Research Programs

SSM Alloy Development

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Introduction

Often newly developed manufacturing processes are evaluated with existing alloys rather than optimizing a special alloy that can take advantage of the attributes of the new process. Currently, conventional cast aluminum alloys, such as 356 and 357 are widely used for SSM processing. SSM alloy development/optimization remains a significant issue in SSM processing.

Historically, the trial-and-error method has been employed for alloy development. This approach has been proven to be cost-intensive and time-consuming. With the development of robust aluminum alloy databases, a new approach based on ***thermodynamic simulations*** has emerged. This approach provides a powerful tool for alloy design. In this approach, the Gibbs free energy of individual phases is calculated as a function of alloy composition, temperature and pressure, and then collected in a thermodynamic database that enables calculation of multi-component phase diagrams. The calculation results provide critical information for alloy design such as the phase formation and transformation temperatures, and the solidification characteristics of the alloy.

Objectives

The aim of this project is to optimize/develop alloys that are better suited for SSM processing. In order to achieve the goal, the following strategies are being pursued:

- Use thermodynamic modeling packages (Pandat/Thermocalc/JMatPro) to determine phase equilibria for SSM alloys.
- Identify desired characteristics of an ideal SSM alloy.
- Use thermodynamic model to optimize the composition of current commercial SSM alloys, and/or develop new alloys with ideal characteristics.
- Carry out plant tests on new alloys through collaboration with ACRC consortium members. Feedback is evaluated, and alloy development is further optimized.

Methodology

Several important factors that need to be considered for SSM alloy development/optimization are outlined as follows:

1. ***Solidification range (ΔT):*** is defined as the temperature range between the solidus and the liquidus lines of the alloy. Pure metals and eutectic alloys are not suitable for SSM processing,

whereas, alloys with too wide a solidification range experience poor resistance to hot tearing. It is therefore suggested that the solidification range of an SSM alloy be between 40-130K.

2. ***Temperature sensitivity of fraction solid:*** For a given alloy composition, temperature sensitivity of the fraction solid (fs) is defined as the slope of the fs vs.T curve, i.e., it is dfs/dT. In order to obtain stable and repeatable processing conditions, the temperature sensitivity of the fraction solid should be as small as possible in the fraction solid range of commercial operations (ideally fs should be 0.3-0.5 for rheocasting, and 0.5-0.7 for thixocasting/thixoforging).
3. ***Temperature process window (ΔT):*** Depending on the application, for rheocasting, ΔT is defined as the temperature difference between 0.3-0.5 fraction solid, whereas, for thixoforging, ΔT is defined as the temperature difference between 0.5-0.7 fraction solid. Considering temperature variations during commercial forming operations, a relatively large temperature window is expected.
4. ***Potential for age hardening:*** In order to achieve high strength, the alloys designed for SSM processing need to have high potential for age hardening. During a T5 temper, SSM parts ejected from the die are quenched immediately in water and then artificially aged at a relatively low temperature. Therefore, the potential for age hardening of a phase can be gauged by the concentration difference (ΔC) of the major alloying elements in the α-phase between the quenching and ageing temperatures

Salient Results:

In this study, extensive thermodynamic calculations are being conducted to evaluate the SSM processability of commercial alloys. These include 356/357, 380/383, 319, 206, and wrought alloys. Subsequently, the effects of various alloying elements on the SSM processability of these alloys are characterized and recommendations are made to allow the optimization of the alloys for semi-solid processing. Some salient results are highlighted below:

Figure 1 compares the fraction solid (fs) vs temperature (T) curves of A356/380/319/206 alloys with nominal composition. Table 1 gives important simulation results. From Figure 1 and Table 1, one can see that:

- 319 alloy has a similar SSM temperature process window for rheocasting as SSM A356 (24°C vs. 23°C), and a much larger temperature window for thixocasting/thixoforging (12°C vs. 3°C). Moreover, the alloy has very small dfs/dT values in the fraction solid range of commercial forming. Thus, from semi-solid processing point of view, it is an excellent candidate material.
- Compared to SSM A356, the SSM temperature process window of 380 for rheocasting is somewhat small. In addition, its relatively high Si content (7.5-9.5%) limits the maximum volume fraction of the primary alpha phase (SSM structure) that can be achieved during commercial forming (for 380 alloy with nominal composition, about 40% primary alpha phase can be formed at the fraction solid of 0.5). The SSM processability of the alloy can be improved by optimizing/modifying the alloy composition.
- 206 alloy has a fairly poor SSM processability. The alloy has a quite small SSM temperature process window, and a high temperature sensitivity of fraction solid for rheocasting applications. Moreover, a large two-phase region makes the alloy susceptible to hot-tearing.

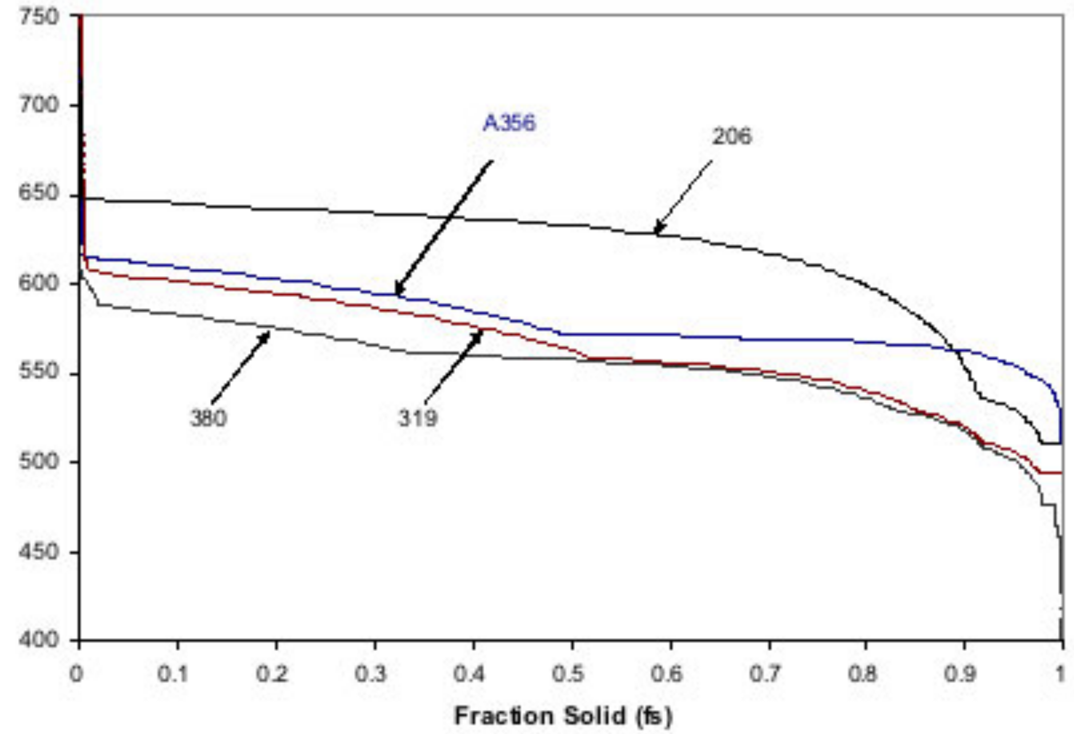

Figure 1: Fraction solid (fs) vs. temperature (T) curves of A356, 206, 380 and 319 alloys with nominal composition.

Alloy	T@fs=0.5	ΔT@ fs:0.3-0.5	ΔT@ fs:0.5-0.7	(dfs/dT) @fs=0.4	(dfs/dT) @fs=0.5	(dfs/dT) @fs=0.6
319	563°C	24°C	12°C	.009	.006	.020
380	556°C	10°C	13°C	.034	.025	.016
206	633°C	7°C	14°C	.027	.019	.013
SSM A356	*575°C*	*23°C*	*3°C*	*.008*	*.112*	*.070*

Table 1: Simulation Results of 319/380/206/A356 Alloys with Nominal Composition

Figures 2 and 3 illustrate the effects of Si, and Ni content on the fs vs T curves of 380 alloy. Simulation results point out that:

- Si does not change the shape of the fraction solid vs. temperature curve of 380 alloy, but it affects the location of the binary eutectic point. With decreasing Si content, the fs vs. T curves shift towards the right, indicating that the temperature of the binary eutectic reaction is decreased, and more primary α phase is formed.
- Ni, Cu, Mg, and Zn increase the slope of the temperature vs. fraction solid curves of 380 alloy, thus leading to a relatively large SSM temperature process window, and relatively small dfs/dT values. As a result, the SSM processability of the alloy is improved. Among these four alloying elements, Ni has the most significant effect (see Figure 3).

As a typical die casting alloy, 380 has a potential for SSM applications by tailoring/optimizing its alloy composition. Thermodynamic simulations point out that Si, Ni, Cu, Mg, and Zn are important alloying elements and should be optimized for successful SSM processing. Specifically, Si has the most significant effect on the processability of the alloy. Whereas, Ni, Cu, Mg, and Zn increase the slope of the temperature vs. fraction solid curves of the alloy, thus leading to a relatively large process window. Among these four alloying elements, Ni has the most significant effect. Based on simulation results, an optimal composition window is given below.

Alloy	Si	Fe	Cu	Mg	Mn	Ni	Zn	Sn
380 (ASTM)	7.5-9.5	2.0	3.0-4.0	0.1	0.5	0.5	3.0	0.35
380 (Recommended)	6.5-8.5	2.0	3.0-4.0	0.1-0.5	0.5	0.5-1.0	3.0	0.35

Table 2: Recommended Composition Window of 380 for Semi-solid Processing

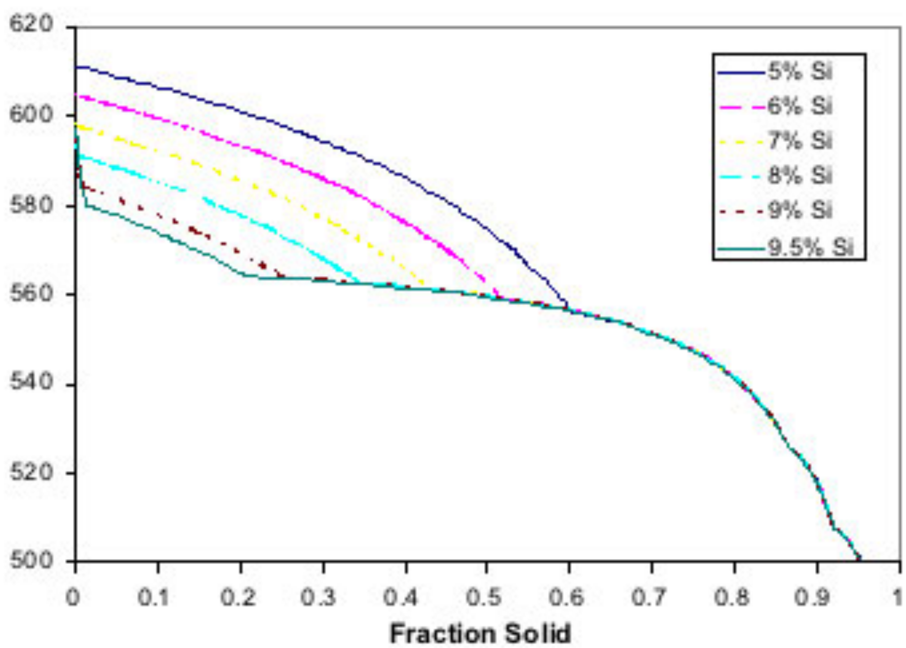

Figure 2: Effect of Si content on fraction solid vs. temperature curves of 380 alloy.

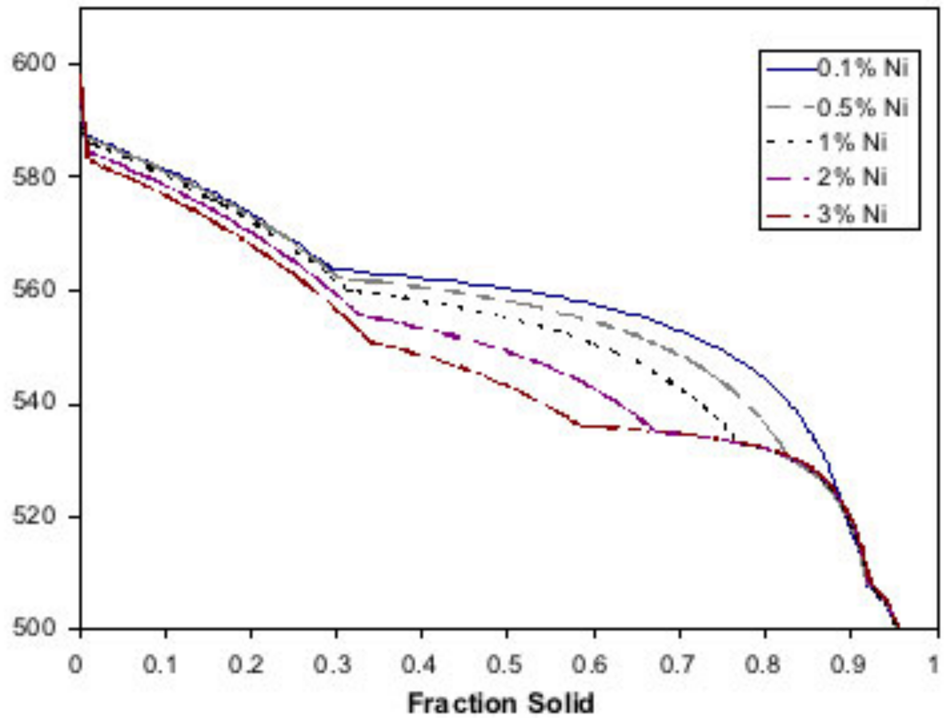

Figure 3: Effect of Ni content on fraction solid vs. temperature curves of 380 alloy.

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