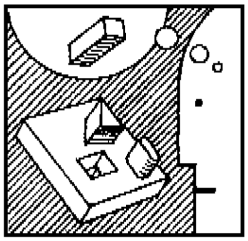
EVALUATING MATERIALS & PROCESSES

An introductory guide to die casting as an optimum process and material choice for the production of engineered components

Prepared for OEM designers, specifiers and purchasers by the Diecasting Development Council

Bulletin No. 1



The expanding range of materials and manufacturing processes open to designers of engineered products has made selection of the optimum production alternative more complex and demanding.

To aid OEM product designers and engineers who are concerned with the optimum material-process decision for their products, this bulletin provides an update on the high-pressure die casting process and the latest die casting alloy properties data.

1. Finding the Right Material and Process Fit

Material developments and important changes in process technology have created new options for product design decision-making.

Along with the introduction of new die casting alloys, methods now being used to produce these alloys have been modified to reduce impurities and improve overall metal quality, with greatly reduced energy consumption.

As post-use recyclability of product parts has become increasingly important in product design, the long-established recycling of die casting alloys has emerged as a new material and process consideration. A worldwide metals reclamation infrastructure has been operative for more than 30 years.

The die casting process itself has been researched and systematically quantified in terms of thermodynamics, heat transfer and fluid flow parameters. This technology has been transferred to the die casting industry, where its use has made a significant improvement in the design of die casting dies and in casting techniques.

Die casting machines today have been fitted with new, high-technology electronic systems that control production processes according to those parameters and continuously monitor production output. Casting accuracy is greatly improved, variations from casting-to-casting are sharply reduced, and production costs are more closely controlled.

Mechanical Requirements

Die casting materials are precisely formulated metal alloys which offer the mechanical properties of medium-strength metals. They are generally several times as strong and many times more rigid than plastics, and their mechanical properties compare favorably with powdered iron, brass, and screw-machined steel.

The ZA die casting alloys offer excellent bearing properties. In some applications designers have been able to incorporate bearings into their components, eliminating bearings that were formerly fabricated separately and inserted.

Product Strength

The product-strength equation contains two key factors: material strength and product configuration. Die casting alloys offer a wide range of as-cast material strengths, ranging as high as 60,000 ksi (415 MPa) ultimate tensile. The designer can usually develop sufficient strength in critical features simply by providing adequate wall thickness. Where additional strength is required, reinforcing features such as ribs, flanges, and locally thickened sections can be accurately computed and precisely cast.

The die casting process allows the product designer freedom to create extremely intricate contours, varying wall thicknesses over various sectors of the product. Where strength requirements are minimal, high-tech die casting processes are producing components with ultra-thin walls. The designer thus has much more latitude with die castings than with plastics, powdered metals, or stampings to design relatively thick walls for strength in some areas, and very thin walls for conserving material in others.

Rigidity

Component rigidity is analogous to strength; it is a function of both the modulus of elasticity of the material and the configuration of the component. Rigidity is, therefore, achieved in the same way as strength: by utilizing adequate wall thickness and adding appropriate reinforcing features.

Large size die castings that are designed primarily for rigidity, which is essential to minimize noise and vibrations, are being used for clutch and transmission housings in passenger cars and light trucks. On the other end of the scale, a die cast carrier for a high-speed printer is selected over filled plastics because it maintains precise alignment under high G-

A complete discussion of die casting material alternatives and their performance characteristics, the considerations which the design engineer must weigh in relation of any production process, and the specific product design factors which relate to the die casting process are covered in the DDC Design Manual, "Product Design for Die Casting." See information in the DDC INSTANT FAX LINE Document Listing Sheet or at the end of this bulletin.

loads, at a weight of three ounces.

Impact and Dent Resistance

Impact resistance is the ability of a component to withstand an impact load without fracture. It is a function of the material impact strength and the configuration of the component, particularly the feature that is impacted.

Dent resistance is the ability of a component to withstand an impact load without undergoing permanent deformation. The moderate-to-high yield strength and low (compared with iron and steel) modulus of elasticity of die casting alloys allow the designer to develop die castings with surprisingly high dent resistance.

The impact and dent resistance of large die castings has been proven in the rugged drivelines of four-wheel drive vehicles. Medium-size die castings display similar properties in hand-operated portable power tools. Small die castings, such as scale-model cars and trucks, routinely survive impacts that are totally unpredictable.

Fatigue Strength

Under cyclic loading, a component can fail at stresses much lower than predicted by tensile strength values. Cyclic loading in metals causes minute cracks that spread, and usually join, reducing the load-carrying area of the section. When the area has been reduced to the point where it will no longer support the load, the component fractures.

The fatigue strength of a part is a function of the fatigue strength of the material and the design of the component. Fatigue strength has been documented for most die casting alloys. These published values are usually conservative and allow for casting variables such as porosity.

Die castings can be successfully used in fatigue applications by following appropriate design procedures, most of which apply to all materials. High-tech die casting processes may improve component fatigue performance by minimizing the minor casting defects that initiate fatigue.

2. The Working Environment: Expecting the Unexpected

A thorough review of the working environment often uncovers unexpected factors that affect the optimum material decision.

For example, peak operating temperatures in an environment may exceed the recommended limit for an otherwise desirable die casting alloy. However, if a temperature-time profile indicates that the peak temperatures are of relatively short duration, the alloy may be satisfactory.

Or the components may conduct fluids that limit the actual temperature to substantially lower levels, which are within the functional range of the desired alloy.

Operating Temperature

When operating temperatures approach the upper limits of the acceptable operating range, the designer must give extra attention to critical details. Features with high loads, such as attachment points, or locations with concentrated loads may require special design techniques to reduce long-term stresses.

Die cast components are operating at temperatures beyond the range indicated by laboratory research. For example, because of careful attention to design details in critical areas, small gasoline engines used on lawn mowers operate satisfactorily at elevated temperatures.

Environmental Exposure

Die cast components are routinely exposed to moisture that can cause galvanic corrosion and to chemicals that can attack the metal. Aluminum alloys exhibit very high resistance to many types of atmospheric corrosion, because a minute amount of initial corrosion forms a tight coating that effectively excludes the corrosive agent. The resistance to atmospheric corrosion of zinc and magnesium alloys has been sharply increased by limiting certain impurities to extremely low levels, making them equivalent to aluminum alloys in some applications.

Where the exposed, uncoated die casting does not offer adequate corrosion resistance, effective, low-cost finishing systems can substantially reduce or virtually eliminate corrosion. Many such systems also offer decorative value.

Design guidelines for corrosion protection and galvanic reactions are usually based on extreme laboratory conditions, and are thus conservative. In many cases, die castings are operating with no corrosion protection in environments where laboratory tests indicate it may be necessary. For example, die cast wheels are performing satisfactorily with minimal corrosion protection on wheelchairs that operate outdoors in salt-laden conditions.

Stress Over Time

All of the materials commonly used in consumer products are subject to creep and stress relaxation at elevated temperatures. Most plastics experience these phenomena at room temperature. The tendency for creep and relaxation in a die casting depends upon the alloy, with zinc alloys being most subject and aluminum least.

The occurrence and severity of these phenomena are a function of the combined effects

Material Properties Comparison

Aluminum Die Casting Alloys

Typical values based on "as-cast" characteristics for separately die cast specimens, not specimens cut from production die castings.

Mechanical Properties

	Aluminum Alloys										
Designation	**360.0**	**A360.0**	**380.0**	**A380.0**	**383.0**	**384.0**	**B390.0**	**413.0**	**A413.0**	**C443.0**	**518.0**
Ultimate Tensile Strength											
ksi	44	46	46	47	45	48	46	43	42	33	45
(MPa)	(300)	(320)	(320)	(320)	(310)	(330)	(320)	(300)	(290)	(230)	(310)
Tensile Yield StrengthⒶ											
ksi	25	24	23	23	22	24	36	21	19	14	28
(MPa)	(170)	(170)	(160)	(160)	(150)	(170)	(250)	(140)	(130)	(100)	(190)
Compressive Yield StrengthⒷ											
ksi (MPa)	—	—	—	—	—	—	—	—	—	—	—
Elongation											
% in 2 in. (51 mm)	2.5	3.5	3.5	3.5	3.5	2.5	<1	2.5	3.5	9.0	5.0
Hardness											
BHN	75Ⓒ	75Ⓒ	80Ⓒ	80Ⓒ	75Ⓒ	85Ⓒ	120Ⓒ	80Ⓒ	80Ⓒ	65Ⓒ	80Ⓒ
Shear Strength											
ksi	28	26	28	27	—	29	—	25	25	19	29
(MPa)	(190)	(180)	(190)	(190)		(200)		(170)	(170)	(130)	(200)
Impact Strength											
ft-lb	—	—	3	—	3Ⓔ	—	—	—	—	—	7
(J)			(4)		(4)						(9)
Fatigue Strength											
ksi	20Ⓓ	18Ⓓ	20Ⓓ	20Ⓓ	21Ⓓ	20Ⓓ	20Ⓓ	19Ⓓ	19Ⓓ	17Ⓓ	20Ⓓ
(MPa)	(140)	(120)	(140)	(140)	(145)	(140)	(140)	(130)	(130)	(120)	(140)
Young's Modulus											
psi x 10^6	10.3	10.3	10.3	10.3	10.3	—	11.8	10.3	—	10.3	—
(GPa)	(71)	(71)	(71)	(71)	(71)		(81.3)	(71)		(71)	

Physical Properties

Designation	**360.0**	**A360.0**	**380.0**	**A380.0**	**383.0**	**384.0**	**B390.0**	**413.0**	**A413.0**	**C443.0**	**518.0**
Density											
lb/in^3	.095	.095	.099	.098	.099	.102	.098	.096	.096	.097	.093
(g/cm^3)	(2.63)	(2.63)	(2.74)	(2.71)	(2.74)	(2.82)	(2.73)	(2.66)	(2.66)	(2.69)	(2.57)
Melting Range											
°F	1035-1105	1035-1105	1000-1100	1000-1100	960-1080	960-1080	950-1200	1065-1080	1065-1080	1065-1170	995-1150
(°C)	(557-596)	(557-596)	(540-595)	(540-595)	(516-582)	(516-582)	(510-650)	(574-582)	(574-582)	(574-632)	(535-621)
Specific Heat											
BTU/lb°F	.230	.230	.230	.230	.230	—	—	.230	.230	.230	—
(J/kg°C)	(963)	(963)	(963)	(963)	(963)			(963)	(963)	(963)	
Coefficient of Thermal Expansion											
μ in./in./°F x 10^{-6}	11.6	11.6	12.2	12.1	11.7	11.6	10.0	11.3	11.9	12.2	13.4
(μ m/m°K)	(21.0)	(21.0)	(22.0)	(21.8)	(21.1)	(21.0)	(18.0)	(20.4)	(21.6)	(22.0)	(24.1)
Thermal Conductivity											
BTU/ft hr °F	65.3	65.3	55.6	55.6	55.6	55.6	77.4	70.1	70.1	82.2	55.6
(W/m°K)	(113)	(113)	(96.2)	(96.2)	(96.2)	(96.2)	(134)	(121)	(121)	(142)	(96.2)
Electrical Conductivity											
% IACS	30	29	27	23	23	22	27	31	31	37	24
Poisson's Ratio	0.33	0.33	0.33	0.33	0.33	—	—	—	—	0.33	—

n/a = data not available Ⓐ 0.2% offset Ⓑ 0.1% offset Ⓒ 500 kg load, 10mm ball Ⓓ Rotary Bend 5 x 10^8 cycles Ⓔ in./in./m/m Ⓕ Notched Charpy. Ⓖ Average hardness based on scattered data. Ⓗ ASTM E 23 unnotched .25 in. die cast bar Ⓘ Rotating Beam fatigue test according to DIN 50113. Stress corresponding to a lifetime of 5 x 10^7 cycles. Conservative values; higher values have been reported. Soundness of samples has great effect on fatigue properties resulting in disagreement

Material Properties Comparison

Magnesium, Zinc (Zamak) and ZA Die Casting Alloys

Typical values based on “as-cast” characteristics for separately die cast specimens, not specimens cut from production die castings.

Mechanical Properties

Magnesium Alloys			Zamak Die Casting Alloys				ZA Die Casting Alloys			
AZ91D	**AM60B**	**AS41B**	**No. 2**	**No. 3**	**No. 5**	**No.7**	**ZA-8**	**ZA-12**	**ZA-27**	**Designation**
34 (230)	32 (220)	31 (215)	52 (359)	41 (283)	48 (328)	41 (283)	53-56 (365-386)	57-60 (393-414)	59-64 (407-441)	**Ultimate Tensile Strength** ksi (MPa)
23 (160)	19 (130)	20 (140)	41 (283)	32 (221)	39 (269)	32 (221)	41-43 (283-296)	45-48 (310-331)	52-55 (359-379)	**Tensile Yield Strength**Ⓐ ksi (MPa)
24 (165)	19 (130)	20 (140)	93 (641)	60Ⓜ (414)	87Ⓜ (600)	60Ⓜ (414)	37 (252)	39 (269)	52 (358)	**Compressive Yield Strength**Ⓑ ksi (MPa)
3	6-8	6	7	10	7	13	6-10	4-7	2.0-3.5	**Elongation** % in 2 in. (51 mm)
75Ⓕ	62Ⓕ	75Ⓕ	100Ⓖ	82Ⓖ	91Ⓖ	80Ⓖ	100-106Ⓖ	95-105Ⓖ	116-122Ⓖ	**Hardness** BHN
20 (140)	n/a	n/a	46 (317)	31 (214)	38 (262)	31 (214)	40 (275)	43 (296)	47 (325)	**Shear Strength** ksi (MPa)
1.6Ⓗ (2.2)	4.5Ⓗ (6.1)	3.0Ⓗ (4.1)	35 (47.5)	43Ⓗ (58)	48Ⓗ (65)	43Ⓗ (58)	24-35Ⓗ (32-48)	15-27Ⓗ (20-37)	7-12Ⓗ (9-16)	**Impact Strength** ft-lb (J)
10Ⓘ (70)	10Ⓘ (70)	n/a	8.5Ⓓ (58.6)	6.9Ⓓ (47.6)	8.2Ⓓ (56.5)	6.9Ⓓ (47.6)	15Ⓓ (103)	—	21Ⓓ (145)	**Fatigue Strength** ksi (MPa)
6.5 (45)	6.5 (45)	6.5 (45)	Ⓝ	Ⓝ	Ⓝ	Ⓝ	12.4 (85.5)	12 (83)	11.3 (77.9)	**Young’s Modulus** psi x 10^6 (GPa)

Physical Properties

AZ91D	AM60B	AS41B	No. 2	No. 3	No. 5	No.7	ZA-8	ZA-12	ZA-27	Designation
.066 (1.81)	.065 (1.79)	.064 (1.77)	.24 (6.6)	.24 (6.6)	.24 (6.7)	.24 (6.6)	.227 (6.3)	.218 (6.03)	.181 (5.00)	**Density** lb/in³ (g/cm³)
875-1105 (470-595)	1005-1140 (540-615)	1050-1150 (565-620)	715-734 (379-390)	718-728 (381-387)	717-727 (380-386)	718-728 (381-387)	707-759 (375-404)	710-810 (377-432)	708-903 (375-484)	**Melting Range** °F (°C)
.25 (1050)	.25 (1050)	.24 (1020)	.1 (419)	.1 (419)	.1 (419)	.1 (419)	.104 (435)	.107 (450)	.125 (525)	**Specific Heat** BTU/lb°F (J/kg°C)
13.8 (25.0)	14.2 (25.6)	14.5 (26.1)	15.4 (27.8)	15.2 (27.4)	15.2 (27.4)	15.2 (27.4)	12.9 23.2	13.4 (24.1)	14.4 (26.0)	**Coefficient of Thermal Expansion** μ in./in./°F x 10^{-6} (μ m/m°K)
41.8Ⓙ (72)	36 (62)	40 (68)	60.5 (104.7)	65.3 (113)	62.9 (109)	65.3 (113)	66.3 (115)	67.1 (116)	72.5 (122.5)	**Thermal Conductivity** BTU/ft hr °F (W/m°K)
10	11	n/a	25.0	27.0	26.0	27.0	27.7	28.3	29.7	**Electrical Conductivity** % IACS
0.35	0.35	0.35	0.30	0.30	0.30	0.30	0.30	0.30	0.30	**Poisson’s Ratio**

among data sources. Ⓙ At 212-572°F (100-300°C) Ⓚ Estimated Ⓛ Casting conditions may significantly affect mold shrinkage. Ⓜ Compressive strength Ⓝ Varies with stress level; applicable only for short-duration loads. Use 10^7 as a first approximation. Al Sources: ASTM Standard B85-92a; ASM; SAE; Wabash Alloys. Mg Source: International Magnesium Assn. Zn/ZA Source: International Lead Zinc Research Organization.

of temperature, time and stress level. Published design data can identify the conditions under which creep and relaxation may occur. Design and testing are usually necessary to determine the tendency and extent.

When redesigning a component from a plastic to a die casting alloy, creep and relaxation may not occur. In those cases, the design may be simplified. When redesigning from brass, iron or steel, creep and relaxation may become a factor that needs to be accommodated in the design.

3. The Economic Equation: Optimizing Your Product

A thorough analysis of the working environment may reveal interfacing parts that can be combined with the component under study. The total costs of fabrication, installation, fastening and joining can often be significantly reduced.

It is particularly important to be aware of overdesign. For example, a material-process that was selected primarily for favorable fabrication costs may incidentally offer strength, rigidity, or wear resistance that is many times greater than the application requires. Die castings with an economic advantage, but lower mechanical properties, may still offer properties adequate for the application.

In all cases, it is essential to define the product function, then review the environment with an eye for function, rather than form. It is rarely desirable to replicate the exact configuration of an existing component by die casting. It is most cost-effective to generate a design that performs the required function and takes maximum advantage of the die casting process.

Die casting holds a significant niche in the marketplace for components produced in large quantities. It can also prove economical at relatively low production levels when costly machining can be eliminated on an as-cast part or several assembled parts can be combined into a single die casting.

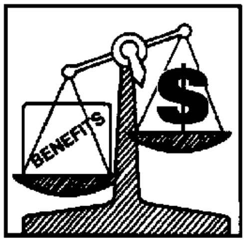
High-Tech Die Casting

Today high-technology die casting systems are producing castings with extremely close tolerances and reduced draft angles (in some cases zero draft) on selected features, eliminating finish machining operations. This casting precision further lowers the break-even point for die casting versus low-volume production processes and increases the economic advantage over high-volume alternatives.

One of the most important but often overlooked factors in the economic equation is the proven track record of die casting alloys, backed by several decades of continuous use and testing. In many cases, thirty-year data are available.

This documentation enables the designer to predict the long-term performance of die castings with a significant level of confidence. Warranty costs may be accurately predicted, or virtually eliminated, as desired. Product liability may also be sharply reduced.

Product designers should work closely—and early—with their custom die caster or other manufacturing resource to maximize material, process and environmental benefits.



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