WHITE PAPER

Specialty Alloys Provide a Range of Die Casting Solutions

NADCA
North American Die Casting Association

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North American die casters consistently strive to expand applications for die cast products, increase the efficiency of the process or create materials that improve the performance of the finished product. A key element in this quest is the development of specialty alloys that solve a particular problem.

Changes in 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 hold onto 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 with industry partners Stroh Die Casting, Brillcast and Kaba-Illco are working on a new zinc alloy that is 40% more fluid, allowing thinner wall zinc 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 .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. Additional information about the use and benefits of 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**.

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 in order 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.

Creation 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 alloy started with a survey of automotive and component manufacturing personnel. A majority of the respondents indicated that a creep resistance of 4,000 psi was considered appropriate for the types of under hood applications, and that a temperature limit of 140°C was required. Furthermore, a total deformation of 1.0% or less was required for an adequate creep resistance and the respondents wanted an exposure time of 1,000 hours.

With these performance parameters in hand, the Council of Scientific Industrial Research (CSIR) and the International Lead Zinc Research Organization Inc. (ILZRO) began research to create an alloy that was hot chamber die castable and had good creep-resistant properties. In order to create an alloy with optimal properties, CSIR and ILZRO investigated more than 40 different compositions. They used a multi-step process to develop a model of creep strengths and other properties that the OEMs wanted.

The ratios of alloying elements, such as aluminum and magnesium, were based on data about existing alloys as well as those that can better form stable precipitates in the die casting. The alloys were also compared with Zamak 5 and ZA 8. The resulting tests identified two compositions – Alloy 4 and Alloy 16 – as exhibiting the best creep resistant properties.

in Eastern Alloys, based in Maybrook, NY, developing the commercial creep resistant zinc now marketed as ZCA-9.

ZCA-9 offers a number of market opportunities in the automotive sector for brackets, fuel rails and air meter bodies, as well as two-cycle crankshafts used in outdoor equipment. Other possibilities include miniature clamps or other parts where zinc might not have been used 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 to lower energy costs 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

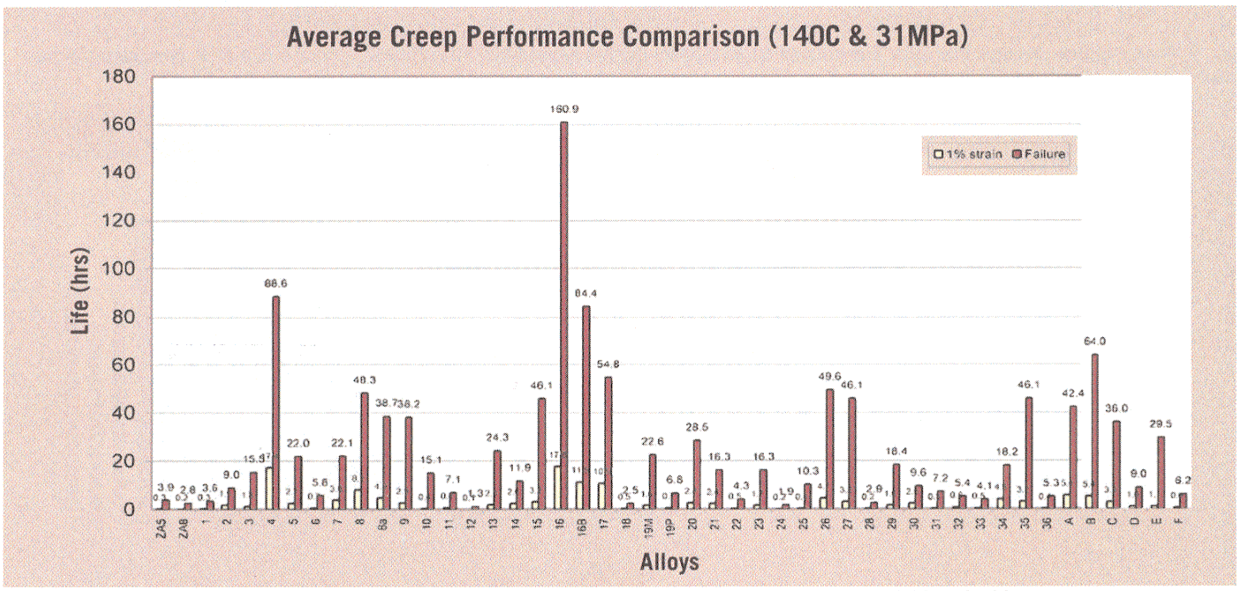

Fig. 1. Listed here is the average creep performance of all of the alloys tested, with alloys 4 and 16 exhibiting significantly better creep-resistant properties than the other alloys.

Although the 1,000 hour goal was not achieved, an alloy was developed with much improved creep resistance (2 orders of Magnitude). The alloy also exhibited the following characteristics:

- Improved tensile strength
- Lower impact strength
- Slightly improved dimensional change
- Slightly improved flow distance
- Improved hardness
- Unaffected die attack

Following the initial research into the alloy properties, additional commercial tests were conducted. This effort resulted

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.

MercAlloy Solves Propeller Problem

Another 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, and 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 0.7-1.3wt% – can be added to 300-series die casting alloys to help eliminate soldering, but these small additions significantly degrade the mechanical properties of the cast product

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.

In order to determine the most appropriate alloy, the researchers cast propellers using Mercalloy 366, Silafont-36 and AA 514. The alloys had the following properties.

Table 1. Alloy Chemistry Data for Propeller Study

Alloying Element	Mercalloy 366 (weight %)	Silafont-36 (weight %)	AA 514 (weight %)
Si	9.50	9.51	0.49
Sr	0.0682	0.023	-
Mg	0.14	0.13	4.12
Fe	0.20	0.12	0.81
Cu	0.12	0.02	0.13
Mn	0.28	0.65	0.45
Ti	-	0.04	-
Al	Balance	Balance	Balance

The alloys were tested for casting performance, and the finished propellers underwent impact testing, as well as tests for load vs. deformation. A summary of the results shows:

• Mercalloy 366 and Silafont-36 exhibited very good castability and solder resistance.

• Mercalloy 366 propellers showed the best energy absorption as determined by drop impact testing.

• 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 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 swivel brackets. Other general market opportunities for the alloy include various brackets and squeeze casting applications for parts such as automotive link arms.

SSM Alloy Development

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 where optimized alloys may be beneficial. SSM is a procedure where semi-solid billet or molten metal cooled to the SSM state is 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 (ΔT)** – The temperature range between the solidus and the liquidus lines of the alloy.

• **Temperature sensitivity of fraction solid** – 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

• **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 thixoforming, ΔT is defined as the temperature difference between 0.5-0.7 fraction solid.

• **Potential for age hardening** – In order 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 processability of commercial alloys, including 356/357, 380/383, 319, 206 and wrought alloys. Among the salient results:

• 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. 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 Si content (7.5-9.5%) limits the maximum volume fraction of the primary alpha phase (SSM structure) that can be achieved during commercial casting (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.

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.

Recommended Composition Window of 380 for Semi-solid Processing

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

Conclusion

Advances in alloy composition are enabling North American die casters to create innovative solutions to production requirements and improve processes for better efficiency and cost reduction. A wealth of additional information and research about die casting may be found on the NADCA website, www.diecasting.org. Another source of research information is the Advanced Casting Research Center at WPI, **www.wpi.edu/Academics/Research/ACRC/Research/**. ■

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Additional information was extracted from several articles and research papers.

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