

# Alloy Data

## SECTION

# 3

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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.

**Note:** Properties shown in this section are typical for the alloy. Changes within the chemistry range will effect the properties slightly. Also, die casting is a highly engineered manufacturing process. Geometry of the casting and the die casting process can also effect the properties. Designer and die caster should start conversations early in the design cycle to ensure the product meets the requirements.

## Frequently Asked Questions (FAQ)

- 1) What type of material best fits my application? See page 3-4, Quick Guide to Alloy Family Selection.
- 2) Is there a cross reference available for different alloy designations? See pages 3-5, 3-6 all charts and pages 3-38 through 3-41.
- 3) How do die cast properties compare to sand cast properties? See pages 3-34 through 3-37, Property Comparison.
- 4) Where can I find general material properties for Aluminum Alloys? See pages 3-7 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 3-9, 3-14, 3-18, 3-27, 3-29, and 3-36.

## 1 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).

Although chemistry is important for determining properties of a die casting there are other factors that should be considered as well, such as geometry and the die casting process. It is important for designers and die casters to start conversations early on in the design cycle to ensure the die casting meets the requirements.

### 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 than 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.

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## 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.

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## 2 Quick Guide to Alloy Family Selection

Table 3-16 Competitive Performance Chart

	Aluminum	Magnesium	Zinc	Zinc-Aluminum
<b>Cost</b>	Lowest cost per unit volume.w	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).	
<b>Weight</b>	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.
<b>Structural Properties</b>	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
<b>Surface Finish &amp; Coatings</b>	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.	
<b>Wear Resistance</b>	*	*	*	Best as-cast wear resist.
<b>Corrosion Resistance</b>	*	*	*	*
<b>Machinability</b>	Good	Best machinability in terms of tool-life, achievable finish, low cutting forces and energy consumption.	Good	Good
<b>Thermal Properties, Conductive, &amp; Electromagnetic Shielding</b>	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.

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## 3 Die Casting Alloy Cross Reference Designations

**Table 3-1 Aluminum Alloy Specifications**

Com- mercial	UNS (H)	ANSI AA (B)	ASTM B85	Former SAE J452	ISO	DIN (G) 1725	JIS H 5302
360	A03600	360.0	SG100B	—	—		
A360 (A)	A13600	A360.0	SG100A	309	Al-Si10Mg	233	ADC3
380 (C)	A03800	380.0	SC84B	308	—		
A380 (A) (C)	A13800	A380.0	SC84A	306	Al-Si8Cu3Fe	226A (E)	ADC10 (C) (D)
383	A03830	383.0	SC102A	383	—	226A (E)	ADC12 (C) (D)
384	A03840	384.0	SC114A	303	—		ADC12 (C) (D)
A384 (A)	—	A384.0	—	—	—		ADC12 (C) (D)
B390	A23900	B390.0	SC174B	—	—		
13	A04130	413.0	S12B	—	—		
A13 (A)	A14130	A413.0	S12A	305	—	231D (F)	ADC1 (C)
43	A34430	C443.0	S5C	304	Al-Si12CuFe		
218	A05180	518.0	G8A	—	—	341	

(A) Similar to preceding entry with slight variations in minor constituents. (B) The Federal specification for aluminum alloy die castings (QQ-A-591) uses the Aluminum Association designations for individual alloys. Military designations superseded by Federal specifications. (C) NADCA and Japanese specifications allow 0.3 magnesium maximum. (D) Japanese specifications allow 1.0 zinc maximum. (E) DIN 1725 spec allows 1.2 max zinc and up to 0.5 max magnesium. (F) DIN 1725 spec allows 0.3 max magnesium. (G) 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. (H) UNS specifications are for as cast condition. This should not be confused with ingot specifications.

**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 3-2 Aluminum Metal Matrix Composite Alloy Specifications**

Rio Tinto	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

**Table 3-3 Copper Alloy Specifications**

Commercial	UNS (A)	ASTM B176	SAE J461/ J462
857	C85700	—	—
858	C85800	Z30A	J462
865	C86500	—	—
878	C87800	ZS144A	J462
997	C99700	—	—
997.5	C99750	—	—

(A) UNS specifications are for as cast condition. This should not be confused with ingot specifications.

## 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

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**Table 3-4 Magnesium Alloy Specifications**

Commercial	UNS Ⓐ	ASTM B93 & B94	Former SAE J465B	ISO	DIN 1729	JIS H 2222 & H 5303
AZ91B	M11912	AZ91B	501A	—	3.5912.05	MDI1B
AZ91D	M11916	AZ91D	—	MgAl9Zn1	—	MDI1D
AZ81	—	—	—	—	—	—
AM60A	M10600	AM60A	—	—	3.5662.05	MDI2A
AM60B	M10602	AM60B	—	MgAl16Mn	—	MDI2B
AM50	—	—	—	MgAl15Mn	—	—
AE42	—	—	—	—	—	—
AS41A	M10410	AS41A	—	—	3.5470.05	MDI3A
AS41B	M10412	AS41B	—	MgAl14Si	—	—
AM20	—	—	—	MgAl12Mn	—	—

Ⓐ UNS specifications are for as cast condition. This should not be confused with ingot specifications. Ⓑ The Federal QQ-M-38 spec is canceled, but cross references to AZ91B for historic reference.

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

**Table 3-5 Zinc and ZA Alloy Specifications**

Commercial	UNS Ⓑ	ASTM B86 Ⓐ	Former SAE J469	ISO	DIN	JIS H 5301
2	Z35545	AC43A	921	ZP0430	1743	
3	Z33525	AG40A	903	ZP0400	1743	ZDC-2
5	Z35533	AC41A	925	ZP0410	1743	ZDC-1
7	Z33527	AG40B	—	—		
ZA-8	Z35638	—	—	ZP0810		
ZA-12	Z35633	—	—	ZP1110		
ZA-27	Z35841	—	—	ZP2720		

Ⓐ The Federal QQ-Z-363a spec is canceled, but for historic reference the designations coincide with ASTM B86. Ⓑ UNS specifications are for as cast conditions. This should not be confused with ingot specifications.

**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

**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

## 4 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 a very good combination of material properties and ease of production. It may be specified for most general purpose 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.
- Alloy A413 (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 518 (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 365, and Silafont 36). Information on these processes and alloys can be found in the NADCA Standards for High Integrity and Structural Die Casting Process (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 518, with magnesium the major alloying element, exhibits among the best machinability. Alloy B390, 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

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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 (NADCA Publication E-606).

**Table A-3-1 Chemical Composition: Al Alloys**

*All single values are maximum composition percentages unless otherwise stated.*

Aluminum Die Casting Alloys <sup>(A)(D)</sup>										
Common: ANSI/AA	360* 360.0	A360* A360.0	380 <sup>(B)</sup> 380.0	A380 <sup>(B)</sup> A380.0	383 383.0	384 <sup>(B)</sup> 384.0	B390 B390.0	413 413.0	A413 A413.0	518 518.0
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	Mg 8.0
Detailed Composition										
<b>Silicon</b> 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	0.35
<b>Iron</b> Fe	2.0	1.3	2.0	1.3	1.3	1.3	1.3	2.0	1.3	1.8
<b>Copper</b> 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	0.25
<b>Magnesium</b> Mg	0.4-0.6	0.4-0.6	0.30 <sup>(E)</sup>	0.30 <sup>(E)</sup>	0.10	0.10	0.45- 0.65	0.10	0.10	7.5-8.5
<b>Manganese</b> Mn	0.35	0.35	0.50	0.50	0.50	0.50	0.50	0.35	0.35	0.35
<b>Nickel</b> Ni	0.50	0.50	0.50	0.50	0.30	0.50	0.10	0.50	0.50	0.15
<b>Zinc</b> Zn	0.50	0.50	3.0	3.0	3.0	3.0	1.5	0.50	0.50	0.15
<b>Tin</b> Sn	0.15	0.15	0.35	0.35	0.15	0.35	—	0.15	0.15	0.15
<b>Titanium</b> Ti	—	—	—	—	—	—	0.20	—	—	—
Others Each	—	—	—	—	—	—	0.10	—	—	—
Total Others <sup>(C)</sup>	0.25	0.25	0.50	0.50	0.50	0.50	0.20	0.25	0.25	0.25
<b>Aluminum</b> Al	Balance	Balance	Balance	Balance	Balance	Balance	Balance	Balance	Balance	Balance

<sup>(A)</sup> 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. <sup>(B)</sup> With respect to mechanical properties, alloys A380.0, 383.0 and 384.0 are substantially interchangeable. <sup>(C)</sup> 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. <sup>(D)</sup> 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). <sup>(E)</sup> 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

NADCA

A-3-2-21

STANDARD

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

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

Aluminum Die Casting Alloys										
Common:	360*	A360*	380	A380 (E)(F)	383 (E)	384	B390	413	A413	518
ANSI/AA	360.0	A360.0	380.0	A380.0	383.0	384.0	B390.0	413.0	A413.0	518.0
Mechanical Properties										
<b>Ultimate Tensile Strength</b>										
ksi	44	46	46	47	45	48	46	43	42	45
(MPa)	(303)	(317)	(317)	(324)	(310)	(331)	(317)	(296)	(290)	(310)
<b>Yield Strength (A)</b>										
ksi	25	24	23	23	22	24	36	21	19	28
(MPa)	(172)	(165)	(159)	(159)	(152)	(165)	(248)	(145)	(131)	(193)
<b>Elongation</b>										
% in 2in. (51mm)	2.5	3.5	3.5	3.5	3.5	2.5	<1	2.5	3.5	5.0
<b>Hardness (B)</b>										
BHN	75	75	80	80	75	85	120	80	80	80
<b>Shear Strength</b>										
ksi	28	26	28	27	—	29	—	25	25	29
(MPa)	(193)	(179)	(193)	(186)	—	(200)	—	(172)	(172)	(200)
<b>Impact Strength (D)</b>										
ft-lb	—	—	3	—	3	—	—	—	—	7
(J)	—	—	(4)	—	(4)	—	—	—	—	(9)
<b>Fatigue Strength (C)</b>										
ksi	20	18	20	20	21	20	20	19	19	20
(MPa)	(138)	(124)	(138)	(138)	(145)	(138)	(138)	(131)	(131)	(138)
<b>Young's Modulus</b>										
psi x 10 <sup>6</sup>	10.3	10.3	10.3	10.3	10.3	—	11.8	10.3	—	—
(GPa)	(71)	(71)	(71)	(71)	(71)	—	(81)	(71)	—	—
Physical Properties										
<b>Density</b>										
lb/in <sup>3</sup>	0.095	0.095	0.099	0.098	0.099	0.102	0.098	0.096	0.096	0.093
(g/cm <sup>3</sup> )	(2.63)	(2.63)	(2.74)	(2.71)	(2.74)	(2.82)	(2.71)	(2.66)	(2.66)	(2.57)
<b>Melting Range</b>										
°F	1035-1105	1035-1105	1000-1100	1000-1100	960-1080	960-1080	950-1200	1065-1080	1065-1080	995-1150
(°C)	(557-596)	(557-596)	(540-595)	(540-595)	(516-582)	(516-582)	(510-650)	(574-582)	(574-582)	(535-621)
<b>Specific Heat</b>										
BTU/lb °F	0.230	0.230	0.230	0.230	0.230	—	—	0.230	0.230	—
(J/kg °C)	(963)	(963)	(963)	(963)	(963)	—	—	(963)	(963)	—
<b>Coefficient of Thermal Expansion</b>										
μ in/in °F	11.6	11.6	12.2	12.1	11.7	11.6	10.0	11.3	11.9	13.4
(μ m/m °K)	(21.0)	(21.0)	(22.0)	(21.8)	(21.1)	(21.0)	(18.0)	(20.4)	(21.6)	(24.1)
<b>Thermal Conductivity</b>										
BTU/ft hr °F	65.3	65.3	55.6	55.6	55.6	55.6	77.4	70.1	70.1	55.6
(W/m °K)	(113)	(113)	(96.2)	(96.2)	(96.2)	(96.2)	(134)	(121)	(121)	(96.2)
<b>Electrical Conductivity</b>										
% IACS	30	29	27	23	23	22	27	31	31	24
<b>Poisson's Ratio</b>	0.33	0.33	0.33	0.33	0.33	—	—	—	—	—

(A) 0.2% offset. (B) 500 kg load, 10mm ball. (C) Rotary Bend 5 x 10<sup>6</sup> cycles. (D) Notched Charpy. Sources: ASTM B85-92a; ASM; SAE; Wabash Alloys. (E) A 0.3% Mg version of A380 and 383 have been registered with the Aluminum Association as E380 and B383. (F) Higher levels of Mg and the addition of Sr to alloy A380 have shown positive results.

\* 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)

Common: ANSI/AA	Aluminum Die Casting Alloys									
	360* 360.0	A360* A360.0	380 380.0	A380 A380.0	383 383.0	384 384.0	390 B390.0	413 413.0	A413 A413.0	518 518.0
Resistance to Hot Cracking <sup>(A)</sup>	1	1	2	2	1	2	4	1	1	5
Pressure Tightness	2	2	2	2	2	2	4	1	1	5
Die-Filling Capacity <sup>(B)</sup>	3	3	2	2	1	1	1	1	1	5
Anti-Soldering to the Die <sup>(C)</sup>	2	2	1	1	2	2	2	1	1	5
Corrosion Resistance <sup>(D)</sup>	2	2	4	4	3	5	3	2	2	1
Machining Ease & Quality <sup>(E)</sup>	3	3	3	3	2	3	5	4	4	3
Polishing Ease & Quality <sup>(F)</sup>	3	3	3	3	3	3	5	5	5	1
Electroplating Ease & Quality <sup>(G)</sup>	2	2	1	1	1	2	3	3	3	5
Anodizing (Appearance) <sup>(H)</sup>	3	3	3	3	3	4	5	5	5	1
Chemical Oxide Protective Coating <sup>(I)</sup>	3	3	4	4	4	5	5	3	3	1
Strength at Elevated Temp. <sup>(J)</sup>	1	1	3	3	2	2	3	3	3	4

<sup>(A)</sup> Ability of alloy to withstand stresses from contraction while cooling through hot-short or brittle temperature ranges. <sup>(B)</sup> Ability of molten alloy to flow readily in die and fill thin sections. <sup>(C)</sup> 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%. <sup>(D)</sup> Based on resistance of alloy in standard type salt spray test. <sup>(E)</sup> Composite rating based on ease of cutting, chip characteristics, quality of finish, and tool life. <sup>(F)</sup> Composite rating based on ease and speed of polishing and quality of finish provided by typical polishing procedure. <sup>(G)</sup> Ability of the die casting to take and hold an electroplate applied by present standard methods. <sup>(H)</sup> Rated on lightness of color, brightness, and uniformity of clear anodized coating applied in sulphuric acid electrolyte. <sup>(I)</sup> Rated on combined resistance of coating and prolonged heating at testing temperature. Sources: ASTM B85-92a; ASM; SAE <sup>(J)</sup> Rating based on tensile and yield strengths at temperatures up to 500F (260C), after prolonged heating at testing temperature. Sources: ASTM B176-93a

\* 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.

**Table 3-6 Additional A380 Alloy Tensile Data**

(Data is from separately cast specimens 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 3-7: 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 3-8: 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)	UTS (MPa)	YS (ksi)	YS (MPa)	e (%)
A380	47.0	324	23.0	159	3.5
Hi Mg 380	45.8	316	27.2	188	3.0
Hi Mg 380-T5	46.7	322	39.3	271	1.2
F380	46.1	318	23.4	161	5.0
F380-T5	48.4	334	31.4	216	3.3
F380-T6	61.0	421	49.0	338	2.9
B360	46.6	321	23.5	162	6.1
B360-T4	38.0	262	18.0	124	15.0
B360-T5	52.0	359	37.1	256	3.6
B360-T6	53.0	434	41.0	283	5.8
B360-T7	29.0	200	18.0	124	11.0
Gibbsalloy MN	30.6	211	15.9	110	12.1
Gibbsalloy MN-T5	32.5	224	18.5	128	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.

**Table 3-9: Tensile Properties of as-cast specimens removed from castings**

Alloy	UTS (ksi)	UTS (MPa)	YS (ksi)	YS (MPa)	e (%)
A380	31.4	216	19.5	134	3.9
E380	31.9	220	24.4	168	2.9
F380	35.6	244	24.0	165	2.6
B360	35.9	248	30.6	211	6

**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.

# Alloy Data

Table 3-10: Tensile Properties of heat treated specimens removed from castings

Alloy	UTS (ksi)	UTS (MPa)	YS (ksi)	YS (MPa)	e (%)
<b>T5</b>					
E380	37.1	256	36.7	253	1.0
F380	35.4	244	33.1	228	1.4
B360	40.8	281	27.6	190	5.1
<b>T6</b>					
E380	42.3	292	40.3	278	2.0
B360	35.3	243	24.5	169	7.9

**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.

## 5 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**

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

<sup>Ⓐ</sup> 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. <sup>Ⓑ</sup> 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.*

Commercial:	Duralcan Aluminum Metal Matrix Composite Alloys			
	F3D.10S-F	F3D.20S-F	F3N.10S-F	F3N.20S-F
<b>Mechanical Properties</b>				
<b>Ultimate Tensile Strength <sup>(A)</sup></b>				
ksi	50	51	45	44
(MPa)	(345)	(352)	(310)	(303)
<b>Yield Strength <sup>(A)</sup></b>				
ksi	35	44	32	36
(MPa)	(241)	(303)	(221)	(248)
<b>Elongation <sup>(A)</sup></b>				
% in 2in. (51mm)	1.2	0.4	0.9	0.5
<b>Rockwell Hardness <sup>(A)</sup></b>				
HRB	77	82	56	73
<b>Impact Energy <sup>(B)</sup></b>				
Charpy impact ASTM E-23				
(J)	1.9	0.7	1.4	0.7
<b>Fatigue Strength <sup>(C)</sup></b>				
ksi	22	22	—	—
(MPa)	(152)	(152)	—	—
<b>Elastic Modulus <sup>(A)</sup></b>				
psi x 10 <sup>6</sup>	10.3	10.3	20	15.7
(GPa)	(71)	(71)	(140)	(108.2)
<b>Physical Properties</b>				
<b>Density</b>				
lb/in <sup>3</sup>	0.0997	0.1019	0.0957	0.0979
(g/cm <sup>3</sup> )	(2.76)	(2.82)	(2.65)	(2.71)
<b>Melting Range</b>				
°F	975-1060	975-1060	1067-1112	1067-1112
(°C)	(524-571)	(524-571)	(575-600)	(575-600)
<b>Specific Heat</b>				
BTU/lb °F @ 77 °F	0.201	0.198	0.208	0.193
(J/kg °C @ 22 °C)	(841.5)	(829.0)	(870.9)	(808.1)
<b>Average Coefficient of Thermal Expansion</b>				
μ in/in°F	10.7	9.4	11.9	9.2
(μ m/m°K)	(19.3)	(16.9)	(21.4)	(16.6)
<b>Thermal Conductivity</b>				
BTU/ft hr°F @ 72 °F	71.6	83.2	93.0	97.1
(W/m °K @ 22 °C)	(123.9)	(144.0)	(161.0)	(168.1)
<b>Electrical Conductivity</b>				
% IACS @ 22 °C	22.0	20.5	32.7	24.7
<b>Poisson's Ratio</b>				
	0.296	0.287	—	0.293

<sup>(A)</sup> Based on cast-to-size tensile bars. <sup>(B)</sup> Cast-to-size test specimens. <sup>(C)</sup> Axial fatigue, R=0.1, RT (room temperature), 1 x 10<sup>7</sup> cycles. Source: Alcan ECP Canada

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)

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

<sup>(A)</sup> Ability of alloy to withstand stresses from contraction while cooling through hot-short or brittle temperature range. <sup>(B)</sup> Ability of molten alloy to flow readily in die and fill thin sections. <sup>(C)</sup> Ability of molten alloy to flow without sticking to the die surfaces. <sup>(D)</sup> Based on resistance of alloy in standard type salt spray test. <sup>(E)</sup> Composite rating based on ease of cutting, chip characteristics, quality of finish, and tool life. <sup>(F)</sup> Composite rating based on ease and speed of polishing and quality of finish provided by typical polishing procedures. <sup>(G)</sup> Ability of the die casting to take and hold an electroplate applied by present standard methods. <sup>(H)</sup> 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. <sup>(I)</sup> 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.

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# Alloy Data

## 6 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](http://www.copper.org).

**Table A-3-7 Chemical Composition: Cu Alloys**

All single values are maximum composition percentages unless otherwise stated.

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

<sup>(A)</sup> 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. <sup>(B)</sup> 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. <sup>(C)</sup> 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	50	55	71	85	65	65
(MPa)	(344)	(379)	(489)	(586)	(448)	(448)
Yield Strength <sup>(A)</sup>						
ksi	18	30	28	50	27	32
(MPa)	(124)	(207)	(193)	(344)	(186)	(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		40	32	70	—	75
(J)		(54)	(43)	(95)		(102)
Fatigue Strength						
ksi	—	—	20	—	—	19
(MPa)			(138)			(128)
Young's Modulus						
psi x 10 <sup>6</sup>	14	15	15	20	16.5	17
(GPa)	(87)	(103.4)	(103.4)	(137.8)	(113.7)	(117.1)
Physical Properties						
Density						
lb/in <sup>3</sup> @ 68 °F	0.304	0.305	0.301	0.300	0.296	0.29
(g/cm <sup>3</sup> ) @ 20 °C	(8.4)	(8.44)	(8.33)	(8.3)	(8.19)	(8.03)
Melting Range						
°F	1675-1725	1600-1650	1583-1616	1510-1680	1615-1655	1505-1550
(°C)	(913-940)	(871-899)	(862-880)	(821-933)	(879-902)	(819-843)
Specific Heat						
BTU/lb °F @ 68 °F	0.09	0.09	0.09	0.09	0.09	0.09
(J/kg °K @ 293 °K)	(377.0)	(377.0)	(377.0)	(377.0)	(377.0)	(377.0)
Average Coefficient of Thermal Expansion						
μ in/in F x 10 <sup>-6</sup>	12	12	11.3	10.9	10.9	13.5
(μ m/m°C x 10 <sup>-6</sup> )	(21.6)	(21.6)	(20.3)	(19.6)	(19.6)	(24.3)
Thermal Conductivity						
BTU•ft/(hr•ft <sup>2</sup> •°F) @ 68 °F	48.5	48.5	49.6	16.0	16.0	—
(W/m °K @ 20 °C)	(83.9)	(83.9)	(85.8)	(27.7)	(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

<sup>(A)</sup> Tensile yield strength at -0.5% extension under load. Sources: ASTM B176-93a and Copper Development Association.

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)

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

<sup>(A)</sup> Ability of alloy to withstand stresses from contraction while cooling through hot-short or brittle temperature range. <sup>(B)</sup> Ability of molten alloy to flow readily in die and fill thin sections. <sup>(C)</sup> Ability of molten alloy to flow without sticking to the die surfaces.

<sup>(D)</sup> Based on resistance of alloy in standard type salt spray test. <sup>(E)</sup> Composite rating based on ease of cutting, chip characteristics, quality of finish, and tool life. <sup>(F)</sup> Composite rating based on ease and speed of polishing and quality of finish provided by typical polishing procedure. <sup>(G)</sup> Ability of the die casting to take and hold an electroplate applied by present standard methods. <sup>(H)</sup> 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.

## 7 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.

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## Alloy Data

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 <sup>(A)</sup> <sup>(F)</sup>							
Commercial:	AZ91D <sup>(A)</sup>	AZ81 <sup>(B)</sup>	AM60B <sup>(B)</sup>	AM50A <sup>(B)</sup>	AM20 <sup>(B)</sup>	AE42 <sup>(B)</sup>	AS41B <sup>(B)</sup>
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							
<b>Aluminum</b> 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
<b>Zinc</b> Zn	0.35-1.0	0.3-1.0	0.22 max	0.22 max	0.1 max	0.22 max	0.12 max
<b>Manganese</b> Mn	0.15-0.50 <sup>(C)</sup>	0.17 min	0.24-0.6 <sup>(C)</sup>	0.26-0.6 <sup>(C)</sup>	0.5 min	0.25 <sup>(D)</sup>	0.35-0.7 <sup>(C)</sup>
<b>Silicon</b> Si	0.10 max	0.05 max	0.10 max	0.10 max	0.10 max	—	0.5-1.5
<b>Iron</b> Fe	0.005 <sup>(C)</sup>	0.004 max	0.005 <sup>(C)</sup>	0.004 <sup>(C)</sup>	0.005 max	0.005 <sup>(D)</sup>	0.0035 <sup>(C)</sup>
<b>Copper, Max</b> Cu	0.030	0.015	0.010	0.010	0.008	0.05	0.02
<b>Nickel, Max</b> Ni	0.002	0.001	0.002	0.002	0.001	0.005	0.002
<b>Rare Earth, Total</b> RE	—	—	—	—	—	1.8-3.0	—
<b>Others Each</b> <sup>(E)</sup>	0.02	0.01	0.02	0.02	0.01	0.02	0.02
<b>Magnesium</b> Mg	Balance	Balance	Balance	Balance	Balance	Balance	Balance

<sup>(A)</sup> ASTM B94-03, based on die cast part. <sup>(B)</sup> Commercial producer specifications, based on ingot. Source: International Magnesium Association. <sup>(C)</sup> 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. <sup>(D)</sup> 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. <sup>(E)</sup> 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. <sup>(F)</sup> 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. Contact your alloy producer for more information.

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

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

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

n/a = data not available. <sup>®</sup> Rotating Beam fatigue test according to DIN 50113. Stress corresponding to a lifetime of  $5 \times 10^7$  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. <sup>®</sup> At 68°F (20°C). <sup>®</sup> At 212-572°F (100-300°C). <sup>®</sup> ASTM E 23 unnotched 0.25 in. die cast bar. <sup>®</sup> 0.2% offset. <sup>®</sup> Average hardness based on scattered data. <sup>®</sup> Estimated. <sup>®</sup> 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. Contact your alloy producer for more information.

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						
	AZ91D	AZ81	AM60B	AM50A	AM20	AE42	AS41B
<b>Resistance to Cold Defects <sup>(A)</sup></b>	2	2	3 <sup>(G)</sup>	3 <sup>(G)</sup>	5 <sup>(G)</sup>	4 <sup>(G)</sup>	4 <sup>(G)</sup>
<b>Pressure Tightness</b>	2	2	1 <sup>(G)</sup>	1 <sup>(G)</sup>	1 <sup>(G)</sup>	1 <sup>(G)</sup>	1 <sup>(G)</sup>
<b>Resistance to Hot Cracking <sup>(B)</sup></b>	2	2	2 <sup>(G)</sup>	2 <sup>(G)</sup>	1 <sup>(G)</sup>	2 <sup>(G)</sup>	1 <sup>(G)</sup>
<b>Machining Ease &amp; Quality <sup>(C)</sup></b>	1	1	1 <sup>(G)</sup>	1 <sup>(G)</sup>	1 <sup>(G)</sup>	1 <sup>(G)</sup>	1 <sup>(G)</sup>
<b>Electroplating Ease &amp; Quality <sup>(D)</sup></b>	2	2	2 <sup>(G)</sup>	2 <sup>(G)</sup>	2 <sup>(G)</sup>	—	2 <sup>(G)</sup>
<b>Surface Treatment <sup>(E)</sup></b>	2	2	1 <sup>(G)</sup>	1 <sup>(G)</sup>	1 <sup>(G)</sup>	1 <sup>(G)</sup>	1 <sup>(G)</sup>
<b>Die-Filling Capacity</b>	1	1	2	2	4	2	2
<b>Anti-Soldering to the Die</b>	1	1	1	1	1	2	1
<b>Corrosion Resistance</b>	1	1	1	1	2	1	2
<b>Polishing Ease &amp; Quality</b>	2	2	2	2	4	3	3
<b>Chemical Oxide Protective Coating</b>	2	2	1	1	1	1	1
<b>Strength at Elevated Temperature <sup>(F)</sup></b>	4	4	3	3	5	1	2

<sup>(A)</sup> The ability of alloy to resist formation of cold defects; for example, cold shuts, cold cracks, non-fill “woody” areas, swirls, etc. <sup>(B)</sup> Ability of alloy to withstand stresses from contraction while cooling through the hot-short or brittle temperature range. <sup>(C)</sup> Composite rating based on ease of cutting, chip characteristics, quality of finish and tool life. <sup>(D)</sup> Ability of the die casting to take and hold on electroplate applied by present standard methods. <sup>(E)</sup> Ability of castings to be cleaned in standard pickle solutions and to be conditioned for pest paint adhesion. <sup>(F)</sup> Rating based on resistance to creep at elevated temperatures. <sup>(G)</sup> 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.

# Alloy Data

## 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](http://www1.eere.energy.gov/vehiclesandfuels/resources/fcvt_reports.htm).

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## 8 Zinc and ZA Alloys

### Selecting Zinc and ZA Alloys

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

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

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

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

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

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

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

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

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

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

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

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

### Machining Characteristics

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

### Surface Treatment Systems

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

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

# Alloy Data

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

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

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

**Table A-3-13 Chemical Composition: Zn Alloys**

*All single values are maximum composition percentages unless otherwise stated.*

	Zamak Die Casting Alloys <sup>©</sup> <sup>Ⓓ</sup>				ZA Die Casting Alloys <sup>©</sup> <sup>Ⓓ</sup>		
	No. 2	No. 3	No. 5	No. 7	ZA-8	ZA-12	ZA-27
Common: ANSI/AA	No. 2 AC43A Al 4.0	No. 3 AG-40A	No. 5 AG-41A	No. 7 AG-40B			
Nominal Comp:	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							
<b>Aluminum</b> 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
<b>Magnesium</b> Mg	0.02-0.06	0.02-0.06 <sup>Ⓐ</sup>	0.02-0.06	0.005-0.020	0.01-0.03	0.01-0.03	0.01-0.02
<b>Copper</b> Cu	2.6-3.3*	0.1 max <sup>Ⓑ</sup>	0.7-1.2	0.1 max <sup>Ⓑ</sup>	0.8-1.3	0.5-1.2	2.0-2.5
<b>Iron</b> Fe (max)	0.05	0.05	0.05	0.05	0.075	0.075	0.075
<b>Lead <sup>©</sup></b> Pb (max)	0.005	0.005	0.005	0.003	0.006	0.006	0.006
<b>Cadmium <sup>©</sup></b> Cd (max)	0.004	0.004	0.004	0.002	0.006	0.006	0.006
<b>Tin</b> Sn (max)	0.002	0.002	0.002	0.001	0.003	0.003	0.003
<b>Nickel</b> Ni	—	—	—	0.005-0.020	—	—	—
<b>Zinc</b> Zn	Balance	Balance	Balance	Balance	Balance	Balance	Balance

<sup>Ⓐ</sup> 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. <sup>Ⓑ</sup> 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. <sup>©</sup> 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. <sup>Ⓓ</sup> Registration for REACH (the European Union's Directive on Registration, Evaluation, and Authorization of Chemicals) is not required for die castings, even if coated, since die castings are considered articles. Notification may be required if some contained substances in the die casting or coating exceed the 0.1% total weight of the article level and are listed as SVHC (substances of very high concern).

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

\*Increased copper to allow EN12844

# Alloy Data

NADCA

A-3-14-21

STANDARD

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

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

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

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

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

# Alloy Data

Zinc HF Alloy Typical Properties	
<b>Mechanical Properties</b>	
<b>Ultimate Tensile Strength <sup>(A)</sup></b>	
As-Cast ksi (MPa)	40 (276)
Aged ksi (MPa)	34 (234)
<b>Yield Strength</b>	
As-Cast ksi (MPa)	35 (241)
Aged ksi (MPa)	29 (200)
<b>Elongation</b>	
As-Cast % in 2 in. (51mm)	5.3
Aged % in 2 in. (51mm)	9.9
<b>Hardness <sup>(B)</sup></b>	
As-Cast BHN	93
Aged BHN	71
<b>Impact Strength <sup>(C)</sup></b>	
As-Cast ft-lb (J)	28 (38)
Aged ft-lb (J)	21 (28)
<b>Young's Modulus <sup>(D)</sup></b>	
psi x 10 <sup>6</sup>	13.3
(GPa)	91.7

Physical Properties	
<b>Density</b>	
lb/in <sup>3</sup>	0.239
(g/cm <sup>3</sup> )	6.602
<b>Melting Range</b>	
°F	716-723
(°C)	380-384
<b>Specific Heat</b>	
BTU/lb °F at 68-212 °F	0.1
(J/kg °C) at 20-100 °C	403
<b>Coefficient of Thermal Expansion</b>	
μ in/in °F at 68-212 °F	16.5
(μ m/m °K) at 20-100 °C	26.2
<b>Thermal Conductivity <sup>(E)</sup></b>	
BTU/ft hr °F at 158-252 °F	65.3
(W/m °K) at 70-140 °C	113
<b>Poisson's Ratio</b>	0.30
<b>Solidification Shrinkage (in/in)</b>	0.0117

Zinc HF Alloy Chemical Composition	
<b>Detailed Composition</b>	
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.

# Alloy Data

## 9 Elevated Temperature Properties

<b>Table 3-12 Elevated Temperature Properties of Aluminum</b>				
<b>Alloy</b>	<b>Temp °F (°C)</b>	<b>Tensile ksi (MPa)</b>	<b>Yield ksi (MPa)</b>	<b>Elong %</b>
<b>360</b>	-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
<b>A360</b>	-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
<b>380</b>	-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
<b>A380</b>	-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.*

# Alloy Data

<b>384</b>	-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
<b>390</b>	-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°)			
<b>13</b>	-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
<b>43</b>	-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
<b>218</b>	-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

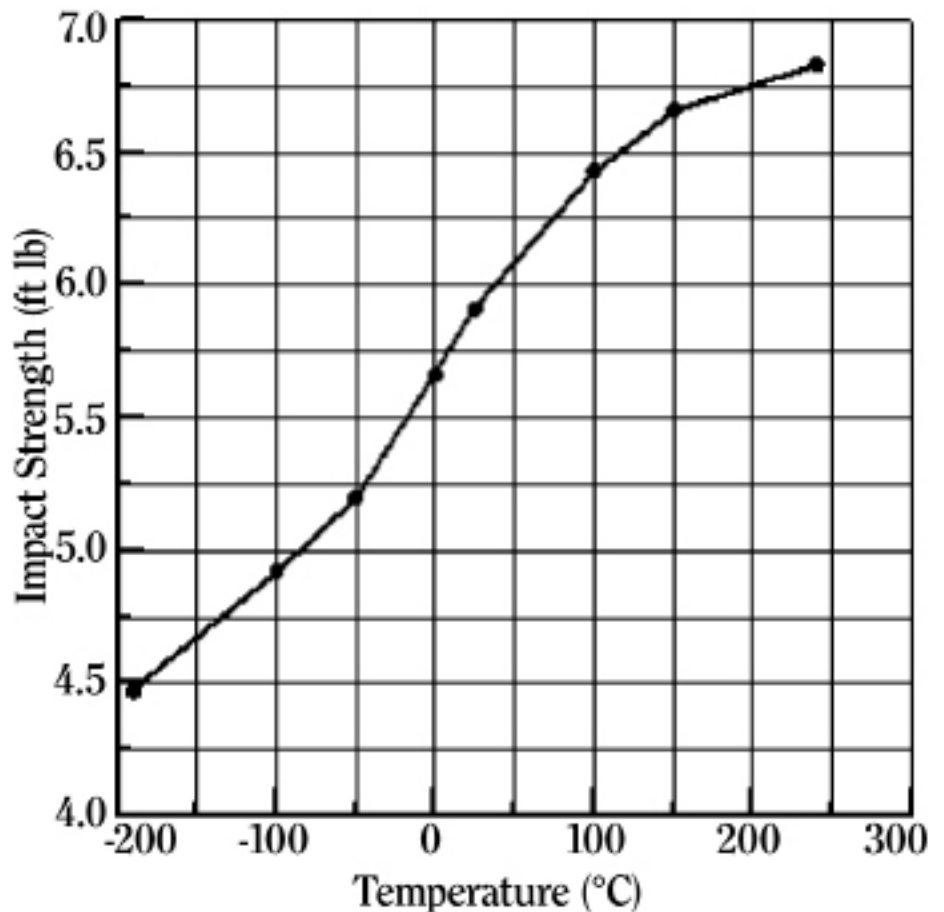
*The values in this table are from various sources and represent typical values. These values do not represent design minimums and should be used for reference only.*

# Alloy Data

Temperature (°C)	Impact Strength (ft-lb)	Standard Deviation
-190	4.47	0.92
-100	4.92	0.80
-50	5.20	0.90
0	5.66	0.93
25	5.91	0.95
100	6.43	0.89
150	6.66	0.94
240	6.83	0.88

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

**Table 3-14 Impact Strength at Temperature**

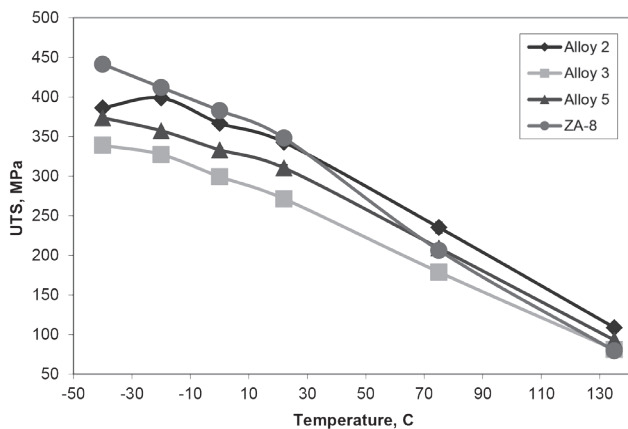


# Alloy Data

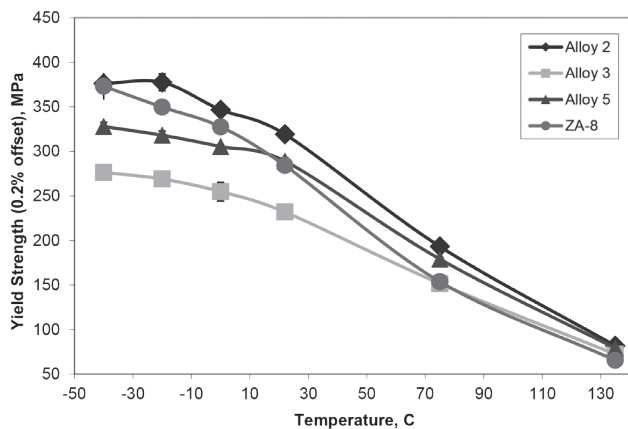
<b>Alloy</b>	<b>Temp °F (°C)</b>	<b>Tensile ksi (MPa)</b>	<b>Yield ksi (MPa)</b>
<b>2</b>	-40° (-40°)	56.0 (386)	54.5 (376)
	-4° (-20°)	57.9 (399)	54.8 (378)
	32° (0°)	53.2 (367)	50.3 (347)
	72° (22°)	49.7 (343)	46.3 (319)
	167° (75°)	34.1 (235)	28.0 (193)
	275° (135°)	15.8 (109)	11.9 (82)
<b>3</b>	-40° (-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)
<b>5</b>	-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)
<b>8</b>	-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

Table 3-16 Competitive Performance Chart

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

\* Minimum Properties

\*\* Complies with ASTM specification B86.

\*\*\* Varies with stress level; applicable only for shot-duration loads.

# Alloy Data

	Aluminum					Magnesium		Iron		Plastic	
	380	319	356-T6	713 -F*	6061-T6	AZ-91D	AM60B	Class 30	32510	ABS	Nylon 6 (30% Glass Filled)
Die Cast	Die Cast	Sand Cast	Sand Cast	Sand Cast	Wrought	Die Cast	Die Cast	Gray Cast Iron	Malleable Iron		
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		

# Alloy Data

**Table 3-16 Competitive Performance Chart**

Alloy Property	ZA-MAK 3**	ZA-MAK 5**	ZA-8**			ZA-12**			ZA-27**	
	Die Cast	Die Cast	Sand Cast	Perm Mold	Die Cast	Sand Cast	Perm Mold	Die Cast	Sand Cast	Perm Mold
<b>Physical Properties</b>										
<b>Density</b>										
lb/in <sup>3</sup> (Kg/m <sup>3</sup> )	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)
<b>Melting Range</b>										
°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)
<b>Electrical Conductivity</b>										
% IACS	27	26	27.7	27.7	27.7	28.3	28.3	28.3	29.7	29.7
<b>Thermal Conductivity</b>										
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)
<b>Coefficient of Thermal Expansion</b>										
1/°F x 10 <sup>-6</sup> (1/°C x 10 <sup>-6</sup> )	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)
<b>Pattern Shrinkage</b>										
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

# Alloy Data

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

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# Alloy Data

## 11 Cross Reference: Alloy Designations and Alloy Compositions

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

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

# Alloy Data

**Table 3-18 International Aluminum Alloy Compositions**

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

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

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

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

EUROPEAN STANDARD EN 1706												
	Cu	Mg	Si	Fe	Mn	Ni	Zn	Pb	Sn	Ti	Each*	Total*
EN AC-43400	0.1	0.20-0.50	9.0-11.0	1.0	0.55	0.15	0.15	0.15	0.05	0.20	—	—
EN AC-46100	1.5-2.5	0.3	10.0-12.0	1.1	0.55	0.45	1.7	0.25	0.15	0.25	0.05	0.25
EN AC-46500	2.0-4.0	0.05-0.55	8.0-11.0	1.3	0.55	0.55	3.0	0.35	0.15	0.25	0.05	0.25
EN AC-47100	0.7-1.2	0.35	10.5-13.5	1.3	0.55	0.30	0.55	0.20	0.10	0.20	0.05	0.25

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

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

# Alloy Data

**Table 3-19 Cross Reference of Equivalent Magnesium Alloy Specifications and Designations**

U.S.A STM	ISO 16220	EN-1753/1997
AZ91D	MgAl9Zn1	AZ91
AM60B	MgAl6Mn	AM60
AM50A	MgAl5Mn	AM50
AM20	MgAl2Mn	AM20
AS21	MgAl2Si	AS21
AS41B	MgAl4Si	AS41

**Table 3-20 International Magnesium Alloy Composition**

U.S. ASTM	%Al	%Zn	%Mn	%Si	%Fe	%Cu	%Ni	0 Each	Fe/Mn Max.
AZ91D	8.3-9.7	0.35-1.0	0.15-0.50	0.10	0.005	0.030	0.002	0.01	0.032***
AM60B	5.5-6.5	0.22	0.24-0.6	0.10	0.005	0.010	0.002	0.02	0.021**
AM50A	4.4-5.4	0.22	0.26-0.6	0.10	0.004	0.010	0.002	0.02	0.015**
AM20	—	—	—	—	—	—	—	—	—
AS21	—	—	—	—	—	—	—	—	—
AS41B	3.5-5.0	0.12	0.35-0.7	0.50-1.5	0.0065	0.02	0.002	0.02	0.010**

## ISO 16220

MgAl9Zn1	8.3-9.7	0.35-1.0	0.15-0.50	0.10	0.005	0.030	0.002	0.01	0.032**
MgAl6Mn	5.5-6.5	0.2-0.2	0.24-0.60	0.10	0.005	0.010	0.002	0.01	0.021*
MgAl5Mn	4.4-5.5	0.2	0.26-0.60	0.10	0.004	0.010	0.002	0.01	0.015*
MgAl2Mn	1.6-2.6	0.2	0.33-0.70	0.10	0.004	0.010	0.002	0.01	0.012*
MgAl2Si	1.8-2.6	0.2	0.18-0.70	0.7-1.2	0.004	0.010	0.002	0.01	0.022*
MgAl4Si	3.5-5.0	0.2	0.18-0.70	0.5-1.5a	0.004	0.010	0.002	0.01	0.022*

## EN-1753/1997

AZ91	8.3-9.7	0.35-1.0	min. 0.1	0.10	0.005	0.030	0.002	0.01	—
AM60	5.5-6.5	0.2	min. 0.1	0.10	0.005	0.010	0.002	0.01	—
AM50	4.4-5.5	0.2	min. 0.1	0.10	0.005	0.010	0.002	0.01	—
AM20	1.6-2.6	0.2	min. 0.1	0.10	0.005	0.010	0.002	0.01	—
AS21	1.8-2.6	0.2	min. 0.1	0.7-1.2	0.005	0.010	0.002	0.01	—
AS41	3.5-5.0	0.2	min. 0.1	0.50-1.5	0.005	0.010	0.002	0.01	—

# Alloy Data

**Table 3-21 Cross Reference of Equivalent Zinc Alloy Specifications and Designations**

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

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**Table 3-22 International Zinc Alloy Composition**

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

**Table 3-23 Chemical Composition of Zinc Alloy Castings**

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

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## **Alloy Data**

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