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.

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

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

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

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

Machining

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

Surface Treatment Systems

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

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

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

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

Table A-3-10 Chemical Composition: Mg Alloys
All single values are maximum composition percentages unless otherwise stated.

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

Ⓐ ASTM B94-03, based on die cast part. Ⓑ Commercial producer specifications, based on ingot. Source: International Magnesium Association. Ⓒ In alloys AS41B, AM50A, AM60B and AZ91D, if either the minimum manganese limit or the maximum iron limit is not met, then the iron/manganese ratio shall not exceed 0.010, 0.015, 0.021 and 0.032, respectively. Ⓓ In alloy AE42, if either the minimum manganese limit or the maximum iron limit is exceeded, then the permissible iron to manganese ratio shall not exceed 0.020. Source: ASTM B94-94, International Magnesium Assn. Ⓔ For RoHS (the European Union's Directive on Restriction of Hazardous Substances) compliance, certification of chemical analysis is required to ensure that the "total others" category does not exceed the following weight percent limits: 0.01% cadmium, 0.4% lead, and 0.1% murcury. Hexavalent chromium does not exist in the alloys and therefore meets the 0.1% limit. Ⓕ Registration for REACH (the European Union's Directive on Registration, Evaluation, and Authorization of Chemicals) is not required for die castings, even if coated, since die castings are considered articles. Notification may be required if some contained substances in the die casting or coating exceed the 0.1% total weight of the article level and are listed as SVHC (substances of very high concern).

** There are additional magnesium alloys that have been and are being developed for elevated temperature and creep resistant applications. 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

	Magnesium Die Casting Alloys						
Commercial:	AZ91D	AZ81	AM60B	AM50A	AM20	AE42	AS41B
Mechanical Properties							
Ultimate Tensile Strength Ⓑ							
ksi	34	32	32	32	32	27	33
(MPa)	(230)	(220)	(220)	(220)	(220)	(185)	(225)
Yield Strength Ⓔ Ⓑ							
ksi	23	21	19	18	15	20	20
(MPa)	(160)	(150)	(130)	(120)	(105)	(140)	(140)
Compressive Yield Strength Ⓗ							
ksi	24	N/A	19	N/A	N/A	N/A	20
(MPa)	(165)		(130)				(140)
Elongation Ⓑ							
% in 2 in. (51mm)	3	3	6-8	6-10	8-12	8-10	6
Hardness Ⓕ							
BHN	75	72	62	57	47	57	75
Shear Strength Ⓑ							
ksi	20	20	N/A	N/A	N/A	N/A	N/A
(MPa)	(140)	(140)					
Impact Strength Ⓓ							
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)
Fatigue Strength Ⓐ							
ksi	10	10	10	10	10	N/A	N/A
(MPa)	(70)	(70)	(70)	(70)	(70)		
Latent Heat of Fusion							
Btu/lb	160	160	160	160	160	160	160
(kJ/kg)	(373)	(373)	(373)	(373)	(373)	(373)	(373)
Young's Modulus Ⓑ							
psi x 10^6	6.5	6.5	6.5	6.5	6.5	6.5	6.5
(GPa)	(45)	(45)	(45)	(45)	(45)	(45)	(45)
Physical Properties							
Density							
lb/in^3	0.066	0.065	0.065	0.064	0.063	0.064	0.064
(g/cm^3)	(1.81)	(1.80)	(1.80)	(1.78)	(1.76)	(1.78)	(1.78)
Melting Range							
°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)
Specific Heat Ⓑ							
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)
Coefficient of Thermal Expansion Ⓑ							
μ in/in°F	13.8	13.8	14.2	14.4	14.4	14.5 Ⓖ	14.5
(μ m/m°K)	(25.0)	(25.0)	(25.6)	(26.0)	(26.0)	(26.1)	(26.1)
Thermal Conductivity							
BTU/ft hr°F	41.8 Ⓒ	30 Ⓑ	36 Ⓑ	36 Ⓑ	35 Ⓑ	40 Ⓑ Ⓖ	40 Ⓑ
(W/m °K)	(72)	(51)	(62)	(62)	(60)	(68)	(68)
Electrical Resistivity Ⓑ							
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)			
Poisson's Ratio	0.35	0.35	0.35	0.35	0.35	0.35	0.35

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

** There are additional magnesium alloys that have been and are being developed for elevated temperature and creep resistant applications. 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)

	Magnesium Die Casting Alloys						
Commercial:	AZ91D	AZ81	AM60B	AM50A	AM20	AE42	AS41B
Resistance to Cold Defects Ⓐ	2	2	3 Ⓖ	3 Ⓖ	5 Ⓖ	4 Ⓖ	4 Ⓖ
Pressure Tightness	2	2	1 Ⓖ	1 Ⓖ	1 Ⓖ	1 Ⓖ	1 Ⓖ
Resistance to Hot Cracking Ⓑ	2	2	2 Ⓖ	2 Ⓖ	1 Ⓖ	2 Ⓖ	1 Ⓖ
Machining Ease & Quality Ⓒ	1	1	1 Ⓖ	1 Ⓖ	1 Ⓖ	1 Ⓖ	1 Ⓖ
Electroplating Ease & Quality Ⓓ	2	2	2 Ⓖ	2 Ⓖ	2 Ⓖ	—	2 Ⓖ
Surface Treatment Ⓔ	2	2	1 Ⓖ	1 Ⓖ	1 Ⓖ	1 Ⓖ	1 Ⓖ
Die-Filling Capacity	1	1	2	2	4	2	2
Anti-Soldering to the Die	1	1	1	1	1	2	1
Corrosion Resistance	1	1	1	1	2	1	2
Polishing Ease & Quality	2	2	2	2	4	3	3
Chemical Oxide Protective Coating	2	2	1	1	1	1	1
Strength at Elevated Temperature Ⓕ	4	4	3	3	5	1	2

Ⓐ The ability of alloy to resist formation of cold defects; for example, cold shuts, cold cracks, non-fill "woody" areas, swirls, etc. Ⓑ Ability of alloy to withstand stresses from contraction while cooling through the hot-short or brittle temperature range. Ⓒ Composite rating based on ease of cutting, chip characteristics, quality of finish and tool life. Ⓓ Ability of the die casting to take and hold on electroplate applied by present standard methods. Ⓔ Ability of castings to be cleaned in standard pickle solutions and to be conditioned for pest paint adhesion. Ⓕ Rating based on resistance to creep at elevated temperatures. Ⓖ Rating based upon limited experience, giving guidance only. Sources: ASTM B94-92, International Magnesium Association.

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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.

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