Alloy Data

SECTION 3

Alloy Data

The cross reference designations shown are for alloy specifications according to widely recognized sources. References apply to the metal in the die cast condition and should not be confused with similar specifications for metal ingot. A "—" in a column indicates that the specific alloy is not registered by the given source.

Frequently Asked Questions (FAQ)

1) Is there a cross reference available for different alloy designations?
   See pages 3-2, 3-3 all charts and pages 3-42 through 3-45.
2) What type of material best fits my application?
   See page 3-33, Quick Guide to Alloy Family Selection.
3) How do die cast properties compare to sand cast properties?
   See pages 3-38 through 3-41, Property Comparison.
4) Where can I find general material properties for Aluminum Alloys?
   See pages 3-4 through 3-11.
5) How can I determine if certain die casting alloys would be a better choice for thermal conductivity? See row "Thermal Conductivity" in tables found on pages 3-6, 3-14, 3-18, 3-22, 3-28, and 3-30.

1 Die Casting Alloy Cross Reference Designations

Aluminum Alloy Specifications

Commercial	UNS	ANSI AA	ASTM B85	Former SAE J452	Federal QQ-A-591 Ⓑ	DIN Ⓖ 1725	JIS H 5302
360	A03600	360.0	SG100B	—	Ⓑ		
A360 Ⓐ	A13600	A360.0	SG100A	309	Ⓑ	233	ADC3
380 Ⓒ	A03800	380.0	SC84B	308	Ⓑ		
A380 Ⓐ Ⓒ	A13800	A380.0	SC84A	306	Ⓑ	226A Ⓔ	ADC10 ⒸⒹ
383	A03830	383.0	SC102A	383	Ⓑ	226A Ⓔ	ADC12 ⒸⒹ
384	A03840	384.0	SC114A	303	Ⓑ		ADC12 ⒸⒹ
A384 Ⓐ	—	A384.0	—	—	Ⓑ		ADC12 ⒸⒹ
B390	A23900	B390.0	SC174B	—	Ⓑ		
13	A04130	413.0	S12B	—	Ⓑ		
A13 Ⓐ	A14130	A413.0	S12A	305	Ⓑ	231D Ⓕ	ADC1 Ⓒ
43	A34430	C443.0	S5C	304	Ⓑ		
218	A05180	518.0	G8A	—	Ⓑ	341	

Ⓐ Similar to preceding entry with slight variations in minor constituents. Ⓑ The Federal specification for aluminum alloy die castings uses the Aluminum Association designations for individual alloys. Military designations superseded by Federal specifications. Ⓒ NADCA and Japanese specifications allow 0.3 magnesium maximum. Ⓓ Japanese specifications allow 1.0 zinc maximum. Ⓔ DIN 1725 spec allows 1.2 max zinc and up to 0.5 max magnesium. Ⓕ DIN 1725 spec allows 0.3 max magnesium. Ⓖ Alloy compositions shown in DIN 1725 tend to be "primary based" and have low impurity limits making it difficult to correlate directly to U.S. alloys.

Note: *Some of these standards are obsolete but included here for historical purposes. For closest cross-reference refer to the tables of foreign alloy designations and chemical constituencies at the end of this section. All specifications are for castings only.*

Table of Symbols

UNS — Unified Numbering System

ANSI — American National Standards Institute

ASTM — American Society for Testing and Materials

AA — Aluminum Association

SAE — Society of Automotive Engineers

FED — Federal Specifications

MIL — Military Specifications

JIS — Japanese Industrial Standard

DIN — German Industrial Standard

Alloy Data

Aluminum Metal Matrix Composite Alloy Specifications		
Rio Tinto Alcan CANADA	UNS	AA
F3D.10S-F		380/SiC/10p
F3D.20S-F		380/SiC/20p
F3N.10S-F		360/SiC/10p
F3N.20S-F		360/SiC/20p

Copper Alloy Specifications			
Commercial	UNS	ASTM B176	SAE J461/
857	C85700	—	—
858	C85800	Z30A	J462
865	C86500	—	—
878	C87800	ZS144A	J462
997	C99700	—	—
997.5	C99750	—	—

Magnesium Alloy Specifications						
Commercial	UNS	ASTM B93 & B94	Former SAE J465B	Federal Ⓐ	DIN 1729	JIS H 2222 & H 5303
AZ91B	M11912	AZ91B	501A	QQ-M-38	3.5912.05	MDI1B
AZ91D	M11916	AZ91D	—	—	—	MDI1D
AZ81	—	—	—	—	—	—
AM60A	M10600	AM60A	—	—	3.5662.05	MDI2A
AM60B	M10602	AM60B	—	—	—	MDI2B
AM50	—	—	—	—	—	—
AE42	—	—	—	—	—	—
AS41A	M10410	AS41A	—	—	3.5470.05	MDI3A
AS41B	M10412	AS41B	—	—	—	—
AM20	—	—	—	—	—	—

Ⓐ This Federal Specification has been canceled and is shown for historic reference only.

Note: *For closest cross-reference refer to the tables of foreign alloy designations and chemical constituencies at the end of this section.*

Zinc and ZA Alloy Specifications						
Commercial	UNS	ASTM B86	Former SAE J469	Federal Ⓐ QQ-Z-363a	DIN	JIS H 5301
2	Z35541	AC43A	921	AC43A	1743	
3	Z33520	AG40A	903	AG40A	1743	ZDC-2
5	Z355310	AC41A	925	AC41A	1743	ZDC-1
7	Z33523	AG40B	—	AG40B		
ZA-8	Z35636	—	—			
ZA-12	Z35631	—	—			
ZA-27	Z35841	—	—			

Ⓐ This Federal Specification has been canceled and is shown for historic reference only.

Note: *For closest cross-reference refer to the tables of foreign alloy designations and chemical constituencies at the end of this section.*

Table of Symbols

UNS — Unified Numbering System

ANSI — American National Standards Institute

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AA — Aluminum Association

SAE — Society of Automotive Engineers

FED — Federal Specifications

MIL — Military Specifications

JIS — Japanese Industrial Standard

DIN — German Industrial Standard

Alloy Data

2 Aluminum Alloys

Selecting Aluminum Alloys

Aluminum (Al) die casting alloys have a specific gravity of approximately 2.7 g/cc, placing them among the lightweight structural metals. The majority of die castings produced worldwide are made from aluminum alloys.

Six major elements constitute the die cast aluminum alloy system: silicon, copper, magnesium, iron, manganese, and zinc. Each element affects the alloy both independently and interactively.

This aluminum alloy subsection presents guideline tables for chemical composition, typical properties, and die casting, machining and finishing characteristics for 11 aluminum die casting alloys. This data can be used in combination with design engineering tolerancing guidelines for aluminum die casting and can be compared with the guidelines for other alloys in this section and in the design engineering section.

Alloy A380 (ANSI/AA A380.0) is by far the most widely cast of the aluminum die casting alloys, offering the best combination of material properties and ease of production. It may be specified for most product applications. Some of the uses of this alloy include electronic and communications equipment, automotive components, engine brackets, transmission and gear cases, appliances, lawn mower housings, furniture components, hand and power tools.

Alloy 383 (ANSI/AA 383.0) and alloy 384 (ANSI/AA 384.0) are alternatives to A380 for intricate components requiring improved die filling characteristics. Alloy 383 offers improved resistance to hot cracking (strength at elevated temperatures).

Alloy A360 (ANSI/AA A360.0) offers higher corrosion resistance, superior strength at elevated temperatures, and somewhat better ductility, but is more difficult to cast.

While not in wide use and difficult to cast, alloy 43 (ANSI/AA C443.0) offers the highest ductility in the aluminum family. It is moderate in corrosion resistance and often can be used in marine grade applications.

Alloy A13 (ANSI/AA A413.0) offers excellent pressure tightness, making it a good choice for hydraulic cylinders and pressure vessels. Its casting characteristics make it useful for intricate components.

Alloy B390 (ANSI/AA B390.0) was developed for automotive engine blocks. Its resistance to wear is excellent but, its ductility is low. It is used for die cast valve bodies and sleeve-less piston housings.

Alloy 218 (ANSI/AA 518.0) provides the best combination of strength, ductility, corrosion resistance and finishing qualities, but it is more difficult to die cast.

* Different sets of properties can be achieved with alternate processes (such as high vacuum, squeeze, and semi-solid casting) and alternate alloys (such as A356, Aural 2 or 356, and Silafont 36). Information on these processes and alloys can be found in the Product Specification Standards for Die castings produced by Semi-Solid and Squeeze Cast Processes (NADCA Publication #403) and the High Integrity Die Castings book (NADCA Publication #404).

Machining Characteristics

Machining characteristics vary somewhat among the commercially available aluminum die casting alloys, but the entire group is superior to iron, steel and titanium. The rapid solidification rate associated with the die casting process makes die casting alloys somewhat superior to wrought and gravity cast alloys of similar chemical composition.

Alloy A380 has better than average machining characteristics. Alloy 218, with magnesium the major alloying element, exhibits among the best machinability. Alloy 390, with the highest silicon content and free silicon constituent, exhibits the lowest.

Surface Treatment Systems

Surface treatment systems are applied to aluminum die castings to provide a decorative finish, to form a protective barrier against environmental exposure, and to improve resistance to wear.

Decorative finishes can be applied to aluminum die castings through painting, powder coat finishing, polishing, epoxy finishing, and electro-chemical processing. Aluminum can be plated by applying an initial immersion zinc coating, followed by conventional copper-nickel-chromium plating procedure similar to that used for plating zinc metal/alloys.

Protection against environmental corrosion for aluminum die castings is achieved through painting, anodizing, chromating, and iridite coatings.

Improved wear resistance can be achieved with aluminum die castings by hard anodizing.

Where a part design does not allow the production of a pressure-tight die casting through control of porosity by gate and overflow die design, the location of ejector pins, and the reconfiguration of hard-to-cast features, impregnation of aluminum die castings can be used. Systems employing anaerobics and methacrylates are employed to produce sealed, pressure-tight castings with smooth surfaces. A detailed discussion of finishing methods for aluminum die castings can be found in *Product Design For Die Casting*.

Table A-3-1 Chemical Composition: Al Alloys
All single values are maximum composition percentages unless otherwise stated.

	Aluminum Die Casting Alloys Ⓐ Ⓔ										
Commercial: ANSI/AA	360 360.0	A360 A360.0	380 Ⓑ 380.0	A380 Ⓑ A380.0	383 383.0	384 Ⓑ 384.0	B390* B390.0	13 413.0	A13 A413.0	43 C443.0	218 518.0
Nominal Comp:	Mg 0.5 Si 9.0	Mg 0.5 Si 9.5	Cu 3.5 Si 8.5	Cu 3.5 Si 8.5	Cu 2.5 Si 10.5	Cu 3.8 Si 11.0	Cu 4.5 Si 17.0	Si 12.0	Si 12.0	Si 5.0	Mg 8.0
Detailed Composition											
Silicon Si	9.0-10.0	9.0-10.0	7.5-9.5	7.5-9.5	9.5-11.5	10.5-12.0	16.0-18.0	11.0-13.0	11.0-13.0	4.5-6.0	0.35
Iron Fe	2.0	1.3	2.0	1.3	1.3	1.3	1.3	2.0	1.3	2.0	1.8
Copper Cu	0.6	0.6	3.0-4.0	3.0-4.0	2.0-3.0	3.0-4.5	4.0-5.0	1.0	1.0	0.6	0.25
Magnesium Mg	0.4-0.6	0.4-0.6	0.30 Ⓕ	0.30 Ⓕ	0.10	0.10	0.45-0.65	0.10	0.10	0.10	7.5-8.5
Manganese Mn	0.35	0.35	0.50	0.50	0.50	0.50	0.50	0.35	0.35	0.35	0.35
Nickel Ni	0.50	0.50	0.50	0.50	0.30	0.50	0.10	0.50	0.50	0.50	0.15
Zinc Zn	0.50	0.50	3.0	3.0	3.0	3.0	1.5	0.50	0.50	0.50	0.15
Tin Sn	0.15	0.15	0.35	0.35	0.15	0.35	—	0.15	0.15	0.15	0.15
Titanium Ti	—	—	—	—	—	—	0.10	—	—	—	—
Others Each	—	—	—	—	—	—	0.10	—	—	—	—
Total Others Ⓒ	0.25	0.25	0.50	0.50	0.50	0.50	0.20	0.25	0.25	0.25	0.25
Aluminum Al	Balance	Balance	Balance	Balance	Balance	Balance	Balance	Balance	Balance	Balance	Balance

Ⓐ Analysis shall ordinarily be made only for the elements mentioned in this table. If, however, the presence of other elements is suspected, or indicated in the course of routine analysis, further analysis shall be made to determine that the total of these other elements are not present in excess of specified limits. Ⓑ With respect to mechanical properties, alloys A380.0, 383.0 and 384.0 are substantially interchangeable. Ⓒ For RoHS (the European Union's Directive on Restriction of Hazardous Substances) compliance, certification of chemical analysis is required to ensure that the "total others" category does not exceed the following weight percent limits: 0.01% cadmium, 0.4% lead, and 0.1% mercury. Hexavalent chromium does not exist in the alloys and therefore meets the 0.1% limit. Ⓓ Notched Charpy. Sources: ASTM B85-92a; ASM; SAE; Wabash Alloys. Ⓔ 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). Ⓕ NADCA allows 0.30 maximum magnesium as opposed to 0.10. A380 with 0.30 magnesium has been registered with the Aluminum Association as E380 and 383 with 0.30 magnesium as B383.

** Two other aluminum alloys, 361 and 369, are being utilized in limited applications where vibration and wear are of concern. There are also other heat treatable specialty alloys available for structural applications, such as the Silafonts and AA365, and high ductility, high strength alloys such as Mercalloy and K-Alloy. Contact your alloy producer for more information. Sources: ASTM B85-92a; Aluminum Association.*

Alloy Data

Table A-3-2 Typical Material Properties: Al Alloys

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

	Aluminum Die Casting Alloys										
Commercial:	360	A360	380	A380 Ⓔ Ⓕ	383 Ⓔ	384	B390*	13	A13	43	218
ANSI/AA	360.0	A360.0	380.0	A380.0	383.0	384.0	B390.0	413.0	A413.0	C443.0	518.0
Mechanical Properties											
Ultimate Tensile Strength ksi	44	46	46	47	45	48	46	43	42	33	45
(MPa)	(303)	(317)	(317)	(324)	(310)	(331)	(317)	(296)	(290)	(228)	(310)
Yield Strength Ⓐ ksi	25	24	23	23	22	24	36	21	19	14	28
(MPa)	(172)	(165)	(159)	(159)	(152)	(165)	(248)	(145)	(131)	(97)	(193)
Elongation % in 2in. (51mm)	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)	(193)	(179)	(193)	(186)		(200)		(172)	(172)	(131)	(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)	(138)	(124)	(138)	(138)	(145)	(138)	(138)	(131)	(131)	(117)	(138)
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)	(71)		(71)	
Physical Properties											
Density lb/in^3	0.095	0.095	0.099	0.098	0.099	0.102	0.098	0.096	0.096	0.097	0.093
(g/cm^3)	(2.63)	(2.63)	(2.74)	(2.71)	(2.74)	(2.82)	(2.71)	(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	0.230	0.230	0.230	0.230	0.230	—	—	0.230	0.230	0.230	—
(J/kg °C)	(963)	(963)	(963)	(963)	(963)			(963)	(963)	(963)	
Coefficient of Thermal Expansion μ in/in°F	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	—

Ⓐ 0.2% offset. Ⓑ 500 kg load, 10mm ball. Ⓒ Rotary Bend 5 x 10^8 cycles. Ⓓ Notched Charpy. Sources: ASTM B85-92a; ASM; SAE; Wabash Alloys. Ⓔ A 0.3% Mg version of A380 and 383 have been registered with the Aluminum Association as E380 and B383. Ⓕ Higher levels of Mg and the addition of Sr to alloy A380 have shown positive results. The limited data on pages 3-7 – 3-11 shows the effect.

** Two other aluminum alloys, 361 and 369, are being utilized in limited applications where vibration and wear are of concern. There are also other heat treatable specialty alloys and processes available for structural applications, such as the Silafonts and AA365 (Aural 2), and high ductility, high strength alloys such as Mercalloy and K-Alloy. Contact your alloy producer for more information. More information can also be obtained from Microstructures and Properties of Aluminum Die Casting Alloys Book, NADCA Publication #215 and the High Integrity Aluminum Die Casting Book, NADCA Publication #307.*

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 an aluminum 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 aluminum alloy being considered are clear.

Table A-3-3 Die Casting And Other Characteristics: Al Alloys
(1 = most desirable, 5 = least desirable)

	Aluminum Die Casting Alloys										
Commercial: ANSI/AA	360 360.0	A360 A360.0	380 380.0	A380 A380.0	383 383.0	384 384.0	390* B390.0	13 413.0	A13 A413.0	43 C443.0	218 518.0
Resistance to Hot Cracking Ⓐ	1	1	2	2	1	2	4	1	1	3	5
Pressure Tightness	2	2	2	2	2	2	4	1	1	3	5
Die-Filling Capacity Ⓑ	3	3	2	2	1	1	1	1	1	4	5
Anti-Soldering to the Die Ⓒ	2	2	1	1	2	2	2	1	1	4	5
Corrosion Resistance Ⓓ	2	2	4	4	3	5	3	2	2	2	1
Machining Ease & Quality Ⓔ	3	3	3	3	2	3	5	4	4	5	3
Polishing Ease & Quality Ⓕ	3	3	3	3	3	3	5	5	5	4	1
Electroplating Ease & Quality Ⓖ	2	2	1	1	1	2	3	3	3	2	5
Anodizing (Appearance) Ⓗ	3	3	3	3	3	4	5	5	5	2	1
Chemical Oxide Protective Coating Ⓘ	3	3	4	4	4	5	5	3	3	2	1
Strength at Elevated Temp. Ⓙ	1	1	3	3	2	2	3	3	3	5	4

Ⓐ Ability of alloy to withstand stresses from contraction while cooling through hot-short or brittle temperature ranges. Ⓑ Ability of molten alloy to flow readily in die and fill thin sections. Ⓒ Ability of molten alloy to flow without sticking to the die surfaces. Ratings given for anti-soldering are based on nominal iron compositions of approximately 1%. Ⓓ Based on resistance of alloy in standard type salt spray test. Ⓔ Composite rating based on ease of cutting, chip characteristics, quality of finish, and tool life. Ⓕ Composite rating based on ease and speed of polishing and quality of finish provided by typical polishing procedure. Ⓖ Ability of the die casting to take and hold an electroplate applied by present standard methods. Ⓗ Rated on lightness of color, brightness, and uniformity of clear anodized coating applied in sulphuric acid electrolyte. Ⓘ Rated on combined resistance of coating and prolonged heating at testing temperature. Sources: ASTM B85-92a; ASM; SAE

** Two other aluminum alloys, 361 & 369, are being utilized in limited applications where vibration and wear are of concern. There are also other heat treatable specialty alloys available for structural applications, such as the Silafonts and AA365, and high ductility, high strength alloys such as Mercalloy and K-Alloy. Contact your alloy producer for more information.*

Note: *Die castings are not usually solution heat treated. Low-temperature aging treatments may be used for stress relief or dimensional stability. A T2 or T5 temper may be given to improve properties. Because of the severe chill rate and ultra-fine grain size in die castings, their "as-cast" structure approaches that of the solution heat-treated condition. T4 and T5 temper results in properties quite similar to those which might be obtained if given a full T6 temper. Die castings are not generally gas or arc welded or brazed.*

Additional A380 Alloy Tensile Data
(Data is from separately cast specimines in the naturally aged condition)

Alloys	Tensile ksi (MPa)	Yield ksi (MPa)	Elong %
A380 at 0.09% Mg	45.5 (243)	23.8 (135)	2.6
A380 with 0.26% Mg	47.0 (201)	26.6 (183)	2.8
A380 with 0.33% Mg + 0.035% Sr*	45.7 (177)	28.5 (196)	2.4

** Identified as AMC380* in research being conducted by WPI and funded by DoD/DLA. The values in this table are the average mean values and are provided to indicate the effect of a higher magnesium content and additional strontium. The properties shown do not represent design minimums and should be used for reference only.*

Alloy Data

Table 1: Composition of Three Experimental Alloys as Compared to A380.

	Composition (%)								
	Si	Cu	Mg	Fe	Mn	Zn	Ni	Ti	Sr
A380	7.5-9.5	3-4	<0.1	<1.3	<0.5	<3	<0.5	–	–
A380*	7.0-8.0	3.8-4.2	0.08-0.12	0.63-0.73	0.47-0.53	2.0-3.0	<0.1	<0.2	<0.005
AMC380	9-10	2.8-3.2	0.27-0.33	0.63-0.73	0.47-0.53	2.0-3.0	–	0.18-0.22	0.018-0.022
AMC 1045Sr	10.5-11.5	1.8-2.2	2.3-2.7	0.27-0.33	0.37-0.43	<0.3	<0.05	<0.01	0.018-0.022

Note: The experimental alloys were developed through research sponsored by NADCA, conducted at WPI, and funded by DOD/DLA.

Table 2: Tensile properties of separately die cast specimens of the experimental alloys compared to separately die cast specimens of alloy A380.

Alloy	Gage length (inch)	UTS		YS		e		Modulus of Elasticity	
		Value (Ksi)	Vs A380 (%)	Value (Ksi)	Vs A380 (%)	Value (%)	Vs A380 (%)	Value (10^3 Ksi)	Vs A380 (%)
A380	1	45.6 ±1.3	–	22.7 ±0.7	–	3.83 ±0.48	–	11.0 ±1.1	–
	2	42.8 ±1.1	–	24.3 ±0.5	–	2.33 ±0.24	–	11.3 ±0.5	–
A380*	1	46.3 ±0.6	+1.4	23.7 ±0.5	+4.4	4.63 ±0.38	+20.8	10.6 ±1.4	-3.5
	2	42.9 ±0.8	+0.3	25.0 ±0.6	+2.8	2.64 ±0.2	+13.4	11.1 ±0.3	-1.1
AMC 380*	1	49.9 ±1.1	+9.4	27.9 ±0.7	+22.9	3.72 ±0.34	-2.7	10.7 ±1.2	-2.8
	2	46.2 ±1.2	+7.9	29.1 ±0.6	+19.8	2.33 ±0.13	-0.2	11.4 ±0.2	+1.1
AMC 1045Sr	1	53.4 ±1.3	+17.1	35.2 ±0.9	+55.1	2.33 ±0.28	-39.2	11.9 ±0.8	+8.7
	2	46.2 ±1.7	+8.1	38.0 ±0.8	+56.2	1.16 ±0.19	-50.2	11.3 ±0.3	+0.3

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 3: Tensile properties measured on specimens that were cut from die cast components.

Alloy	UTS		YS		e		Modulus of Elasticity	
	Value (Ksi)	Vs A380 (%)	Value (Ksi)	Vs A380 (%)	Value (%)	Vs A380 (%)	Value (10^3 Ksi)	Vs A380 (%)
A380	39.4 ±1.8	–	21.4 ±1.7	–	2.32 ±0.47	–	235.2 ±16.0	–
AMC 380	47.1 ±3.2	+19.6	31.0 ±1.4	+45.0	2.38 ±0.64	+2.7	302.6 ±28.4	+28.6
AMC 1045Sr	54.9 ±2.6	+39.4	42.2 ±4.6	+97.4	1.76 ±0.68	-24.3	350.4 ±21.1	+49.0
AMC 1045	53.9 ±2.8	+36.8	45.7 ±2.4	+114	1.17 ±0.29	-49.5	339.8 ±19.2	+44.4

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 4: Elevated temperature and room temperature tensile properties of the experimental alloys and commercial A380 alloy. Tests were conducted at temperature on separately die cast tensile specimens.

Alloy	Test Condition		TS (Ksi)	YS (Ksi)	e (%)	Modules of Elasticity ($X10^3$Ksi)
A380	25°C (as-cast)		45.6±1.3	22.7±0.7	3.83±0.48	11.0±1.1
	100°C	0.5 h	42.0±0.6	23.3±0.3	4.2±0.63	10.2±0.5
		500 h	42.7±0.6	25.4±0.4	4.17±0.6	9.5±0.4
		1000 h	43.4±0.3	26.5±0.2	4.20±0.1	9.8±0.5
	200°C	0.5 h	30.1±0.9	20.7±0.3	6.17±0.78	8.4±0.6
		500 h	25.0±0.3	17.6±0.3	6.7±2.0	8.4±0.7
		1000 h	24.2±0.3	17.0±0.3	7.2±1.3	7.6±2.0
A380*	25°C (as-cast)		46.3±0.6	23.7±0.5	4.63±0.38	10.6±1.4
	100°C	0.5 h	41.1±0.8	23.6±0.4	4.46±0.53	9.6±0.7
		500 h	41.5±0.8	25.4±0.3	4.18±0.6	8.7±0.9
		1000 h	42.50.6	26.5±0.2	4.29±0.4	9.8±0.6
	200°C	0.5 h	30.1±0.6	23.1±0.4	5.01±0.14	8.4±0.6
		500 h	25.6±0.4	19.2±0.6	5.8±1.0	9.2±0.6
		1000 h	24.4±0.2	18.2±0.2	6.3±0.6	8.2±1.6
AMC380	25°C (as-cast)		49.9±1.1	27.9±0.7	3.72±0.34	10.7±1.2
	100°C	0.5 h	46.6±1.0	28.1±0.5	4.20±0.22	9.7±0.3
		500 h	46.5±0.7	30.3±0.4	3.70±0.2	9.8±0.4
		1000 h	46.9±0.6	32.2±0.8	3.21±0.2	9.9±0.4
	200°C	0.5 h	36.5±0.5	28.5±0.5	4.51±0.35	8.7±0.4
		500 h	31.8±0.8	24.9±0.8	4.3±0.4	9.1±0.6
		1000 h	29.3±0.7	22.9±0.6	4.4±1.0	8.6±1.0
AMC1045Sr	25°C (as-cast)		53.4±1.3	35.2±0.9	2.33±0.28	11.9±0.8
	100°C	0.5 h	50.1±1.3	34.4±1.5	2.60±0.43	10.1±0.2
		500 h	50.2±2.7	37.0±0.6	2.27±0.6	9.8±0.4
		1000 h	50.4±1.1	39.0±0.9	1.89±0.3	10.0±0.4
	200°C	0.5 h	45.0±0.4	36.3±0.6	3.18±0.29	8.8±0.5
		500 h	33.5±0.2	25.0±0.2	4.0±0.4	9.5±0.7
		1000 h	30.8±0.5	22.3±0.5	5.0±0.6	8.4±0.4

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 5: Tensile properties of the experimental alloys at temperature and after exposure to temperature. Specimens were separately die cast.

Alloy	Test Condition		TS (Ksi)	YS (Ksi)	e (%)	Modules of Elasticity (X10^{3}Ksi)
A380	25°C (as-cast)		45.6±1.3	22.7±0.7	3.83±0.48	11.0±1.1
	Cooled to 25°C	0.5 h	45.0±0.9	21.8±0.2	3.25±0.47	11.8±1.2
		500 h	38.4±0.7	22.2±1.9	2.91±0.77	11.5±0.5
		1000 h	38.5±0.2	22.4±1.5	2.81±0.49	12.4±1.7
	Tested at 200°C	0.5 h	30.1±0.9	20.7±0.3	6.17±0.78	8.4±0.6
		500 h	25.0±0.3	17.6±0.3	6.7±2.0	8.4±0.7
		1000 h	24.2±0.3	17.0±0.3	7.2±1.3	7.6±2.0
A380*	25°C (as-cast)		46.3±0.6	23.7±0.5	4.63±0.38	10.6±1.4
	Cooled to 25°C	0.5 h	41.4±3.1	25.0±1.9	2.72±0.42	11.2±1.6
		500 h	39.0±0.2	22.7±0.4	3.34±0.50	9.1±0.8
		1000 h	37.3±0.1	21.3±0.2	3.13±0.11	12.5±0.11
	Tested at 200°C	0.5 h	30.1±0.6	23.1±0.4	5.01±0.14	8.4±0.6
		500 h	25.6±0.4	19.2±0.6	5.8±1.0	9.2±0.6
		1000 h	24.4±0.2	18.2±0.2	6.3±0.6	8.2±1.6
AMC380	25°C (as-cast)		49.9±1.1	27.9±0.7	3.72±0.34	10.7±1.2
	Cooled to 25°C	0.5 h	48.0±0.7	27.6±0.5	3.13±0.22	12.5±1.7
		500 h	43.9±0.8	29.3±1.0	2.33±0.36	11.6±2.0
		1000 h	45.1±1.4	29.5±0.8	2.68±0.31	12.2±2.5
	Tested at 200°C	0.5 h	36.5±0.5	28.5±0.5	4.51±0.35	8.7±0.4
		500 h	31.8±0.8	24.9±0.8	4.3±0.4	9.1±0.6
		1000 h	29.3±0.7	22.9±0.6	4.4±1.0	8.6±1.0
AMC1045Sr	25°C (as-cast)		53.4±1.3	35.2±0.9	2.33±0.28	11.9±0.8
	Cooled to 25°C	0.5 h	49.5±3.5	36.0±3.3	1.42±0.39	12.7±1.4
		500 h	45.1±1.3	28.5±0.6	2.47±0.52	12.2±1.7
		1000 h	44.1±1.2	25.7±0.7	3.13±0.09	12.0±0.3
	Tested at 200°C	0.5 h	45.0±0.4	36.3±0.6	3.18±0.29	8.8±0.5
		500 h	33.5±0.2	25.0±0.2	4.0±0.4	9.5±0.7
		1000 h	30.8±0.5	22.3±0.5	5.0±0.6	8.4±0.4

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 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.

3 Aluminum Metal Matrix Composites

Selecting Aluminum Composites

Aluminum metal matrix composites (MMC) are aluminum-based alloys reinforced with up to 20% silicon carbide (SiC) particles, which are now being used for high-performance die cast components.

The mechanical properties of ASTM test specimens made from these materials typically exceed those of most aluminum, magnesium, zinc and bronze components produced by die casting, and match or approach many of the characteristics of iron castings and steel at lighter weight.

The expected properties of MMC parts are higher stiffness and thermal conductivity, improved wear resistance, lower coefficient of thermal expansion, and higher tensile and fatigue strengths at elevated temperature, with densities within 5% of aluminum die casting alloys. These composites can also yield castings with reduced porosity.

Preliminary data also indicates that less vibrational noise is generated by parts made from these composites, under certain conditions, than by identical parts made from unreinforced aluminum.

Duralcan F3D.10%v/v and 20%v/v aluminum metal matrix composites reinforced with SiC ceramic powder are general purpose die casting alloys.

Duralcan F3N.10%v/v and 20%v/v aluminum metal matrix composites reinforced with SiC ceramic powder contain virtually no copper or nickel and are designed for use in corrosion sensitive applications. All of these composites are heat treatable.

Machining Characteristics

Al-MMCs are significantly more abrasive to cutting tools than all other aluminum die cast and gravity cast alloys, except for hypereutectic Al-Si alloys (those containing primary Si phases).

Coarse grades of polycrystalline diamond (PCD) tools are recommended for anything more than prototype quantities of machining.

With the proper tooling, Al-MMC can be readily turned, milled, or drilled. However, cutting speeds are lower and feed rates are higher than for unreinforced alloys. General machining guidelines are described in Volume 1 of the SME Tool & Manufacturing Engineers Handbook.

Surface Treatment Systems

Surface treatments are generally applied to aluminum MMC to provide a protective barrier to environmental exposure, to provide decorative finish, or to reduce the abrasiveness of the MMC to a counterface material. Because of the inherently high wear resistance of the Al-MMCs, surface treatments on these materials are generally not used to improve their wear resistance.

Decorative finishes can be applied by painting, powder coat finishing, epoxy finishing and plating, using procedures similar to those used for conventional aluminum alloys.

Although conventional and hard-coat anodized finishes can be applied to Al-MMC die castings, the results are not as cosmetically appealing as for conventional aluminum. The presence of the SiC particles results in a darker, more mottled appearance. This problem can be minimized, although not entirely eliminated, by using the darker, more intensely colored dyes to color the anodic coatings. Another problem often noted is that the presence of the ceramic particles produces a rougher surface, particularly after chemical etching. This, in turn, leads to a less lustrous anodic coating than usually seen with unreinforced aluminum.

Recommended procedures for painting, plating and anodizing Duralcan MMCs can be obtained through Rio Tinto Alcan, 2040 Chemin de la Reserve, Chicoutimi (Quebec) G7H 5B3, Canada.

This aluminum composite subsection presents guideline tables for chemical composition, typical properties, and die casting and other characteristics for the two families of aluminum matrix composite alloys for die casting. Design engineering tolerancing guidelines have yet to be developed.

Rio Tinto Alcan - Dubuc Works, produces Duralcan metal matrix composites for die casting using a patented process and proprietary technology, mixing ceramic powder into molten aluminum. Further technical and application information can be obtained from Rio Tinto Alcan, 2040 Chemin de la Reserve, Chicoutimi (Quebec) G7H 5B3, Canada.

Table A-3-4 Chemical Composition: Al-MMC Alloys

	Duralcan Aluminum Metal Matrix Composite Alloys Ⓑ			
Commercial:	F3D.10S-F	F3D.20S-F	F3N.10S-F	F3N.20S-F
Detailed Composition				
SiC Particulate Volume Percent	10%	20%	10%	20%
Silicon Si	9.50-10.50	9.50-10.50	9.50-10.50	9.50-10.50
Iron Fe	0.8-1.20	0.8-1.20	0.8-1.20	0.8-1.20
Copper Cu	3.0-0.50	3.0-3.50	0.20 max.	0.20 max.
Magnesium Mg	0.30-0.50	0.30-0.50	0.50-0.70	0.50-0.70
Manganese Mn	0.50-0.80	0.50-0.80	0.50-0.80	0.50-0.80
Nickel Ni	1.00-1.50	1.00-1.50	—	—
Titanium Ti	0.05 max.	0.20 max.	0.20 max.	0.20 max.
Zinc Zn	0.05 max.	0.05 max.	0.05 max.	0.05 max.
Total Others Ⓐ	0.10 Total 0.03 max.	0.10 Total 0.03 max.	0.10 Total 0.03 max.	0.10 Total 0.03 max.
Aluminum Al	Balance	Balance	Balance	Balance

Ⓐ For RoHS (the European Union's Directive on Restriction of Hazardous Substances) compliance, certification of chemical analysis is required to ensure that the "total others" category does not exceed the following weight percent limits: 0.01% cadmium, 0.4% lead, and 0.1% mercury. 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).
Source: Rio Tinto Alcan Dubuc Works

Alloy Data

Table A-3-5 Typical Material Properties: Al-MMC Alloys

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

	Duralcan Aluminum Metal Matrix Composite Alloys			
Commercial:	F30D.10S-F	F30D.20S-F	F30N.10S-F	F30N.20S-F
Mechanical Properties				
Ultimate Tensile Strength Ⓐ ksi (MPa)	50 (345)	51 (352)	45 (310)	44 (303)
Yield Strength Ⓐ ksi (MPa)	35 (241)	44 (303)	32 (221)	36 (248)
Elongation Ⓐ % in 2in. (51mm)	1.2	0.4	0.9	0.5
Rockwell Hardness Ⓐ HRB	77	82	56	73
Impact Energy Ⓑ Charpy impact ASTM E-23 (J)	1.9	0.7	1.4	0.7
Fatigue Strength Ⓒ ksi (MPa)	22 (152)	22 (152)	—	—
Elastic Modulus Ⓐ psi x 10^6 (GPa)	10.3 (71)	10.3 (71)	20 (140)	15.7 (108.2)
Physical Properties				
Density lb/in^3 (g/cm^3)	0.0997 (2.76)	0.1019 (2.82)	0.0957 (2.65)	0.0979 (2.71)
Melting Range °F (°C)	975-1060 (524-571)	975-1060 (524-571)	1067-1112 (575-600)	1067-1112 (575-600)
Specific Heat BTU/lb °F @ 77 °F (J/kg °C @ 22 °C)	0.201 (841.5)	0.198 (829.0)	0.208 (870.9)	0.193 (808.1)
Average Coefficient of Thermal Expansion μ in/in°F (μ m/m°K)	10.7 (19.3)	9.4 (16.9)	11.9 (21.4)	9.2 (16.6)
Thermal Conductivity BTU/ft hr°F @ 72 °F (W/m °K @ 22 °C)	71.6 (123.9)	83.2 (144.0)	93.0 (161.0)	97.1 (168.1)
Electrical Conductivity % IACS @ 22 °C	22.0	20.5	32.7	24.7
Poisson's Ratio	0.296	0.287	—	0.293

Ⓐ *Based on cast-to-size tensile bars.* Ⓑ *Cast-to-size test specimens.* Ⓒ *Axial fatigue, R=0.1, RT (room temperature), 1 x 107 cycles. Source: Alcan ECP Canada*

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 an aluminum matrix 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 aluminum matrix alloy being considered are clear.

Table A-3-6 Die Casting and Other Characteristics: Al-MMC Alloys
(1 = most desirable, 5 = least desirable)

	Duralcan Aluminum Metal Matrix Composite Alloys			
Commercial: ANSI/AA	F3D.10S-F	F3D.20S-F	F3N.10S-F	F3N.20S-F
Resistance to Hot Cracking Ⓐ	1	1	1	1
Die-Filling Capacity Ⓑ	1	1	1	1
Anti-Soldering to the Die Ⓒ	3	3	2	2
Pressure Tightness	2	2	2	2
Corrosion Resistance Ⓓ	5	5	3	3
Machining Ease & Quality Ⓔ	4	4	4	4
Polishing Ease & Quality Ⓕ	5	5	5	5
Electroplating Ease & Quality Ⓖ	2	2	2	2
Anodizing (Appearance) Ⓗ	4	4	4	4
Anodizing (Protection)	5	5	4	4
Strength at Elevated Temp. Ⓘ	1	1	1	1
Resistance to Wear	1	1	1	1

Ⓐ *Ability of alloy to withstand stresses from contraction while cooling through hot-short or brittle temperature range.* Ⓑ *Ability of molten alloy to flow readily in die and fill thin sections.* Ⓒ *Ability of molten alloy to flow without sticking to the die surfaces.* Ⓓ *Based on resistance of alloy in standard type salt spray test.* Ⓔ *Composite rating based on ease of cutting, ship characteristics, quality of finish, and tool life.* Ⓕ *Composite rating based on ease and speed of polishing and quality of finish provided by typical polishing procedures.* Ⓖ *Ability of the die casting to take and hold an electroplate applied by present standard methods.* Ⓗ *Rated on lightness of color, brightness, and uniformity of clear anodized coating applied in sulphuric acid electrolyte. Generally aluminum die castings are unsuitable for light color anodizing where pleasing appearance is required.* Ⓘ *Rating based on tensile and yield strengths at temperatures up to 500 °F (260 °C), after prolonged heating at testing temperatures. Source: Alcan ECP Canada*

Note: *There are additional metal matrix composites materials being developed. These include Aluminum and Magnesium matrix composites and nano-composites are being produced by means of SHS (Self-propagating high-temperature synthesis) technology under NADCA sponsored research projects. Contact the NADCA Technology Department for more information about these composite materials.*

4 Copper Alloys

Selecting Copper (Brass) Alloys

Copper alloy (Cu) die castings (brass and bronze) have the highest mechanical properties and corrosion resistance of all die cast materials.

The standard copper-base alloys in general use are readily die cast in intricate shapes. The high temperatures and pressures at which they are cast — 1800° to 1950°F (982°-1066°C) — result in shortened die life, compared to the other nonferrous alloys. While this will result in higher die replacement costs for brass castings, total product cost can be lower compared to brass machined parts or brass investment castings.

Where added strength, corrosion resistance, wear resistance and greater hardness are required for a product, the possible economies of brass die castings over other production processes should be carefully considered.

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

Copper alloy 858 is a general-purpose, lower-cost yellow brass alloy with good machinability and soldering characteristics.

Alloy 878 has the highest mechanical strength, hardness and wear resistance of the copper die casting alloys, but is the most difficult to machine. It is generally used only when the application requires its high strength and resistance to wear, although its lower lead content makes it environmentally more attractive.

Where environmental and health concerns are a factor in an application, those alloys with low lead content, as shown in table A-3-7, will be increasingly preferred.

Some examples of copper alloys in die casting are lock cases, lids and shrouds for water meters, door hardware, electrical floor plates, plumbing hardware and locomotive components.

Machining

Copper alloy die castings in general are more difficult to machine than other nonferrous components, since their excellent conductivity results in rapid heating during machining operations. However, there are significant differences in machining characteristics among the copper alloys, as can be determined from Table A-3-9.

Ratings in Table A-3-9 are based on free machining yellow brass as a standard of 100. Most copper alloys are machined dry. Three of the six alloys listed have a rating of 80, which is excellent. Copper alloys 878 and 865 are not difficult to machine if carbide tools and cutting oil are used. The chips from alloy 878 break up into fine particles while alloy 865 produces a long spiral which does not break up easily into chips.

Surface Finishing Systems

The temperature characteristics of copper alloy castings require special care in surface finishing. While a range of processes are available, electroplating is especially effective. Brass castings yield a bright chrome plate finish equal to or superior to zinc.

Natural surface color ranges from a golden yellow for the yellow brass, to a buff brown for the silicon brass alloys, to a silver color for the white manganese alloys. Copper alloys may be buffed and polished to a high luster. Polishing shines the metal; sand or shot blasting will give it a satin finish.

Final finishing choices are available through chemical and electrochemical treatments which impart greens, reds, blues, yellows, browns, black, or shades of gray. Clear organic finishes, consisting of nitrocellulose, polyvinyl fluoride or benzotriazole, are also available for copper alloys.

For more detailed finishing information contact the Copper Development Association Inc., 260 Madison Ave., New York, NY 10016 or visit www.copper.org.

Alloy Data

Table A-3-7 Chemical Composition: Cu Alloys

All single values are maximum composition percentages unless otherwise stated.

	Copper Die Casting Alloys Ⓐ Ⓒ					
Commercial: ANSI/AA Nominal Comp:	857 C85700 Yellow Brass Cu 63.0 Al 0.3 Pb 1.0 Sn 1.0 Zn 36.0	858 C85800 Yellow Brass Cu 61.5 Pb 1.0 Sn 1.0 Zn 36.0	865 C86500 Manganese Bronze Cu 58.0 Al 1.0 Fe 1.2 Sn 0.5 Mn 0.8 Zn 39.0	878 C87800 Si Bronze Cu 82.0 Si 4.0 Zn 14.0	997.0 C99700 White Tombasil Cu 56.5 Al 1.8 Pb 1.5 Mn 13.0 Ni 5.0 Zn 22.0	997.5 C99750 White Brass Cu 58.0 Al 1.6 Mn 20.0 Pb 1.5 Zn 20.0
Detailed Composition						
Copper Cu	58.0-64.0	57.0 min	55.0-60.0	80.0-84.2	54.0 min	55.0-61.0
Tin Sn	0.5-1.5	1.5	1.0	0.25	1.0	
Lead Pb Ⓑ	0.8-1.5	1.5	0.4	0.09	2.0	0.5-2.5
Zinc Zn	32.0-40.0	31.0-41.0	36.0-42.0	12.0-16.0	19.0-25.0	17.0-23.0
Iron Fe	0.7	0.50	0.4-2.0	0.15	1.0	1.0
Aluminum Al	0.8	0.55	0.5-1.5	0.15	0.5-3.0	0.25-3.0
Manganese Mn		0.25	0.1-1.5	0.15	11.0-15.0	17.0-23.0
Antimony Sb		0.05		0.05		
Nickel (incl. Cobalt) Ni	1.0	0.5	1.0	0.20	4.0-6.0	5.0
Sulphur S		0.05		0.05		
Phosphorus P		0.01		0.01		
Silicon Si	0.05	0.25		3.8-4.2		
Arsenic As		0.05		0.05		
Magnesium Mg				0.01		
Copper + Sum of Named Elements Ⓑ	98.7 min.	98.7 min.	99.0 min.	99.5 min.	99.7 min.	99.7 min.

Ⓐ Analysis shall ordinarily be made only for the elements mentioned in this table. If, however, the presence of other elements is suspected, or indicated in the course of routine analysis, further analysis shall be made to determine that the total of these other elements are not present in excess of specified limits. Ⓑ For RoHS (the European Union's Directive on Restriction of Hazardous Substances) compliance, certification of chemical analysis is required to ensure that the "total others" category does not exceed the following weight percent limits: 0.01% cadmium, 0.4% lead, and 0.1% mercury. 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).

Alloy Data

Table A-3-8 Typical Material Properties: Cu Alloys
Typical values based on "as-cast" characteristics for separately die cast specimens, not specimens cut from production die castings.

	Copper Die Casting Alloys					
Commercial:	857	858	865	878	997.0	997.5
ANSI/AA:	C85700	C85800	C86500	C87800	C99700	C99750
Common Name:	Yellow Brass	Yellow Brass	Mn Bronze	Si Bronze	White Tombasil	White Brass
Mechanical Properties						
Ultimate Tensile Strength ksi (MPa)	50 (344)	55 (379)	71 (489)	85 (586)	65 (448)	65 (448)
Yield Strength Ⓐ ksi (MPa)	18 (124)	30 (207)	28 (193)	50 (344)	27 (186)	32 (221)
Elongation % in 2in. (51mm)	15	15	30	25	15	30
Hardness BHN (500)	75	55-60HRB	100	85-90HRB	125 (@300kg)	110
Impact Strength ft-lb (J)		40 (54)	32 (43)	70 (95)	—	75 (102)
Fatigue Strength ksi (MPa)	—	—	20 (138)	—	—	19 (128)
Young's Modulus psi x 10^6 (GPa)	14 (87)	15 (103.4)	15 (103.4)	20 (137.8)	16.5 (113.7)	17 (117.1)
Physical Properties						
Density lb/in^3 @ 68 °F (g/cm^3) @20 °C	0.304 (8.4)	0.305 (8.44)	0.301 (8.33)	0.300 (8.3)	0.296 (8.19)	0.29 (8.03)
Melting Range °F (°C)	1675-1725 (913-940)	1600-1650 (871-899)	1583-1616 (862-880)	1510-1680 (821-933)	1615-1655 (879-902)	1505-1550 (819-843)
Specific Heat BTU/lb °F @ 68 °F (J/kg °K @ 293 °K)	0.09 (377.0)	0.09 (377.0)	0.09 (377.0)	0.09 (377.0)	0.09 (377.0)	0.09 (377.0)
Average Coefficient of Thermal Expansion μ in/in°F x 10^{-6} (μ m/m°C x 10^{-6})	12 (21.6)	12 (21.6)	11.3 (20.3)	10.9 (19.6)	10.9 (19.6)	13.5 (24.3)
Thermal Conductivity BTU•ft/(hr•ft^2•°F) @ 68 °F (W/m °K @ 20 °C)	48.5 (83.9)	48.5 (83.9)	49.6 (85.8)	16.0 (27.7)	16.0 (27.7)	—
Electrical Conductivity % IACS @ 20 °C	22	20	22	6.7	3.0	2.0
Poisson's Ratio	80	80	26	40	80	80

Ⓐ *Tensile yield strength at –0.5% extension under load. Sources: ASTM B176-93a and Copper Development Association.*

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 copper 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 copper alloy being considered are clear.

Table A-3-9 Die Casting and Other Characteristics: Cu Alloys
(1 = most desirable, 5 = least desirable)

	Copper Die Casting Alloys					
Commercial: UNS:	857 C85700	858 C85800	865 C86500	878 C87800	997.0 C99700	997.5 C99750
Resistance to Hot Cracking Ⓐ	2	2	3	2	2	3
Pressure Tightness	3	3	2	2	3	3
Die-Filling Capacity Ⓑ	2	3	2	2	2	2
Anti-Soldering to the Die Ⓒ	2	2	2	1	3	3
As Cast Surface Smoothness	3	4	2	1	3	3
Corrosion Resistance Ⓓ	4	4	2	3	1	2
Machining Ease & Quality Ⓔ	1	1	4	3	2	2
Polishing Ease & Quality Ⓕ	3	3	3	4	3	3
Electroplating Ease & Quality Ⓖ	1	1	3	2	3	3
High Temperature Strength Ⓗ	3	3	3	1	3	3

Ⓐ *Ability of alloy to withstand stresses from contraction while cooling through hot-short or brittle temperature range.* Ⓑ *Ability of molten alloy to flow readily in die and fill thin sections.* Ⓒ *Ability of molten alloy to flow without sticking to the die surfaces.* Ⓓ *Based on resistance of alloy in standard type salt spray test.* Ⓔ *Composite rating based on ease of cutting, chip characteristics, quality of finish, and tool life.* Ⓕ *Composite rating based on ease and speed of polishing and quality of finish provided by typical polishing procedure.* Ⓖ *Ability of the die casting to take and hold an electroplate applied by present standard methods.* Ⓗ *Rating based on tensile and yield strengths at temperatures up to 500°F (260°C), after prolonged heating at testing temperature. Sources: ASTM B176-93a; R. Lavin & Sons, Inc.*

5 Magnesium Alloys

Selecting Magnesium Alloys

Magnesium (Mg) has a specific gravity of 1.74 g/cc, making it the lightest commonly used structural metal.

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

Alloy AZ91D and AZ81 offer the highest strength of the commercial magnesium die casting alloys.

Alloy AZ91D is the most widely-used magnesium die casting alloy. It is a high-purity alloy with excellent corrosion resistance, excellent castability, and excellent strength. Corrosion resistance is achieved by enforcing strict limits on three metallic impurities: iron, copper and nickel.

AZ81 use is minimal since its properties are very close to those of AZ91D. Alloys AM60B, AM50A and AM20 are used in applications requiring good elongation, toughness and impact resistance combined with reasonably good strength and excellent corrosion resistance. Ductility increases at the expense of castability and strength, as aluminum content decreases. Therefore, the alloy with the lowest aluminum content that will meet the application requirements should be chosen.

Alloys AS41B and AE42 are used in applications requiring improved elevated temperature strength and creep resistance combined with excellent ductility and corrosion resistance. The properties of AS41B make it a good choice for crankcases of air-cooled automotive engines.

Among the more common applications of magnesium alloys can be found the following: auto parts such as transfer cases, cam covers, steering columns, brake and clutch pedal brackets, clutch housings, seat frames, and dashboard supports. Non-automotive products would include chain saws, portable tools, vacuum cleaners, lawn mowers, household mixers, floor polishers, blood pressure testing machines, projectors, cameras, radar indicators, tape recorders, sports equipment, calculators, postage meters, computers, telecommunications equipment, fractional horsepower motors, levels, sewing machines, solar cells, snowmobiles and luggage.

Machining

The magnesium alloys exhibit the best machinability of any group of commercially used metal alloys. Special precautions must routinely be taken when machining or grinding magnesium castings.

Surface Treatment Systems

Decorative finishes can be applied to magnesium die castings by painting, chromate and phosphate coatings, as well as plating. Magnesium castings can be effectively plated by applying an initial immersion zinc coating, followed by conventional copper-nickel-chromium plating procedure generally used for plating zinc metal/alloys.

Magnesium underbody auto parts, exposed to severe environmental conditions, are now used with no special coatings or protection. Other Mg die castings, such as computer parts, are often given a chemical treatment. This treatment or coating protects against tarnishing or slight surface corrosion which can occur on unprotected magnesium die castings during storage in moist atmospheres. Painting and anodizing further serve as an environmental corrosion barrier.

Improved wear resistance can be provided to magnesium die castings with hard anodizing or hard chrome plating.

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

Table A-3-10 Chemical Composition: Mg Alloys

All single values are maximum composition percentages unless otherwise stated.

	Magnesium Die Casting Alloys Ⓐ Ⓕ						
Commercial:	AZ91D Ⓐ	AZ81 Ⓑ	AM60B Ⓑ	AM50A Ⓑ	AM20 Ⓑ	AE42 Ⓑ	AS41B Ⓑ
Nominal Comp:	Al 9.0 Zn 0.7 Mn 0.2	Al 8.0 Zn 0.7 Mn 0.22	Al 6.0 Mn 0.3	Al 5.0 Mn 0.35	Al 2.0 Mn 0.55	Al 4.0 RE 2.4 Mn 0.3	Al 4.0 Si 1.0 Mn 0.37
Detailed Composition							
Aluminum Al	8.3-9.7	7.0-8.5	5.5-6.5	4.4-5.4	1.7-2.2	3.4-4.6	3.5-5.0
Zinc Zn	0.35-1.0	0.3-1.0	0.22 max	0.22 max	0.1 max	0.22 max	0.12 max
Manganese Mn	0.15-0.50 Ⓒ	0.17 min	0.24-0.6 Ⓒ	0.26-0.6 Ⓒ	0.5 min	0.25 Ⓓ	0.35-0.7 Ⓒ
Silicon Si	0.10 max	0.05 max	0.10 max	0.10 max	0.10 max	—	0.5-1.5
Iron Fe	0.005 Ⓒ	0.004 max	0.005 Ⓒ	0.004 Ⓒ	0.005 max	0.005 Ⓓ	0.0035 Ⓒ
Copper, Max Cu	0.030	0.015	0.010	0.010	0.008	0.05	0.02
Nickel, Max Ni	0.002	0.001	0.002	0.002	0.001	0.005	0.002
Rare Earth, Total RE	—	—	—	—	—	1.8-3.0	—
Others Each Ⓔ	0.02	0.01	0.02	0.02	0.01	0.02	0.02
Magnesium Mg	Balance	Balance	Balance	Balance	Balance	Balance	Balance

Ⓐ ASTM B94-03, based on die cast part. Ⓑ Commercial producer specifications, based on ingot. Source: International Magnesium Association. Ⓒ In alloys AS41B, AM50A, AM60B and AZ91D, if either the minimum manganese limit or the maximum iron limit is not met, then the iron/manganese ratio shall not exceed 0.010, 0.015, 0.021 and 0.032, respectively. Ⓓ In alloy AE42, if either the minimum manganese limit or the maximum iron limit is exceeded, then the permissible iron to manganese ratio shall not exceed 0.020. Source: ASTM B94-94, International Magnesium Assn. Ⓔ For RoHS (the European Union's Directive on Restriction of Hazardous Substances) compliance, certification of chemical analysis is required to ensure that the "total others" category does not exceed the following weight percent limits: 0.01% cadmium, 0.4% lead, and 0.1% murcury. 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).

** There are additional magnesium alloys that have been and are being developed for elevated temperature and creep resistant applications. See the data table on page 3-24. Contact your alloy producer for more information.*

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STANDARD

Alloy Data

Table A-3-11 Typical Material Properties: Mg Alloys

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

	Magnesium Die Casting Alloys						
Commercial:	AZ91D	AZ81	AM60B	AM50A	AM20	AE42	AS41B
Mechanical Properties							
Ultimate Tensile Strength Ⓑ							
ksi (MPa)	34 (230)	32 (220)	32 (220)	32 (220)	32 (220)	27 (185)	33 (225)
Yield Strength Ⓔ Ⓑ							
ksi (MPa)	23 (160)	21 (150)	19 (130)	18 (120)	15 (105)	20 (140)	20 (140)
Compressive Yield Strength Ⓗ							
ksi (MPa)	24 (165)	N/A	19 (130)	N/A	N/A	N/A	20 (140)
Elongation Ⓑ							
% in 2 in. (51mm)	3	3	6-8	6-10	8-12	8-10	6
Hardness Ⓕ							
BHN	75	72	62	57	47	57	75
Shear Strength Ⓑ							
ksi (MPa)	20 (140)	20 (140)	N/A	N/A	N/A	N/A	N/A
Impact Strength Ⓓ							
ft-lb (J)	1.6 (2.2)	N/A	4.5 (6.1)	7.0 (9.5)	N/A	4.3 (5.8)	3.0 (4.1)
Fatigue Strength Ⓐ							
ksi (MPa)	10 (70)	10 (70)	10 (70)	10 (70)	10 (70)	N/A	N/A
Latent Heat of Fusion							
Btu/lb (kJ/kg)	160 (373)	160 (373)	160 (373)	160 (373)	160 (373)	160 (373)	160 (373)
Young's Modulus Ⓑ							
psi x 10^6 (GPa)	6.5 (45)	6.5 (45)	6.5 (45)	6.5 (45)	6.5 (45)	6.5 (45)	6.5 (45)
Physical Properties							
Density							
lb/in^3 (g/cm^3)	0.066 (1.81)	0.065 (1.80)	0.065 (1.80)	0.064 (1.78)	0.063 (1.76)	0.064 (1.78)	0.064 (1.78)
Melting Range							
°F (°C)	875-1105 (470-595)	915-1130 (490-610)	1005-1140 (540-615)	1010-1150 (543-620)	1145-1190 (618-643)	1050-1150 (565-620)	1050-1150 (565-620)
Specific Heat Ⓑ							
BTU/lb °F (J/kg °C)	0.25 (1050)	0.25 (1050)	0.25 (1050)	0.25 (1050)	0.24 (1000)	0.24 (1000)	0.24 (1000)
Coefficient of Thermal Expansion Ⓑ							
µ in/in°F (µ m/m°K)	13.8 (25.0)	13.8 (25.0)	14.2 (25.6)	14.4 (26.0)	14.4 (26.0)	14.5 Ⓖ (26.1)	14.5 (26.1)
Thermal Conductivity							
BTU/ft hr°F (W/m °K)	41.8 Ⓒ (72)	30 Ⓑ (51)	36 Ⓑ (62)	36 Ⓑ (62)	35 Ⓑ (60)	40 Ⓑ Ⓖ (68)	40 Ⓑ (68)
Electrical Resistivity Ⓑ							
µ Ω in. (µ Ω cm.)	35.8 (14.1)	33.0 (13.0)	31.8 (12.5)	31.8 (12.5)	N/A	N/A	N/A
Poisson's Ratio	0.35	0.35	0.35	0.35	0.35	0.35	0.35

n/a = data not available. Ⓐ Rotating Beam fatigue test according to DIN 50113. Stress corresponding to a lifetime of 5 x 10^7 cycles. Higher values have been reported. These are conservative values. Soundness of samples has great effect on fatigue properties resulting in disagreement among data sources. Ⓑ At 68°F (20°C). Ⓒ At 212-572°F (100-300°C). Ⓓ ASTM E 23 unnotched 0.25 in. die cast bar. Ⓔ 0.2% offset. Ⓕ Average hardness based on scattered data. Ⓖ Estimated. Ⓗ 0.1% offset. Source: International Magnesium Assn.

** There are additional magnesium alloys that have been and are being developed for elevated temperature and creep resistant applications. See the data table on page 3-20. Contact your alloy producer for more information.*

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 magnesium 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 magnesium alloy being considered are clear.

Table A-3-12 Die Casting and Other Characteristics: Mg Alloys
(1 = most desirable, 5 = least desirable)

Commercial:	Magnesium Die Casting Alloys						
		AZ81		AM50A	AM20	AE42	
Resistance to Cold Defects Ⓐ	2	2	3 Ⓖ	3 Ⓖ	5 Ⓖ	4 Ⓖ	4 Ⓖ
Pressure Tightness	2	2	1 Ⓖ	1 Ⓖ	1 Ⓖ	1 Ⓖ	1 Ⓖ
Resistance to Hot Cracking Ⓑ	2	2	2 Ⓖ	2 Ⓖ	1 Ⓖ	2 Ⓖ	1 Ⓖ
Machining Ease & Quality Ⓒ	1	1	1 Ⓖ	1 Ⓖ	1 Ⓖ	1 Ⓖ	1 Ⓖ
Electroplating Ease & Quality Ⓓ	2	2	2 Ⓖ	2 Ⓖ	2 Ⓖ	—	2 Ⓖ
Surface Treatment Ⓔ	2	2	1 Ⓖ	1 Ⓖ	1 Ⓖ	1 Ⓖ	1 Ⓖ
Die-Filling Capacity	1	1	2	2	4	2	2
Anti-Soldering to the Die	1	1	1	1	1	2	1
Corrosion Resistance	1	1	1	1	2	1	2
Polishing Ease & Quality	2	2	2	2	4	3	3
Chemical Oxide Protective Coating	2	2	1	1	1	1	1
Strength at Elevated Temperature Ⓕ	4	4	3	3	5	1	2

Ⓐ 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 on electroplate applied by present standard methods. Ⓔ Ability of castings to be cleaned in standard pickle solutions and to be conditioned for pest paint adhesion. Ⓕ Rating based on resistance to creep at elevated temperatures. Ⓖ Rating based upon limited experience, giving guidance only. Sources: ASTM B94-92, International Magnesium Association.

** There are additional magnesium alloys that have been and are being developed for elevated temperature and creep resistant applications. Contact your alloy producer for more information.*

Additional Magnesium Alloy Tensile Data

(Data is from separately cast specimens in as-cast condition)

Alloy	Temp °F (°C)	Tensile ksi (MPa)	Yield ksi (MPa)	Elong %
AE44-F	Room	35 (243)	20 (135)	8.3
	250 (121)	32 (160)	16 (112)	32.0
MRI 153M-F	Room	29 (201)	27 (183)	1.7
	257 (125)	28 (193)	21 (148)	6.0
	302 (150)	26 (181)	20 (140)	6.6
	356 (180)	24 (166)	20 (137)	8.6
MRI 230D-F	Room	30 (206)	25 (172)	2.9
	257 (125)	26 (177)	21 (144)	3.7
	302 (150	24 (164)	20 (137)	3.2
	356 (180)	22 (151)	19 (132)	3.0
AJ52X-F	Room	34 (234)	20 (136)	9.8
	257 (125)	22 (155)	16 (110)	19.6
	302 (150)	20 (141)	16 (107)	18.5
	356 (180)	18 (125)	16 (112)	15.7
AS21X-F	Room	31 (216)	18 (123)	10.1
	257 (125)	19 (132)	13 (91)	30.6
	302 (150)	17 (144)	12 (85)	26.3
	356 (180)	14 (95)	11 (76)	26.4
AS31-F	Room	31 (212)	18 (127)	7.5
	257 (125)	21 (148)	14 (98)	15.1
	302 (150)	19 (131)	13 (93)	16.7
	356 (180)	16 (108)	12 (84)	16.4
AXJ530-F	Room	31 (213)	22 (155)	3.9
	257 (125)	25 (174)	19 (132)	4.4
	302 (150)	23 (158)	18 (124)	4.4
	356 (180)	20 (139)	17 (115)	4.8

The values in this table are average mean values and are provided for awareness of the new and emerging class of creep-resistant magnesium alloys that are available. The properties shown do not represent design minimums and should be used for reference only.

The property values in this table have been selected from data produced by the Structural Cast Magnesium Development (SCMD) Project and by the Magnesium Powertrain Cast Components (MPCC) Project of USAMP known as AMD-111 and AMD-304 respectively. For information about these projects, please refer to USCAR http://www.uscar.org or the DOE Energy Efficiency and Renewable Energy Vehicle Technologies Program http://www1.eere.energy.gov/vehiclesandfuels/resources/fcvt_reports.htm.

Acknowledgement

This material is based upon work supported by the Department of Energy National Energy Technology Laboratory under Award Nos. DE-FC05-95OR22363, DE-FC05-02OR22910, and DE-FC26-02OR22910.

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6 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.

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 Ⓒ Ⓓ		
Commercial: ANSI/AA	No. 2	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	0.010-0.030	0.010-0.030	0.010-0.020
Copper Cu	2.6-3.3*	0.1 max Ⓑ	0.70-1.20	0.1 max	0.8-1.3	0.5-1.2	2.0-2.5
Iron Fe (max)	0.05	0.05	0.05	0.005	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 and ASTM B791. Ⓒ 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.

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 (328)	41 (283)	54 (372)	59 (400)	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)	39 (269)	32 (221)	41-43 (283-296)	45-48 (310-331)	52-55 (359-379)
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	6-10	4-7	2.0-3.5
Aged % in 2 in. (51mm)	2	16	13	18	20	10	3
Hardness Ⓓ							
As-Cast BHN	100	82	91	80	100-106	95-105	116-122
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 Ⓔ	24-35 Ⓔ	15-27 Ⓔ	7-12 Ⓔ
(J)	(47.5)	(58)	(65)	(58)	(32-48)	(20-37)	(9-16)
Aged ft-lb	5	41	40	41	13	14	3.5
Fatigue Strength Ⓕ							
As-Cast ksi (MPa)	8.5 (58.6)	6.9 (47.6)	8.2 (56.5)	6.9 (47.6)	15 (103)	—	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)	(83)	(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)	(372-484)
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)	(24.1)	(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)	(115)	(116)	(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	113
(W/m ˚K) at 70-140 ˚C	65.3
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.

7 Selecting An Alloy Family

Overview

Although this product specification standards document addresses copper and metal matrix composites (MMC), the four main alloy families are Aluminum, Zinc, Magnesium, and Zinc-Aluminum. This subsection is presented to assist in selecting an alloy family, which is the precursor to selecting a specific alloy within a family. Information on selecting the specific alloys is presented at the beginning of each alloy family subsection.

Typical considerations in selecting an alloy family include; alloy cost and weight, die casting process cost, structural properties, surface finish, corrosion resistance, bearing properties and corrosion resistance, machinability, thermal properties, and shielding (EMI/electrical conductivity).

Cost & Weight

Alloy cost and weight is an important factor in the overall product cost, therefore the amount or volume of material used should be taken into consideration. Aluminum alloys usually yield the lowest cost per unit volume. Magnesium and zinc can be competitive because they can generally be cast with thinner walls, thereby reducing the volume of alloy needed. If weight minimization is the over-riding factor, magnesium alloys are the choice to make. It should be noted that zinc alloys have a distinct advantage in the production of miniature parts and may be the dominant choice if the casting configuration is of a very small size.

Another important component of the overall product cost is the die casting process. Alloys produced by the hot chamber process such as magnesium and much of the zinc are typically run in smaller die casting machines and at higher production rates then those produced by the cold chamber process such as aluminum and zinc-aluminum.

Production tooling maintenance and replacement costs can be significant. Tooling for zinc generally lasts longer than aluminum and magnesium tooling. This is due primarily to the higher casting temperatures of aluminum and magnesium.

Structural Properties

Each alloy has a unique set of properties. However, if one is in search of one or two properties that are most important for a specific design or interested in which properties are characteristic of an alloy family, the following generalizations may be helpful. Aluminum alloys yield the highest modulus of elasticity. Magnesium alloys offer the highest strength-to-weight ratio and the best dampening characteristics. The zinc alloys offer the highest ductility and impact strength. The ZA alloys offer the highest tensile and yield strength.

Surface Finish and Coatings

Whether a high surface finish is for functional or aesthetic reasons, it is often a requirement. As-cast surface finishes are best achieved with zinc and magnesium alloys. Zinc alloys most readily accept electro-coatings and decorative finishes. The relatively higher temperature resistance of the aluminum alloys makes them best suited for elevated temperature coating processes.

Corrosion Resistance

Corrosion resistance varies from alloy family to alloy family and within an alloy family. If corrosion resistance is a concern, it can be improved with surface treatments and coatings. Refer to the information on selecting specific alloys at the beginning of each alloy family subsection to see which specific alloys yield higher corrosion resistance.

Bearing Properties and Wear Resistance

The ZA alloys and some of the aluminum alloys are more resistant to abrasion and wear than the other die casting alloys. As for corrosion resistance, abrasion and wear resistance can be improved with surface treatments and coatings.

Machinability

Even though die castings can be produced to net or near-net shape, machining is often required. When required, machining is easily accomplished on all of the die casting alloys. Magnesium, however offers the best machinability in terms of tool life, achievable finish, low cutting forces and energy consumption.

Thermal Properties and Shielding

Aluminum alloys are typically the best choice for heat transfer applications with zinc alloys as a close second. Aluminum and zinc alloys are top choices for electrical conductivity. Of the die casting alloys, magnesium alloys offer the best shielding of electromagnetic emissions.

8 Quick Guide to Alloy Family Selection

	Aluminum	Magnesium	Zinc	Zinc-Aluminum
Cost	Lowest cost per unit volume.	Can compete with aluminum if thinner wall sections are used. Faster hot-chamber process possible on smaller parts.	Effective production of miniature parts. Significant long-term tooling cost savings (tooling lasts up to 10 times longer than aluminum).	
Weight	Second lowest in density next to magnesium.	Lowest density.	Heaviest of die cast alloys, but castable with thinner walls than aluminum, which can offset the weight disadvantage.	Weight reduction as compared with the Zinc family of alloys.
Structural Properties	High Modules of Elasticity	Highest strength-to-weight ration, best vibration dampening characteristics.	Highest ductility and impact strength.	Highest tensile and yield strength. High Modules of Elasticity
Surface Finish & Coatings	Good choice for coating processes that require high temperatures.	Good as-cast surface finishes can be achieved.	Best as-cast surface finish readily accepts electro-coatings and decorative finishes.	
Wear Resistance	*	*	*	Best as-cast wear resist.
Corrosion Resistance	*	*	*	*
Machinability	Good	Best machinability in terms of tool-life, achievable finish, low cutting forces and energy consumption.	Good	Good
Thermal Properties, Conductive, & Electromagnetic Shielding	Best choice for heat transfer Good electrical conductivity Electromagnetic shielding	Electromagnetic shielding	Best electrical conductor. Good heat transfer Electromagnetic shielding	Electromagnetic shielding

** Wear and corrosion resistance can be improved in all alloys through surface treatments and coatings.*

9 Elevated Temperature Properties

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.

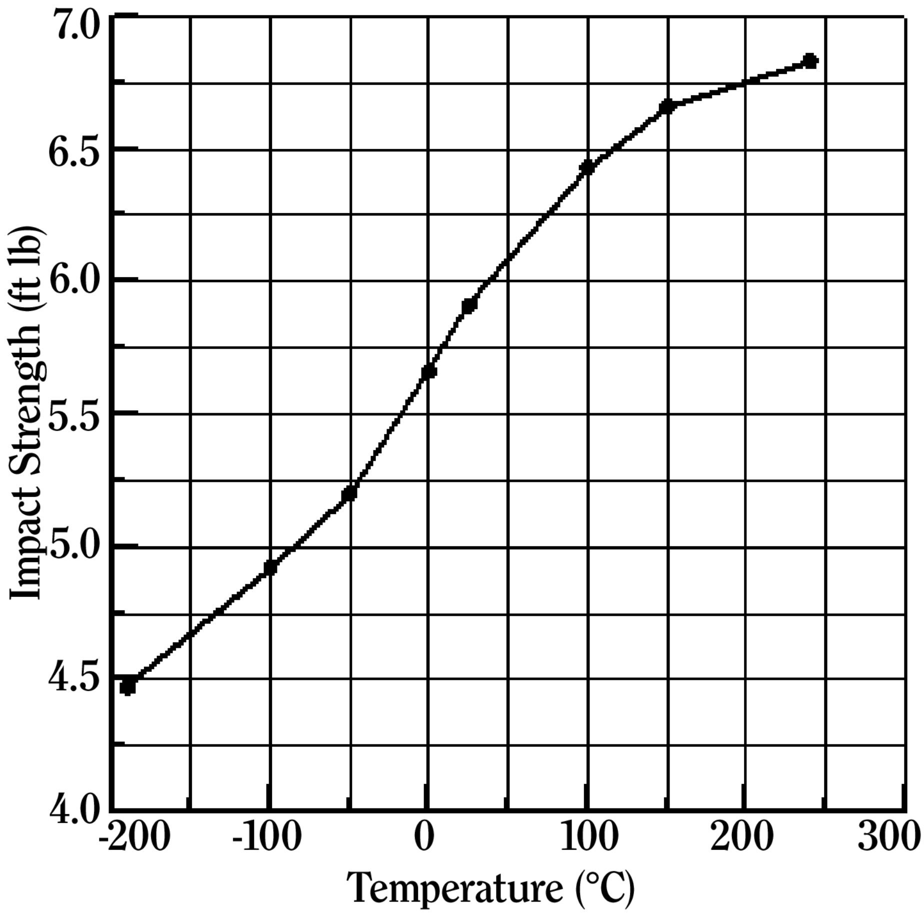
Elevated Temperature Properties of Aluminum —				
Alloy	**Temp °F (°C)**	**Tensile ksi (MPa)**	**Yield ksi (MPa)**	**Elong %**
384	-112° (-80°)			
	-18° (-26°)			
	68° (20°)	48 (330)	24 (165)	2.5
	212° (100°)	44 (303)	24 (165)	2.5
	300° (150°)	38 (262)	24 (165)	5
	400° (205°)	26 (179)	18 (124)	6
	500° (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.

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.

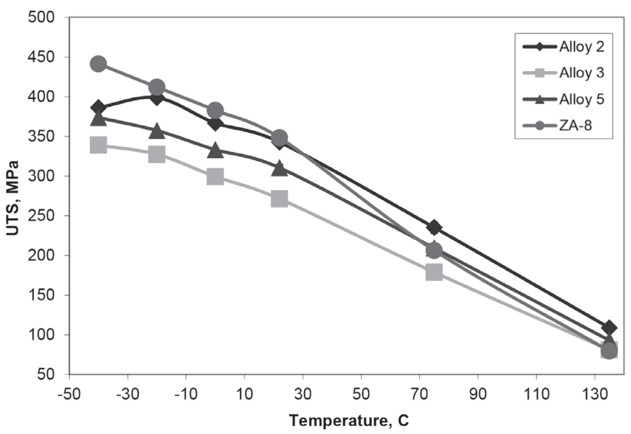
A380 Impact Strength at Temperature



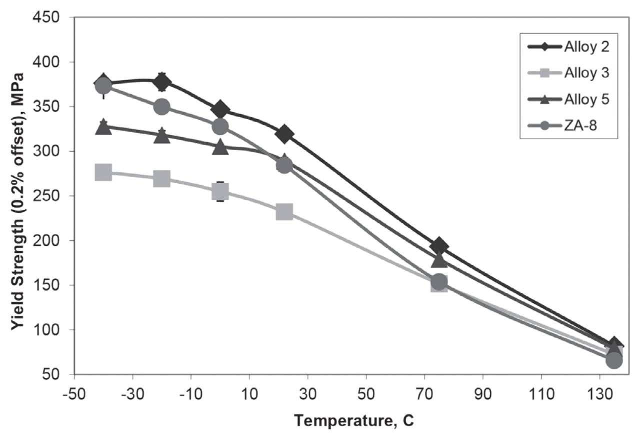
Elevated Temperature Properties of Zinc			
Alloy	**Temp °F (°C)**	**Tensile ksi (MPa)**	**Yield ksi (MPa)**
2	-40° (-40°)	56.0 (386)	54.5 (376)
	-4° (-20°)	57.9 (399)	54.8 (378)
	32° (0°)	53.2 (367)	50.3 (347)
	72° (22°)	49.7 (343)	46.3 (319)
	167° (75°)	34.1 (235)	28.0 (193)
	275° (135°)	15.8 (109)	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



Alloy Data

10 Property Comparison

Competitive Performance

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 x10³ (MPa)	41 (283)	48 (331)	38 (263)	35 (240)	54 (374)	43 (299)	48 (328)	59 (404)	61 (421)	64 (441)
Yield Strength										
psi x10³ (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 x10⁶ (MPa x 10³)	≥ 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 x10⁶ (MPa x 10³)	≥ 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 x10³ (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 10⁶ cycles)										
psi x10³ (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 x10³ (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.
*** Complies with ASTM specification B669.
**** Varies with stress level; applicable only for shot-duration loads.

Alloy Data

Chart

	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		Die Cast	Die Cast	Gray Cast Iron	Mal-leable 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		

3

Alloy Data

Alloy Property	ZA-MAK 3** Die Cast	ZA-MAK 5** Die Cast	ZA-8*** Sand Cast	ZA-8*** Perm Mold	ZA-8*** Die Cast	ZA-12*** Sand Cast	ZA-12*** Perm Mold	ZA-12*** Die Cast	ZA-27*** Sand Cast	ZA-27*** 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

Competitive Performance

Alloy Data

Chart

	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		Die Cast	Die Cast	Gray Cast Iron	Mal-leable 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

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	—	—	—	—	—	—

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	—

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

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	—

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

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

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