NEW HEAT TREATMENT FOR

Al HIGH PRESSURE DIE-CASTINGS

Conventionally produced aluminum alloy high pressure die-castings containing normal porosity levels can be successfully heat treated without incurring surface blistering, and can have a large response to age hardening resulting in substantial improvement in tensile properties.

R.N. Lumley, R.G. O'Donnell, D.R Gunasegaram, and M. Givord
CSIRO Manufacturing and Infrastructure Technology
Victoria, Australia

High pressure die-casting (HPDC) is a popular, cost-effective method for mass producing metal components where physical dimensions must be accurately replicated and surface finish is important. Approximately half of all castings worldwide made of aluminum alloys are manufactured this way, and are used for a wide range of automotive parts and other consumer goods.

Two features of the conventional HPDC process are high turbulence experienced by the shot of molten metal as it is forced at high speed into a die and the very rapid rate at which it solidifies. The castings, therefore, usually contain internal pores comprising entrapped gases such as air, hydrogen, and vapors formed by the decomposition of organic die-wall lubricants. Metal shrinkage during solidification and planar defects such as oxide skins and cold shuts can also result in porosity.

While some level of porosity in die castings is normally accepted, a major disadvantage of porosity is that components cannot subsequently be heat treated at high temperatures. The pores expand during solution treatment (e.g., at 540°C, or 1000°F, for 8h) resulting in unacceptable surface blistering. Furthermore, the dimensions of die cast parts can change due to swelling and mechanical properties are adversely affected.

Common aluminum alloys for HPDC are based mainly on the Al-Si system, with the most common examples being AA360 (Al-9.5Si-0.5Mg) and AA380 (Al-8.5Si-3.5Cu). Table 1 lists the chemical composition ranges for these alloys. Microstructures of these alloys are similar and comprise aluminum grains in a matrix of Al-Si eutectic. The presence of Cu, Fe, and other elements such as Mn introduce fine intermetallic compounds, which are normally dispersed among the eutectic. Both alloys may contain potent age hardening elements copper and magnesium to enhance age hardening via heat treatment. In both conventional wrought and cast heat-treated products, strengthening precipitate phases such as θ′ (Al_2Cu), S (Al_2CuMg) and β′ (Mg_2Si) form within the aluminum grains and provide an impediment to the process of crystallographic slip. Although up to 3% Zn is permissible in some 380 alloy variants, there is insufficient magnesium present to form substantial quantities of Zn-containing precipitates.

CSIRO Light Metals Flagship has developed a novel heat treatment whereby conventional high pressure die-castings made of alloys 360 and 380 can be heat treated at high temperatures without incurring blistering problems[1]. The alloys may then respond to age hardening resulting in significant improvements in mechanical properties. In addition, tensile properties are

Aluminum diecast samples being loaded into furnace for heat treating

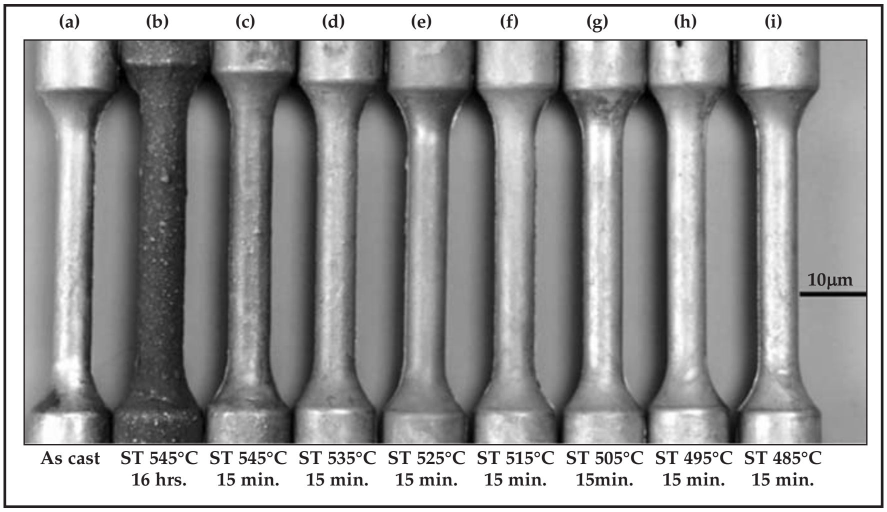

Fig. 1 — Surface appearance of Al alloy 360 HPDC tensile specimens in the as-cast condition and after different solution treatment schedules.

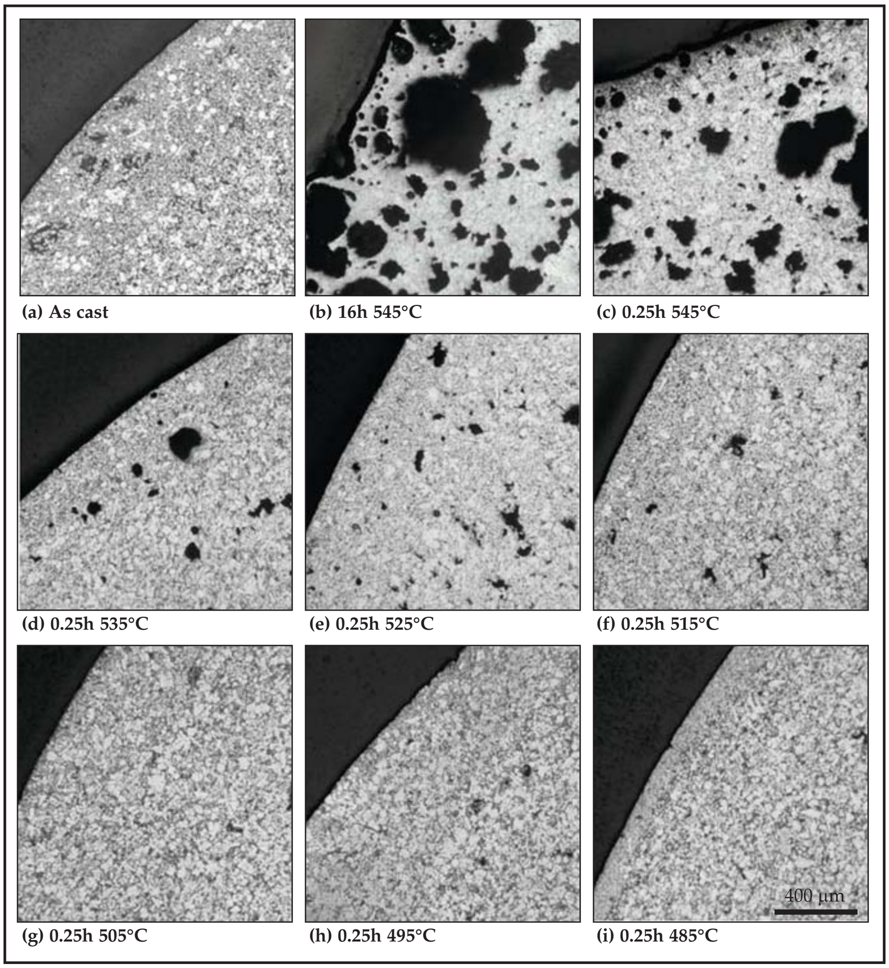

Fig. 2 — Microstructures of the Al 360 alloy in the different heat treated conditions shown in Fig. 1. Etchant: 0.5% HF.

maximized via modifications to the composition of alloy 380. Results of the development work are described in this article.

Experimental

HPDC alloy specimens for tensile testing were produced using a Toshiba horizontal cold chamber die casting machine with a 250 metric ton locking force and a 50-mm diameter by 400-mm long (2 by 15.75 in.) shot sleeve. Three tensile specimens (two cylindrical and one flat) conforming to specification AS1391were produced from each shot. Cylindrical bars were ~5.55 mm in diameter by 100 mm long with a central parallel gauge length 33 mm long. Flat specimens were 70 mm long by 14 mm wide and 3 mm thick with a central gauge length of 30 mm and width of 5.65 mm. Tensile properties were determined for the as-cast condition and two heat treated (modified T4 and modified T6 tempers) conditions.

Results and Discussion

Aluminum alloy 360 (Al-9Si-0.7Fe-0.6Mg-0.3Cu-0.2Zn-0.1Mn) specimens used to develop the heat treatment of HPDCs are shown in Fig. 1. Compared with the as-cast specimen (Fig. 1a), the conventionally heat treated cast specimen (Fig. 1b) shows severe surface blistering, pore expansion, and discoloration, as well as significant dimensional changes. Blistering is substantially reduced and eventually completely eliminated as the temperature and time of solution treatment are decreased; samples solution treated at or below a temperature of 525°C (~975°F) for 15 minutes have no blistering or dimensional instability. Corresponding photomicrographs of sample cross sections are shown in Figure 2. The appropriate duration for solution treatment of the HPDCs to achieve an adequate subsequent hardening response without substantial blistering is less than 30 minutes at the selected solution treatment temperature.

Hardnesses of samples in Fig. 2 given an age hardening heat treatment at 180°C (355°F) are shown in Figure 3. Even though the time of solution treatment is short and the solution temperature is low compared with other Al-Si-Mg alloys (such as 356 or 357), the response to age hardening is very strong, showing little variation among the different solution treatment temperatures used. Also, the hardness levels reached suggested that good levels of tensile properties should be readily achievable.

Batches of five or ten tensile samples for alloy 360 were prepared in T6 conditions and compared to as-cast sam-

Table 1 — Chemical compositions of the common high pressure die-casting alloys 360 and 380

Composition, wt% (balance Al)	360	A360	380	A380	B380	C380	D380
Si	9–10	9–10	7.5–9.5	7.5–9.5	7.5–9.5	7.5–9.5	7.5–9.5
Fe	2.0 max	1.3 max	2 max	1.3 max	1.3 max	1.3 max	1.3 max
Cu	0.6 max	0.6 max	3.0–4.0	3.0–4.0	3.0–4.0	3.0–4.0	3.0–4.0
Mn	0.35 max	0.35 max	0.5 max	0.5 max	0.5 max	0.5 max	0.5 max
Mg	0.4–0.6	0.4–0.6	0.1 max	0.1 max	0.1 max	0.1–0.3	0.1–0.3
Ni	0.5 max	0.5 max	0.5 max	0.5 max	0.5 max	0.5 max	0.5 max
Zn	0.5 max	0.5 max	3.0 max	3.0 max	1.0 max	3.0 max	1.0 max
Sn	0.15 max	0.15 max	0.35 max	0.35 max	0.35 max	0.35 max	0.35 max
Other elements (total)	0.25 max	0.25 max	0.5 max	0.5 max	0.5 max	0.5 max	0.5 max

ples. All heat treated samples were free from blisters or dimensional instability. Test results for samples made using two different shot velocities (velocity of the molten metal at the in-gate) are shown in Table 2. In the T6 condition, 0.2% proof stress and ultimate tensile strength increased 80% and 20%, respectively, with a small reduction in average ductility.

Similar heat treatment procedures were developed for a 380 type alloy (Al-8.8Si-0.86Fe-3Cu-0.2Mn-0.22Mg-0.59Zn) made from secondary alloy. Solution treatment temperatures between 530 and 440°C (985 and 825°F) for a time of 15 minutes were examined, followed by age hardening at a temperature of 150°C (300°F). Blistering occurred at all temperatures above 490°C (915°F). Hardness values of the samples are shown in Fig. 4; a solution treatment temperature of 490°C produced the optimum hardness values. Even for solution treatment temperatures as low as 440°C, there still is a good response to age hardening. Tensile results for both types of samples cast at two different shot velocities and solution treated at different temperatures are shown in Table 3. In general, the higher shot velocities produce moderately better mechanical properties.

Table 2 – Tensile properties of alloy 360 in the as-cast and T6 conditions

Sample	Solution treatment	Ageing	0.2% proof stress, MPa	Tensile strength, MPa	Elongation, %
HPDC 26 m/s	N/A	N/A	162	253	2
HPDC 26 m/s	515°C 15 minutes then CWQ	180°C 2h	302	326	1
HPDC 82 m/s	N/A	N/A	178	310	3.5
HPDC 82 m/s	515°C 5 minutes then CWQ	180°C 2h	333	404	3

Following on from these initial trials, batches of alloy samples having other compositions were tested. The compositions evaluated are shown in Table 4.

Cylindrical test pieces were used for development of mechanical properties, and were tested in the as-cast, as-solution treated and immediately tested, and in the T4 (14 days at 25°C, or 75°F) and T6 conditions. Test results are summarized in Figure 5, showing the relationship between 0.2% proof strength and ductility. Universally, the as-solution treated material displays a lower 0.2% proof stress than the as-cast material, but a substantially higher

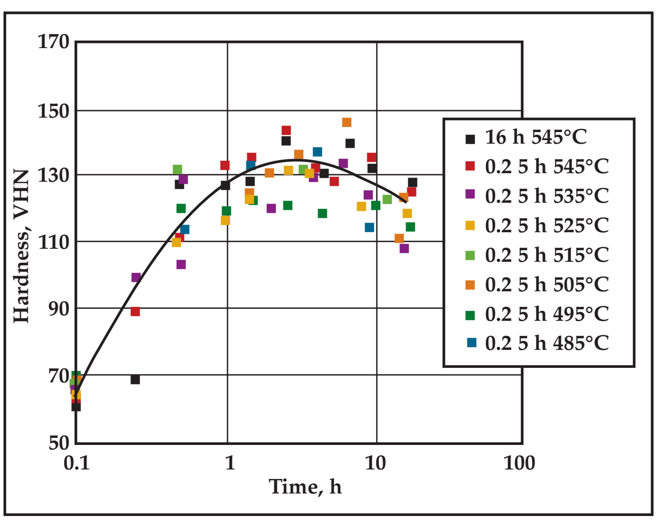

Fig. 3 — Hardness-time curves for Al alloy 360 aged at a temperature of 180°C following solution treatment at different times and temperatures.

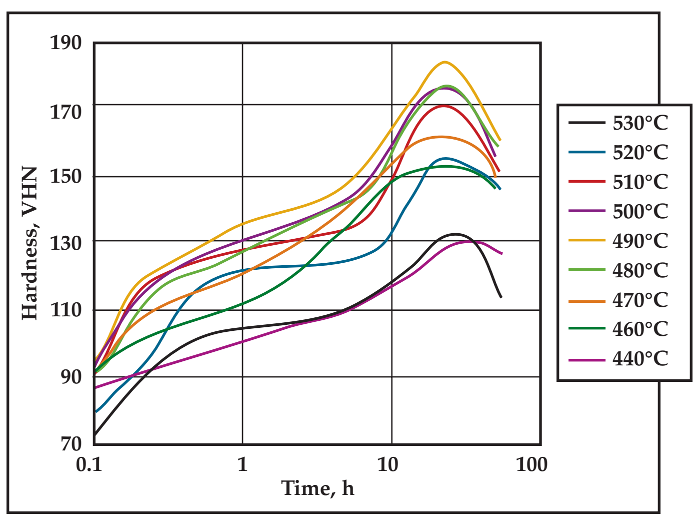

Fig. 4 — Hardness-time curves for Al alloy 380 solution treated at different temperatures for 15 minutes and aged at a temperature of 150°C.

Table 3 — Effect of specimen size, metal velocity and solution treatment temperature

Condition	Solution treatment temperature, °C	Surface condition	0.2% Proof stress, MPa	Tensile strength, MPa	Elongation, %
Cylindrical test bars, 26 m/s, as cast	N/A	Excellent	167	281	2
Cylindrical test bars, 82 m/s, as cast	N/A	Excellent	164	326	3
Cylindrical test bars, 26 m/s, T6	490	Good (occasional minor blisters)	363	366	1
Cylindrical test bars, 82 m/s, T6	490	Excellent	394	428	1
Flat test bars, 26 m/s, as cast	N/A	Excellent	182	277	2
Flat test bars, 26 m/s, T6	490	Some blisters	368	385	1
	480	Good	371	401	1
	470	Excellent	347	362	1
	460	Excellent	335	359	1
	440	Excellent	283	338	1.5
Flat test bars, 82 m/s, as cast	N/A	Excellent	187	320	2.5
Flat test bars, 82 m/s, T6	490	Excellent	392	432	1.5
	480	Excellent	394	442	2
	470	Excellent	372	418	1.5
	460	Excellent	341	405	2
	440	Excellent	285	362	2

Table 4 — Alloys examined for evaluation of CSIRO's novel heat treatment

Composition, wt% (balance Al)	Alloy 1 380 spec	Alloy 2 380 spec	Alloy 3 380 spec	Alloy 4 380 spec	Alloy 5 380 spec
Si	9.0	9.2	9.1	8.6	8.6
Fe	0.86	0.9	0.86	0.93	1
Cu	3.1	3.11	3.2	3.6	3.6
Mn	0.16	0.16	0.14	0.18	0.2
Mg	0.1	0.09	0.29	0.1	0.3
Ni	0.11	0.11	0.11	0.11	0.11
Zn	0.53	2.9	0.6	0.53	0.53
Other elements (total)	<0.2	<0.2	<0.2	<0.2	<0.2
Figure 5 legend					

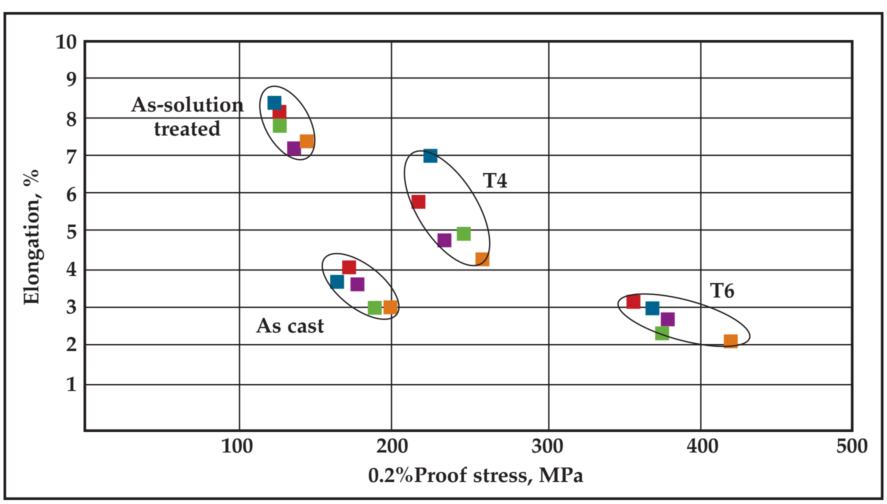

Fig. 5 — Properties of the alloys shown in Table 4 comparing the 0.2% proof stress and elongation for the as-cast, as solution treated, T4, and T6 conditions.

elongation. The T4 temper produces higher 0.2% proof strengths, still with higher levels of elongation than the as-cast material. The T6 temper produces material typically having double the 0.2% proof strength of the as-cast alloy, with elongation values similar to the as-cast condition.

Comparing Experimental vs. Industrial Results

Robustness of the treatment was examined using six different production parts purchased from industry in batches of either 75 or 100. Components having differing levels of shape complexity weighed between 50 and 550 g (1.76 and 19.4 oz.), had wall thicknesses between 1.5 to 16 mm (0.06 and 0.6 in.), and included both structural and nonstructural parts. Parts were not screened (such as by x-ray evaluation) before delivery. In the as-cast condition, the parts were all classified as being between "utility grade (1)" and "commercial grade (3)" according to the NADCA guidelines on surface quality [2]. X-ray evaluation of all parts prior to heat treatment showed almost all had substantial quantities of porosity throughout the microstructure ranging up to several millimeters in size.

Blister-free heat treatments were

adapted to the part size and complexity to provide hardness similar to the laboratory specimens. The critical parameters for heat treatment were the length of time spent within the appropriate temperature range (e.g., 420 to 490°C, or 790 to 915°F) and the maximum temperature reached, rather than the total time spent at the maximum temperature of that range. That is, the appropriate solution treatment procedures for the alloys were effective even if they were largely non-isothermal.

For some components displaying high levels of blister-forming porosity (especially in thin-walled sections), the maximum temperature also required reduction toward the lower limits of the solution treatment window (e.g., 440°C, or 825°F). This, however, was still sufficient to produce a good age hardening response as indicated by hardness levels of the parts and by the comparable properties shown in Table 3 for tensile test pieces.

Using the NADCA classification system for surface quality as a guide, less than 1% of these components were classified as rejects due to blistering after heat treatment, maintaining the same high levels of surface quality and functionality as in the as-cast parts.

The new heat treatment for HPDCs provides major property improvements over the as-cast condition, and compares very favorably with other age-hardenable cast and wrought light alloys. Heat treatment of conventionally produced HPDCs has some requirements that are unique to this process. Because HPDCs are produced in high volumes, often as a continuous process with several parts being manufactured per minute, batch processing is not considered to be practical for heat treatment of components, except when using facilities such as fluidized beds. However, the schedules developed fit very well with the capabilities of continuous heat treatment belt furnaces, and, therefore, could be used in-line with a typical die-casting cell in some cases.

Because the new technology can substantially increase the strength of HPDC components, there is the possibility they may be redesigned with substantially less metal. Additionally, the ability to heat treat HPDCs means they can replace more costly gravity and low-pressure castings, and even some wrought products.

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For more information: R.N. Lumley, Light Metals Flagship, CSIRO Manufacturing and Infrastructure Technology, Private Bag 33, Clayton South MDC, Victoria 3169, Australia; e-mail: roger.lumley@csiro.au; Internet: www.csiro.au.