# Research Programs

## Yield Stress Measurements and Microstructure Evolution in SSM Al-Based Alloys

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### Introduction

Semi-solid metal slurry is a mixture of liquid metal and solid particles. The solid particles have predominantly a globular shape during the reheating stage. In essence, the rheological behavior of semisolid metal slurry is similar to that of visco-plastic materials such as concentrated suspensions, pastes, foodstuffs, emulsions and foams. This class of materials is characterized by the existence of a yield stress, which implies the material behaves as a "solid" if the applied stress is below the yield stress; if the applied stress exceeds the yield stress, however, the material will flow and show liquid-like behavior. Yield stress of semi-solid metals has a significant effect on its filling behavior during semi-solid forming, and needs to be determined experimentally.

### Objectives

The aim of this project was to establish yield stress vs. temperature/fraction solid relationship for various commercial semi-solid aluminum alloys. Experimental data have been provided to the modeling team and also utilized to optimize industrial practice. In this project, a new methodology was developed for yield stress measurement of semi-solid slurry at different processing conditions. In addition, quantitative image analysis was conducted to characterize microstructure evolution of semisolid alloys in the two-phase region, and thus to reveal its effect on flow/yielding behavior.

### Salient Results

Figures 1 and 2 give the yield stress measurement results of A356 and 357 alloys as a function of temperature. Figures 3 and 4 give the yield stress measurement results of A356 and 357 alloys as a function of fraction solid. Figure 5 compares yield stress values of commercial A356 billets as a function of processing method and temperature. From Figures 1 through 5, one can see that:

- The yield stress of commercial semi-solid aluminum alloys is a strong function of temperature (fraction solid). In the two-phase region, with increasing temperature yield stress decreases dramatically, varying between $10^{3}$-$10^{-1}$ kPa. The dramatic change in yield stress in the two-phase range is certainly a challenge during commercial processing. This is particularly for alloy systems with a relatively small freezing range.
- Billet processing method has a significant influence on the yield stress of the material in the two-phase region. For a given temperature/solid fraction, GR billets have the highest yield stress value, while UBE/NRC billets show the lowest.
- The difference in yield stress values among the alloys under the same temperature (fraction solid) is intricately related to the microstructual indices. Low entrapped liquid content, and small, round

alpha particles tend to decrease the stress needed to initiate the flow, *i.e.*, the yield stress of the slurry.

- Numerical simulations of semi-solid processing (SSP) pointed out that the finite yield stress of semi-solid metals has a significant effect on flow pattern during die filling. It is also responsible for flow instabilities encountered in commercial forming operations. The inclusion of yield stress in modeling SSP is critical. Ignoring the yield stress of semi-solid slurries may give erroneous conclusions.

# SSM Related Publications (2002-Present)

## 2009

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- A. M. de Figueredo, D. Apelian, M. Findon, and N. Saddock, "Alloy Substantially Free of Dendrites and Method of Forming the Same", US Patent No. 7,513,962, April 7, 2009.

## 2007

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- Q.Y. Pan, P. Hogan, D. Apelian, and M.M.Makhlouf, "The Continuous Rheoconversion Process (CRP™ )", in the Proceedings of LMT – Light Metals Technology 2007, September 2007, Saint-Sauveur, Québec, CA, published by CANMET.
- Q. Y. Pan, D. Apelian, "Semi-Solid Metal (SSM) Processing Methods: An Overview", in Proceedings of 2007 Xi'an International Symposium on Solidification, Northwestern Polytechnical University, May 29-31,2007.
- Q.Y Pan, Diran Apelian & John Jorstad, "Semi-Solid Casting: Introduction and Fundamentals", ASM Vol. 15: Casting, published by ASM (2007), pp. 761-763.
- Q.Y Pan, Diran Apelian & John Jorstad, "Rheocasting", ASM Vol. 15: Casting, published by ASM (2007), pp. 773-776.
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- Q.Y. Pan, P. Hogan, and D. Apelian, "*Optimization of Commercial Alloys for Semi-Solid Processing*", NADCA Transactions (2006).
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- Q.Y. Pan, L. Wang, D. Apelian and M.M. Makhlouf , "*Optimization of 380 Alloy for Semi-Solid Processing*", NADCA Transactions, #T05-143 (2005).
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- B. Dewhirst, J.L. Jorstad, and D. Apelian, "Effect of Artificial Aging on Microstructure and Mechanical Properties of Semi-Solid Processed A356 Castings", NADCA Transactions, #T05-063 (2005) - Selected as the Best Paper of the Congress.
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