Casting Solutions for Readiness Program

Development of Mechanical Properties for High Performance Die Casting Alloys for Specifications and Standards/ Design and Manufacturing Resources

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Beau Glim and Stephen Udvardy, NADCA
Stephen Midson, The Midson Group

Abstract

The objective of this project was to collect information from North American die casting companies on new alloy compositions that might exhibit better mechanical properties than conventional aluminum die casting alloys. Cast-to-size tensile bars were produced from these alloys, and mechanical properties measured in three tempers, as-cast, T5 heat treated (low temperature age) and T6 heat treated (solution heat treat, water quench and age).

End users of die castings are starting to utilize die castings for structural applications, and so structural modeling such as Finite Element Analysis (FEA) is becoming more common. However, die castings typically have a heterogeneous structure, and so tensile samples machined from actual castings can exhibit inferior properties to the cast-to-size tensile bars normally used to characterize properties. Therefore, a second objective of this project was to provide a comparison between the mechanical properties of cast-to-size tensile bars and bars machined from commercial castings. Production castings were made from the new alloy compositions, tensile bars machined from these castings, and mechanical properties measured. A third objective of this project was to seek Aluminum Association registration for alloy compositions found to provide better mechanical properties than the conventional die casting alloys.

The fourth and final objective of the project was to transfer information from the project to industry. Project information was transferred through various presentations to North American Die Casting Association (NADCA) Chapter regions, during plant visits, and at meetings and conferences. In addition, the mechanical property data generated in this study will be transferred to industry through incorporation in the NADCA Product Specification Standards for Die Castings, as well through inclusion in NADCA's educational webinars and classes.

1. Introduction

Die casting generally has the lowest production costs of all the methods for producing aluminum castings, and this is certainly true when production volumes are high. In general, however, the mechanical properties of conventional aluminum die casting alloys are relatively low. For example, Table 1 lists handbook data for commonly used aluminum die casting alloys. In addition, historically die castings have not been heat treated to increase and optimize strength, as air entrapped in the castings will expand during heating at elevated temperature, creating unacceptable blisters on the surface of the castings.

Table 1: *Handbook data for conventional aluminum die casting alloys*

Process	Alloy	UTS (ksi)	0.2% YS (ksi)	Elongation (%)
Die Casting	A380	47	23	3.5
	A360	46	24	3.5
	383	45	22	3.5
	384	48	24	2.5
Extruded	6061-T6	45	40	12-17

NADCA has been aware for some time of the limited mechanical properties of conventional die casting alloys, and has worked with universities on past American Metalcasting Consortium (AMC) projects (funded by the Defense Logistics Agency) to develop aluminum die casting alloys with improved mechanical properties. For example, data in Table 2 shows die casting alloys identified by researchers at Worcester Polytechnic Institute having improved mechanical properties. However, although the yield strengths of two alloys (AMC380* and AMC1045Sr) are significantly better than conventional A380, the elongation value of the four alloys listed in Table 2 are still of the same magnitude as conventional A380.

Table 2: *Mechanical property data for aluminum die casting alloys identified in previous AMC projects*[(1)]

Alloy	UTS (ksi)	0.2% YS (ksi)	Elongation (%)
A380	45.6	22.7	3.8
A380*	46.3	23.7	4.6
AMC380*	49.9	27.9	3.7
AMC1045Sr	53.4	35.2	2.3

Recently, however, individual die casting companies have also been developing their own aluminum alloy compositions that can provide improved mechanical properties. Many of these new alloys contain lower iron concentrations (<0.4%Fe), as iron is known to reduce ductility in aluminum alloys. Iron is added to conventional aluminum die casting alloys to minimize soldering (sticking) of the castings to the steel die, but recently manganese and strontium have also been shown to minimize soldering, and so, many of the new alloys have lower iron concentrations. One of the goals of this project, therefore, was to collect information from North American die casters on recently developed alloys, and to characterize the mechanical properties of these alloys.

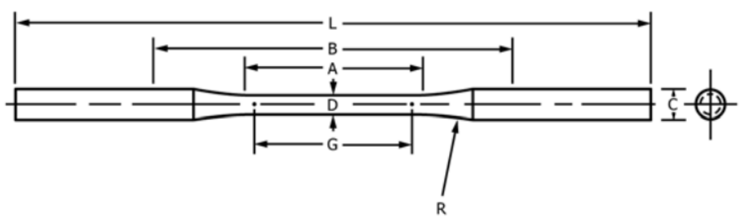
Recent research has also demonstrated that aluminum die castings can indeed be heat treated. In the USA, Midson and Brennan(2) have shown that the yield strength of conventional die casting alloys can be increased by close to 50% by simply giving the die castings a low temperature aging treatment (heat treating to the T5 temper). In addition, research out of Australia(3) has shown that die castings can be fully heat treated to the T6 temper (solution heat treatment + water quench + low temperature age) without blistering, as long as the time at the solution heat treatment temperature is kept short (typically 15 minutes at temperature or less). Published data for conventional aluminum die casting alloys heat treated to the T5 and T6 tempers are listed in Table 3, but again note that ductility values are ≤3.5%.

Table 3: *Mechanical properties of T5 and T6 heat treated conventional die casting alloys*

Alloy	Temper	UTS (ksi)	0.2% YS (ksi)	Elongation (%)	Reference
E380	T5	37	51	2.1	2
A360	T6	48-53	41-48	3.5	3
A380	T6	62-67	49-55	3	3

End users of die castings are starting to utilize these alloys with improved properties, and for structural applications many Original Equipment Manufacturers (OEMs) utilize structural modeling (such as FEA) to ensure that castings will meet required performance parameters. However, one problem with the die casting process is that properties of actual die castings, as measured by machining tensile bars from production castings, are often not the same as handbook data (which are generated from the cylindrical cast-to-size tensile bar shape shown in Figure 1). The reason for this difference is the non-uniform macrostructure obtained with die castings. As shown schematically in Figure 2, die castings tend to have a dense surface layer (about 0.020-inches thick), while the central portion of the die castings tends to be more heterogeneous in nature, containing some retained shrinkage and gas porosity. When the tensile bars are cast-to-size, the bars contain the dense surface around their circumference, but this dense surface is removed when the tensile bars are machined from production castings, and therefore samples machined from production castings tend to have lower strength and ductility (due to the retained porosity present in the central region of the die castings). Furthermore, the small cross-section of the cast-to-size bars cool very quickly and thicker sections in casting cool more slowly resulting in a larger grain structure. Typically, the faster the cooling rate and the finer the grain size, the higher the mechanical properties.

For modeling purposes, it is important that the mechanical properties of production die casting be accurately represented, and so another goal of this project was to compare mechanical properties of cast-to-size against machined tensile bars, to provide data to casters and OEMs that can be used when performing FEA structural modeling of die castings.



	Dimensions, in.
G—Gage length	2.000 ± 0.005
D—Diameter (see Note)	0.250 ± 0.005
R—Radius of filet, min	3
A—Length of reduced section, min	2¼
L—Overall length, min	9
B—Distance between grips, min	4½
C—Diameter of end section, approximate	⅜

Figure 1: *Dimensions of standard cylindrical cast-to-size tension test specimen for die castings (taken from ASTM B557, Figure 13)*

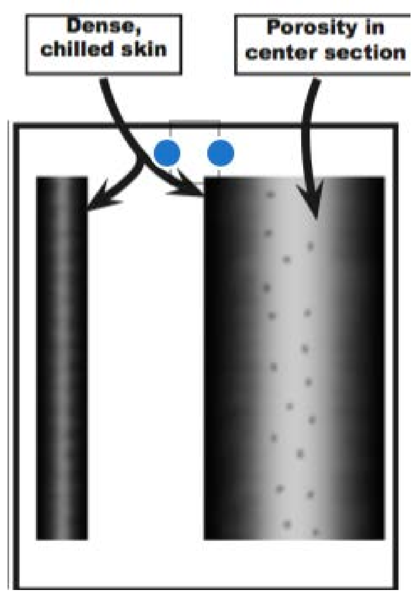


Figure 2: *Schematic drawing showing the dense skin and central porous region for thin-walled and thick-walled die castings*

For recently developed alloys identified at die casters that are shown to provide mechanical property benefits over the standard die casting alloys, another goal was to transfer information about the alloys and their properties to the industry. To make adoption of the alloys by designers of die castings and die casters as easy as possible, alloy chemistry and mechanical properties of the most beneficial alloys were to be added to the NADCA Product Specification Standards and registered with the Aluminum Association.

To summarize, the goals of this project were as follows:

1. Collect information from North American die casters on new alloy compositions that might exhibit better mechanical properties than conventional aluminum die casting alloys.
2. Die cast tensile bars of these alloys, and measure the mechanical properties of these cast-to-size tensile bars in both the as-cast and heat treated tempers.
3. Die cast production castings using these new alloys, machine tensile bars from these castings, and compare the mechanical properties of machined tensile bars to the cast-to-size tensile bars described in point 2 above.
4. Transfer information about the alloys to industry.

2. Experimental Procedures

2.1 Alloys and Compositions

Table 4 summarizes characteristics of alloys examined in this study. Nominal chemical compositions of the alloys are listed in Table 5.

Table 4: *Alloys examined in this study*

Alloy	Condition
A380 standard	Standard 380 alloy containing around 1% iron
E380	380-type alloy containing about 1% iron, but higher magnesium
F380	New low-iron version of 380
A360	Conventional 360 composition containing about 1% iron
B360	New low-iron version of 360
383	Standard 383 alloy containing around 1% iron
C383	New low-iron version of 383
384	Standard 384 alloy containing around 1% iron
D384	New low-iron version of 384
367	Low-iron die casting alloy developed by Mercury Castings
Gibbsalloy MN	Low iron, low silicon alloy available from Gibbs Die Casting
AlMg2MN	Low iron, low silicon alloy available from Gibbs Die Casting

2.2 Production of Cast-to-Size Tensile Bars

The cast-to-size tensile bars were produced at Premier Tool and Die Cast, located in Berrien Springs, MI. The tensile bar castings were produced using a die that produces several specimens for testing mechanical properties. A photograph of a full shot is shown in Figure 3, where the two tensile bar castings are identified by the red arrows. Note that these cast-to-size tensile bars have dimensions listed in Figure 1.

Table 5: *Nominal alloy compositions*

Alloy	Composition (%)									
	Si	**Cu**	**Mg**	**Fe**	**Mn**	**Zn**	**Ni**	**Ti**	**Sr**	**Other**
A380	7.5-9.5	3.0-4.0	0.1	1.3	0.5	3.0	0.5	-	-	0.5
High Mg A380	7.5-9.5	3.0-4.0	0.5	1.3	0.5	3.0	0.5	-	-	0.5
E380	7.5-9.5	3.0-4.0	0.30	1.3	0.50	3.0	0.5	-	-	0.5
F380	8.5-9.5	3.0-4.0	0.1-0.3	0.4	0.25-0.35	1.0	0.1	-	0.05-0.07	0.5
A360	9.0-10.0	0.6	0.4-0.6	1.3	0.35	0.50	0.50	-	-	0.25
B360	9.0-10.0	0.25	0.4-0.6	0.4	0.25-0.35	0.5	0.1	-	0.05-0.07	0.25
383	9.5-11.5	2.0-3.0	0.10	1.3	0.50	3.0	0.30			0.50
C383	9.5-11.5	2.0-3.0	0.1-0.3	0.4	0.25-0.35	3.0	0.5	-	0.05-0.07	0.5
384	10.5-12.0	3.0-4.5	0.10	1.3	0.50	3.0	0.5			0.50
D384	10.5-11.5	3.0-4.5	0.1-0.3	0.4	0.25-0.35	3.0	0.1	-	0.05-0.07	0.5
367	8.5-9.5	0.25	0.30-0.50	0.25	0.25-0.35	0.10	-	0.20	0.05-0.07	0.15
Low Si A365	9.5	0.03	0.1-0.5	0.15	0.5-0.8	0.07	-	0.04-0.15	0.005-0.02	0.1
Gibbsalloy MN	0.1-0.3	0.1	2.6-3.7	0.2-0.5	0.4-1.0	0.05	-	0.03-0.07	-	0.5
AlMg2MN	0.2-0.4	0.05	1.85-2.3	0.6-0.8	0.4-0.6	0	-	0.05	-	0.5

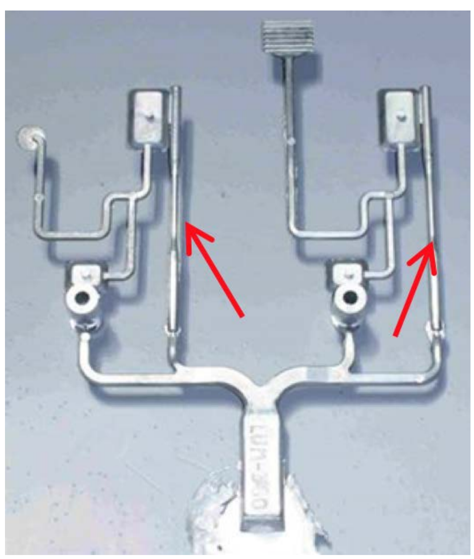


Figure 3: *Photograph of a full shot produced using the die at Premier Tool and Die Casting. The two cast-to-size tensile bars are identified by the red arrows*

2.3 Production of Machined Tensile Bars

Machined tensile bars were extracted from three commercial castings, produced at three aluminum die casting plants. The missile heat sink shown in Figure 4a was produced at Twin City Die Castings located in Minneapolis, MN, the moving sidewalk component shown in Figure 4b was produced at Falcon Lakeside Manufacturing in Stevensville, MI, and the drive shaft housing shown in Figure 4c was produced by Mercury Castings, located in Fond du Lac, WI.

a)

b)

c)

Figure 4: *Machined tensile bars were obtained from these three castings*

a) Missile heat sink produced at Twin City Die Castings

b) Moving sidewalk component produced at Falcon Lakeside Manufacturing

c) Drive shaft housing produced by Mercury Castings

The tensile bars were machined from the three production castings by Exova, located in Glendale Heights, IL. Exova (www.exova.com) is a commercial laboratory-based testing company, focusing on the processing and testing of metals and materials.

2.4. Heat Treatments

All heat treatments for the machined tensile bars were performed by Exova. A summary of the heat treatment conditions is listed in Table 6.

Table 6: *Summary of heat treatment conditions*

Alloy	Temper	Solution Heat Treatment	Cooling	Aging
A380, F380 & 367	T5	--	--	4 hrs at 356^{o}F
	T6	15 mins at 887^{o}F	Water quenched	4 hrs at 356^{o}F
B360	T5	--	--	4 hrs at 356^{o}F
	T6	15 mins at 887^{o}F	Water quenched	4 hrs at 356^{o}F
	T6	60 mins at 887^{o}F	Water quenched	4 hrs at 356^{o}F
	T6	90 mins at 887^{o}F	Water quenched	4 hrs at 356^{o}F

2.5 Tensile Testing

Tensile testing was also performed at Exova, following procedures outlined in ASTM E8.

3. Results/Discussion

3.1 Cast-to-Size Tensile Samples

As noted in Section 2.2, these cast-to-size tensile samples were produced at Premier Tool and Die Casting in the two-cavity die shown in Figure 3. Ten to fifteen bars of each alloy composition were cast and tested at Exova for strength and ductility. Average values for mechanical properties for a number of the die casting alloys are summarized in Table 7.

Table 7: *Average mechanical properties for cast-to-size tensile samples (note that the rows shaded in gray are handbook data and are shown for comparison purposes only)*

Alloy	UTS (ksi)	0.2% YS (ksi)	Elongation (%)
A380 standard	47.0	23.0	3.5
E380	45.8	27.2	3.0
E380-T5	46.7	39.3	1.2
F380	46.1	23.4	5.0
F380-T5	48.4	31.4	3.3
F380-T6	61.0	49.0	2.9
A360	46.0	24.0	3.5
B360	46.6	23.5	6.1
B360-T5	52.0	37.1	3.6
B360-T6	53.0	41.0	5.8
383	45.0	22.0	3.5
C383	45.8	23.7	4.5
384	48.0	24.0	2.5
D384	46.1	28.0	2.4
Gibbsalloy MN	30.6	15.9	12.1
Gibbsalloy MN-T5	32.5	18.5	11.7
AlMg2MN	29.1	15.4	10

More details on specific alloy-types are given below.

3.1.1 380-Type alloys

As summarized in Table 5, three 380-type alloys were examined in this study. A380 is the standard alloy used by most die casters in the USA (containing about 1% iron), and E380 is a similar alloy but with a higher magnesium concentration. F380 is a new variant of the alloy, containing a much lower iron content.

The data in Table 7 shows that, in the as-cast condition, E380 has a slightly higher yield strength than the conventional A380 alloy, most likely due to E380's higher magnesium content. After heat treating to the T5 temper, the yield strength of the E380 alloy significantly increases, while elongation is lower.

Due to the lower iron concentration of the F380 alloy (see Table 5), the ductility of the F380 alloy in the as-cast temper is much higher than either A380 or E380 (data in Table 7). After heat treating to the T5 and T6 temper, strength significantly increased, while ductility is lowered, but the ductility of the low-iron F380 alloy in the heat treated temper is only marginally lower than that of the as-cast conventional A380 alloy.

3.1.2 360-Type Alloys

As shown in Table 5, 360-type alloys have lower copper concentrations and higher magnesium contents as compared with 380-type alloys. Two 360-type alloys were evaluated in this study – A360 is the alloy commonly used in the die casting industry (containing around 1% iron), while B360 is the new low-iron version of the alloy.

Table 7 shows that, in the as-cast condition, the low-iron B360 alloy has a significantly higher ductility than the conventional A360 alloy. After heat treating to the T5 and T6 tempers, both the yield strength and tensile strength of the B360 alloy are increased. In the T5 temper, the B360 alloy had a similar ductility to as-cast A360, while in the T6 temper, both strength and ductility of the B360 alloy are higher than the as-cast A360 alloy.

3.1.3 383- and 384-Type Alloys

The nominal compositions of the 383- and 384-type alloys examined in this study are listed in Table 5. Both 383 and 384 contained about 1.0% iron, while the C383 and D384 alloys have a much lower maximum iron content of 0.4%. Mechanical properties of the three alloys are listed in Table 7. The low-iron C383 has slightly higher ductility than the conventional 383 alloy that contains about 1.0% Fe.

Surprising, the elongation value for the low iron version of 384 (alloy D384) was no better than the alloy with conventional iron concentration (alloy 384). The reason for this is not clear, but the D384 alloy contained a higher than targeted level of magnesium (0.57% as opposed to the target of 0.30%),which may have compromised elongation.

3.1.4 Gibbsalloys

The remaining two alloys listed in Table 7, Gibbsalloy MN and AlMg2MN, both have relatively low iron concentrations as well as very low silicon concentrations (Table 5), and so have extremely high ductility values (Table 7), both in the as-cast and T5 tempers. However, both alloys also exhibit lower strengths than the other die casting alloys listed in Table 5, and the Gibbsalloy MN only displayed a slight increase in strength after T5 heat treating.

As the strength of the two alloys from Gibbs Die Casting were relatively low, both in the as-cast condition and after heat treating, these two alloys were not carried forward to the second part of the study, to evaluate the properties of tensile samples machined from actual castings.

3.2 Tensile Samples Machined from Castings

This section describes the mechanical properties of tensile samples machined from the three commercial die castings shown in Figure 4.

3.2.1 Alloys A380 & E380

Tensile samples for these two alloys were machined from the heat sink samples produced at Twin City Die Castings (shown in Figure 4a). Castings were produced at four different magnesium concentrations, 0.03%, 0.16%, 0.3% and 0.5%. Note that the alloy containing 0.03% magnesium meets the alloy A380 compositional specification, while the alloy containing 0.3% magnesium is close to the maximum for the E380 specification. Mechanical properties in the as-cast condition are listed in Table 8, and they show that yield strength increases and ductility generally decrease as the magnesium concentration increases. The tensile strength is little impacted by the magnesium concentration.

Comparison of the mechanical properties of tensile samples machined from actual castings (data in Table 8) with the mechanical properties of cast-to-shape tensile samples (Table 7) shows that the machined samples have significantly lower values of tensile strength, while yield strength and elongation values for the machined samples are similar or only slightly lower.

Table 8: *Mechanical properties in the as-cast temper of A380 and E380 tensile samples machined from castings*

Mg-Concentration (wt%)	Temper	UTS (ksi)	0.2% YS (ksi)	Elongation (%)
0.03	As-cast	31.4	19.5	3.6
0.16	As-cast	29.3	22.8	2.7
0.3	As-cast	31.9	24.4	2.9
0.5	As-cast	31.9	27.8	2.1

Mechanical properties for the A380 and E380 alloy samples machined from castings after heat treating to the T5 condition are listed in Table 9. Except for the lowest magnesium concentration (0.03%), strength values after T5 heat treating were higher than for the as-cast condition, while elongation values were lower. Little strengthening after T5 heat treating was observed for the 380-type alloy containing 0.03% Mg, while the largest strength increase was observed for the alloy containing the highest magnesium concentration (0.5%).

Table 9: *Mechanical properties in the T5 temper of A380 and E380 tensile samples machined from castings*

Mg-Concentration (wt%)	Temper	UTS (ksi)	0.2% YS (ksi)	Elongation (%)
0.03	T5	26.4	20.4	2.5
0.16	T5	36.0	33.6	1.3
0.3	T5	37.1	36.7	1.0
0.5	T5	40.1	38.5	2.0

Mechanical properties for the E380 alloy samples machined from castings after heat treating to the T6 temper are listed in Table 10. Strength and ductility values are higher than the T5 temper data shown in Table 9.

Table 10: *Mechanical properties in the T6 temper of E380 tensile samples machined from castings*

Mg-Concentration (wt%)	Temper	UTS (ksi)	0.2% YS (ksi)	Elongation (%)
0.3	T6	42.3	40.3	2.0

3.2.2 Alloy B360

The tensile bars for the B380 alloy were machined from the drive shaft housing (Figure 4c) produced by Mercury Castings. Table 11 lists average mechanical property data in three tempers, and the results are summarized below.

- As-cast: A comparison of the data in Table 11 and Table 7 in the as-cast temper shows that the strength of the machined tensile bars is slightly lower than for the cast-to-size bars, while ductility values are similar
- T5 Temper: In the T5 temper, strength is again lower for the machined test bars (as compared with the cast-to-size bars), while in this case the elongation values are higher for the machined bars.
- T6 Temper: As shown in Table 11, three different solutions times were examined for the machined tensile bars, 15 minutes, 60 minutes and 90 minutes. Comparing mechanical properties for these three solution heat treatment times suggests that the 15 minute treatment was insufficient for adequate solutionization. Strength values increased, and elongation values decreased, when the solution heat treatment time was extended to 60 and 90 minutes.

Table 11: *Average mechanical property data for tensile bars machined from B360 die castings*

Temper	Solution Heat Treatment Time	UTS (ksi)	0.2% YS (ksi)	Elongation (%)
As-cast	--	36.0	20.6	6.0
T5	--	40.8	27.6	5.1
T6	15 mins	35.5	24.5	7.9
	60 mins	39.3	34.4	1.3
	90 mins	37.3	32.9	1.0

3.2.3 Alloy 367

Table 11 shows average mechanical property data for alloy 367 tensile bars machined from the drive shaft housing component. Only two tensile bars were machined for each heat treatment temper, and the data listed in Table 12 are the average of the two tests.

The ductility values of the as-cast samples are surprisingly low, while ductility is higher after both T5 and T6 heat treatments. Strength was also observed to increase after heat treatment. However, it would be expected that highest strength values would be obtained with the T6 heat treatment (rather than T5), which suggests that the T6 heat treatment used in this study did not achieve peak strength.

Table 12: *Average mechanical property data for tensile bars machined from 367 die castings*

Temper	UTS (ksi)	0.2% YS (ksi)	Elongation (%)
As-cast	27.3	16.8	3.0
T5	45.2	31.3	8.0
T6	30.6	20.7	7.0

3.2.4 Alloy F380

The tensile samples for the F380 alloy were machined from the moving sidewalk component produced at Falcon Lakeside Manufacturing (shown in Figure 4b). Initial evaluation of tensile bars cut from these castings showed that they contained relatively high levels of porosity, and so these samples were discarded and a second set of bars produced, which were x-rayed, and only samples containing lower levels of porosity were chosen for testing. Table 13 shows that the yield strength values of the machined tensile bars are similar to the cast-to-size data shown in Table 7, while tensile strength and elongation of the machined bars are lower. Similar to the cast-to-size bars, however, after T5 heat treating, yield strength of the machined tensile bars was found to increase, while elongation decreased.

Table 13: *Average mechanical property data for tensile bars machined from F380 die castings*

Temper	UTS (ksi)	0.2% YS (ksi)	Elongation (%)
As-cast	35.6	24.0	2.6
T5	35.4	33.1	1.4

4.3 Technology Transfer

Some initial data generated in this project has already been included in the 2015 edition of the NADCA Product Specification Standards for Die Castings (Figure 5 highlights Table 8 extracted from the 2015 edition). In addition, most of the data in this project is planned to be included in the upcoming 10th edition of the Product Specifications Standards, which will be published in 2018. A screen print of proposed information is shown in Figure 6. The NADCA Product Specification Standards for Die Castings has been formulated to assist both users of die castings (product designers and specifiers) as well as casters in the successful production and use of die cast components.

Over the course of this project, information on the project was transferred during NADCA technical committee meetings, NADCA conferences, NADCA Chapter presentations and member company visits as well as project update posting on the NADCA website. Projects updates were provided at 15 NADCA R&D Committee meetings. Presentations containing information on the project were provided at 4 NADCA conferences, over 45 NADCA Chapter meetings, and at several die casting companies.

In addition, the information generated in this project will be included in both webinars and face-to-face classes, both of which are designed to inform, educate and train producers and end users of die castings.

Alloy Data

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Table 6: Fatigue strength of experimental alloys as compare to A380. Specimens were separately die cast and tested using the R.R Moore rotating bending fatigue test.

Alloy	A380		A380*		AMC380		AMC1045Sr	
Cycles	$1x10^8$	$5x10^8$	$1x10^8$	$5x10^8$	$1x10^8$	$5x10^8$	$1x10^8$	$5x10^8$
Maximum stress (ksi)	22.6	22.1	20.4	20.1	23.3	22.5	24.4	24.1
Change vs. A380	–	–	-9.75%	-9.22%	+3.34%	+1.39%	+8.33%	+8.98%

Note: The experimental alloys were developed through research sponsored by NADCA, conducted at WPI, and funded by DOD/DLA. The properties shown do not represent design minimums and should be used for reference only.

Table 7: Composition of suggested alloys and company specific alloys as compared to A380

	Composition (%)									
	Si	Cu	Mg	Fe	Mn	Zn	Ni	Ti	Sr	Other
A380	7.5-9.5	3-4	0.1	1.3	0.5	3	0.5	-	-	0.5
High Mg A380	7.5-9.5	3-4	0.5	1.3	0.5	3	0.5	-	-	0.5
F380	8.5-9.5	3-4	0.1-0.3	0.4	0.25-0.35	1	0.1	-	0.05-0.07	0.5
B360	9.0-10.0	0.25	0.4-0.6	0.4	0.25-0.35	0.5	0.1	-	0.05-0.07	0.25
Gibbsalloy MN	0.1-0.3	0.1	2.6-3.7	0.2-0.5	0.4-1.0	0.05	-	0.03-0.07	-	0.5

Table 8: Tensile properties of separately die cast specimens of the suggested and company specific alloys compared to separately die cast specimens of alloy A380.

Alloy	UTS (ksi)	YS (ksi)	e (%)
A380	47.0	23.0	3.5
Hi Mg 380	45.8	27.2	3.0
Hi Mg 380-T5	46.7	39.3	1.2
F380	46.1	23.4	5.0
B360	46.6	23.5	6.1
B360-T5	52	37.1	3.6
Gibbsalloy MN	30.6	15.9	12.1
Gibbsalloy MN-T5	32.5	18.5	11.7

Note: This data was developed through research sponsored by NADCA and funded by DOD/DLA and NADCA. The properties shown do not represent design minimums and should be used for reference only.

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Figure 5: *A screen-print from the 9th edition of the NADCA Product Specification Standards for Die Castings published in 2015. Table 8 in the screen-print highlights data generated in this project*

Alloy Data

SECTION

3

Table 9: Tensile Properties of as-cast specimens removed from castings

Alloy	UTS (ksi)	UTS (MPa)	YS (ksi)	YS (MPa)	e (%)
A380	31.4	216	19.5	134	3.9
E380	31.9	220	24.4	168	2.9
F380	TBD	TBD	TBD	TBD	TBD
B360	35.9	248	30.6	211	6

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Table 10: Tensile Properties of heat treated specimens removed from castings

Alloy	UTS (ksi)	UTS (MPa)	YS (ksi)	YS (MPa)	e (%)
T5					
E380	37.1	256	36.7	253	1.0
F380	TBD	TBD	TBD	TBD	TBD
B360	40.8	281	27.6	190	5.1
T6					
E380	42.3	292	40.3	278	2.0
F380	TBD	TBD	TBD	TBD	TBD
B360	35.3	243	24.5	169	7.9

<u>Figure 6:</u> *Screen print of a page taken from the upcoming 10th edition of the NADCA Product Specification Standards for Die Castings, again highlighting data generated in this project*

4. Summary and Conclusions

1. In general the mechanical properties of conventional aluminum die castings are relatively low, especially when compared with other aluminum fabrication processes. In additional, historically die castings have not been heat treated to optimize properties, further limiting mechanical performance.

2. In the past NADCA has worked with universities to develop new die casting alloys with better properties. This has been partially successful, as new compositions have been identified with higher strength values, but elongations are still typically limited to 4% or so.

3. However, North American die casters have also been developing their own compositions that exhibit improved properties. One of the objectives of this project was to collect mechanical property data from North American die casters. These casters have also been utilizing recently developed data that allow die casting properties to be improved through the use of heat treatment.

4. In addition, as end users of die castings are starting to utilize die castings for structural applications, structural modeling is becoming more common. However, die castings typically exhibit heterogeneous structures, and so tensile samples machined from actual castings often exhibit inferior properties to the machined-to-size tensile bars normally used to characterize properties. Therefore, one of the goals of this project is also to provide a comparison of the mechanical properties of cast-to-size tensile bars with bars machined from commercial castings.

5. Information on the project was transferred during NADCA technical committee meetings, NADCA conferences, NADCA Chapter presentations and member company visits as well as project update posting on the NADCA website.

6. To summarize, the goals of this project were as follows:
   a) Collect information from North American die casters on new alloy compositions that might exhibit better mechanical properties than conventional aluminum die casting alloys.
   b) Die cast tensile bars of these alloys, and measure the mechanical properties of these cast-to-size tensile bars in both the as-cast and heat treated tempers.
   c) Die cast production castings, machine tensile bars from these castings, and compare the mechanical properties of machined tensile bars to the cast-to-size tensile bars described in point 2 above.
   d) Transfer information about the alloys to industry.

7. The table below summarizes the mechanical property data generated in this study.

Alloy	Temper	Cast-to-Size Tensile Bars	Tensile Bars Machined from Castings
A380	F	Handbook data	Yes
E380	F	Yes	Yes
	T5	Yes	No
F380	F	Yes	Yes
	T5	Yes	Yes
	T6	Yes	No
B360	F	Yes	Yes
	T5	Yes	Yes
	T6	Yes	Yes
367	F	No	Yes
	T5	No	Yes
	T6	No	Yes
Gibbsalloy MN	F	Yes	No
AlMg2MN	F	Yes	No

8. Two alloys, considered to yield the most advantageous properties, have been registered with the Aluminum Association as F380 and B360.

9. The mechanical property data generated in this study will be transferred to industry through incorporation in the NADCA Product Specification Standards for Die Castings, as well as including in educational webinars and classes.

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