean in terms of a series of measurable experimental parameters, casters will have a greater degree of control over their products, especially those possessing thin sections.
12. These improved testing procedures will allow for improved communication between research groups and greater confidence in fluidity testing results.

References

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