8 Zinc and ZA Alloys

Selecting Zinc and ZA Alloys

Zinc (Zn) alloy die castings offer a broad range of excellent physical and mechanical properties, castability, and finishing characteristics. Thinner sections can be die cast in zinc alloy than in any of the commonly used die casting alloys.

Zinc alloy generally allows for greater variation in section design and for the maintenance of closer dimensional tolerances. The impact strength of zinc components is higher than other die casting alloys, with the exception of brass. Due to the lower pressures and temperatures under which zinc alloy is die cast, die life is significantly lengthened and die maintenance minimized.

This zinc alloy subsection presents guideline tables for chemical composition, typical properties, and die casting, machining and finishing characteristics for the two groups of zinc die casting alloys. This data can be used in combination with design engineering tolerancing guidelines for zinc die casting and can be compared with the guidelines for other alloys in this section and the Design Engineering section.

The zinc alloys include the traditional Zamak (acronym for zinc, aluminum, magnesium and copper) group, Nos. 2, 3, 5, and 7, and the high-aluminum or ZA® alloy group, ZA-8, ZA-12 and ZA-27.

The Zamak alloys all contain nominally 4% aluminum and a small amount of magnesium to improve strength and hardness and to protect castings from intergranular corrosion. These alloys all use the rapid-cycling hot-chamber process which allows maximum casting speed.

Miniature zinc die castings can be produced at high volume using special hot-chamber die casting machines that yield castings which are flash-free, with zero draft and very close tolerances, requiring no secondary trimming or machining.

Zinc No. 3 is the most widely used zinc alloy in North America, offering the best combination of mechanical properties, castability, and economics. It can produce castings with intricate detail and excellent surface finish at high production rates. The other alloys in the Zamak group are slightly more expensive and are used only where their specific properties are required

Alloys 2 and 5 have a higher copper content, which further strengthens and improves wear resistance, but at the expense of dimensional and property stability. No. 5 offers higher creep resistance and somewhat lower ductility and is often preferred whenever these qualities are required. No. 7 is a special high-purity alloy which has somewhat better fluidity and allows thinner walls to be cast.

The ZA alloys contain substantially more aluminum than the Zamak group, with the numerical designation representing the ZA alloy's approximate percent Al content.

The higher aluminum and copper content of the ZA alloys give them several distinct advantages over the traditional zinc alloys, including higher strength, superior wear resistance, superior creep resistance and lower densities.

ZA-8, with a nominal aluminum content of 8.4%, is the only ZA alloy that can be cast by the faster hot-chamber process. It has the highest strength of any hot-chamber zinc alloy, and the highest creep strength of any zinc alloy.

ZA-12, with a nominal aluminum content of 11%, has properties that fall midway in the ZA group. ZA-27, with a nominal aluminum content of 27%, has the highest melting point, the highest strength, and the lowest density of the ZA alloys.

Machining Characteristics

The machining characteristics of the Zamak and ZA alloys are considered very good. High-quality surface finishes and good productivity are achieved when routine guidelines for machining zinc are followed.

Surface Treatment Systems

In many applications, zinc alloy die castings are used without any applied surface finish or treatment.

Differences in the polishing, electroplating, anodizing and chemical coating characteristics of the Zamak and ZA alloys can be noted in table A-3-15.

Alloy Data

Painting, chromating, phosphate coating and chrome plating can be used for decorative finishes. Painting, chromating, anodizing, and iridite coatings can be used as corrosion barriers. Hard chrome plating can be used to improve wear resistance, with the exception of ZA-27.

The bright chrome plating characteristics of the Zamak alloys and ZA-8 make these alloys a prevailing choice for hardware applications.

A detailed discussion of finishing methods for zinc die castings can be found in Product Design for Die Casting.

Table A-3-13 Chemical Composition: Zn Alloys

All single values are maximum composition percentages unless otherwise stated.

	Zamak Die Casting Alloys Ⓒ Ⓓ				ZA Die Casting Alloys Ⓒ Ⓓ		
Common: ANSI/AA	No. 2 AC43A	No. 3 AG-40A	No. 5 AG-41A	No. 7 AG-40B	ZA-8	ZA-12	ZA-27
Nominal Comp:	Al 4.0 Mg 0.035 Cu 3.0	Al 4.0 Mg 0.035	Al 4.0 Mg 0.055 Cu 1.0	Al 4.0 Mg 0.013 Cu 0.013	Al 8.4 Mg 0.023 Cu 1.0	Al 11.0 Mg 0.023 Cu 0.88	Al 27.0 Mg 0.015 Cu 2.25
Detailed Composition							
Aluminum Al	3.7-4.3	3.7-4.3	3.7-4.3	3.7-4.3	8.0-8.8	10.5-11.5	25.0-28.0
Magnesium Mg	0.02-0.06	0.02-0.06 Ⓐ	0.02-0.06	0.005-0.020	0.01-0.03	0.01-0.03	0.01-0.02
Copper Cu	2.6-3.3*	0.1 max Ⓑ	0.7-1.2	0.1 max Ⓑ	0.8-1.3	0.5-1.2	2.0-2.5
Iron Fe (max)	0.05	0.05	0.05	0.05	0.075	0.075	0.075
Lead Ⓒ Pb (max)	0.005	0.005	0.005	0.003	0.006	0.006	0.006
Cadmium Ⓒ Cd (max)	0.004	0.004	0.004	0.002	0.006	0.006	0.006
Tin Sn (max)	0.002	0.002	0.002	0.001	0.003	0.003	0.003
Nickel Ni	—	—	—	0.005-0.020	—	—	—
Zinc Zn	Balance	Balance	Balance	Balance	Balance	Balance	Balance

Ⓐ The magnesium may be as low as 0.015 percent provided that the lead, cadmium and tin do not exceed 0.003, 0.003 and 0.001 percent, respectively. Ⓑ For the majority of commercial applications, a copper content of up to 0.7 percent will not adversely affect the serviceability of die castings and should not serve as a basis for rejection. Sources: ASTM B86. Ⓒ As specified, the chemical composition of zinc and ZA alloys are in compliance with RoHS (the European Union's Directive on Restriction of Hazardous Substances) If the presence of mercury is suspected, analysis shall be made to determine that the amount does not exceed 0.1 weight percent. Hexavalent chromium does not exist in the alloys and therefore meets the 0.1% limit. Ⓓ Registration for REACH (the European Union's Directive on Registration, Evaluation, and Authorization of Chemicals) is not required for die castings, even if coated, since die castings are considered articles. Notification may be required if some contained substances in the die casting or coating exceed the 0.1% total weight of the article level and are listed as SVHC (substances of very high concern).

Note: *There are newly developed zinc alloys (a result of through NADCA sponsored research) for elevated temperature creep resistance applications (such as ZCA-9). Contact your alloy producer for more information.*

**Increased copper to allow EN12844*

Alloy Data

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

Table A-3-14
Typical Material Properties: Zn and ZA Alloys

	Zamak Die Casting Alloys				ZA Die Casting Alloys		
Commercial:	No. 2	No. 3 AG-40A	No. 5 AG-41A	No. 7 AG-40B	ZA-8	ZA-12	ZA-27
Mechanical Properties							
Ultimate Tensile Strength							
As-Cast ksi (MPa)	52 (359)	41 (283)	48 (331)	41 (283)	54 (374)	59 (404)	62 (426)
Aged ksi (MPa)	48 (331)	35 (241)	39 (269)	41 (283)	43 (297)	45 (310)	52 (359)
Yield Strength Ⓐ							
As-Cast ksi (MPa)	41 (283)	32 (221)	33 (228)	32 (221)	42 (290)	46 (320)	54 (371)
Aged ksi (MPa)					32 (224)	35 (245)	46 (322)
Compressive Yield Strength Ⓑ							
As-Cast ksi (MPa)	93 (641)	60 (414) Ⓒ	87 (600) Ⓒ	60 (414) Ⓒ	37 (252)	39 (269)	52 (358)
Aged ksi (MPa)	93 (641)	60 (414)	87 (600)	60 (414)	25 (172)	27 (186)	37 (255)
Elongation							
As-Cast % in 2 in. (51mm)	7	10	7	13	8	5	2.5
Aged % in 2 in. (51mm)	2	16	13	18	20	10	3
Hardness Ⓓ							
As-Cast BHN	100	82	91	80	103	100	119
Aged BHN	98	72	80	67	91	91	100
Shear Strength							
As-Cast ksi (MPa)	46 (317)	31 (214)	38 (262)	31 (214)	40 (275)	43 (296)	47 (325)
Aged ksi (MPa)	46 (317)	31 (214)	38 (262)	31 (214)	33 (228)	33 (228)	37 (255)
Impact Strength							
As-Cast ft-lb	35	43 Ⓔ	48 Ⓔ	43 Ⓔ	31 Ⓔ	21 Ⓔ	9 Ⓔ
(J)	(47.5)	(58)	(65)	(58)	(42)	(29)	(13)
Aged ft-lb	5	41	40	41	13	14	3.5
(J)	(7)	(56)	(54)	(56)	(18)	(19)	(5)
Fatigue Strength Ⓕ							
As-Cast ksi (MPa)	8.5 (58.6)	6.9 (47.6)	8.2 (56.5)	6.8 (46.9)	15 (103)	17 (117)	21 (145)
Aged ksi (MPa)	8.5 (58.6)	6.9 (47.6)	8.2 (56.5)	6.8 (46.9)	15 (103)	—	21 (145)
Young's Modulus							
psi x 10^6	Ⓖ	Ⓖ	Ⓖ	Ⓖ	12.4	12	11.3
(GPa)					(85.5)	(82.7)	(77.9)
Physical Properties							
Density							
lb/in^3	0.24	0.24	0.24	0.24	0.227	0.218	0.181
(g/cm^3)	(6.6)	(6.6)	(6.6)	(6.6)	(6.3)	(6.03)	(5.000)
Melting Range							
°F	715-734	718-728	717-727	718-728	707-759	710-810	708-903
(°C)	(379-390)	(381-387)	(380-386)	(381-387)	(375-404)	(377-432)	(375-487)
Specific Heat							
BTU/lb °F	0.10	0.10	0.10	0.10	0.104	0.107	0.125
(J/kg °C)	(419)	(419)	(419)	(419)	(435)	(450)	(525)
Coefficient of Thermal Expansion							
µ in/in°F	15.4	15.2	15.2	15.2	12.9	13.4	14.4
(µ m/m°K)	(27.8)	(27.4)	(27.4)	(27.4)	(23.2)	(24.2)	(26.0)
Thermal Conductivity							
BTU/ft hr°F	60.5	65.3	62.9	65.3	66.3	67.1	72.5
(W/m °K)	(104.7)	(113)	(109)	(113)	(114.7)	(116.1)	(122.5)
Electrical Conductivity							
µ Ω in.	25.0	27.0	26.0	27.0	27.7	28.3	29.7
Poisson's Ratio	0.30	0.30	0.30	0.30	0.30	0.30	0.30

Ⓐ 0.2% offset, strain rate sensitive, values obtained at a strain rate of 0.125/min (12.5% per minute). Ⓑ 0.1% offset. Ⓒ Compressive strength. Ⓓ 500 kg load, 10 mm ball. Ⓔ ASTM 23 unnotched 0.25 in. die cast bar. Ⓕ Rotary Bend 5 x 10^8 cycles. Ⓖ Varies with stress level; applicable only for short-duration loads. Use 10^7 as a first approximation. Source: International Lead Zinc Research Organization.

Alloy Data

Die casting alloy selection requires evaluation not only of physical and mechanical properties, and chemical composition, but also of inherent alloy characteristics and their effect on die casting production as well as possible machining and final surface finishing.

This table includes selected die casting and other special characteristics which are usually considered in selecting a zinc alloy for a specific application.

The characteristics are rated from (1) to (5), (1) being the most desirable and (5) being the least. In applying these ratings, it should be noted that all the alloys have sufficiently good characteristics to be accepted by users and producers of die castings. A rating of (5) in one or more categories would not rule out an alloy if other attributes are particularly favorable, but ratings of (5) may present manufacturing difficulties.

The benefits of consulting a custom die caster experienced in casting the zinc alloy being considered are clear.

Table A-3-15 Die Casting and Other Characteristics: Zn and ZA Alloys
(1 = most desirable, 5 = least desirable)

	Zamak Die Casting Alloys						
Commercial: ANSI/AA	No. 2	No. 3 AG-40A	No. 5 AG-41A	No. 7 AG-40B	ZA-8	ZA-12	ZA-27
Resistance to Hot Cracking Ⓑ	1	1	2	1	2	3	4
Pressure Tightness	3	1	2	1	3	3	4
Casting Ease	1	1	1	1	2	3	3
Part Complexity	1	1	1	1	2	3	3
Dimensional Accuracy	4	2	2	1	2	3	4
Dimensional Stability	2	3	3	2	2	2	1
Corrosion Resistance	2	3	3	2	2	2	1
Resistance to Cold Defects Ⓐ	2	2	2	1	2	3	4
Machining Ease & Quality Ⓒ	1	1	1	1	2	3	4
Polishing Ease & Quality	2	1	1	1	2	3	4
Electroplating Ease & Quality Ⓓ	1	1	1	1	1	2	3
Anodizing (Protection)	1	1	1	1	1	2	2
Chemical Coating (Protection)	1	1	1	1	2	3	3

Ⓐ *The ability of alloy to resist formation of cold defects; for example, cold shuts, cold cracks, non-fill "woody" areas, swirls, etc.* Ⓑ *Ability of alloy to withstand stresses from contraction while cooling through the hot-short or brittle temperature range.* Ⓒ *Composite rating based on ease of cutting. Chip characteristics, quality of finish and tool life.* Ⓓ *Ability of the die casting to take and hold an electroplate applied by present standard methods. Source: International Lead Zinc Research Organization.*

Zinc HF Alloy Typical Properties	
Mechanical Properties	
Ultimate Tensile Strength [A]	
As-Cast ksi (MPa)	40 (276)
Aged ksi (MPa)	34 (234)
Yield Strength	
As-Cast ksi (MPa)	35 (241)
Aged ksi (MPa)	29 (200)
Elongation	
As-Cast % in 2 in. (51mm)	5.3
Aged % in 2 in. (51mm)	9.9
Hardness [B]	
As-Cast BHN	93
Aged BHN	71
Impact Strength [C]	
As-Cast ft-lb (J)	28 (38)
Aged ft-lb (J)	21 (28)
Young's Modulus [D]	
psi x 106	13.3
(GPa)	91.7

Physical Properties	
Density	
lb/in3	0.239
(g/cm3)	6.602
Melting Range	
˚F	716-723
(˚C)	380-384
Specific Heat	
BTU/lb ˚F at 68-212 ˚F	0.1
(J/kg ˚C) at 20-100 ˚C	403
Coefficient of Thermal Expansion	
µ in/in˚F at 68-212 ˚F	16.5
(µ m/m˚K) at 20-100 ˚C	26.2
Thermal Conductivity [E]	
BTU/ft hr˚F at 158-252 ˚F	65.3
(W/m ˚K) at 70-140 ˚C	113
Poisson's Ratio	0.30
Solidification Shrinkage (in/in)	0.0117

Zinc HF Alloy Chemical Composition	
Detailed Composition	
Aluminum Al	4.3-4.7
Magnesium Mg	0.01 nominal
Copper Cu	0.03 nominal
Iron Fe	0.03 max
Lead Pb	0.003 max
Cadmium Cd	0.002 max
Tin Sn	0.001 max
Nickel Ni	-
Zinc Zn	Remainder

(A) - Sample cross-section dimensions 0.040 x 0.500 in.; tensile strength increased to 54 ksi when sample cross-section was reduced to 0.020 x 0.300 in.

(B) - Tested under 250 kg weight with 5 mm ball

(C) - Sample dimensions 0.25 x 0.25 x 3 in.

(D) - Calculated using stress-strain curve

(E) - Based on published data for Alloy 7

Note: Samples "as-cast" were tested at 68 ˚F (20 ˚C). Samples "aged" were kept at 203 ˚F (95 ˚C) for 10 days.

9 Elevated Temperature Properties

Table 3-12 Elevated Temperature Properties of Aluminum				
Alloy	**Temp °F (°C)**	**Tensile ksi (MPa)**	**Yield ksi (MPa)**	**Elong %**
360	-112° (-80°)	50 (345)	25 (172)	2
	-18° (-26°)	48 (330)	25 (172)	2
	68° (20°)	44 (303)	25 (172)	2.5
	212° (100°)	44 (303)	25 (172)	2.5
	300° (150°)	35 (241)	24 (166)	4
	400° (205°)	22 (152)	14 (97)	8
	500° (260°)	12 (83)	7.5 (52)	20
	600° (315°)	7 (48)	4.5 (31)	35
	700° (370°)	4.5 (31)	3 (21)	40
A360	-112° (-80°)			
	-18° (-26°)			
	68° (20°)	46 (317)	24 (166)	3.5
	212° (100°)	43 (296)	24 (166)	3.5
	300° (150°)	34 (234)	23 (159)	5
	400° (205°)	21 (145)	13 (90)	14
	500° (260°)	11 (76)	6.5 (45)	30
	600° (315°)	6.5 (45)	4 (28)	45
	700° (370°)	4 (30)	2.5 (15)	45
380	-112° (-80°)	49 (338)	23 (159)	2.5
	-18° (-26°)	49 (338)	23 (159)	3
	68° (20°)	46 (317)	23 (159)	3.5
	212° (100°)	45 (310)	24 (166)	4
	300° (150°)	34 (234)	22 (152)	5
	400° (205°)	24 (165)	16 (110)	8
	500° (260°)	13 (90)	8 (55)	20
	600° (315°)	7 (48)	4 (28)	30
	700° (370°)	4 (28)	2.5 (17)	35
A380	-112° (-80°)			
	-18° (-26°)			
	68° (20°)	47 (324)	23 (159)	3.5
	212° (100°)	44 (303)	23 (159)	5
	300° (150°)	33 (228)	21 (145)	10
	400° (205°)	23 (159)	15 (103)	15
	500° (260°)	12 (83)	7 (48)	30
	600° (315°)	6 (41)	6 (41)	45

The values in this table are from various sources and represent typical values. These values do not represent design minimums and should be used for reference only.

384	-112° (-80°)			
	-18° (-26°)			
	68° (20°)	48 (330)	24 (165)	2.5
	212° (100°)	44 (303)	24 (165)	2.5
	300° (150°)	38 (262)	24 (165)	5
	400° (205°)	26 (179)	18 (124)	6
	500° (260°)	14 (97)	9 (62)	25
	600° (315°)	7 (48)	4 (28)	45
390	-112° (-80°)			
	-18° (-26°)			
	68° (20°)	46 (317)	36 (250)	< 1
	212° (100°)	41 (283)	27 (186)	1
	300° (150°)	37 (255)		1
	400° (205°)	29 (200)		1
	500° (260°)	19 (131)		2
	600° (315°)			
13	-112° (-80°)	45 (310)	21 (145)	2
	-18° (-26°)	44 (303)	21 (145)	2
	68° (20°)	42 (290)	19 (131)	3.5
	212° (100°)	37 (255)	19 (131)	5
	300° (150°)	32 (221)	19 (131)	8
	400° (205°)	24 (166)	15 (103)	15
	500° (260°)	13 (90)	9 (62)	29
	600° (315°)	7 (48)	5 (34)	35
43	-112° (-80°)	35 (241)	16 (110)	12
	-18° (-26°)	35 (241)	16 (110)	13
	68° (20°)	33 (228)	14 (97)	9
	212° (100°)	28 (193)	14 (97)	9
	300° (150°)	22 (152)	14 (97)	10
	400° (205°)	16 (110)	12 (83)	25
	500° (260°)	9 (62)	6 (41)	30
	600° (315°)	5 (34)	4 (28)	35
218	-112° (-80°)	51 (352)	29 (200)	14
	-18° (-26°)	50 (345)	29 (200)	10
	68° (20°)	44 (310)	28 (193)	5
	212° (100°)	40 (276)	25 (172)	8
	300° (150°)	32 (221)	21 (145)	25
	400° (205°)	21 (145)	15 (104)	40
	500° (260°)	13 (90)	9 (62)	45
	600° (315°)	9 (62)	5 (34)	46

The values in this table are from various sources and represent typical values. These values do not represent design minimums and should be used for reference only.

Table 3-13 Impact Strength Of Aluminum A380 Die Casting Alloy as a Function of Temperature		
Temperature (°C)	**Impact Strength (ft-lb)**	**Standard Deviation**
-190	4.47	0.92
-100	4.92	0.80
-50	5.20	0.90
0	5.66	0.93
25	5.91	0.95
100	6.43	0.89
150	6.66	0.94
240	6.83	0.88

The values in this table are from various sources and represent typical values. These values do not represent design minimums and should be used for reference only.

Table 3-14 Impact Strength at Temperature

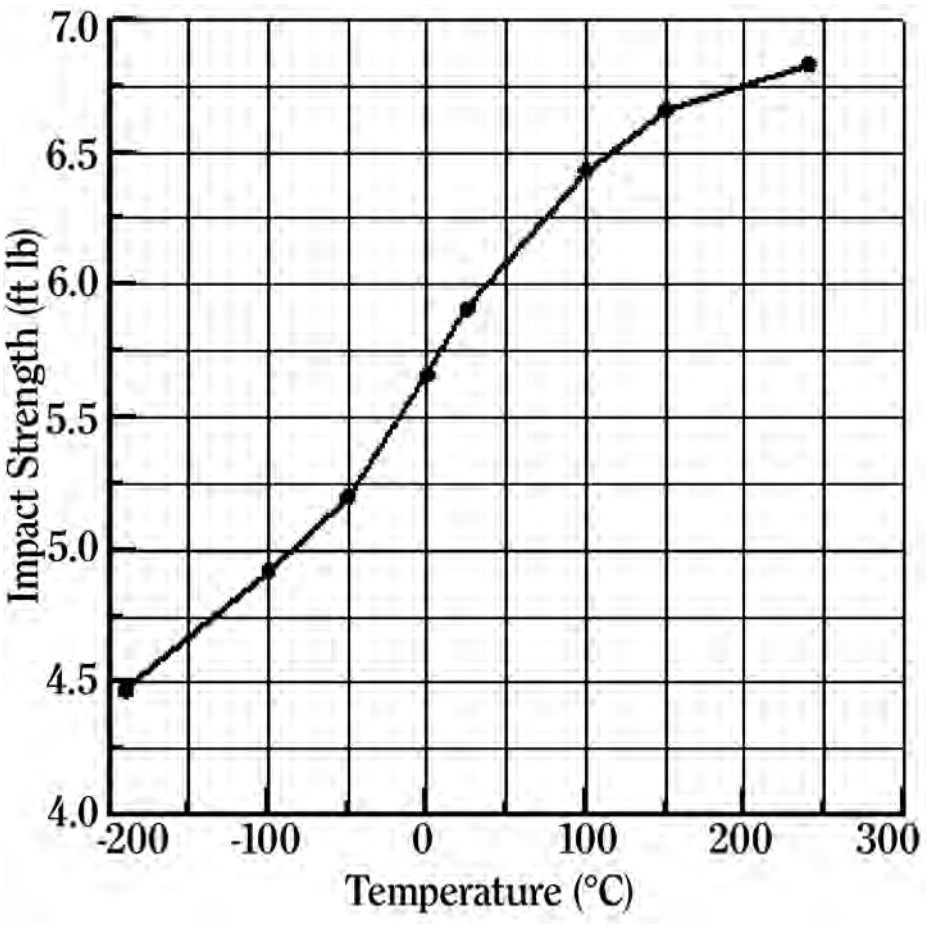
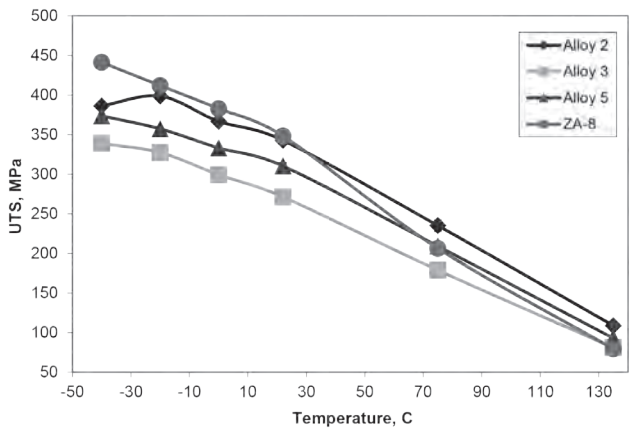


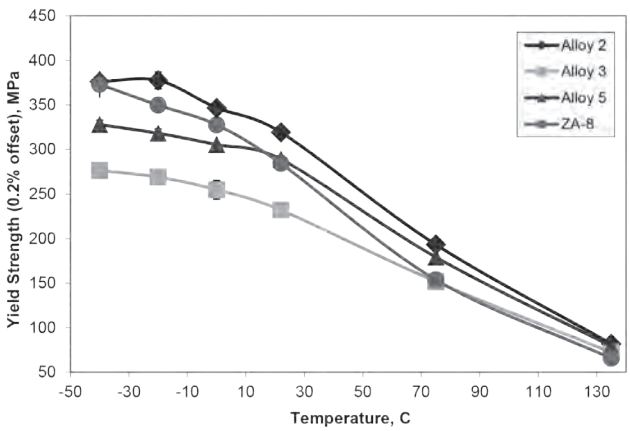
Table 3-15 Elevated Temperature Properties of Zinc			
Alloy	**Temp °F (°C)**	**Tensile ksi (MPa)**	**Yield ksi (MPa)**
2	-40° (-40°)	56.0 (386)	54.5 (376)
	-4° (-20°)	57.9 (399)	54.8 (378)
	32° (0°)	53.2 (367)	50.3 (347)
	72° (22°)	49.7 (343)	46.3 (319)
	167° (75°)	34.1 (235)	28.0 (193)
	275° (135°)	15.8 (109)	11.9 (82)
3	-40° (-40°)	49.2 (339)	40.0 (276)
	-4° (-20°)	47.4 (327)	39.0 (269)
	32° (0°)	43.4 (299)	37.0 (255)
	72° (22°)	39.3 (271)	33.6 (232)
	167° (75°)	26.0 (179)	22.0 (152)
	275° (135°)	11.7 (81)	10.4 (72)
5	-40° (-40°)	54.2 (374)	47.6 (328)
	-4° (-20°)	51.8 (357)	46.1 (318)
	32° (0°)	48.3 (333)	44.2 (305)
	72° (22°)	45.0 (310)	41.9 (289)
	167° (75°)	30.3 (209)	26.0 (179)
	275° (135°)	11.7 (81)	11.5 (79)
8	-40° (-40°)	64.0 (441)	54.1 (373)
	-4° (-20°)	59.8 (412)	50.8 (350)
	32° (0°)	55.5 (383)	47.6 (328)
	72° (22°)	50.5 (348)	41.2 (284)
	167° (75°)	29.9 (206)	22.3 (154)
	275° (135°)	11.6 (80)	9.6 (66)

The values in this table are from Omer Dogan and Karol Schrems, "Determination of Mechanical Properties of Die Cast Zinc Alloys for Automotive Applications", Final Report, prepared for International Lead Zinc Research Organization, NETL-A-TR-2007-08, work performed under CRADA 05-05 ILZRO, March 2007.. These values do not represent design minimums and should be used for reference only.

Zinc Tensil Strength at Temperature



Zinc Yield Strength at Temperature



10 Property Comparison

Table 3-16 Competitive Performance Chart

Alloy Property	ZA-MAK 3**	ZA-MAK 5**	ZA-8**			ZA-12**			ZA-27**	
	Die Cast	Die Cast	Sand Cast	Perm Mold	Die Cast	Sand Cast	Perm Mold	Die Cast	Sand Cast	Perm Mold
Mechanical Properties										
Ultimate Tensile Strength										
psi x10^3 (MPa)	41 (283)	48 (331)	38 (263)	35 (240)	54 (374)	43 (299)	48 (328)	59 (404)	61 (421)	64 (441)
Yield Strength										
psi x10^3 (MPa)	32 (221)	33 (228)	29 (198)	30 (208)	42 (290)	31 (211)	39 (268)	46 (320)	54 (371)	55 (376)
Elongation										
% in 2in.	10	7	1.7	1.3	8	1.5	2.2	5	4.6	2.5
Young's Modulus										
psi x10^6 (MPa x 10^3)	12.4*** (85.5)	12.4*** (85.5)	12.4 (85.5)	12.4 (85.5)	12.4 (85.5)	12.0 (82.7)	12.0 (82.7)	12.0 (82.7)	11.3 (77.9)	11.3 (77.9)
Torsional Modulus										
psi x10^6 (MPa x 10^3)	4.8 (33.1)	4.8 (33.1)	4.8 (33.1)	4.8 (33.1)	4.8 (33.1)	4.6 (31.7)	4.6 (31.7)	4.6 (31.7)	4.3 (29.6)	4.3 (29.6)
Shear Strength										
psi x10^3 (MPa)	31 (214)	38 (262)	N/A	35 (241)	40 (275)	37 (253)	35 (241)	43 (296)	42 (292)	N/A
Hardness										
(Brinell)	82	91	85	87	103	94	89	100	113	114
Impact Strength										
ft-lb (J)	43 (58)	48 (65)	15 (20)	N/A	31 (42)	19 (25)	N/A	21 (29)	35 (48)	N/A
Fatigue Strength Rotoary Bedn (5 x 10^6 cycles)										
psi x10^3 (MPa)	6.9 (47.6)	8.2 (56.5)	N/A	7.5 (57.1)	15 (103)	15 (103)	N/A	17 (117)	25 (172)	N/A
Compressive Yield Strength 0.1% Offset										
psi x10^3 (MPa)	60 (414)	87 (600)	29 (199)	31 (210)	37 (252)	33 (230)	34 (235)	39 (269)	48 (330)	N/A

* Minimum Properties
** Complies with ASTM specification B86.
*** Varies with stress level; applicable only for shot-duration loads.

	Aluminum					Magnesium		Iron		Plastic	
	380	319	356-T6	713 -F*	6061-T6	AZ-91D	AM60B	Class 30	32510		
Die Cast	Die Cast	Sand Cast	Sand Cast	Sand Cast	Wrought	Die Cast	Die Cast	Gray Cast Iron	Malleable Iron	ABS	Nylon 6 (30% Glass Filled)
62 (426)	47 (324)	27 (186)	33 (228)	32 (220)	45 (310)	34 (234)	32 (220)	31 (214)	50 (345)	8	22
54 (371)	24 (165)	18 (124)	24 (165)	22 (150)	40 (276)	23 (159)	19 (130)	18 (124)	32 (221)		
2.5	3.0	2	3.5	3	17	3	7	nil	10		7
11.3 (77.9)	10.3 (71.0)	10.7 (73.8)	10.5 (72.4)	—	—	6.5 (44.8)	6.5 (44.8)	13-16 (89.6)	25 (172.4)	1	1.5
4.3 (29.6)	3.9 (26.9)	4.0 (27.6)	3.9 (26.9)	—	—	2.4 (16.5)	N/A	N/A	9.3 (64.1)		
47 (325)	27 (186)	22 (152)	26 (179)	—	30 (—)	20 (138)	N/A	43 296	45 (310)		
119	80	70	70	60-90	95	63	62	170-269	110-156		
9 (13)	3 (4)	4 (5)	8 (11)	—	—	2.7 (3.7)	5 (6)	nil	40-65 (54-88)		
21 (145)	20 (138)	10 (69)	8.5 (58.6)	—	14 (—)	14 (97)	10 (70)	14 (97)	28 (193)	0.15	0.3
52 (359)	N/A	19 (131)	25 (172)	—	—	23 (159)	19 (130)	109 (752)	N/A		

Table 3-16 Competitive Performance Chart

Alloy Property	ZA-MAK 3**	ZA-MAK 5**	ZA-8**			ZA-12**			ZA-27**	
	Die Cast	Die Cast	Sand Cast	Perm Mold	Die Cast	Sand Cast	Perm Mold	Die Cast	Sand Cast	Perm Mold
Physical Properties										
Density										
lb/in^3 (Kg/m^3)	0.24 (6600)	0.24 (6600)	0.227 (6300)	0.227 (6300)	0.227 (6300)	0.218 (6030)	0.218 (6030)	0.218 (6030)	0.181 (5000)	0.181 (5000)
Melting Range										
°F (°C)	718-728 (381-387)	717-727 (380-386)	707-759 (375-404)	707-759 (375-404)	707-759 (375-404)	710-810 (377-432)	710-810 (377-432)	710-810 (377-432)	708-903 (376-484)	708-903 (376-484)
Electrical Conductivity										
% IACS	27	26	27.7	27.7	27.7	28.3	28.3	28.3	29.7	29.7
Thermal Conductivity										
BTU/ft hr°F (W/m °K)	65.3 (113.0)	62.9 (108.9)	66.3 (114.7)	66.3 (114.7)	66.3 (114.7)	67.1 (116.1)	67.1 (116.1)	67.1 (116.1)	72.5 (125.5)	72.5 (125.5)
Coefficient of Thermal Expansion										
1/°F x 10^{-6} (1/°C x 10^{-6})	15.2 (27.4)	15.2 (27.4)	12.9 (23.3)	12.9 (23.3)	12.9 23.3)	13.4 (24.2)	13.4 (24.2)	13.4 (24.2)	14.4 (26.0)	14.4 (26.0)
Pattern Shrinkage										
in/in or mm/mm	0.006	0.006	0.010	0.010	0.007	0.013	0.013	0.0075	0.013	0.013

	Aluminum					Magnesium		Iron	
	380	319	356-T6	713 -F*	6061-T6	AZ-91D	AM60B	Class 30	32510
Die Cast	Die Cast	Sand Cast	Sand Cast	Sand Cast	Wrought	Die Cast	Die Cast	Gray Cast Iron	Malleable Iron
0.181 (5000)	0.098 (2713)	0.101 (2796)	0.097 (2685)	0.100 (—)	—	0.066 (1827)	0.065 (1790)	0.25 (6920)	0.26 (7198)
708-903 (376-484)	1000-1100 (538-593)	960-1120 (516-604)	1035-1135 (557-613)	1100-1180 (593-638)	1080-1205 (—)	875-1105 (468-596)	1005-1140 (540-615)	>2150 (>1177)	>2250 (>1232)
29.7	27	27	39	30	43	11.5	N/A	N/A	6
72.5 (125.5)	55.6 (96.2)	65.5 (113.4)	87 (151)	—	97 (168)	41.8 (72.3)	36 (62)	28-30 (48-52)	N/A
14.4 (26.0)	11.8 (21.2)	11.9 (21.4)	11.9 (21.4)	13.4 (24.2)	13.1 (23.7)	14 (25.2)	14.2 (25.6)	6.7 (12.1)	6.6 (11.9)
0.008	0.006	N/A	N/A	—		N/A	N/A	0.010	0.010

11 Cross Reference: Alloy Designations and Alloy Compositions

Table 3-17 Cross Reference of Equivalent Aluminum Alloy Specifications and Designations

ANSI ASTM or AA Number	Former Designation	UNS Unified No. System	SAE	Old ASTM	QQ-A-371c.	Canada	United Kingdom	Japan	Germany	ISO	EN 1706	China
360	360	AO3601	309	SG 100B	360	—	—	JIS H5302 ADC3	—	—	—	—
A360	A360	AO3602	309	SG 100A	360	—	—	—	GD-AlSi10Mg	Al-Si10Mg	EN AC-43400	YL104
380	380	AO3801	306.308	SC84A-B	380	143	—	JIS H5302 ADC10	—	—	—	—
A380	A380	AO3802	306.308	SC84-A	380	—	LM24	—	GD-AlSi8Cu	Al-Si-8Cu3Fe	EN AC-46500	YL112
383	383	AO3831	306.308	—	—	—	LM2	JIS H5302 ADC12	—	—	EN AC-46100	YL113
384	384	AO3841	313	SC114A	384	A143	LM26	—	—	—	—	—
A384	A384	AO3842	303	SC114A	384	—	—	—	—	—	—	—
390	—	AO3902	—	—	—	—	LM28	—	—	—	—	—
B390	—	AO3901	—	—	—	—	—	—	—	—	—	—
413	13	AO4131	305	S12A.B	13	162	LM6	JIS H5302 ADC1	—	—	—	—
A413	A13	A14132	305	S12A	13	—	—	—	—	AlSi-12CuFe	EN AC-47100	YL108
443	43	AO4431	35	S5B	43	123	LM18	—	—	—	—	—
518	218	AO5181	—	—	218	340	—	—	—	—	—	—

Table 3-18 International Aluminum Alloy Compositions

JAPAN

	Cu	Mg	Si	Fe	Mn	Ni	Zn	Pb	Sn	Ti	Each	Total
JIS H5302 ADC1	1.0	0.3	11.0-13.0	1.3	0.3	0.5	0.5	—	0.1	—	—	—
JIS H5302 ADC3	0.6	0.4-0.6	9.0-10.0	1.3	0.3	0.5	0.5	—	0.1	—	—	—
JIS H5302 ADC10	2.0-4.0	0.3	7.5-9.5	1.3	0.3	0.5	1.0	—	0.3	—	—	—
JIS H5302 ADC12	1.5-3.5	0.3	9.6-12.0	1.3	0.3	0.5	1.0	—	0.3	—	—	—

UNITED KINGDOM

B.S.1490	Cu	Mg	Si	Fe	Mn	Ni	Zn	Pb	Sn	Ti	Others
LM2	0.7-2.5	0.30	9.0-11.5	1.0	0.5	0.5	2.0	0.3	0.2	0.2	—
LM6	0.1	0.10	10.0-13.0	0.6	0.5	0.1	0.1	0.1	0.05	0.2	—
LM18	0.1	0.10	4.5-6.0	0.6	0.5	0.1	0.1	0.1	0.05	0.2	—
LM24	3.0-4.0	0.30	7.5-9.5	1.3	0.5	0.5	0.3	0.3	0.2	0.2	—
LM26	2.0-4.0	0.5-1.5	8.5-10.5	1.2	0.5	0.1	0.2	0.2	0.1	0.2	—

GERMANY

	Cu	Mg	Si	Fe	Mn	Ni	Zn	Pb	Sn	Ti	Each	Total
GD-Al-Si8Cu3	2.0-3.5	0-0.3	7.5-9.5	1.3	0.2-0.5	0.3	0.7	0.2	0.1	0.15	0.05	0.15
GD-Al-Si10Mg	0.10	0.20-0.50	9.0-11.0	1.0	0-0.4	—	0.1	—	—	0.15	0.05	0.15

ISO

	Cu	Mg	Si	Fe	Mn	Ni	Zn	Pb	Sn	Ti	Each
Al-Si8Cu3Fe	2.5-4.0	0.3 max	7.5-9.5	1.3 max	0.6 max	0.5 max	1.2 max	0.3 max	0.2 max	0.2 max	0.5 max
Al-Si10Mg	0.1 max	0.15-0.40	9.0-11.0	0.6 max	0.6 max	0.05 max	0.1 max	0.05 max	0.05 max	0.2 max	—

EUROPEAN STANDARD EN 1706

	Cu	Mg	Si	Fe	Mn	Ni	Zn	Pb	Sn	Ti	Each*	Total*
EN AC-43400	0.1	0.20-0.50	9.0-11.0	1.0	0.55	0.15	0.15	0.15	0.05	0.20	—	—
EN AC-46100	1.5-2.5	0.3	10.0-12.0	1.1	0.55	0.45	1.7	0.25	0.15	0.25	0.05	0.25
EN AC-46500	2.0-4.0	0.05-0.55	8.0-11.0	1.3	0.55	0.55	3.0	0.35	0.15	0.25	0.05	0.25
EN AC-47100	0.7-1.2	0.35	10.5-13.5	1.3	0.55	0.30	0.55	0.20	0.10	0.20	0.05	0.25

*AC=Component cast in aluminum *=other trace elements*

China

	Cu	Mg	Si	Fe	Mn	Ni	Zn	Pb	Sn	Ti
YZA1Si10Mg	≤0.3	0.17--0.3	8-10.5	≤1.0	0.2-0.5	—	≤0.3	≤0.05	≤0.01	—
YZA1Si12Cu2	1-2	0.4--1	11-13	≤1.0	0.3-0.9	≤0.05	≤1.0	≤0.05	≤0.01	—
YZA1Si9Cu4	3-4	≤0.3	7.5-9.5	≤1.2	≤0.5	≤0.5	≤1.2	≤0.1	≤0.1	—
YZA1Si11Cu3	1.5-3.5	≤0.3	9.6-12	≤1.2	≤0.5	≤0.5	≤1.0	≤0.1	≤0.1	—

Table 3-19 Cross Reference of Equivalent Magnesium Alloy Specifications and Designations		
U.S.A STM	ISO 16220	EN-1753/1997
AZ91D	MgAl9Zn1	AZ91
AM60B	MgAl6Mn	AM60
AM50A	MgAl5Mn	AM50
AM20	MgAl2Mn	AM20
AS21	MgAl2Si	AS21
AS41B	MgAl4Si	AS41

Table 3-20 International Magnesium Alloy Composition									
U.S. ASTM	**%Al**	**%Zn**	**%Mn**	**%Si**	**%Fe**	**%Cu**	**%Ni**	**0 Each**	**Fe/Mn Max.**
AZ91D	8.3-9.7	0.35-1.0	0.15-0.50	0.10	0.005	0.030	0.002	0.01	0.032***
AM60B	5.5-6.5	0.22	0.24-0.6	0.10	0.005	0.010	0.002	0.02	0.021**
AM50A	4.4-5.4	0.22	0.26-0.6	0.10	0.004	0.010	0.002	0.02	0.015**
AM20	—	—	—	—	—	—	—	—	—
AS21	—	—	—	—	—	—	—	—	—
AS41B	3.5-5.0	0.12	0.35-0.7	0.50-1.5	0.0065	0.02	0.002	0.02	0.010**
ISO 16220									
MgAl9Zn1	8.3-9.7	0.35-1.0	0.15-0.50	0.10	0.005	0.030	0.002	0.01	0.032**
MgAl6Mn	5.5-6.5	0.2 0.2	0.24-0.60	0.10	0.005	0.010	0.002	0.01	0.021*
MgAl5Mn	4.4-5.5	0.2	0.26-0.60	0.10	0.004	0.010	0.002	0.01	0.015*
MgAl2Mn	1.6-2.6	0.2	0.33-0.70	0.10	0.004	0.010	0.002	0.01	0.012*
MgAl2Si	1.8-2.6	0.2	0.18-0.70	0.7-1.2	0.004	0.010	0.002	0.01	0.022*
MgAl4Si	3.5-5.0	0.2	0.18-0.70	0.5-1.5a	0.004	0.010	0.002	0.01	0.022*
EN-1753/1997									
AZ91	8.3-9.7	0.35-1.0	min. 0.1	0.10	0.005	0.030	0.002	0.01	—
AM60	5.5-6.5	0.2	min. 0.1	0.10	0.005	0.010	0.002	0.01	—
AM50	4.4-5.5	0.2	min. 0.1	0.10	0.005	0.010	0.002	0.01	—
AM20	1.6-2.6	0.2	min. 0.1	0.10	0.005	0.010	0.002	0.01	—
AS21	1.8-2.6	0.2	min. 0.1	0.7-1.2	0.005	0.010	0.002	0.01	—
AS41	3.5-5.0	0.2	min. 0.1	0.50-1.5	0.005	0.010	0.002	0.01	—

Table 3-21 Cross Reference of Equivalent Zinc Alloy Specifications and Designations									
U.S. Commercial	ASTM	SAE	Canada	United Kingdom	Japan	Germany	ISO	EN	UNS
#2	AC43A	-	-	-	-	-	ZP0430	ZnAl4Cu3	Z35541
#3	AG40A	903	AG40	A	Class 2	Z400	ZP0400	ZnAl4	Z33521
#5	AC41A	905	-	B	Class 1	Z410	ZP0410	ZnAl4Cu1	Z35531
ZA-8	ZA8	-	-	-	-	-	ZP0810	ZnAl8Cu1	Z35636
ZA-12	ZA12	-	-	-	-	-	ZP1110	ZnAl11Cu1	Z35631
ZA-27	ZA27	-	-	-	-	-	ZP2720	ZnAl27Cu2	Z35841

Table 3-22 International Zinc Alloy Composition									
EN 12844	% Al	% Cu	% Mg	% Pb	% Cd	% Sn	% Fe	% Ni	% Si
ZnAl4-P	3.7-4.3	0.1	0.025-0.06	0.005	0.005	0.002	0.05	0.02	0.03
ZnAl4Cu1-P	3.7-4.3	0.7-1.3	0.4-0.6	0.005	0.005	0.002	0.05	0.02	0.03

Table 3-23 Chemical Composition of Zinc Alloy Castings								
ISO 15201	Short Designation	% Al	% Cu	% Mg	% Pb	% Cd	% Sn	% Fe
ZP0430	ZP2	3.7-4.3	2.6-3.3	.02-.06	.005	.004	.002	.05
ZP0400	ZP3	3.7-4.3	.1	.02-.06	.005	.004	.002	.05
ZP0410	ZP5	3.7-4.3	.7-1.2	.02-.06	.005	.004	.002	.05
ZP0810	ZP8	8.0-8.8	.8-1.3	.01-.03	.006	.006	.003	.075
ZP1110	ZP12	10.5-11.5	.5-1.2	.01-.03	.006	.006	.003	.075
ZP2720	ZP27	25.0-28.0	2.0-2.5	.01-.02	.006	.006	.003	.075