WHITE PAPER

Using Custom Aluminum Alloys To Expand Die Casting Applications

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Introduction

Die casters trying to strike a balance between performance, price and product innovation are increasingly turning to the benefits of custom aluminum alloys to create the exact characteristics needed for a die cast part.

Custom alloys can deliver a variety of benefits, including increased strength, better corrosion resistance, increased wear resistance or improved thermal conductivity. Alloys can also be modified to affect the casting characteristics of the metal, improving production efficiency, or even to reduce the price of alloy compared to standard compositions.

The North American Die Casting Association (NADCA) has been involved in several research studies identifying various characteristics of specialized aluminum die casting alloys. NADCA in conjunction with Worcester Polytechnic Institute (WPI) has created i-Select Al software to help 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.

The research studies were funded by the Department of Energy through the Industrial Technologies Program (ITP) and the Cast Metals Coalition (CMC) and by the Department of Defense through the American Metalcasting Consortium (AMC). The software was produced with funding provided by the AMC and the North American Die Casting Association. The AMC Program is sponsored by the DOD Defense Supply Center Philadelphia, Philadelphia, PA and the Defense Logistics Agency, Ft. Belvoir, VA. The research studies and software development were conducted at Advanced Casting Research Center (ACRC) at the WPI.

Custom Alloy Examples

Aluminum alloy can be modified by changing the percentages of 10 alloying elements that are used in addition to aluminum in creating casting alloys. These elements are:

- Silicon
- Copper
- Iron
- Nickel
- Magnesium
- Chromium
- Zinc
- Manganese
- Titanium
- Strontium

One example of how custom aluminum alloys can be used to solve a design problem is the change made to a rack & pinion housing. The casting had a thin section and the light weight design was not meeting proof load with the standard 380 aluminum alloy composition. After studying the problem, a higher level of magnesium content was employed to achieve a higher tensile strength and meet the required proof load without having to revert back to a heavier casting with thicker cross sections.

Compared with designs based on standard 380 properties, this rack & pinion housing used 7% less aluminum and was 0.2 pounds lighter. The housing cast with the new alloy not only met the strength requirements, but at the current production demand, this translated to 30,000 pounds of aluminum alloy saved each year.

Reducing the amount of alloy not only reduced raw material costs, but there were energy savings of $45x10^6$ BTU's of energy on an annual basis because a smaller amount of material is used. This die caster buys molten metal so the energy savings do not include energy for melting. Plants that melt ingot would show greater energy savings!

Fan Housing Produced Using Thermalloy™

Other examples of improved performance from custom alloys include a marine manufacturer that reduced the copper content in aluminum alloy for improved corrosion resistance, or the development of Thermalloy™ which has a significantly higher thermal conductivity than previously used die casting alloys. Originally a custom alloy, Thermalloy™ has now become a standard specification in products requiring high thermal conductivity such as heat sinks.

Achieving equivalent casting properties with a less expensive alloy is another possibility with custom alloys. One die caster increased the iron, zinc and magnesium in an Al 380 style alloy and reduced the cost of the metal by three cents a pound, which was significant because the die caster was using 150 million pounds of aluminum alloy a year.

Production Characteristics

The physical properties of custom alloys are a primary consideration in formulating new chemistries. However, the casting characteristics also need to be factored into the equation.

One study supported by NADCA evaluated the ways die casters and designers could optimize aluminum die casting alloys to enhance mechanical and physical properties without necessarily sacrificing castability.

The study, "Casting Characteristics of Aluminum Die Casting Alloys," by M. Makhlouf and D. Apelian, Worcester Polytechnic Institute, evaluated five experimental alloys and commercial A380 alloy to determine four casting characteristics:

- Die soldering
- Sludge formation
- Fluidity
- Machinability

For purposes of the study, the researchers created alloys with the following composition:

Alloy No.	Composition* (%)										
	Si	Cu	Fe	Mn	Mg	Ni	Cr	Zn	Ti	Sr	Others Total
1	13.0	5.0	1.6	0.25	0.50	0.25	0.05	3.0	0.20	<0.02	0.50
2	7.0	1.25	0.7	0.50	0.05	0.05	0	3.0	0.20	0.02	0.50
3	13.0	5.0	1.2	0.50	0.25	0.25	0.05	3.0	0.20	<0.02	0.50
4	7.0	1.25	0.7	0	0.05	0.25	0.15	0.50	0	<0.02	0.50
5	7.0	1.25	0.7	0.25	0.05	0.05	0	3.0	<0.2	<0.02	0.50
A380.0	7.5-9.5	3.0-4.0	1.3	0.50	0.10	0.5	-	3.0	-	-	0.50

* Al - Balance

The study determined that the five experimental alloys had no major problem in die casting in terms of die soldering and sludge formation. The fluidity test suggested that the fluidities of these alloys are fairly comparable to those of A380 alloy. From the microstructure analysis it also can be predicted that these alloys should not have machining problems provided that appropriate machining technique and parameters are used. The study indicated that all of these alloys are suitable for die casting.

However, particular alloys require special treatment in some instances. For example, when the Fe and Mn contents of the alloys are small, precautions have to be taken against possible die soldering problems. Alloy #4, which contained 0.7%Fe and 0%Mn and was predicted to have high thermal conductivity, also had a high die soldering tendency. For this kind of alloy, the Fe and Mn contents should be kept at its allowable upper level and/or reduce Ni to a minimum.

Based on previous studies, Mn and Ni additions in the ranges of Mn 0-0.5% and Ni 0.05-0.5% do not affect the variation of the alloy thermal conductivity. So, for this alloy to keep the required thermal conductivity Mn can be raised to 0.25-0.5% and Ni can be reduced to a minimum.

More detailed information about this research can be found in the new NADCA "Turn Research Into Action" research report series, and the paper devoted specifically to cast materials. For further information, refer to: www.diecasting.org/research

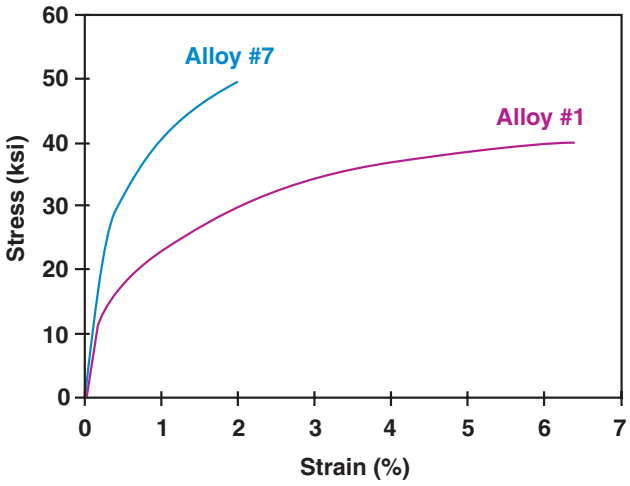
Evaluating Alloy Options

Like most design challenges, recommending a custom alloy requires balancing the alloy chemical content and benefits against the cost. As one die caster noted, the customer needs to be aware of the tradeoffs and feel comfortable that the solution is worth it. While the decision point may be different in each case, a 5% increase in strength may not be worth the additional cost.

Graphing the benefits of specific custom alloys is one way to show customers the flexibility available to die casters to meet specific strength requirements.

The curve below illustrates the way the data can be presented. This graph shows alloy 380 with two different magnesium compositions and plots stress versus strain for those alloys in a tensile test. Alloy #7 has higher magnesium content and exhibits a higher tensile strength than alloy #1, which has a more typical alloy 380 magnesium composition.

TYPICAL STRESS VS STRAIN CURVE



Additional Resources

Another source for providing customers with the benefits of custom alloys is the book "Alloy Chemistry-Microstructure-Properties Interactions in Aluminum Die Casting Alloys," by M. Makhlouf, L. Wang and D. Apelian that was published by the North American Die Casting Association. The work developed a series of optimizing equations that can be used to tailor alloy compositions for specific properties.

Research Paper, "A Study of Aluminum Alloy-Microstructure-Performance Interaction"

The following properties were measured:

Metallurgical Integrity	Mechanical Properties	Physical Properties
	Room Temperature	
SDTA/Cooling Curves	Tensile Strength, Yield Strength	Thermal Conductivity
Microstructure	Elongation, Charpy Impact, Fatigue	Electric Conductivity
Fracture Surface	Wear Resistance, Hardness	Specific Gravity
	Elevated Temperature	
Porosity & Inclusion	Tensile Strength, Yield Strength, Elongation	

Based on this research, several thousand data points were collected into a database identifying the influence of key elements on each property. The database enables the die caster to take advantage of the full potential of die casting alloys, and provides design engineers with additional data on die-cast parts.

This research was taken a step further with the development of NADCA's i-Select Al software. This software package allows the user to select an alloy from a comprehensive database of aluminum die casting alloy chemistries and properties covered by over 300 worldwide standards.

In the selection module, alloys are selected based on chemistry or desired mechanical and physical properties. The greatest power of the program lies in the prediction module which predicts the chemistry based on an input of desired properties, or vice-versa, predicts properties based on an input of alloy chemistry.

In addition to the program's extensive property database are casting characteristics, photomicrographs of representative microstructures, stress-strain curves, fatigue curves and cooling curves of select aluminum die casting alloys. For a demonstration of the i-Select Al software, visit: **http://www.diecasting.org/publications/215CD**

Conclusion

The use of custom aluminum alloys gives the die caster one more resource to help position the industry as a partner with designers and OEMs. Along with other methods, such as collaborative engineering and rapid tooling, recommendations about custom alloys can help solve customer problems and expand the market for die cast products.

Explaining the benefits of custom alloys is made easier for die casters through the various research projects supported by NADCA and the development of materials such as the i-Select Al software. ■

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Additional information was extracted from two research papers.

A Study of Aluminum Alloy-Microstructure-Performance Interaction
D. Apelian, M. Makhlouf and L. Wang
Worcester Polytechnic Institute

Casting Characteristics of Aluminum Die Casting Alloys
M. Makhlouf and D. Apelian
Worcester Polytechnic Institute

Based in Wheeling, IL, the North American Die Casting Association represents the world's most effective die casters creating the world's best cast products. The organization serves as the voice of the industry, promoting growth and enhancing its members' ability to compete domestically in the global marketplace.

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