Changes in die casting alloy composition can affect the physical characteristics of a finished part, resulting in increased strength or improved thermal conductivity, or the alloy may be modified to improve production efficiency by reducing die soldering or allowing thinner wall castings. Specialty alloys may be developed to meet a specific product need, or to provide solutions for a general set of industry criteria.

New alloys may even be developed to help keep markets for a particular metal. For example, as zinc prices have tripled, the industry has lost 250 tons of zinc castings, according to the International Lead Zinc Research Organization Inc. (ILZRO). To help mitigate this problem, ILZRO and industry partners Stroh Die Casting, Brillacast, and Il Kaba are working on a new zinc alloy that is 40% more fluid, allowing thinner wall castings that retain the coating characteristics and other advantages of zinc. Since less material is used in the thin wall castings, the overall cost of zinc products can be reduced. Although the alloy is not yet ready for commercial introduction, Stroh has cast sample products with wall thicknesses of 0.012 inch, leading to a 25% reduction in casting cost.

Extensive research by the North American Die Casting Association (NADCA) and other partners has created a vast body of knowledge about aluminum alloys, and breakthroughs are being made with other metals. NADCA, in conjunction with Worcester Polytechnic Institute (WPI), has created I-Select Al software focused specifically on aluminum alloys.

The I-Select Al software helps designers, product specifiers, and die casters identify the alloy chemistry needed to meet a specific set of casting properties, such as density, thermal conductivity, ultimate tensile strength, tensile yield strength, ductility, and elasticity.

Ongoing alloy research

The development of I-Select Al software is part of an ongoing research effort to define a set of premium grade alloys that are optimized for specific properties. The program, “Castings for Improved Readiness,” is being conducted by NADCA, WPI, the Defense Logistics Agency (DLA), and several industry partners that are testing alloys for various applications.

One of the goals of the program is to meet industry and DLA needs for better procurement data to reduce lead times while tailoring the alloy composition to ensure cost-effective, high-quality parts. This data for optimized alloys is essential because current chemistry specification limits are wide, resulting in large variations in mechanical properties and leading to non-compliance issues.

The program is examining a total of 36 alloy formulations. Two of the alloys have been selected for trials with die cast military parts that are already in production. Twin City Die Castings Company and Premier Tool and Die Casting are industry partners in this effort. Casting samples are being analyzed at WPI to delineate the specific performance characteristics that need to be optimized via microstructural control. As these properties are defined, they will be included in new specification standards, which should be completed by the first quarter of 2008.

Design of ZCA-9

While the I-Select Al software allows the die caster to create alloys for a variety of situations, another approach is to identify a need and then develop a specialty alloy that fits the bill. A good example of taking the market based approach to alloy development is the creation of a new zinc alloy, ZCA-9. The goal for the new alloy was to capitalize on the high strength properties of Zamak and ZA zinc alloys, while improving high temperature performance. Development of the
Aluminum propeller alloy

An aluminum alloy based on a specific market need is Mercalloy 366, developed by Mercury Marine and now marketed commercially by Alcan. The development of Mercalloy grew from the need to find a durable, easy-to-cast alloy for marine propellers. The material had to provide superior ductility and impact resistance over traditional high pressure die casting alloys in case the propeller hit a rock, stump, or other underwater object. The development of Mercalloy, described in a paper presented at the 110th Metalcasting Congress in 2006 (“Innovations in Marine Propeller Technology: High Ductility Mercalloy 366 Alloy”), shows some of the many tradeoffs and considerations that enter into developing a new material. In this case, the metallurgists were trying to balance the ductility of the alloy with the need to prevent die soldering.

For example, Al-Si-Mg or 300-series alloys offer many processing advantages such as high fluidity, excellent castability, and good machinability. Strength and ductility can be tailored through chemistry. For example, corrosion resistance is excellent when the copper content is low. Strength is typically increased as magnesium content is increased. Typically, iron has not been adjusted in 300-series aluminum die casting alloys because removal of iron leads to die soldering. A small amount of iron — in the range of 0.7 to 1.3 wt% — can be added to 300-series die casting alloys to help eliminate soldering, but these small additions significantly degrade the mechanical properties of the casting. Adding manganese to replace the iron can mitigate soldering, while maintaining ductility and strength. However, manganese forms blocky intermetallic compounds that could limit the amount of ductility gained.

The research team at Mercury Marine sought to eliminate the iron and die soldering without introducing new intermetallic phases. To design the most appropriate alloy, the researchers cast propellers of Mercalloy 366, Silafont-36, and AA 514 (See table below). The alloys had the following properties:

- Energy absorption: Mercalloy 366 propellers showed the best energy absorption as determined by drop impact testing.
- Deflection: Mercalloy 366 and Silafont-36 propellers demonstrated similar peak loads in load vs. deflection testing. Mercalloy 366 propellers displayed consistently higher deflection in load vs. deflection testing.
- Die soldering: Die soldering issues were not observed in this study and have not been seen in the 250,000 propellers that have been cast since the completion of the research. The researchers believe Mercalloy achieves its solder resistance through strontium content, as opposed to manganese additions. The lack of any blocky intermetallic phases combined with a finely modified eutectic microstructure is the basis of the increased ductility Mercalloy demonstrates.

Although Mercalloy was developed to solve a specific product need, Mercury Marine is now using the alloy for engine drive shaft housing and swirl brackets. Other general market opportunities for the alloy include various brackets and squeeze casting applications for parts such as automotive link arms.

**Alloy chemistry data for propeller study**

<table>
<thead>
<tr>
<th>Alloying element</th>
<th>Mercalloy 366, wt.%</th>
<th>Silafont-36, wt.%</th>
<th>AA514, wt.%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Silicon</td>
<td>9.50</td>
<td>9.51</td>
<td>0.49</td>
</tr>
<tr>
<td>Strontium</td>
<td>0.0682</td>
<td>0.0236</td>
<td>—</td>
</tr>
<tr>
<td>Magnesium</td>
<td>0.14</td>
<td>0.13</td>
<td>4.12</td>
</tr>
<tr>
<td>Iron</td>
<td>0.20</td>
<td>0.12</td>
<td>0.81</td>
</tr>
<tr>
<td>Copper</td>
<td>0.12</td>
<td>0.02</td>
<td>0.13</td>
</tr>
<tr>
<td>Manganese</td>
<td>0.28</td>
<td>0.65</td>
<td>0.45</td>
</tr>
<tr>
<td>Titanium</td>
<td>—</td>
<td>—</td>
<td>0.04</td>
</tr>
<tr>
<td>Aluminum</td>
<td>Balance</td>
<td>Balance</td>
<td>Balance</td>
</tr>
</tbody>
</table>

Zinc was chosen for the Gentex rearview mirror mount for Volvo autos and SUVs because of its wear resistance, tensile strength, and ability to mold thin wall sections, says Cast Products Inc., Norridge, Ill. The part won the award for zinc parts under 6 ounces at the North American Die Casting Association’s 2007 International Die Casting Competition. www.castproducts.com
rails, and air meter bodies, as well as two-cycle crankshafts for outdoor equipment. Other possibilities include miniature clamps or other parts where zinc might not have been suitable before because of thread relaxation.

The new alloy enables die casters to capitalize on some of zinc’s traditional advantages, including low porosity, reduced melting temperatures, and low die erosion, with an alloy that has improved creep resistance and higher tensile strength. In one example of how this can benefit die casters, Eastern has used the new alloy to reduce manufacturing costs by 30% for a Panther Crankshaft for a two-cycle engine. The ZCA-9 net shape die casting incorporated the shaft and pin as inserts, replacing a sintered iron crankshaft with a secondary operation to install the shaft and pin. At the current production of approximately six million parts/year, the potential yearly savings is $600,000.

**Semi-solid metal processing**

New manufacturing processes may be another reason to develop specialty alloys. Semi-solid metal processing (SSM) is one of the more recent die casting techniques for which optimized alloys may be beneficial. SSM is a procedure in which semi-solid metal billets are cast to provide dense, heat treatable castings with low porosity. The study evaluated four key factors that are essential for SSM alloy development/optimization.

- **Solidification range (T):** The temperature range between the solidus and the liquidus lines of the alloy.
- **Temperature sensitivity of fraction solid:** For 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.
- **Temperature process window (T):** Depending on the application, for rheocasting _T_ is defined as the temperature difference between 0.3 and 0.5 fraction solid; whereas for thixo-forming _T_ is defined as the temperature difference between 0.5 and 0.7 fraction solid.
- **Potential for age hardening:** To achieve high strength, the alloys designed for SSM processing need to have high potential for age hardening. Extensive thermodynamic calculations were conducted to evaluate the SSM processibility of commercial alloys, including 356/357, 380/383, 319, 306, and wrought alloys.

Among the salient results:

- A319 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/thixoformg (12°C vs. 3°C).
- Moreover, the alloy has very small ds/dT values in the fraction solid range of commercial forming. This makes it an excellent material for semi-solid processing.
  - Compared to SSM A356, the SSM temperature process window of 380 for rheocasting is somewhat small. In addition, its relatively high silicon content (7.5 to 9.5%) limits the maximum volume fraction of the primary alpha phase (SSM structure) that can be achieved during commercial casting. For the A380 alloy with nominal composition, about 40% primary alpha phase can be formed at the fraction solid of 0.5.
  - The SSM processibility of the alloy can be improved by optimizing/ modifying the alloy composition.
  - The 206 alloy has a fairly poor SSM processibility. 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. As a typical die casting alloy, 380 has a potential for SSM applications by tailoring/optimizing its alloy composition.

Thermodynamic simulations indicate that silicon, nickel, copper, magnesium, and zinc are important alloying elements and should be optimized for successful SSM processing. Specifically, silicon has the most significant effect on processibility. Nickel, copper, magnesium, and zinc 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, nickel has the most significant effect. Based on simulation results, an optimal composition window is shown in the table below.

**Recommended composition window for A380 for semi-solid processing**

<table>
<thead>
<tr>
<th>Alloy</th>
<th>Silicon</th>
<th>Iron</th>
<th>Copper</th>
<th>Magnesium</th>
<th>Manganese</th>
<th>Nickel</th>
<th>Zinc</th>
<th>Tin</th>
</tr>
</thead>
<tbody>
<tr>
<td>380 (ASTM)</td>
<td>7.5-9.5</td>
<td>2.0</td>
<td>3.0-4.0</td>
<td>0.1</td>
<td>0.5</td>
<td>0.5</td>
<td>3.0</td>
<td>0.35</td>
</tr>
<tr>
<td>380 (Recommended)</td>
<td>6.5-8.5</td>
<td>2.0</td>
<td>3.0-4.0</td>
<td>0.1-0.5</td>
<td>0.5</td>
<td>0.5-1.0</td>
<td>3.0</td>
<td>0.35</td>
</tr>
</tbody>
</table>


Additional information about the software for creating custom aluminum alloys may be found in a previous NADCA White Paper, “Using Custom Aluminum Alloys To Expand Die Casting Applications.” For more information, visit www.diecasting.org/oem.htm.