

1 General

EZ33A is a heat treatable magnesium casting alloy normally used in the T5 (artificially-aged) condition. It has only moderate room-temperature strength in comparison with other magnesium alloys, and its elevated-temperature strength is not as high as those of the thorium-containing alloys or of the silver-bearing alloy QE22A. Nevertheless, it is an excellent alloy for aerospace and other applications in the temperature range 300 to 500F because of its reasonably good elevated-temperature strength, strength stability at high temperatures, good foundry characteristics, excellent pressure tightness, uniformity of properties in heavy sections, weldability, and relatively low cost. EZ33A is also produced in the form of welding electrodes; it is the recommended filler metal for welding magnesium alloys for elevated-temperature applications (Refs. 3, 4, 9, 27, 28).

1.1 Commercial Designation

EZ33A.

1.2 Alternate Designations

EZ33, ZREI (British), UNS No. M12330.

1.3 Specifications

1.3.1 [Table] Specifications.

1.4 Composition

1.4.1 [Table] Composition.

1.5 Heat Treatment

Condition T5 (artificially-aged), which provides optimum mechanical properties in EZ33A, is obtained by aging the as-cast alloy (condition F) at 420F for 5 hours or, alternatively, at 650F for 2 hours, air cool. Whereas the 650F treatment provides more stress relief, the 420F is recommended when maximum resistance to high-temperature creep is desired (Refs. 1, 8). Other alternative treatments consisting of lower temperatures for longer times can also be effective: for example, 350F for 12-16 hours (Refs. 19, 21).

The suggested holding times at the artificial aging temperatures are adequate for sections up to at least 2-inches thick. Longer times may be required for thicker sections (Refs. 8, 19).

After the alloy in either the as-cast (F) or artificially aged (T5) condition has been welded, stress relief and optimum properties in the weld areas can be obtained by any of the T5 treatments, the 650F treatment being somewhat more effective for stress relief but less effective for creep resistance (Refs. 1, 8, 9, 19, 20).

The furnaces or ovens used for artificial aging treatments may be heated by electricity, gas, or oil. Since the temperatures for this treatment are below 750F, no protective atmosphere is required (Refs. 8, 17).

1.6 Hardness

1.6.1 Brinell hardness for T5 condition: 48-60 using 500 kg load and 10 mm ball, or 57-72 using 1000 kg load and 10 mm ball (Ref. 1).

1.6.2 Rockwell E hardness for T5 condition: 59 (Ref. 17).

1.7 Forms and Conditions Available

Sand, permanent-mold, and investment castings are used primarily in the T5 (artificially-aged) condition (Refs. 1, 3, 4, 5).

Welding wire, primarily for GMAW and GTAW, are particularly suitable for joints requiring high strength at elevated temperatures (Refs. 2, 18, 25).

1.8 Melting and Casting Practice

EZ33A is melted and cast similarly to other zirconium-containing magnesium casting alloys (see HZ32A, Code 3408, Section 1.08). The rare earths are introduced into the melt as a rare-earth mixture known as misch-metal, and zirconium is normally added as a magnesium-zirconium hardener containing 30 to 50 percent zirconium. Although zinc losses are negligible for each melting cycle, losses of rare earths and of zirconium are substantial but variable, depending on local foundry practice. The losses must be taken into account by proper adjustments in the additions of these elements to the melt. A special crucible flux containing no magnesium chloride should be used because magnesium chloride in the normal crucible flux will combine with rare earths to form rare-earth chloride, which will settle out of the melt and thus decrease the alloying efficiency (Refs. 26, 29).

1.9 Special Considerations

1.9.1 The zirconium ingredient in this alloy serves as a grain refiner; consequently, the carbon-innoculation or superheating methods of refinement used for magnesium alloys containing aluminum are not applied to EZ33A (Ref. 26).

1.9.2 Contamination with aluminum, iron, manganese, or silicon must be prevented as these elements inhibit zirconium from performing its desired grain-refining function (Ref. 30).

1.9.3 During T5 heat treatment, EZ33A castings contract linearly about 0.019 percent (Ref. 17).

1.9.4 EZ33A castings, both as-cast (F) or artificially aged (T5), tend to contract slightly with increasing holding times at elevated temperatures (Refs. 28, 31).

1.9.4.1 [Figure] Linear contraction in castings during long-time exposures to elevated temperatures.

	Mg
3.0	RE
2.5	Zn
0.6	Zr

EZ33A

- 1.9.5 Long exposures in the temperature range 400 to 600F tend to cause increases in room-temperature strength but decreases in ductility (see Figure 3.2.1.4).
- 1.9.6 The AMS specification (Ref. 1) prohibits the suppliers of EZ33A castings from repairing defects by peening, plugging, welding, impregnation, or other methods unless they obtain written permission from the purchaser.
- 1.9.7 Safety precautions should be directed to the prevention of fires, burns, and explosions (see AZ91, Code 3402, Section 1.9.3, and HZ32A, Code 3408, Section 2.3.2).

2 Physical Properties and Environmental Effects

2.1 Thermal Properties

- 2.1.1 Melting Range: 1010-1189F (Refs. 3, 4).
- 2.1.2 Phase Changes. In the as-cast condition, a complex compound network, in which all of the ingredients have not been identified, forms at the interdendritic grain boundaries. The artificial-aging (T5) treatment converts the network into an eutectic in which the major ingredients are magnesium solid solution and the magnesium-cerium compound Mg_2Ce (Refs. 13, 14, 15).
 - 2.1.2.1 Time-temperature-transformation diagrams.
- 2.1.3 Thermal Conductivity.
 - 2.1.3.1 [Figure] Effect of temperatures up to 500F on thermal conductivity.
- 2.1.4 Thermal Expansion.
 - 2.1.4.1 Mean coefficient of thermal expansion from 68 to 392F: $14.7\text{-}14.8 \times 10^{-6}$ in/in/F (Ref. 11).
- 2.1.5 Specific Heat.
 - 2.1.5.1 Specific heat at 68F: 0.25 Btu/lbF (Ref. 9).
- 2.1.6 Thermal Diffusivity.
 - 2.1.6.1 Thermal diffusivity for T5 condition at 68F: $2.13 \text{ ft}^2/\text{hr}$ (Ref. 16).

2.2 Other Physical Properties

- 2.2.1 Density: 0.0665 lb/in³, 1.84 gr/cm³ (Refs. 3, 4).
- 2.2.2 Electrical Properties.
 - 2.2.2.1 [Figure] Effect of temperatures up to 500F on electrical resistivity.
- 2.2.3 Magnetic Properties. Nonmagnetic.
- 2.2.4 Emittance, see ZK60A, Code 3506, Figure 2.024.
- 2.2.5 Damping Capacity.
 - 2.2.5.1 [Figure] Effect of stress on specific damping capacity.

2.3 Chemical Environments

- 2.3.1 General Corrosion. EZ33A, like other magnesium alloys, is susceptible to general and pitting corrosion in industrial, marine, and moist environments. With suitable surface treatment and painting, it performs satisfactorily in all types of natural environments with the exception of continuous immersion in water (Refs. 22, 23).

- 2.3.1.1 [Table] Comparison of the corrosion rates of EZ33A with averages of other magnesium alloys in various natural environments.

Magnesium alloys, in general, are anodic to all other structural metals; consequently, they are susceptible to galvanic corrosion where they are in electrical contact with other structural metals in the presence of an electrolyte (Refs. 22, 24). For a more detailed discussion of galvanic corrosion of magnesium alloys, see AZ31B, Code 3601, Section 2.0312.

- 2.3.2 Stress Corrosion. Whereas there is little documented evidence of stress-corrosion failures of EZ33A and other magnesium-alloy castings in service, laboratory tests have produced failures under tensile loads as low as 50 percent of yield strength in environments causing negligible general corrosion. The protective finishes used on magnesium are effective but not totally reliable in controlling stress corrosion. An additional recommended controlling method is to maintain the working stresses below 50 percent of tensile yield strength, which will inhibit most stress corrosion in magnesium alloys with proper protective finishes (see Section 4.4). In the few applications where stresses are constant over long periods of time, for example clamp fittings, it is considered prudent to maintain the service tensile stresses below 30 percent of yield strength. Residual stresses in welded areas can also be sufficient to induce stress corrosion in active environments; consequently, post-weld thermal treatment as discussed in Section 1.5.2 is recommended (Refs. 22, 24).

2.4 Nuclear Environments

The large nuclear cross section of rare earths makes this alloy unsuitable for reactor equipment where low cross section is desired.

3 Mechanical Properties

3.1 Specified Mechanical Properties

- 3.1.1 [Table] AMS and ASTM specified mechanical properties.

3.2 Mechanical Properties at Room Temperature

3.2.1 Tension Stress-Strain Diagrams and Tension Properties.

- 3.2.1.1 Stress-strain diagram, see Figure 3.3.1.1.
- 3.2.1.2 Tensile properties of sand-cast test bars and production castings, see Figure 3.3.1.3.
- 3.2.1.3 [Table] Tensile properties of investment-cast test bars with various pouring temperatures and mold temperatures.
- 3.2.1.4 [Figure] Effects of exposures at elevated temperatures on tensile properties at room temperature.
- 3.2.1.5 [Figure] Effects of end chill on tensile properties of sand-cast plates of two different thicknesses.

3.2.2 Compression Stress-Strain Diagrams and Compression Properties.

- 3.2.2.1 Compression yield strength for T5 condition, sand-cast test bars: $F_{cy} = 15 - 16$ ksi (Refs. 9, 17).

3.2.3 Impact, see Figure 3.3.3.1.

3.2.4 Bending.

3.2.5 Torsion and Shear.

- 3.2.5.1 Shear strength for T5 condition: $F_{su} = 19.8 - 22$ ksi (Refs. 9, 17; see also Figure 3.3.5.1).

3.2.6 Bearing.

- 3.2.6.1 Bearing strength for T5 condition and edge-distance-to-diameter ratio of 2.5: $F_{bru} = 57$ ksi and $F_{bry} = 40$ ksi (Refs. 9, 17; see also Figure 3.3.6.1).

3.2.7 Stress Concentration.

- 3.2.7.1 Notch properties.
- 3.2.7.2 Fracture toughness.

3.2.8 Combined Loading.

3.3 Mechanical Properties at Various Temperatures

3.3.1 Tension Stress-Strain Diagrams and Tension Properties.

- 3.3.1.1 [Figure] Stress-strain curves at room and elevated temperatures.
- 3.3.1.2 [Figure] Elevated-temperature tensile properties after various exposure times at test temperatures.
- 3.3.1.3 [Figure] Comparison of room- and elevated-temperature tensile properties of sand-cast test bars and production castings; holding time at elevated test temperatures was 10 minutes (Ref. 28).
- 3.3.1.4 [Figure] Effect of low temperatures on tensile properties.

- 3.3.1.5 [Figure] Effect of temperature and strain rate on tensile properties.

3.3.2 Compression Stress-Strain Diagrams and Compression Properties.

3.3.3 Impact.

- 3.3.3.1 [Figure] Effect of low temperatures on Charpy impact resistance.

3.3.4 Bending.

3.3.5 Torsion and Shear.

- 3.3.5.1 [Figure] Effect of temperature on shear strength.

3.3.6 Bearing.

- 3.3.6.1 [Figure] Effect of temperature on bearing properties.

3.3.7 Stress Concentration.

- 3.3.7.1 Notch properties.
- 3.3.7.2 Fracture toughness.

3.3.8 Combined Loading.

3.4 Creep and Creep Rupture Properties

- 3.4.1 [Figure] Isochronous stress-strain curves at 400 and 800F.

- 3.4.2 [Figure] Isochronous stress-strain curves at 600, 700, and 800F.

- 3.4.3 [Figure] Total creep strain curves.

- 3.4.4 [Figure] Effects of exposure time at test temperature prior to loading on 100-hour creep strength.

3.5 Fatigue Properties

- 3.5.1 [Figure] Fatigue cycles to failure as a function of maximum cyclic stress for both rotating-beam and flexure specimens.

- 3.5.2 [Figure] Effect of elevated temperatures on fatigue strength (maximum cyclic stress) at 5×10^7 cycles.

- 3.5.3 [Figure] Fatigue crack growth rates at three R levels (ratio of minimum to maximum cyclic stress).

3.6 Elastic Properties

- 3.6.1 Poisson's Ratio. 0.35 (Refs. 31, 41).

3.6.2 Modulus of Elasticity.

- 3.6.2.1 [Figure] Modulus of elasticity at room and elevated temperatures.

- 3.6.3 Modulus of Rigidity. 2.4×10^3 ksi (Ref. 31).

3.6.4 Tangent Modulus.

3.6.5 Secant Modulus.

EZ33A**4 Fabrication****4.1 Forming****4.2 Machining and Grinding**

EZ33A, as well as other magnesium alloys, has excellent machinability, which enables it to be machined at high speeds and feeds. The low cutting pressures and rapid dissipation of generated heat combine to provide long tool life, dimensional stability, and good surface finish (Refs. 9, 43). For further details, see HZ32A, Code 3408, Sections 4.021 and 4.022.

4.3 Joining

EZ33A, in either the as-cast or T5 condition, is readily weldable by both the gas-tungsten-arc (GTAW) and the gas-metal-arc (GMAW) welding processes with either argon or helium shielding. For repair welding and for joining EZ33A castings to each other or to other high-temperature magnesium alloys, such as HK31A, HM21A, and HM31A, EZ33A is the recommended filler metal; however, AZ92A or AZ61A filler metal is recommended for joining EZ33A to the aluminum-containing magnesium alloys (AZ series). Generally, preheating is not necessary; but for thin or complex or restrained sections, preheating up to 500F maximum can be used to minimize the possibility of distortion. Post heat treatment in accordance with Section 1.5.2 is required to develop optimum strength (T5 condition) (Refs. 9, 18, 45).

4.3.1 [Figure] Effect of low temperatures on tensile properties of weld metal deposited by GMAW process.

4.3.2 [Figure] Tensile properties at various temperatures of specimens containing GTAW butt weld between EZ33A-T5 sand casting and HM21A-T8 magnesium alloy plate with EZ33A filler metal.

Gas welding, spot welding, brazing, and soldering are not normally recommended for EZ33A castings in aerospace applications where good combinations of strength and fatigue resistance are required (Refs. 9, 18, 31, 41, 45, 46).

4.4 Surface Treating

According to both AMS and ASTM specifications, EZ33A castings should normally be chrome pickled (AMS 2475) by the producing foundries prior to shipment. As a possible alternative, the AMS specification mentions protection of the casting with a light corrosion-inhibiting oil in lieu of chrome pickling (Refs. 1, 3, 4, 5).

A wide range of chemical and electrochemical cleaning and surface treatments is available for paint adhesion and corrosion protection (Ref. 22; see also AM 100A, Code 3410, Sections 4.042, 4.034, and 4.04; also HK32A, Code 3408, Sections 4.042, and 4.043).

A study of the effects of various surface treatments on the rotating-beam fatigue strength of EZ33A sand castings showed that acid pickling has detrimental effects on fatigue strength, whereas shot peening prior to pickling has beneficial effects sufficient to more than overcome any detrimental effects of acid pickling (Ref. 10).

4.4.1 [Table] Effects of various surface treatments on the rotating-beam fatigue strength of sand castings at 10 million cycles.

Table 1.3.1 Specifications (Refs. 1-9)

Alloy: EZ33A (UNS M12330)	
Specification	Form
AMS 4442D	Sand castings
AMS 4396C	Welding wire
ASTM B 80-91	Sand castings
ASTM B 199-87	Permanent mold castings
ASTM B 403-90	Investment castings
ASTM B 93-92	Ingot
SAE J465	Castings
QQ-M-56	Sand castings
QQ-M-55	Permanent mold castings
MIL-R-6944	Welding rod

Note: In addition to the product specifications, ASTM B 661-90 and MIL-M-6857 cover heat treatment of magnesium alloys including EZ33A.

Table 1.4.1 Composition (Refs. 1, 3, 4, 5, 6)

Alloy: EZ33A						
Source	AMS (1)		ASTM (3, 4, 5)		ASTM (6)	
Form	Sand Cast		Sand, Investment and Permanent Mold Cast		Ingot	
Element	Percent		Percent		Percent	
	Minimum	Maximum	Minimum	Maximum	Minimum	Maximum
Cerium (total rare earths)	2.5	4.0	2.5	4.0	2.6	3.9
Zinc	2.0	3.1	2.0	3.1	2.0	3.0
Zirconium (total)	0.40	1.0	0.50	1.0	0.3	1.0
Zirconium (soluble) ^a	0.40	—	—	—	—	—
Copper	—	0.10	—	0.10	—	0.03
Nickel	—	0.01	—	0.01	—	0.010
Silicon	—	—	—	—	—	0.01
Other impurities (total)	—	0.30	—	0.30	—	0.30
Magnesium	Balance		Balance		Balance	

^a Soluble zirconium is that portion of the zirconium that is soluble in 1:4 hydrochloric acid held below its boiling point.

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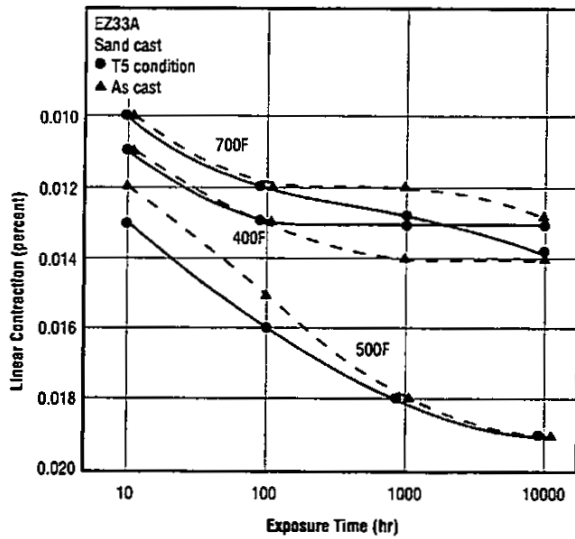


Fig. 1.9.4.1 Linear contraction in castings during long-time exposure to elevated temperatures (Refs. 28, 31)

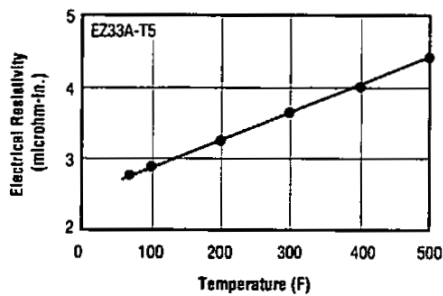


Fig. 2.2.2.1 Effect of temperatures up to 500F on electrical resistivity (Ref. 11)

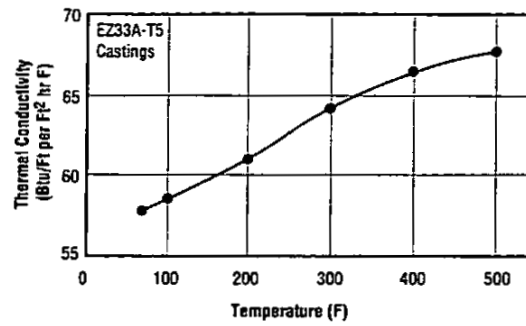


Fig. 2.1.3.1 Effect of temperatures up to 500F on thermal conductivity (Ref. 11)

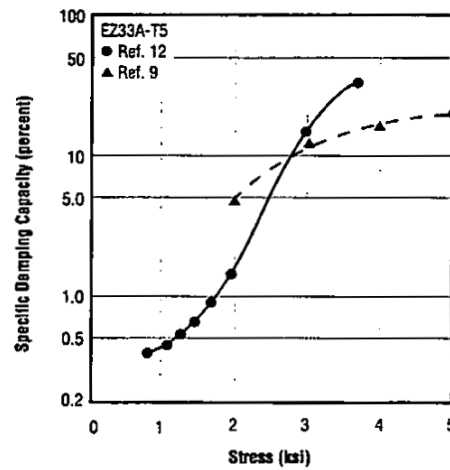


Fig. 2.2.5.1 Effect of stress on specific damping capacity (Refs. 9, 12)

Table 2.3.1.1 Comparison of the corrosion rates of EZ33A with averages of other magnesium alloys in various natural environments (Ref. 22)

Alloy: EZ33A			
Condition	T5		
Form	Sand Castings		
	Corrosion Rate (mils per year)		
Alloy	Rural	Industrial	Marine
EZ33A	0.79	1.6	1.1
Others ^a	0.56	1.2	1.0

^a Average of nine magnesium casting alloys.

Table 3.1.1 AMS and ASTM specified mechanical properties (Refs. 1, 3, 4, 5)

Alloy: EZ33A										
Condition		T5								
Specification		AMS (1) ^a			ASTM (4)			ASTM (5)		
Type of Casting		Sand			Permanent Mold			Investment		
Specimen	Temp (F)	F _{ty} (ksi)	F _{tu} (ksi)	e, 2 in. (percent)	F _{ty} (ksi)	F _{tu} (ksi)	e, 2 in. (percent)	F _{ty} (ksi)	F _{tu} (ksi)	e, 2 in. (percent)
		Minimum								
Separately cast	Room	14.0	20.0	2.0	14.0	20.0	2.0	14.0	20.0	2.0
	500	8.0	13.0	—	—	—	—	—	—	—
Cut from casting										
single	Room	11.0	13.0	—	—	—	—	—	—	—
average 4 or more	Room	12.5	15.0	1.0	—	—	—	—	—	—
single	500	6.0	10.0	—	—	—	—	—	—	—
All sand castings		Brinell Hardness								
		Minimum	Maximum							
		500 kg load and 10 mm ball	48	60						
		1000 kg load and 10 mm ball	57	72						

^a Generally, the tensile property requirements for sand castings in ASTM B 80-90 (Ref. 3) are similar to those in AMS 4442D (Ref. 1) except that ASTM B 80-90 does not specify properties at 500F for separately cast tensile specimens and does not specify hardness.

EZ33ATable 3.2.1.3 Tensile properties of investment-cast test bars with various pouring temperatures and mold temperatures
(Ref. 33)

Alloy: EZ33A								
Form			Separate investment-cast test bars					
Condition			T5					
			Range of Properties					
Pouring Temperature (F)	Mold Temperature (F)	Number of Tests	F _{tu} (ksi)		F _{ty} (ksi)		e, 2 in. (percent)	
			Minimum	Maximum	Minimum	Maximum	Minimum	Maximum
1250	70	9	22.3	26.7	15.8	18.7	4	5
	400	9	23.8	25.1	14.9	17.3	4	5
	650	9	25.3	26.0	15.1	17.8	6	7
1350	70	12	25.0	26.0	14.7	17.5	4	5
	400	12	25.5	26.9	16.5	17.3	4	6
	650	5	23.0	24.3	15.1	15.6	4	5
1450	70	8	25.5	26.6	15.7	16.8	5	6
	400	8	24.6	25.5	16.2	17.9	5	7
	650	8	22.3	24.0	14.3	15.5	4	5

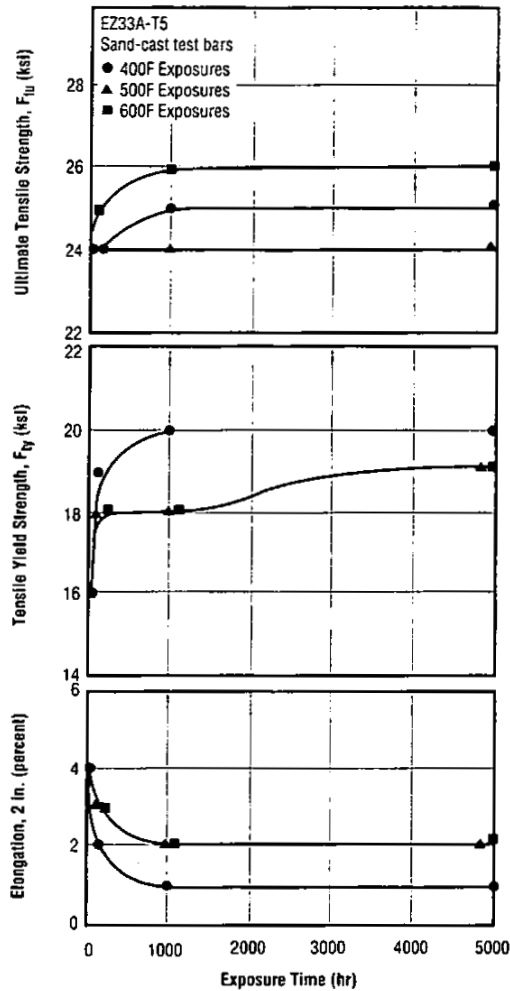


Fig. 3.2.1.4 Effects of exposure at elevated temperatures on tensile properties at room temperature (Ref. 31)

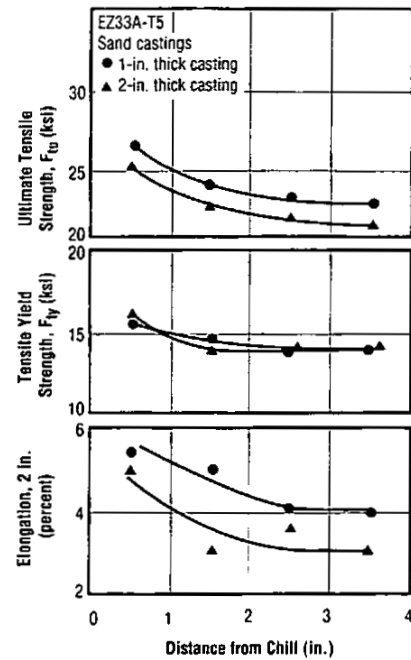


Fig. 3.2.1.5 Effects of end chill on tensile properties of sand-cast plates of two different thicknesses (Ref. 34)

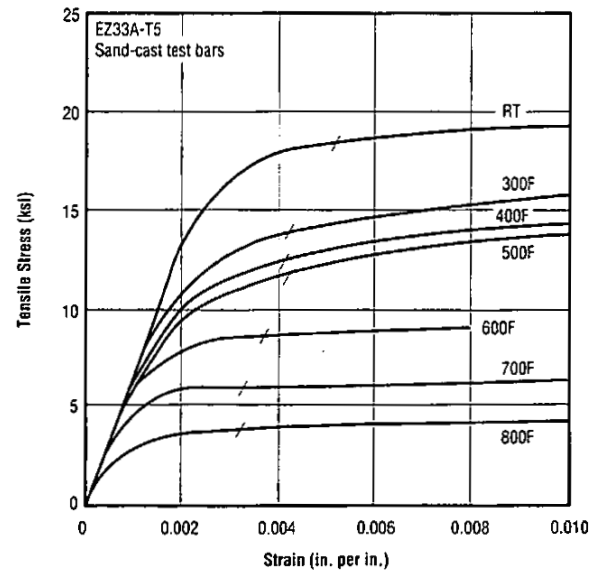


Fig. 3.3.1.1 Stress-strain curves at room and elevated temperatures (Ref. 28)

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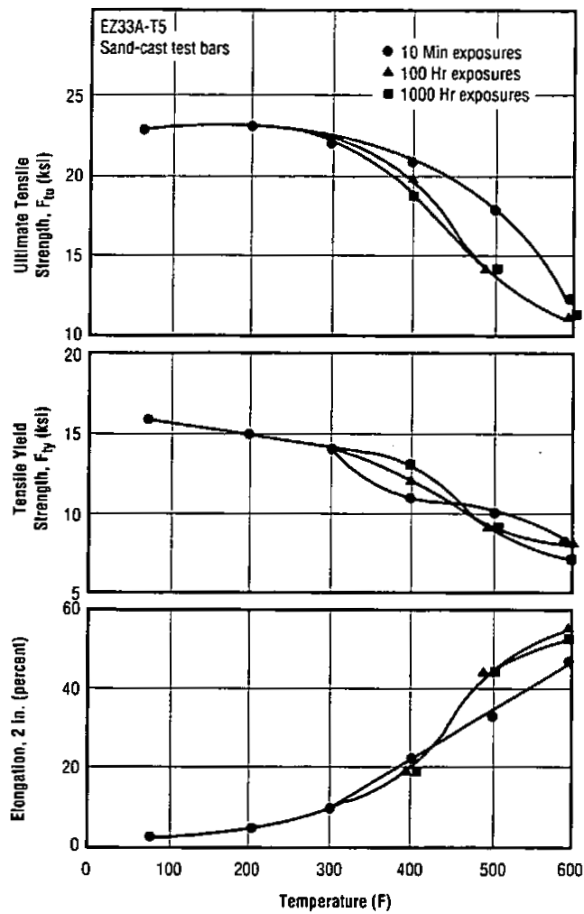


Fig. 3.3.1.2 Elevated-temperature tensile properties after various exposure times at test temperatures (Refs. 28, 31)

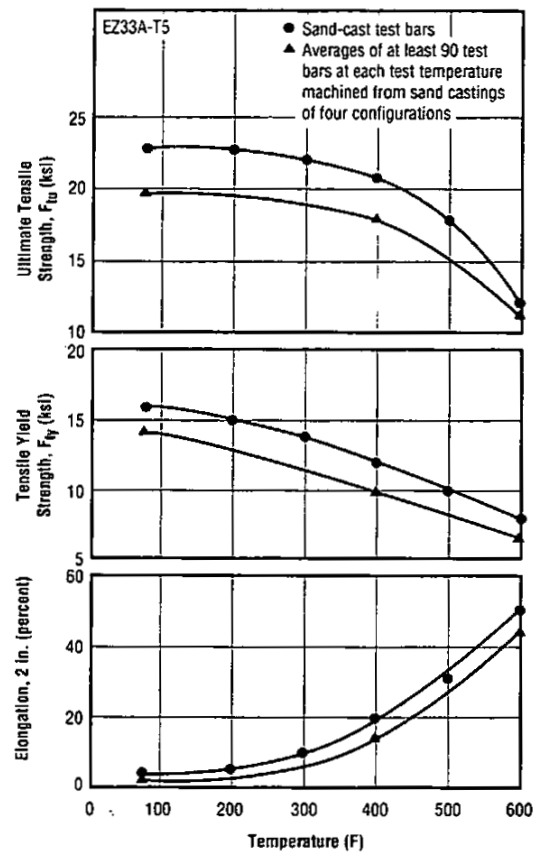


Fig. 3.3.1.3 Comparison of room- and elevated-temperature tensile properties of sand-cast test bars and production castings; holding time at elevated test temperatures was 10 minutes (Ref. 28)

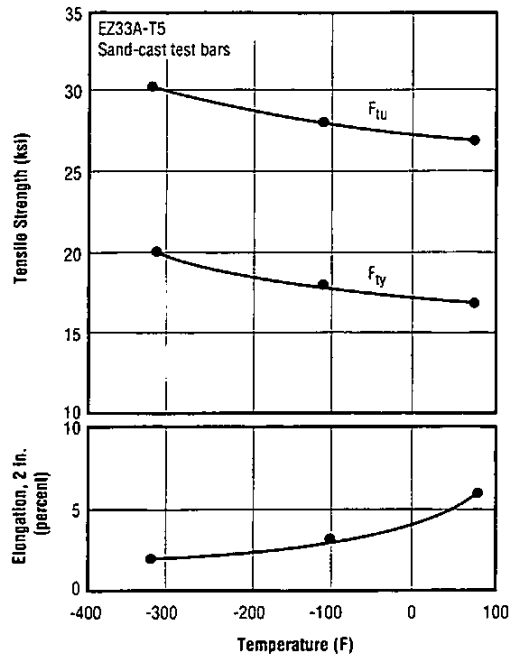


Fig. 3.3.1.4 Effect of low temperatures on tensile properties (Ref. 35)

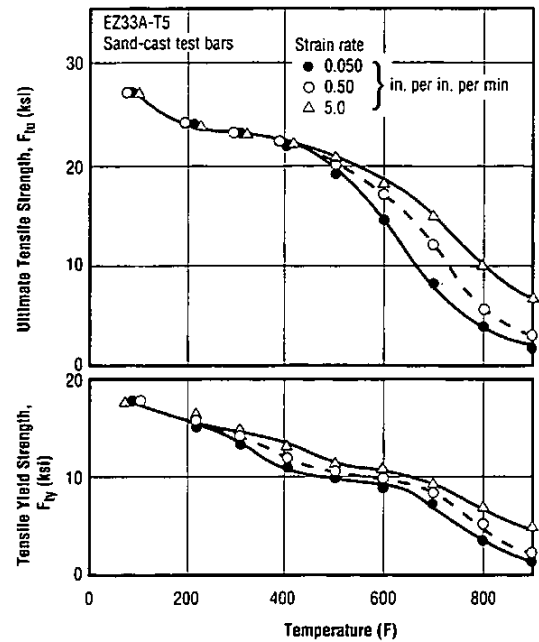


Fig. 3.3.1.5 Effect of temperature and strain rate on tensile properties (Ref. 36)

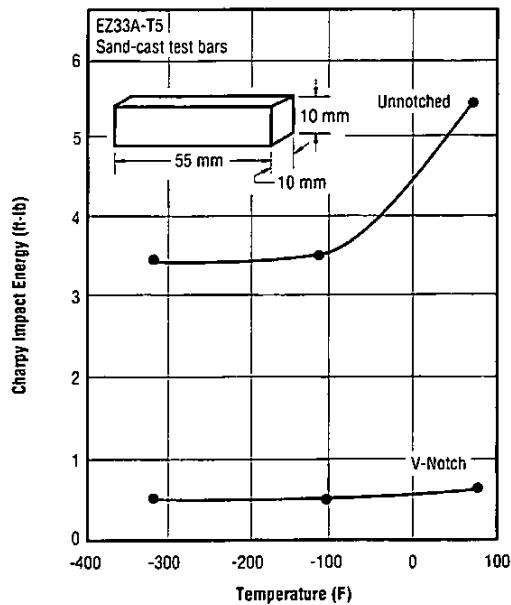


Fig. 3.3.3.1 Effect of low temperatures on Charpy impact resistance (Refs. 9, 35)

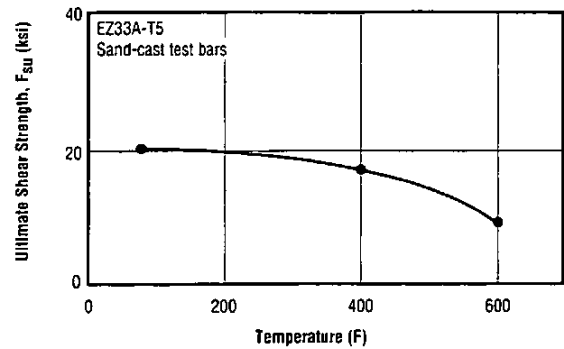


Fig. 3.3.5.1 Effect of temperature on shear strength (Ref. 37)

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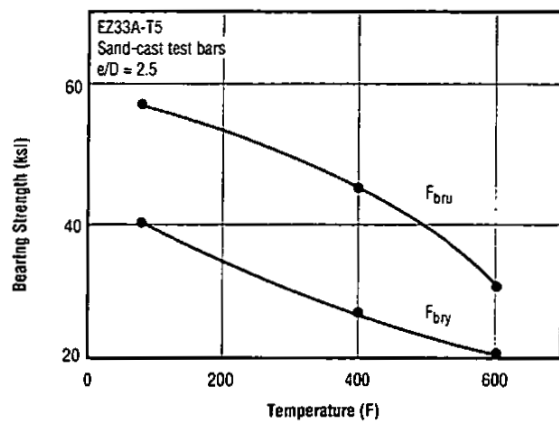


Fig. 3.3.6.1 Effect of temperature on bearing properties (Ref. 37)

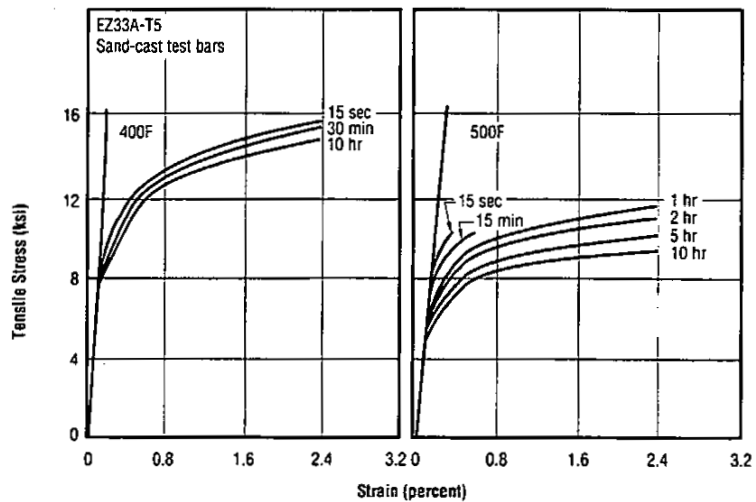


Fig. 3.4.1 Isochronous stress-strain curves at 400 and 500F (Refs. 9, 28)

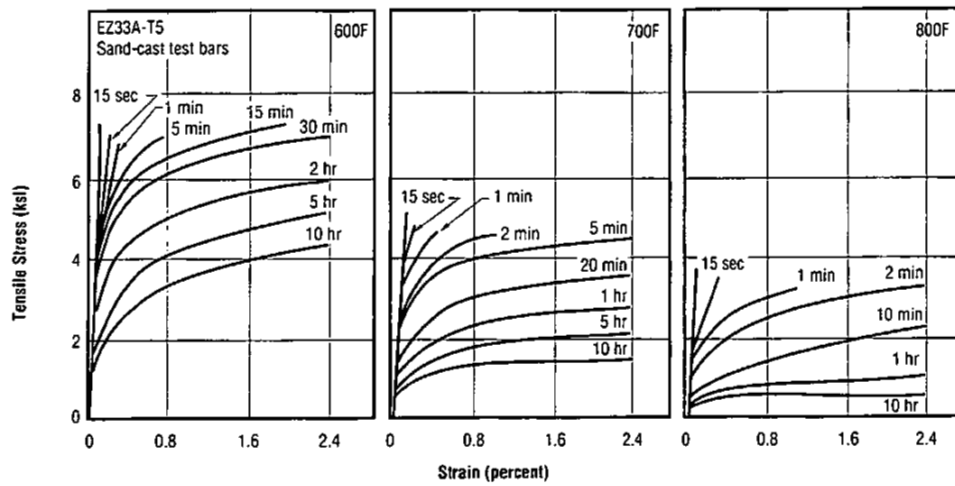


Fig. 3.4.2 Isochronous stress-strain curves at 600, 700 and 800F (Refs. 9, 28)

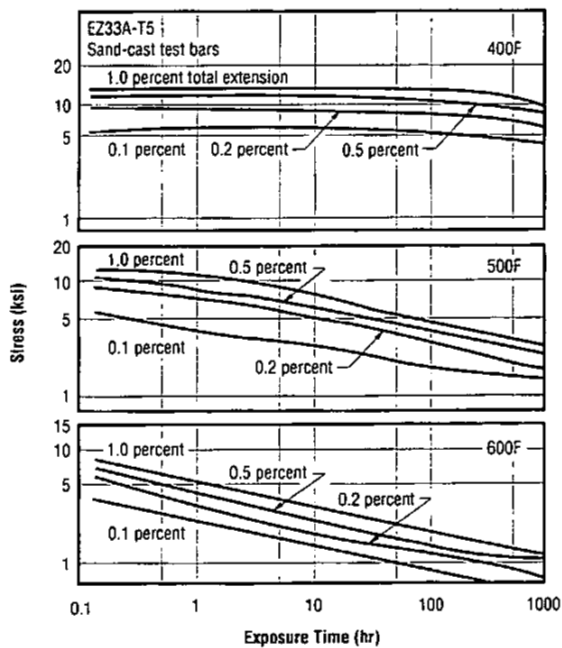


Fig. 3.4.3 Total creep strain curves (Ref. 28)

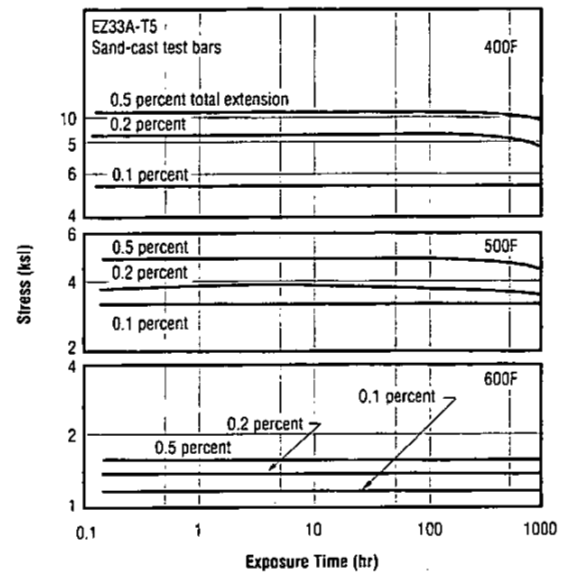


Fig. 3.4.4 Effects of exposure time at test temperature prior to loading on 100-hour creep strength (Ref. 28)

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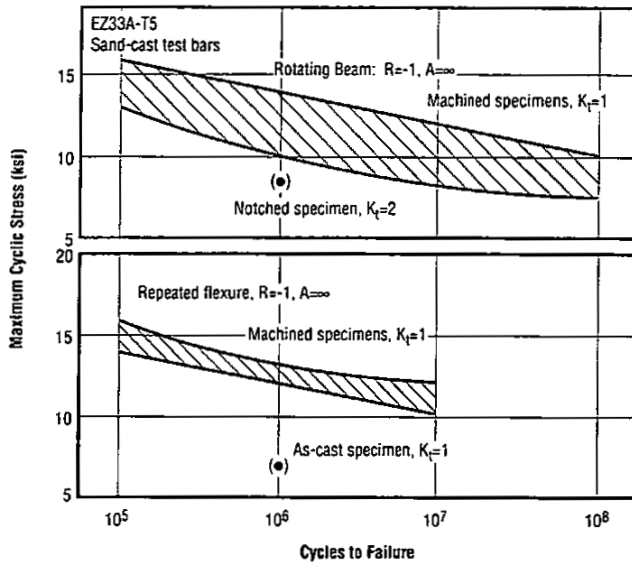


Fig. 3.5.1 Fatigue cycles to failure as a function of maximum cyclic stress for both rotating-beam and flexure specimens (Refs. 38, 39, 40)

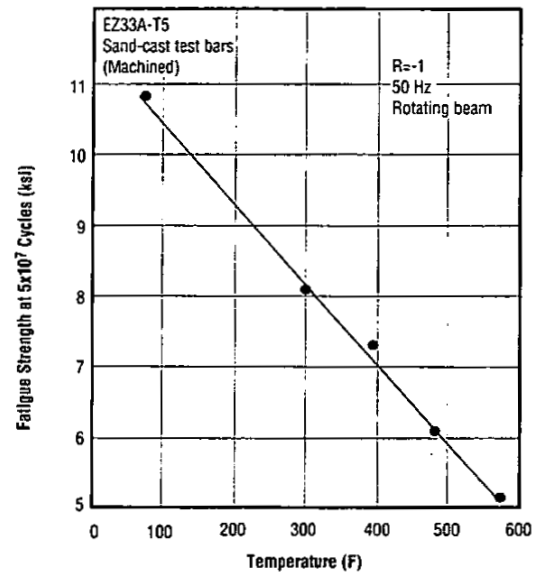


Fig. 3.5.2 Effect of elevated temperatures on fatigue strength (maximum cyclic stress) at 5×10^7 cycles (Ref. 41)

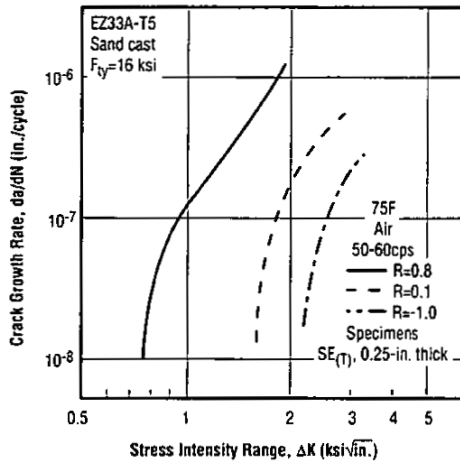


Fig. 3.5.3 Fatigue crack growth rates at three R levels (ratio of minimum to maximum cyclic stress) (Ref. 32)

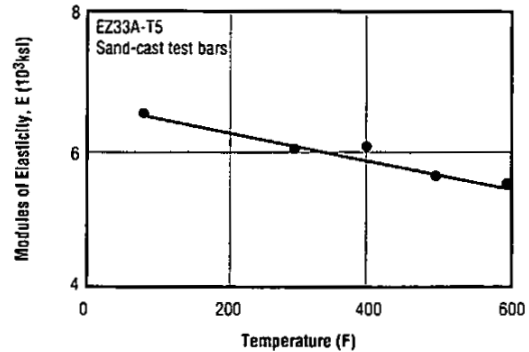


Fig. 3.6.2.1 Modulus of elasticity at room and elevated temperatures (Ref. 42)

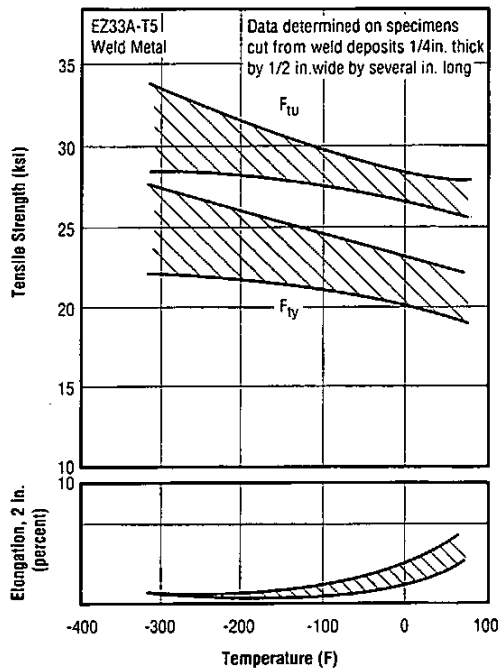


Fig. 4.3.1 Effect of low temperatures on tensile properties of weld metal deposited by GMAW process (Ref. 44)

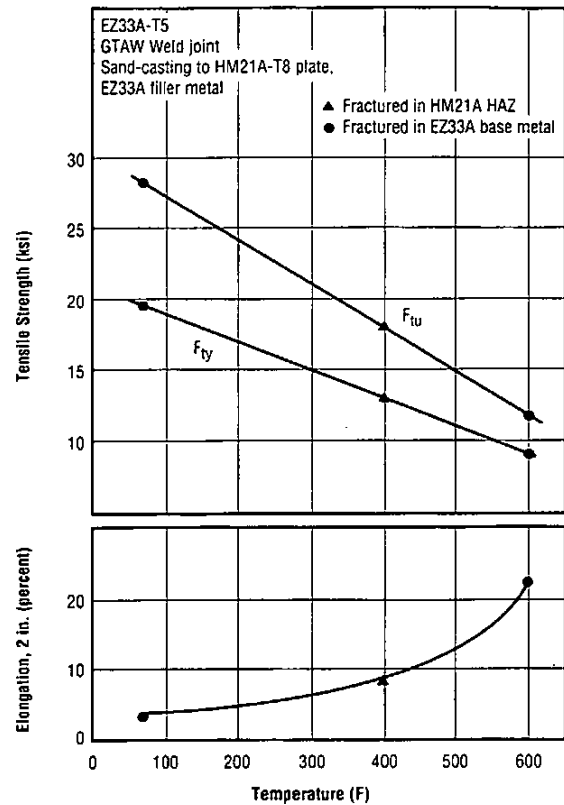


Fig. 4.3.2 Tensile properties at various temperatures of specimens containing GTAW butt weld between EZ33A-T5 sand casting and HM21A-T8 magnesium-alloy plate with EZ33A filler metal (Ref. 45)

Note: The EZ33A was in the T5 condition prior to welding, and a T5 post weld treatment (420F, 5 hr) was applied.

EZ33A

Table 4.4.1 Effects of various surface treatments on the rotating-beam fatigue strength of sand castings at 10 million cycles (Ref. 10)

Alloy: EZ33A		
Form	Sand cast 0.625 in. thick plates	
Condition	T5 ($F_{tu} = 21.3$ ksi)	
Surface Condition	Fatigue Strength at 10^7 cycles (ksi)	Percent of Control
As polished (control samples)	8.5	100
Polished, peened	11.5	135
Polished, alkaline cleaned, pickled	8	94
plus, No. 1 chromate conversion coating	7	82
No. 7 chromate conversion coating	6.5	76
HAE light anodic coat	7	82
HAE heavy anodic coat	7	82
No. 17 light anodic coat	5.5	65
No. 17 heavy anodic coat	7	82
Polished, peened, alkaline cleaned, pickled	11.5	135
plus, No. 1 chromate conversion coating	11.5	135
No. 7 chromate conversion coating	11.5	135
HAE light anodic coat	11.5	135
HAE heavy anodic coat	10.5	123
No. 17 light anodic coat	11.5	135
No. 17 heavy anodic coat	11	130
Polished, alkaline cleaned		
plus, HAE light anodic coat	8	94
HAE heavy anodic coat	9	105

Notes

1. Fatigue test conditions: $R = -1$; 70F; 10,000 cpm.
2. Polished: No. 400 polishing paper in longitudinal direction.
3. Peened: 0.125 in. diameter steel shot to 5A Almen intensity.
4. Pickled: Dilute nitric plus sulfuric acid for 10 sec.
5. Alkaline cleaned: Immersed in sodium orthosilicate solution.

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EZ33A

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REVISED: DECEMBER 1971
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NONFERROUS ALLOYS

1. GENERAL

This magnesium alloy is produced both in the form of castings and in the form of wrought products, primarily sheet and plate and to a very limited extent forgings. Casting production is primarily in sand molds, but permanent-mold and investment castings can also be produced. Castings develop optimum properties in the T6 condition (solution treated and artificially aged) and forgings in the T5 condition (forged and artificially aged). Sheet and plate are produced and used in the O condition (fully annealed) and the H24 condition (strain hardened and partially annealed). The alloy is intended for elevated temperature applications. Of the sheet and plate alloys, HK31A-H24 has the best short-time strength in the range 250 to 550 F; at lower temperature AZ31B-H24 is stronger and at higher temperatures HM21A-T8 is stronger. HM21A-T8, however, has superior long-time creep properties at all elevated temperatures. Of the magnesium casting alloys, HK31A-T6 has the best short-time strength at temperatures above 540 F; at lower temperatures QE22A-T6 has superior strength. HK31A-T6 also has the best creep resistance of the magnesium casting alloys at temperatures up to 500 F, but HZ32A-T6 has better creep resistance at higher temperatures. The alloy has good formability, excellent weldability, and good foundry characteristics with the exception of only moderate resistance to hot cracking. It is used mostly for aerospace and missile applications where temperatures in the range 300 to 600 F are encountered. Like other magnesium alloys, it requires a surface coating for corrosion protection over long periods of time.

1.01 Commercial Designation
HK31A1.02 Alternate Designations
HK31XA (obsolete), MTZ (British)1.03 Specifications
Table 1.03.1.04 Composition
Table 1.041.05 Heat Treatment

1.051 T6 condition: Solution treat at 1045 to 1055 F 2 hours in furnace atmosphere containing 1.0 percent minimum SO₂ or 6 percent minimum CO₂ (the furnace should be at temperature before it is loaded), cool by strong air blast, artificially age at 390 to 410 F 16 hours, air cool (9)(12).

1.052 T5 condition: Artificially age as forged (F condition) at 440 to 460 F 16 hours, air cool (9)(10).

1.053 O condition, full anneal: 750 F 1 hour, air cool (9).

1.054 Partial anneal after strain hardening, H24 condition: 550 F 1/2 hour, air cool (9).

1.055 Stress relief after forming: for material in O condition 650 F 1 hour, air cool; for material in H24 condition 550 F 1/2 hour, air cool (9).

1.056 Thermal treatment after welding: for castings 400 F 16 hours, air cool; for sheet and plate in H24 condition 600 F 1/2 hour, air cool (9)(11).

1.06 Hardness

1.061 H24 condition: 57 Brinell Hardness No. (13).

1.062 T6 condition: 55 Brinell, 56 Rockwell E (12).

1.07 Forms and Conditions Available
Table 1.07.1.08 Melting and Casting Practice

See AZ31B, Code 3601, section 1.08. For more details of foundry melting procedures, see HZ32A, Code 3408 section 1.08.

1.09 Special Considerations

1.091 HK31A-T6 castings tend to grow slightly with increasing holding times at elevated temperatures.

1.092 Dimensional changes in castings at elevated temperatures, Figure 1.092.
1.093 Contamination with aluminum must be avoided because aluminum forms undesirable compounds with zirconium (16).

2. PHYSICAL AND CHEMICAL PROPERTIES

2.01 Thermal Properties

2.011 Melting range, 1092-1202 F (18).

2.012 Phase changes. A corundum network, which has not been identified chemically, tends to form at the grain boundaries in the as-cast condition. Hot and cold working tends to break up the network and solution treatment at 1050 F causes it to coalesce. No metallographically visible precipitation occurs during artificial aging at 400 F (17).

2.021 Time-temperature-transformation diagrams.

2.013 Thermal conductivity, Figure 2.013.

2.014 Thermal expansion.

2.0141 Mean coefficient of thermal expansion from 68 to 392 F, 14.9×10^{-6} per F (14).

2.015 Specific heat, Figure 2.015.

2.016 Thermal diffusivity, Figure 2.016.

2.02 Other Physical Properties

2.021 Density, 0.0648 lb per cu in (18).

2.022 Electrical properties, Table 2.022.

2.023 Magnetic properties. Nonmagnetic.

2.024 Emissance. (see ZK60A, Figure 2.0241, Code 3506)

2.025 Damping capacity. At a stress equal to 0.1 F_{ty} the specific damping capacity of cast HK31A-T6 is 0.52, which is a low level compared with other magnesium alloys (19).

2.03 Chemical Properties

2.031 Corrosion resistance.

2.0311 The galvanic and general corrosion characteristics of HK31A are similar to those of AZ31B, Code 3601, sections 2.0311 and 2.0312.

2.0312 The resistance of HK31A to stress corrosion is somewhat better than that of AZ31B, Code 3601, section 2.0313.

2.032 Safety precautions should be directed to the prevention of fires, burns, and explosions. (See HZ32A, Code 3408, section 2.032).

2.04 Nuclear Properties

2.041 Thorium is a radioactive metal. For comments on precautions required by this characteristic, see HZ32A, Code 3408, sections 2.041 and 2.042.

3. MECHANICAL PROPERTIES

3.01 Specified Mechanical Properties

3.011 Sheet and plate, Table 3.011.

3.012 Castings, Table 3.012.

3.013 Premium quality sand castings, Table 3.013.

3.02 Mechanical Properties at Room Temperature

3.021 Tension.

3.0211 Stress-strain diagrams. (see Figure 3.03111, 3.03112, 3.03113, 3.03114, 3.03115)

3.0212 Tensile properties of sheet and plate, sand castings, and forgings, Table 3.0212.

3.0213 Effect of exposures at elevated temperatures on tensile properties at room temperature of sheet in H24 condition, Figure 3.0213.

3.0214 Effect of exposures at elevated temperatures on tensile properties at room temperature of castings in T6 condition, Figure 3.0214.

3.022 Compression.

3.0221 Stress-strain diagrams (see Figures 3.03211 and 3.03212).

3.0222 Compressive strength of sheet and plate, sand castings, and forgings, Table 3.0222.

Mg
3 Th
0.7 Zr

HK31A

	Mg
3	Th
0.7	Zr

HK31A

- 3.0223 Effect of exposures at elevated temperatures on compressive yield strength at room temperature, Figure 3.0223.
- 3.023 Impact (see Figure 3.0331).
- 3.024 Bending.
- 3.025 Torsion and shear.
- 3.0251 Shear strength of sheet and plate and castings, Table 3.0251.
- 3.026 Bearing.
- 3.0261 Bearing properties of sheet and plate and castings, Table 3.0261.
- 3.027 Stress concentration.
- 3.0271 Notch properties.
- 3.0272 Fracture toughness.
- 3.028 Combined properties.
- 3.03 Mechanical Properties at Various Temperatures
- 3.031 Tension.
- 3.0311 Stress-strain diagrams.
- 3.03111 Stress-strain curves for sheet in H24 condition at room and elevated temperatures, Figure 3.03111.
- 3.03112 Stress-strain curves for sheet in O condition at room and elevated temperatures, Figure 3.03112.
- 3.03113 Stress-strain curves for castings in T6 condition at room and elevated temperatures, Figure 3.03113.
- 3.03114 Complete stress-strain curves for sheet at low temperatures, Figure 3.03114.
- 3.03115 Complete stress-strain curves for castings at low temperatures, Figure 3.03115.
- 3.0312 Elevated temperature tensile properties of sheet in H24 condition after various exposure times at test temperature, Figure 3.0312.
- 3.0313 Elevated temperature tensile properties of castings in T6 condition after various exposure times at test temperature, Figure 3.0313.
- 3.0314 Elevated temperature tensile properties of sheet in O and H24 conditions at various strain rates, Figure 3.0314.
- 3.0315 Elevated temperature tensile properties of castings in T6 condition at various strain rates, Figure 3.0315.
- 3.0316 Elevated temperature tensile properties of forgings forged at various temperatures, Figure 3.0316.
- 3.0317 Low temperature tensile properties of sheet, Figure 3.0317.
- 3.032 Compression.
- 3.0321 Stress-strain diagrams.
- 3.03211 Stress-strain curves in compression for sheet in H24 condition at room and elevated temperatures, Figure 3.03211.
- 3.03212 Stress-strain curves in compression for sheet in O condition at room and elevated temperatures, Figure 3.03212.
- 3.0322 Elevated temperature compressive strength of sheet in H24 condition after various exposure times at test temperature, Figure 3.0322.
- 3.033 Impact.
- 3.0331 Charpy impact properties at low temperatures, Figure 3.0331.
- 3.034 Bending.
- 3.035 Torsion and shear.
- 3.0351 Elevated temperature shear strength of sheet in H24 condition after various exposure times at test temperature, Figure 3.0351.
- 3.036 Bearing.
- 3.0361 Elevated temperature bearing properties of sheet in H24 condition after various exposure times at test temperature, Figure 3.0361.
- 3.037 Stress concentration.
- 3.0371 Notch properties.
- 3.0372 Fracture toughness.
- 3.038 Combined properties.
- 3.04 Creep and Creep Rupture Properties
- 3.041 Isochronous stress-strain curves for sheet in H24 condition, Figure 3.041.
- 3.042 Isochronous stress-strain curves for sheet in O condition, Figure 3.042.
- 3.043 Isochronous stress-strain curves for castings in T6 condition at temperature of 400, 500, and 600F, Figure 3.043.

- 3.044 Isochronous stress-strain curves for castings in T6 condition at 700 and 800F, Figure 3.044.
- 3.045 Total creep strain curves for castings in T6 condition, Figure 3.045.
- 3.046 Effect of exposure time at test temperature prior to loading on the 100 hour creep strength of castings in T6 condition, Figure 3.046.
- 3.047 One hundred hour creep strength of forgings in T5 condition, Table 3.047.
- 3.05 Fatigue Properties
- 3.051 Fatigue strength of castings and sheet, Table 3.051.
- 3.052 Axial fatigue properties of smooth and notched sheet specimens at room temperature, Figure 3.052.
- 3.053 Axial fatigue properties of smooth and notched sheet specimens at 300F, Figure 3.053.
- 3.054 Axial fatigue properties of smooth and notched sheet specimens at 500F, Figure 3.054.
- 3.06 Elastic Properties
- 3.061 Poisson's ratio, 0.35 (13)(14).
- 3.062 Modulus of elasticity.
- 3.0621 Effect of temperature on static modulus of elasticity, Figure 3.0621.
- 3.0622 Compressive tangent modulus curves at room and elevated temperatures, Figure 3.0622.
- 3.0623 Compressive secant modulus curves at room and elevated temperatures, Figure 3.0623.
- 3.063 Modulus of rigidity, 2.4×10^3 ksi.
4. FABRICATION
- 4.01 Formability
- 4.011 HK31A sheet and plate products, like most other wrought magnesium alloys, have good formability at elevated temperatures but only limited formability at room temperature. All of the common metal forming methods are applicable. The optimum forming temperature range is somewhat higher than for AZ31B (Code 3601). For the O condition forming temperatures approaching 750F are recommended for forming times up to one hour; whereas for the H24 condition forming in the temperature range 650 to 750F is recommended, the maximum allowable time at temperature decreasing with increasing temperature from 1 hour at 650F to 1 minute at 750F as shown in Figure 4.011 (14)(29)(30).
- 4.012 Minimum bend factor (ratio of bend radius to sheet or plate thickness) as function of temperature, Figure 4.012.
- 4.013 Although it is not necessary in all instances, stress relief in accordance with section 1.055 is recommended after severe forming operations, particularly if carried out below 650F.
- 4.014 HK31A has good forgeability in the range 700 to 1000F. A T5 (artificial aging) treatment following forging is recommended for optimum properties. The mechanical properties are highly dependent on forging temperature. Forging at the lower temperature provides better short time strength at temperatures up to about 550F; whereas, superior short time strength above 550F and creep strength above 400F are obtained by forging at the higher end of the temperature range.
- 4.02 Machining and Grinding
- 4.021 This alloy, like other magnesium alloys, has exceptionally good machinability, which enables it to be machined at high speeds and feeds. For further details see H232A, Code 3408, section 4.021.
- 4.022 The alloy can be chem-milled with sulfuric, nitric, or hydrochloric acid of 5 percent strength or greater (32).
- 4.03 Welding
- 4.031 HK31A has excellent weldability by arc and electric-resistance methods. Gas welding is not recommended because of the corrosive fluxes used and the difficulty of removing such flux from the joints. For arc welding E233A magnesium alloy filler metal is generally used

except when joining to ZE10A or to an aluminum-containing magnesium alloy, in which instances AZ92A or AZ61A are suitable filler alloys. For maximum weld efficiencies, thermal treatment in accordance with section 1.056 is recommended after welding. For further details, see AZ31B, Code 3601, section 4.031 (14)(33).

- 4.032 Effect of temperature on tensile properties of 0.063 inch sheet, both unwelded and with arc-welded butt joints transverse to gage length, Figure 4.032.
- 4.033 Effect of low temperatures on tensile properties of 0.125 inch sheet, both unwelded and with transverse butt welds made by inert-gas-shield tungsten-arc process, Figure 4.033.
- 4.034 Shear strength of spot welds, Table 4.033.
- 4.035 Effect of temperature on the shear strength of resistance spot welds in 0.063 inch sheet, Figure 4.035.
- 4.04 Surface Treatment
- 4.041 The sheet and plate products are normally oiled by the producer with a light corrosion inhibiting oil for protection during shipment and storage (1)(2). Castings can be treated similarly for this purpose or alternatively they can be chrome pickled (4).
- 4.042 For a discussion of the various surface treatments that can be applied for corrosion protection, see HZ32A, Code 3403, sections 4.042 and 4.043.

TABLE 1.04

Alloy Source	HK31A					
	(2)(3)		(4)		(5)(6)(7)(8)	
	Percent		Percent		Percent	
Composition	Min	Max	Min	Max	Min	Max
Thorium	2.5	4.0	2.5	4.0	2.5	4.0
Zirconium, total	0.45	1.0	0.50	1.0	0.40	1.0
Zirconium, soluble*	-	-	0.50	-	-	-
Zinc	-	-	-	0.30	-	0.30
Copper	-	-	-	0.10	-	0.10
Nickel	-	-	-	0.01	-	0.01
Impurities, each	-	0.15	-	-	-	-
Impurities, total	-	0.30	-	0.20	-	0.30
Magnesium	Balance		Balance		Balance	

* Soluble zirconium is that portion of the zirconium which is soluble in 1:4 hydrochloric acid held below its boiling point.

Mg
3 Th
0.7 Zr
HK31A

TABLE 1.07

Alloy Source	HK31A	
	(14)(10)	
Form	Condition	Thickness - in
Flat sheet and plate	O (fully annealed)	0.010 to 3.000
Flat sheet and plate	H24 (strain hardened and partially annealed)	0.010 to 3.000
Coiled sheet	O	0.032 to 0.250
Coiled sheet	H24	0.032 to 0.250
Castings	T6	-
Forgings (very limited availability)	T5	-

TABLE 1.03

Alloy	HK31A
Source	(1)
Forms	Specifications
Sand	AMS 4445C
Sand castings	ASTM B80-69 MIL-M-46062A Federal QQ-M-56b(1) SAE 507
Permanent mold castings	ASTM B199-65 MIL-M-46062A SAE 507
Investment castings	ASTM B403-67
Sheet and plate	AMS 4384D (O condition) AMS 4385E (H24 condition) ASTM B90-69 MIL-M-26075D SAE 507

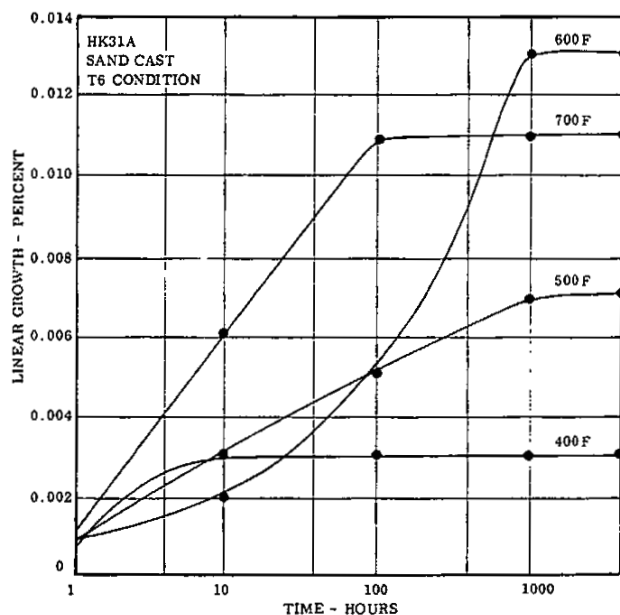


FIG. 1.092 DIMENSIONAL CHANGES IN CASTINGS AT ELEVATED TEMPERATURES. (15)

Mg
3 Th
0.7 Zr

HK31A

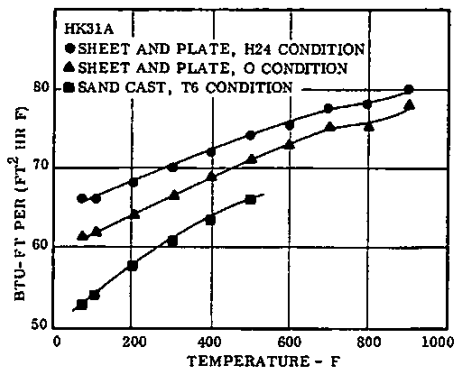


FIG. 2.013 THERMAL CONDUCTIVITY. (14)(18)

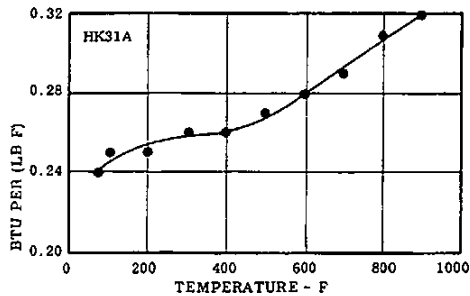


FIG. 2.015 SPECIFIC HEAT. (14)

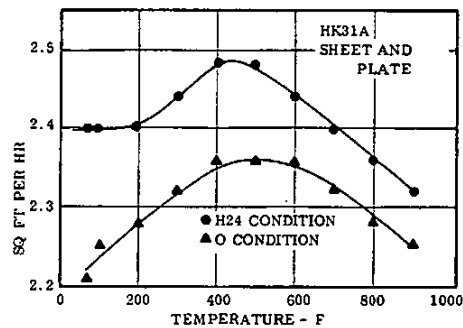


FIG. 2.016 THERMAL DIFFUSIVITY. (14)

TABLE 2.022									
HK31A									
(14)(18)									
Condition	Electrical Conductivity						Electrical Resistivity		
	Percent IACS			Megmhos per in³			microhm in		
Temp-F	H24	O	T6	H24	O	T6	H24	O	T6
68	28.3	26.2	22.5	0.416	0.384	0.331	2.40	2.60	3.03
100	26.5	24.6	21.6	0.390	0.363	0.317	2.56	2.76	3.16
200	23.0	21.6	19.5	0.339	0.318	0.287	2.95	3.14	3.49
300	20.6	19.7	17.7	0.303	0.290	0.260	3.30	3.46	3.65
400	18.6	17.8	16.2	0.274	0.262	0.239	3.66	3.82	4.19
500	16.9	16.3	15.0	0.249	0.240	0.220	4.01	4.17	4.55

TABLE 3.011							
Alloy		HK31A					
Form		Sheet and Plate					
Condition	Source	Temp F	Thickness in	F _{tu} ksi min	F _{ty} ksi min	e (2 in) min	F _{cy} * ksi min
H24	(3)	Room	0.016-0.125	34.0	26.0	4	-
			0.063-0.125	-	-	-	20.0
			0.125-0.250	34.0	24.0	4	22.0
			0.250-1.000	34.0	25.0	4	20.0
			1.000-3.000	33.0	25.0	4	17.0
O	(2)	Room	0.016-0.250	10.0	-	20	-
			0.016-0.250	30.0	18.0	12	-
			0.250-0.500	30.0	16.0	12	10.0
			0.500-1.000	30.0	15.0	12	10.0
			1.000-3.000	29.0	14.0	12	10.0
			0.063-0.250	-	-	-	12.0

* Compression specimens oriented in longitudinal direction.
Orientation of tensile specimens not specified.

* Compression specimens oriented in longitudinal direction.
Orientation of tensile specimens not specified.

TABLE 3.012										
HK31A										
T6										
(4)										
(6)										
(7)										
Type Casting		Sand			Permanent Mold			Investment		
Specimen	Temp F	F _{tu} -ksi min	F _{ty} -ksi min	e(2 in) min	F _{tu} -ksi min	F _{ty} -ksi min	e(2 in) min	F _{tu} -ksi min	F _{ty} -ksi min	e(2 in) min
Separately cast	Room	27.0	13.0	4	27.0	13.0	4	27.0	13.0	4
	600	19.0	12.0	-	-	-	-	-	-	-
Cut from casting										
single	Room	19.0	10.5	-	-	-	-	-	-	-
average 4 or more	Room	23.0	11.7	2	-	-	-	-	-	-
single	600	13.0	9.5	-	-	-	-	-	-	-

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TABLE 3.013

Alloy	HK31A		
Condition	T6		
Form	Premium Quality Sand Castings		
Source	(20)		
Information	Tensile properties in designated sections of castings		
Section*	F_{TU} - ksi min	F_{TY} - ksi min	$e(2 \text{ in})$ min
1	33.0	16.0	6
2	29.0	14.0	3
3	25.0	12.0	1
X	19.0	10.5	1

* Sections 1, 2, and 3 are designated critical sections of castings and would be specified for the particular casting in question; section X covers unspecified sections.

TABLE 3.0212

Alloy	HK31A					
Condition	Form	Thickness in	Source	F_{TU} ksi	F_{TY} ksi	e (2 in)
O	sheet and plate	0.016-0.250	(14)*	33.0	20.0	23
		0.251-0.500		33.0	19.0	20
		0.501-1.000		33.0	18.0	17
		1.001-3.000		32.0	17.0	17
H24	sheet and plate	0.016-0.125	(14)*	38.0	30.0	9
		0.126-0.250		37.0	30.0	9
		0.251-1.000		39.0	31.0	14
		1.001-3.000		37.0	29.0	10
T6	sand cast	Diameter - in 1/2 in test bar	(15)	32.0	15.0	8
T5	upset forgings	Forge Temp F	(10)	38.0	33.0	17
		700				
		1000		39.0	21.0	14

* Data shown are typical values for the lowest strength direction.

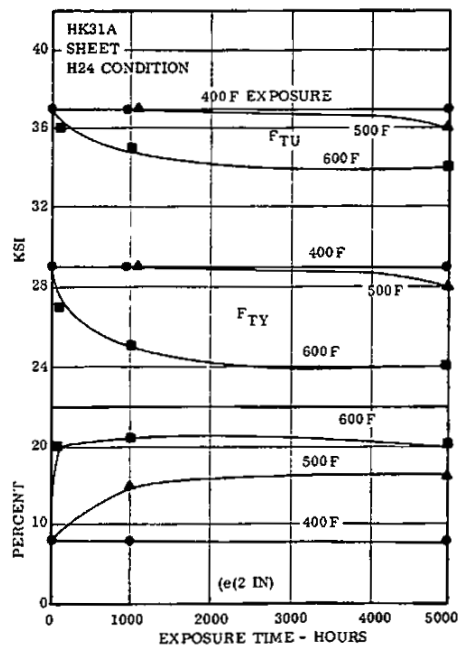


FIG. 3.0213 EFFECT OF EXPOSURES AT ELEVATED TEMPERATURES ON TENSILE PROPERTIES AT ROOM TEMPERATURE OF SHEET IN H24 CONDITION. (14)

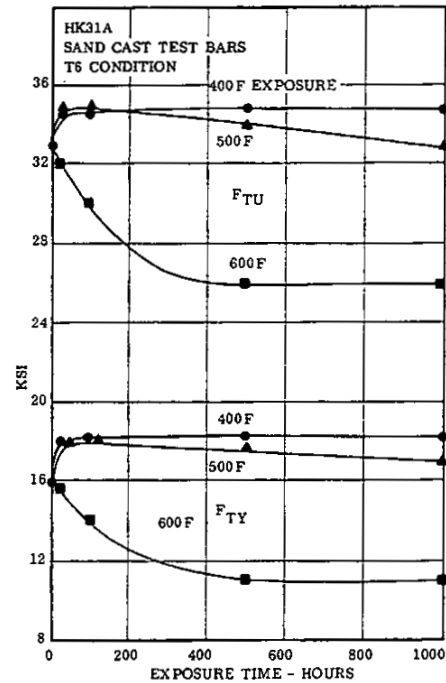


FIG. 3.0214 EFFECT OF EXPOSURES AT ELEVATED TEMPERATURES ON TENSILE PROPERTIES AT ROOM TEMPERATURE OF CASTINGS IN T6 CONDITION. (15)

TABLE 3.0222

Alloy	HK31A			
Condition	Form	Thickness in	Source	F_{CY} ksi
O	sheet and plate	0.016-0.250	(14)*	14.0
		0.251-0.500		13.0
		0.501-1.000		13.0
		1.001-3.000		13.0
H24	sheet and plate	0.016-0.125	(14)*	23.0
		0.126-0.250		27.0
		0.251-1.000		25.0
		1.001-3.000		22.0
T6	sand cast	Diameter - in 1/2 in test bar	(21)	15.0
T5	upset forgings	Forge temp - F	(10)	27
		700		
		1000		23

* Data shown are typical values for the lowest strength direction.

Mg
3 Th
0.7 Zr
HK31A

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Mg
3 Th
0.7 Zr

HK31A

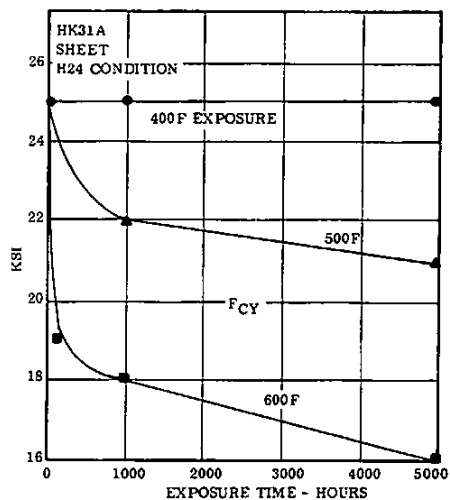


FIG. 3.0223 EFFECT OF EXPOSURES AT ELEVATED TEMPERATURES ON COMPRESSIVE YIELD STRENGTH AT ROOM TEMPERATURE. (14)

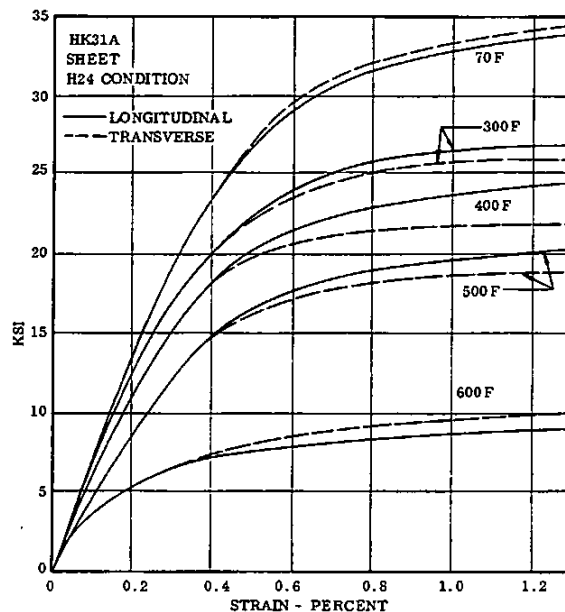


FIG. 3.03111 STRESS-STRAIN CURVES FOR SHEET IN H24 CONDITION AT ROOM AND ELEVATED TEMPERATURES. (14)

TABLE 3.0251

Alloy HK31A				
Condition	Form	Thickness - in	Source	F _{su} ksi
O	sheet and plate	0.016-0.250	(14)*	24.0
		0.251-0.500		24.0
		0.501-1.000		24.0
		1.001-3.000		24.0
H24	sheet and plate	0.016-0.125	(14)*	26.0
		0.126-0.250		26.0
		0.251-1.000		27.0
		1.001-3.000		26.0
T6	sand cast	Diameter - in	(12)	22.0
		1/2 in test bar		

* Data shown are typical values for the lowest strength direction.

TABLE 3.0261

Alloy HK31A						
Condition	Form	Thickness in	Source	e/D*	F _{bu} ksi	F _{bu} ksi
O	sheet and plate	0.016-0.250	(14)**	2.5	58.0	28.0
		0.251-0.500			58.0	27.0
		0.501-1.000			58.0	27.0
		1.001-3.000			57.0	27.0
H24	sheet and plate	0.016-0.125	(14)**	2.5	67.0	41.0
		0.126-0.250			65.0	41.0
		0.251-1.000			68.0	44.0
		1.001-3.000			65.0	40.0
H24	sheet	0.064	(22)	2.0	59.1	34.8
		0.064		1.5	50.3	35.1
T6	sand cast	Diameter-in	(12)	2.5	61.0	40.0
		1/2 in test bar				

* e/D = Edge distance to diameter ratio.

** Data shown are typical values for the minimum strength direction.

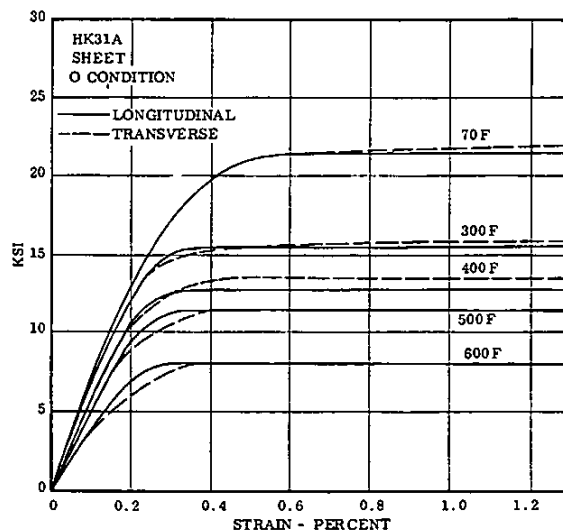


FIG. 3.03112 STRESS-STRAIN CURVES FOR SHEET IN O CONDITION AT ROOM AND ELEVATED TEMPERATURES. (14)

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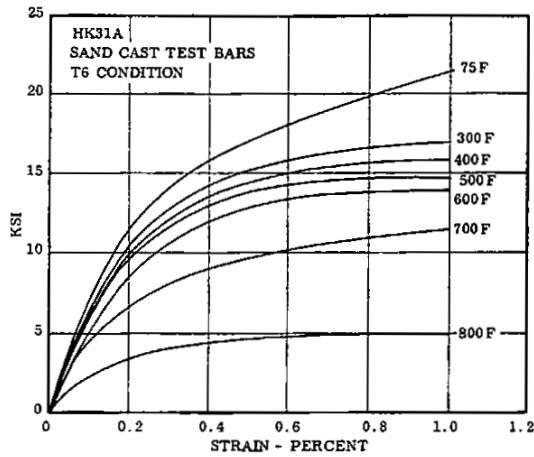


FIG. 3.03113 STRESS-STRAIN CURVES FOR CASTINGS IN T6 CONDITION AT ROOM AND ELEVATED TEMPERATURES. (15)

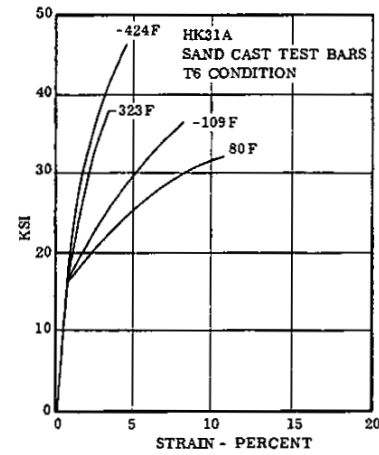


FIG. 3.03115 COMPLETE STRESS-STRAIN CURVES FOR CASTINGS AT LOW TEMPERATURE. (23)

	Mg
3	Th
0.7	Zr
HK31A	

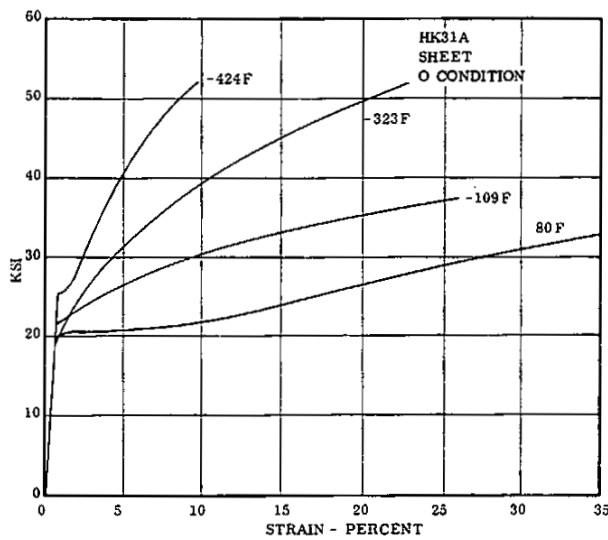


FIG. 3.03114 COMPLETE STRESS-STRAIN CURVES FOR SHEET AT LOW TEMPERATURES. (23)

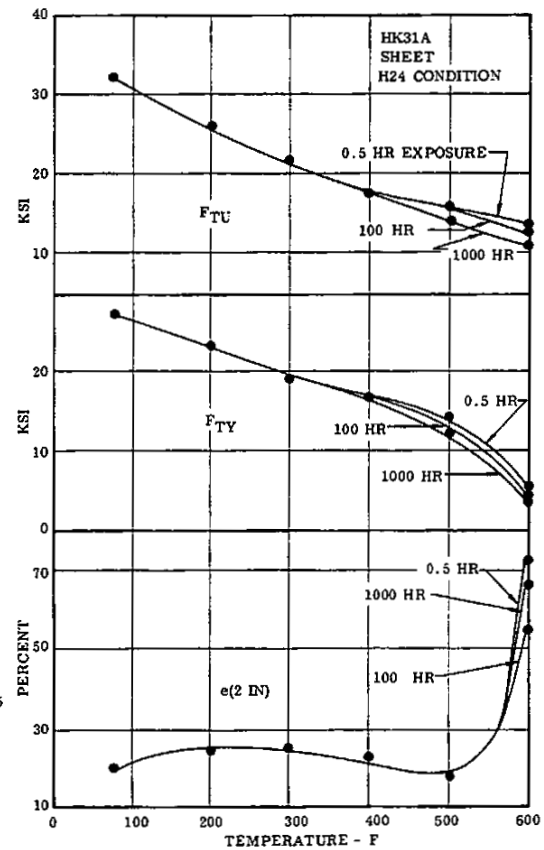


FIG. 3.0312 ELEVATED TEMPERATURE TENSILE PROPERTIES OF SHEET IN H24 CONDITION AFTER VARIOUS EXPOSURE TIMES AT TEST TEMPERATURE. (22)

Mg
3 Th
0.7 Zr

HK31A

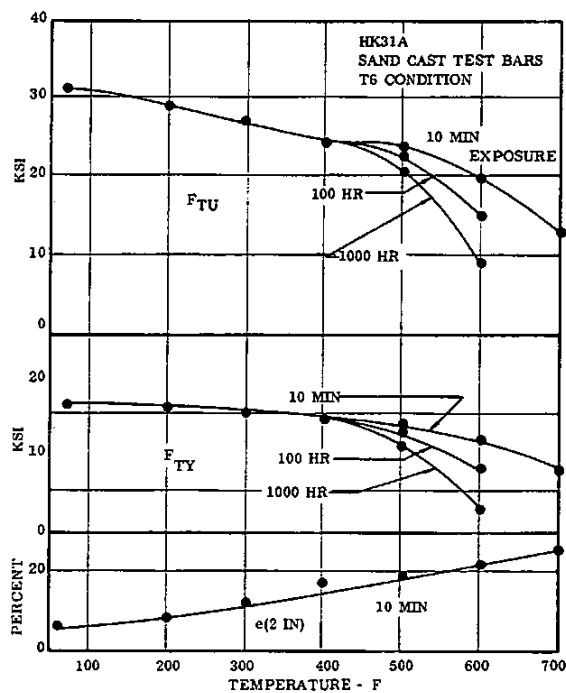


FIG. 3.0313 ELEVATED TEMPERATURE TENSILE PROPERTIES OF CASTINGS IN T6 CONDITION AFTER VARIOUS EXPOSURE TIMES AT TEST TEMPERATURE. (15)

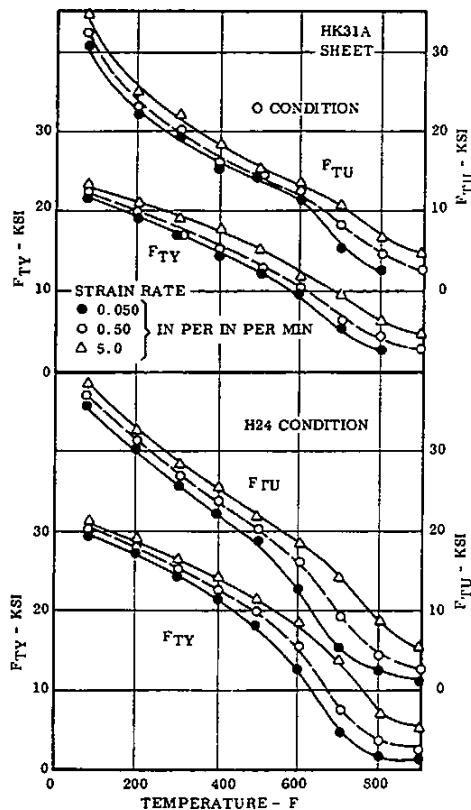


FIG. 3.0314 ELEVATED TEMPERATURE TENSILE PROPERTIES OF SHEET IN O AND H24 CONDITIONS AT VARIOUS STRAIN RATES. (14)

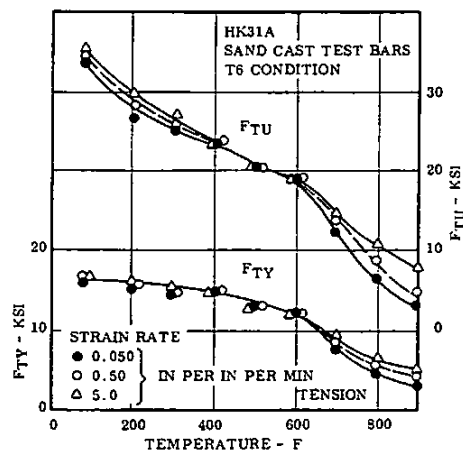


FIG. 3.0315 ELEVATED TEMPERATURE TENSILE PROPERTIES OF CASTINGS IN T6 CONDITION AT VARIOUS STRAIN RATES. (24)

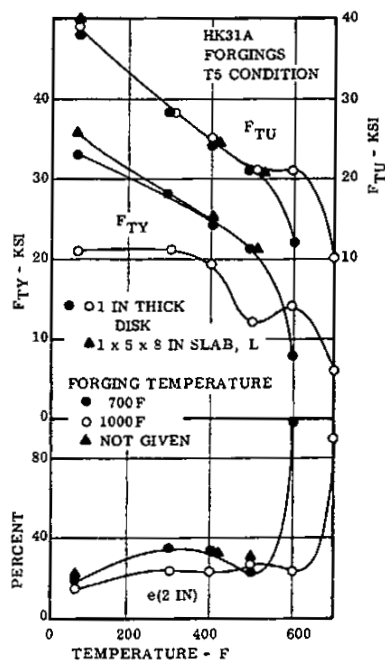


FIG. 3.0316 ELEVATED TEMPERATURE TENSILE PROPERTIES OF FORGINGS FORGED AT VARIOUS TEMPERATURES.
(10)

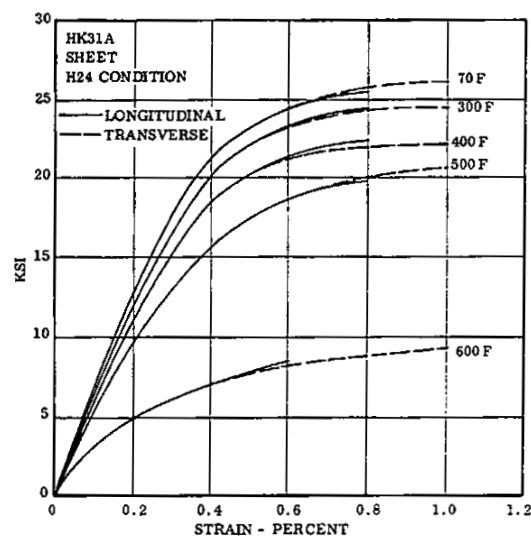


FIG. 3.03211 STRESS-STRAIN CURVES IN COMPRESSION FOR SHEET IN H24 CONDITION AT ROOM AND ELEVATED TEMPERATURES.
(14)

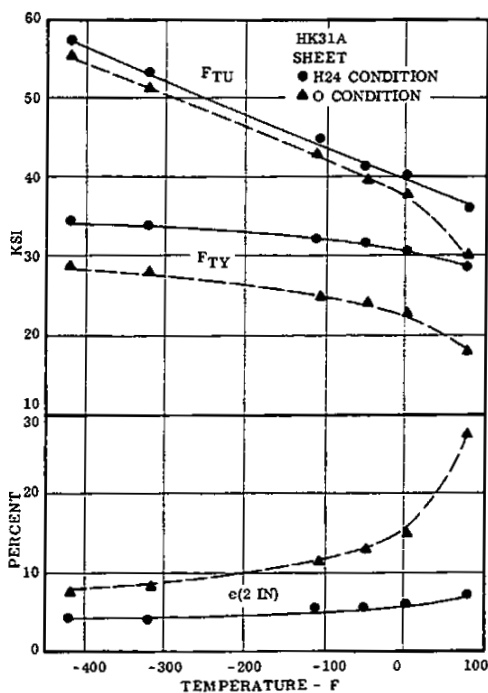


FIG. 3.0317 LOW TEMPERATURE TENSILE PROPERTIES OF SHEET.
(14)

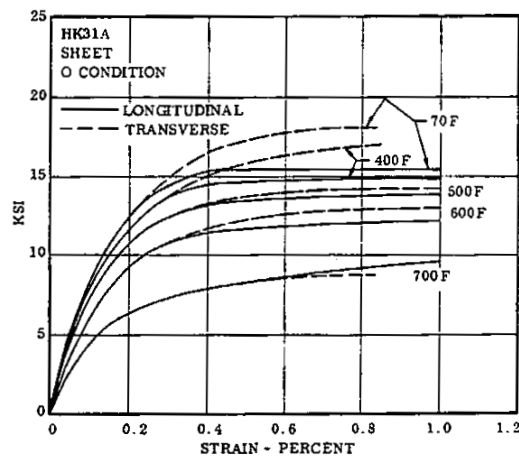


FIG. 3.03212 STRESS-STRAIN CURVES IN COMPRESSION FOR SHEET IN O CONDITION AT ROOM AND ELEVATED TEMPERATURES.
(14)

	Mg
3	Th
0.7	Zr
HK31A	

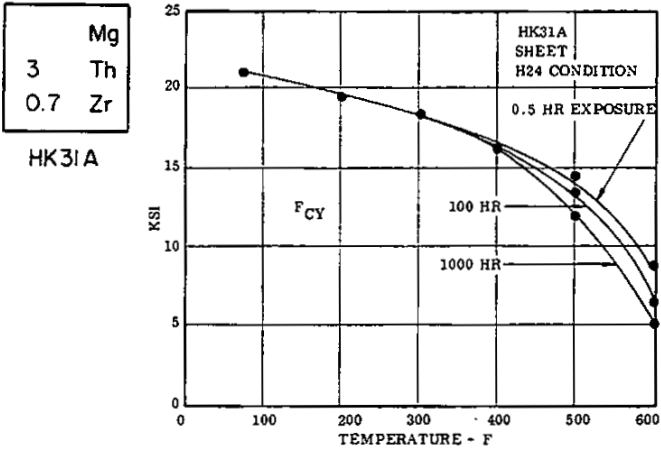


FIG. 3.0322 ELEVATED TEMPERATURE COMPRESSIVE STRENGTH OF SHEET IN H24 CONDITION AFTER VARIOUS EXPOSURE TIMES AT TEST TEMPERATURE. (22)

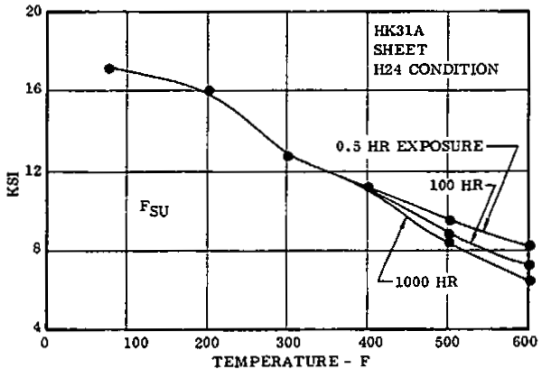


FIG. 3.0351 ELEVATED TEMPERATURE SHEAR STRENGTH OF SHEET IN H24 CONDITION AFTER VARIOUS EXPOSURE TIMES AT TEST TEMPERATURE. (22)

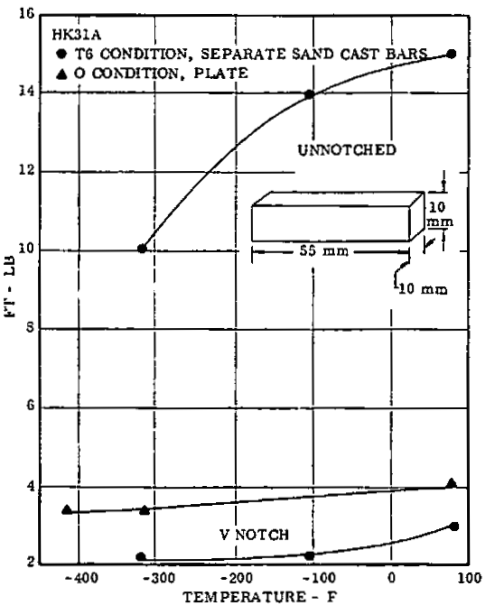


FIG. 3.0331 CHARPY IMPACT PROPERTIES AT LOW TEMPERATURES. (23)(25)

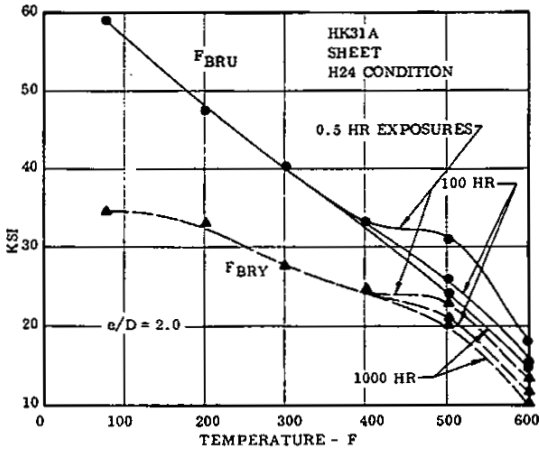


FIG. 3.0361 ELEVATED TEMPERATURE BEARING PROPERTIES OF SHEET IN H24 CONDITION AFTER VARIOUS EXPOSURE TIMES AT TEST TEMPERATURE. (22)

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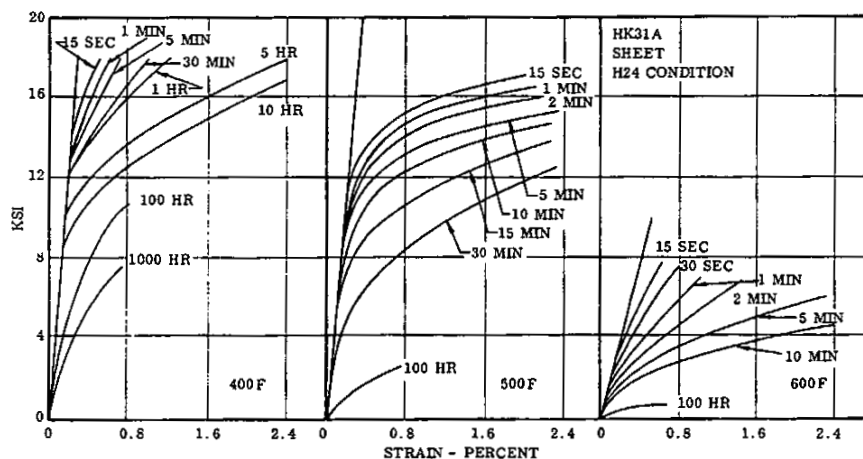


FIG. 3.041 ISOCHRONOUS STRESS-STRAIN CURVES FOR SHEET IN H24 CONDITION.

(14)

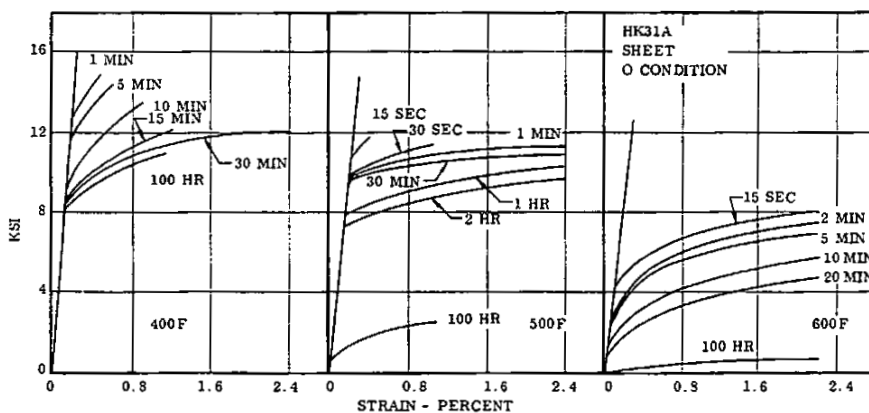


FIG. 3.042 ISOCHRONOUS STRESS-STRAIN CURVES FOR SHEET IN O CONDITION.

(14)

Mg
3 Th
0.7 Zr

HK31A

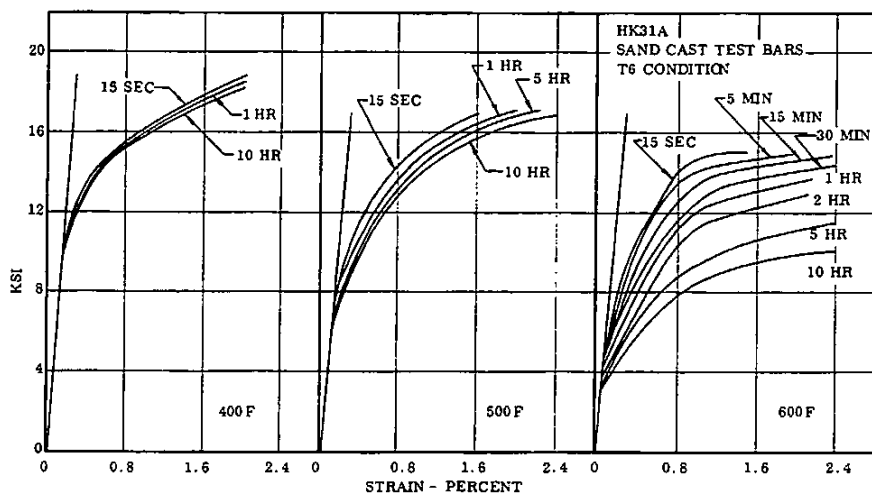


FIG. 3.043 ISOCHRONOUS STRESS-STRAIN CURVES FOR CASTINGS IN T6 CONDITION AT TEMPERATURES OF 400, 500, AND 600 F. (15)

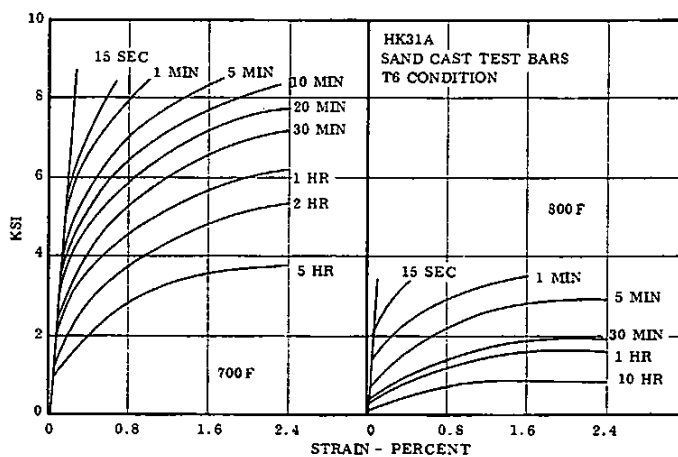


FIG. 3.044 ISOCHRONOUS STRESS-STRAIN CURVES FOR CASTINGS IN T6 CONDITION AT 700 AND 800 F. (15)

	Mg
3	Th
0.7	Zr

HK31A

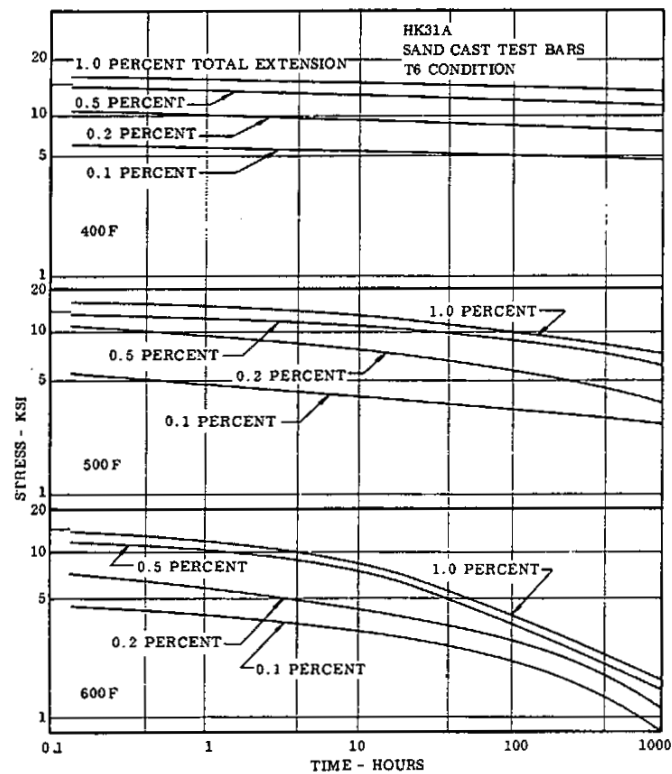


FIG. 3.045 TOTAL CREEP STRAIN CURVES FOR CASTINGS IN T6 CONDITION. (15)

Mg

3 Th

0.7 Zr

HK31A

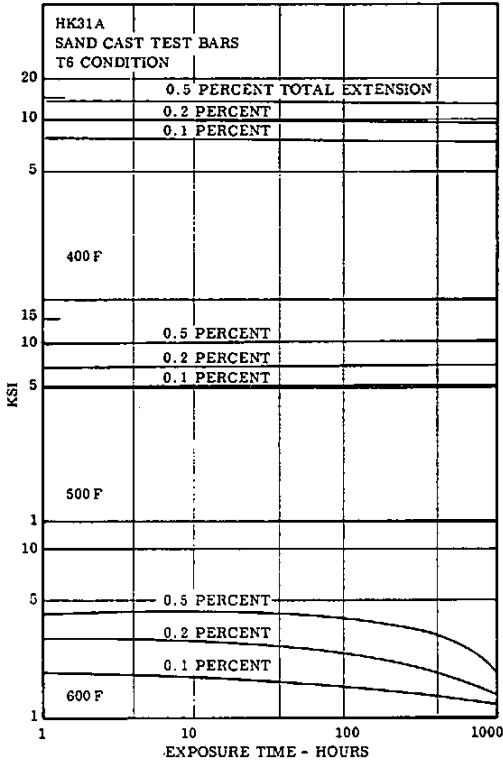


FIG. 3.046 EFFECT OF EXPOSURE TIME AT TEST TEMPERATURE PRIOR TO LOADING ON THE 100 HOUR CREEP STRENGTH OF SAND CASTINGS IN T6 CONDITION. (15)(26)

TABLE 3.047				
Alloy	HK31A			
Condition	T6			
Form	Forgings			
Source	(10)			
Test Temp - F	Forge Temp - F	Stresses for the following extensions in 100 hr. ksi		
		0.1 percent creep	0.2 percent total	0.5 percent total
400	700	17.0	12.0	18.0
	1000	18.5	11.9	19.0
500	700	1.4	1.5	2.4
	1000	8.0	7.4	9.8
600	700	1.6	1.8	2.5
	1000	1.6	1.8	2.5

TABLE 3.051									
Source	(15)(27)								
Form	(a) Sand Casting				(b) Sheet				
Condition	Temp F	Method	Stress Ratio		Stress Concentration	Fatigue Strength-ksi at Cycles			
			A	R		10 ⁵	10 ⁶	10 ⁷	10 ⁸
(a) T6	RT	Rot bend	∞	-1	Smooth	15 to 18	12 to 14	10 to 12	9 to 11
		Rev bend	∞	-1	Smooth	16 to 20	10 to 12	8 to 10	-
(b) H24	RT	Direct stress	0.60	0.25	As rolled	22 to 25	19 to 22	18 to 20	-
	400					18 to 20	13 to 16	10 to 14	-

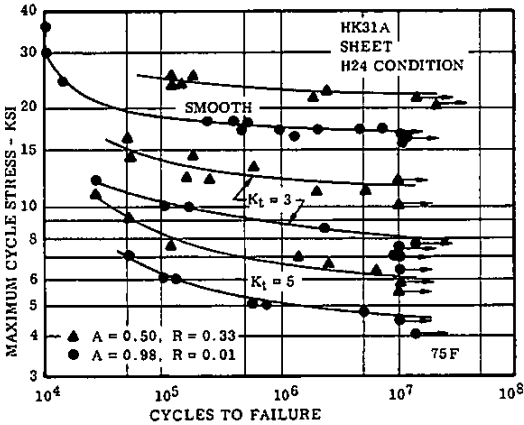


FIG. 3.052 AXIAL FATIGUE PROPERTIES OF SMOOTH AND NOTCHED SHEET SPECIMENS AT ROOM TEMPERATURE. (36)

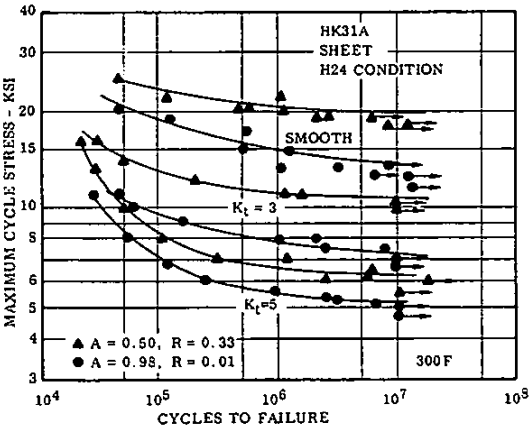


FIG. 3.053 AXIAL FATIGUE PROPERTIES OF SMOOTH AND NOTCHED SHEET SPECIMENS AT 300 F. (36)

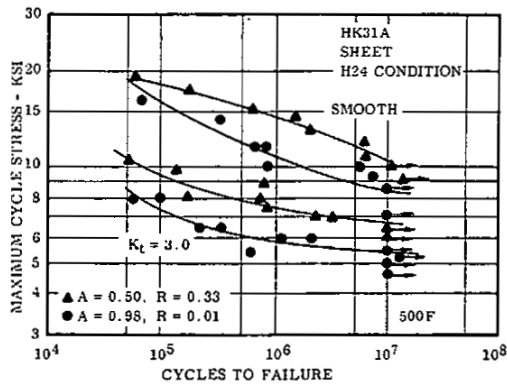


FIG. 3.054 AXIAL FATIGUE PROPERTIES OF SMOOTH AND NOTCHED SHEET SPECIMENS AT 500 F. (36)

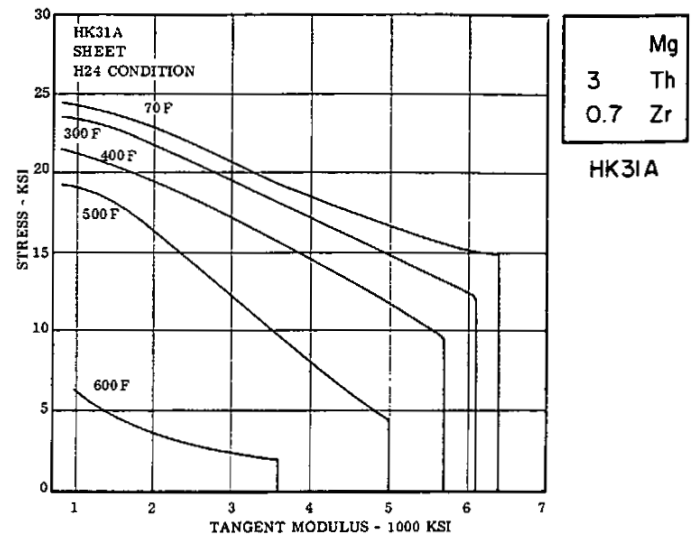


FIG. 3.0622 COMPRESSIVE TANGENT MODULUS CURVES AT ROOM AND ELEVATED TEMPERATURES. (14)

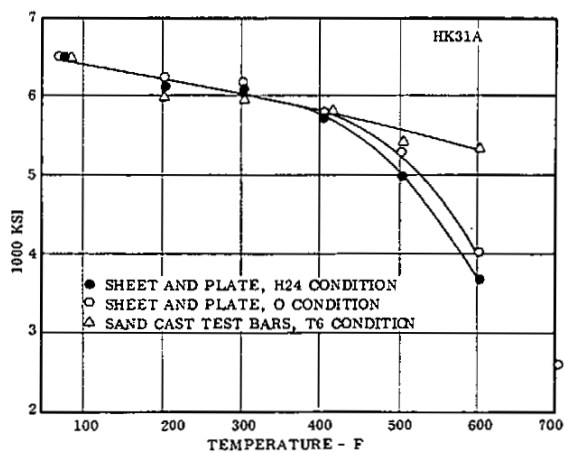


FIG. 3.0621 EFFECT OF TEMPERATURE ON STATIC MODULUS OF ELASTICITY. (28)

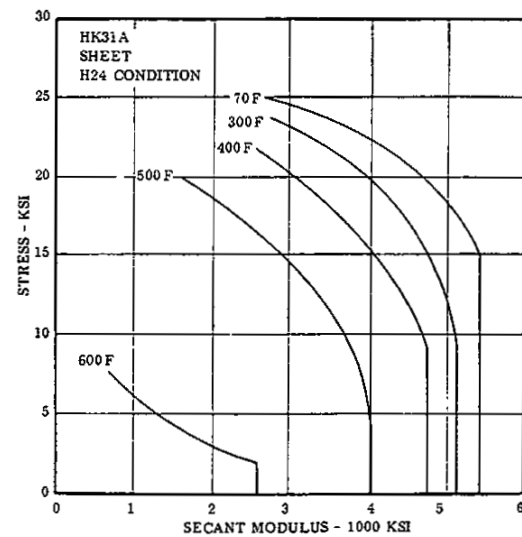


FIG. 3.0623 COMPRESSIVE SECANT MODULUS CURVES AT ROOM AND ELEVATED TEMPERATURES. (14)

	Mg
3	Th
0.7	Zr

HK31A

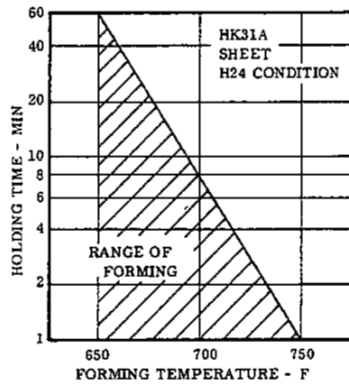


FIG. 4.011 MAXIMUM ALLOWABLE FORMING TIME AS A FUNCTION OF FORMING TEMPERATURE. (14)(29)(30)

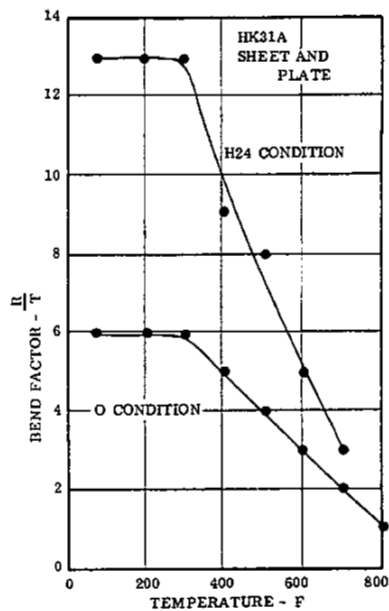


FIG. 4.012 MINIMUM BEND FACTOR (RATIO OF BEND RADIUS TO SHEET OR PLATE THICKNESS) AS FUNCTION OF TEMPERATURE. (14)(31)

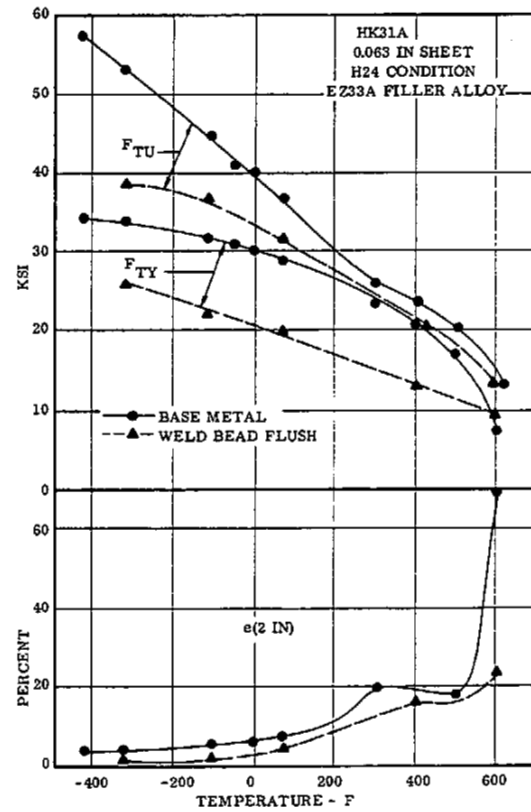


FIG. 4.032 EFFECT OF TEMPERATURE ON TENSILE PROPERTIES OF 0.063 INCH SHEET, BOTH UNWELDED AND WITH ARC WELDED BUTT JOINTS TRANSVERSE TO GAGE LENGTH. (14)

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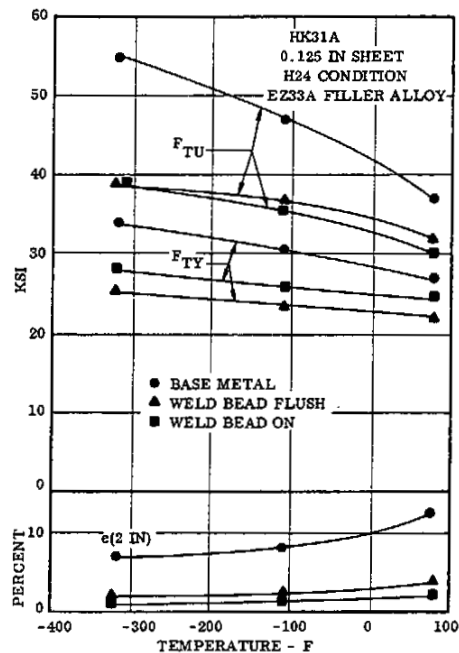


FIG. 4.033 EFFECT OF LOW TEMPERATURES ON TENSILE PROPERTIES OF 0.125 INCH SHEET, BOTH UNWELDED AND WITH TRANSVERSE BUTT WELDS MADE BY INERT-GAS-SHIELD TUNGSTEN ARC PROCESS. (35)

TABLE 4.034

Alloy		
HK31A		
Form		
Sheet		
Condition		
H24		
Source		
(34)		
Sheet Thickness in	Spot Weld Diameter Range in	Shear Strength Range lb/spot
0.032	0.16-0.23	250-350
0.040	0.15-0.25	250-480
0.063	0.25-0.35	660-990
0.090	0.28-0.36	840-1200
0.125	0.25-0.45	880-1820

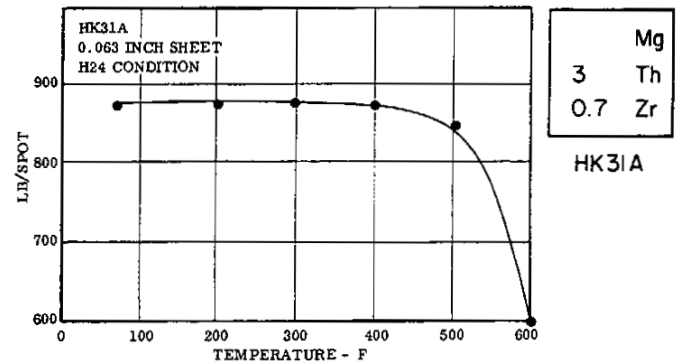


FIG. 4.035 EFFECT OF TEMPERATURE ON THE SHEAR STRENGTH OF RESISTANCE SPOT WELDS IN 0.063 INCH SHEET. (34)

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- ASTM B90-69, Sheet and Plate.
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	Mg
3	Th
0.7	Zr

HK31A

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REVISED: MARCH 1968
J. G. SESSLER

NONFERROUS ALLOYS

1. **GENERAL**
HM21A is one of a recently developed series of heat treatable magnesium alloys containing thorium and manganese as hardeners. It is available in the form of sheet, plate and forgings for service at temperatures up to 700F. Sheet and plate in the T8 condition are superior to HK31A-H24 for short time service above 550F and, at lower temperatures for long time service. Sheet and plate in the T81 condition are superior to HM21A-T8 at temperatures up to 600F and are comparable with HM21A-T8 at 600F and above. Forgings in the T5 condition offer the best combination of properties for magnesium alloys in the temperature range of 500 to 700F. This alloy can be readily welded and it is free from stress cracking.

1.01 Commercial Designation
HM21A

1.02 Alternate Designation
None

1.03 Specifications
Table 1.03

TABLE 1.03

Source	(4) (5)	
Alloy	HM21A	
Form and Condition	AMS	U.S. Government
Sheet and Plate - T8 Condition	4390D	MIL-M-8917 (a)
Sheet and Plate - T81 Condition	4383	-
Forgings - T5 Condition	4363A	-
Forgings	-	QQ-M-40b (b)
(a) Military specification		
(b) Federal specification		

1.04 Composition
Table 1.04

TABLE 1.04

Source	(4)	
Alloy	HM21A	
	Percent	
	Min	Max
Thorium	1.5	2.5
Manganese	0.45	1.1
Impurities		
each	-	0.10
total	-	0.30
Magnesium	Balance	

1.05 Heat Treatment

- 1.051 Sheet and plate are heat treated to T8 condition or T81 condition by the producer of the alloy. Its' favorable properties of T8 sheet and plate are obtained by cold work between solution treating and aging. The T81 condition is obtained by modifications at the rolling mill of the basic T8 condition material, (Ref 8).
- 1.052 Forgings. Age F condition (as forged) to T5 condition 450F, 16 hours.

1.06 Hardness

- 1.061 Hardness of T5 forgings. At RT 53-62 RE (2).
67 RE (14).
- 1.062 This alloy hardens fully on heat treating in all commercial section sizes.

1.07 Forms and Conditions Available

- 1.071 Sheet and plate are available in the full commercial range of sizes in the T8 condition but are limited to the thickness range of 0.125 to 0.312 inch in the T81 condition.
- 1.072 Forgings are available in all commercial sizes and generally are in the T5 condition.

1.08 Melting and Casting Practice

- 1.081 Magnesium melting practice for ingots comprises alloying and melting in iron pots under flux and continuous casting of ingots up to about 28 inches diameter.

1.09 Special Considerations

- 1.091 Alloys containing thorium require dust and fume control to prevent radiation poisoning. Normal dust control for fire hazard during grinding is satisfactory. Welding requires local exhaust of the fumes.
- 1.092 AEC license is required for fabrication and application of this alloy.

2. PHYSICAL AND CHEMICAL PROPERTIES

2.01 Thermal Properties

- 2.011 Melting range. Solidus temp: 1121F
Liquidus temp. 1202F,
(Ref 8)(Ref 16).
- 2.012 Phase changes. Alloy is subject to precipitation.
- 2.013 Thermal conductivity.
At RT. 79.2 Btu ft per (hr sq ft F).
At 600F. 81.7 Btu ft per (hr sq ft F),
(Ref 8).
- 2.014 Thermal expansion, Figure 2.014.

2.015 Specific heat, Figure 2.015.

2.016 Diffusivity, Figure 2.016

2.02 Other Physical Properties

- 2.021 Density. 0.642 lb per cu in
1.776 gr per cu cm,
(Ref 10)(Ref 15).
- 2.022 Electrical resistivity, Figure 2.022.
- 2.023 Magnetic properties. Alloy is non-magnetic.
- 2.024 Emissivity.
- 2.025 Damping capacity, Figure 2.025.
- 2.026 Ignition temperature (estimated) 1180 to 1200F,
(Ref 8).

2.03 Chemical Properties

- (See also AZ31B).
- 2.031 General. The base metal salt water corrosion resistance of the wrought magnesium thorium alloys is somewhat better than that of other wrought and cast magnesium alloys. HM21A is believed not to be susceptible to stress corrosion. No failures have occurred in T8 sheet specimens exposed to a rural environment for over 7 years when stressed to 75 percent of F_{ty}. Surface preparation of these specimens consisted of acetic nitrate pickle plus abrasive cleaning with #100 grit aloxite cloth, (Ref 1) (Ref 15).

2.04 Nuclear Properties

- 2.041 Alloy is slightly radioactive, equivalent to a watch dial.
- 2.042 The manganese content and resulting high nuclear cross section make this alloy unsuitable for applications where nuclear shielding is undesirable.

Mg
2 Th
0.8 Mn

HM 21 A

CODE 3504

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3. MECHANICAL PROPERTIES

3.01 Specified Mechanical Properties

3.011 AMS specified mechanical properties, Table 3.011.

TABLE 3.011

Source	AMS 4390					AMS 4383	AMS 4363A		
Form	Sheet, Plate					Sheet, Plate	Die Forgings	Ring Forgings	
Condition	T8					T81	T5	T5	
Thickness, inch	0.016 to 0.250	0.250 to 0.500	0.500 to 1.000	1.000 to 2.000	2.000 to 3.000	0.125 to 0.312	up to 4.000	All	up to 2.000 over 2.000
Direction							Parallel to Flow	Circum.	Axial
F_{tu} , min, ksi	33	32	30	30	30	34	33	32	28
F_{ty} , min, ksi	18	21	21	21	21	25	25	26	13
F_{cy} , min, ksi	15	20	17	15	14	22			10
$e(2 \text{ in})$, min, percent	6	6	6	6	6	4	3	4	6

3.0213 Minimum design properties for T81 sheet and plate, Table 3.0213.

TABLE 3.0213

Source	(S)	
Alloy	HM21A	
Form	Sheet and Plate	
Condition	T81	
Thickness, inch	0.125 to 0.250	0.250 to 0.312
F_{tu} , ksi, min	33	34
F_{ty} , ksi, min	25	25
$e(2 \text{ in})$, percent	4	4
F_{cy} , ksi, min	22	22

3.02 Mechanical Properties At Room Temperature

3.021 Tension. See also 3.031.

3.0211 Stress strain diagrams. See 3.0311.

3.0212 Typical mechanical properties of sheet and plate, Table 3.0212.

TABLE 3.0212

Source	(1)					
Alloy	HM21A					
Form	Sheet and Plate					
Condition	T8					
Thickness, inch	0.016 to 0.250	0.250 to 0.500	0.500 to 1.000	1.000 to 2.000	2.000 to 3.000	
F_{tu} , ksi	L	36	37	35	34	34
	T	35	39	37	37	39
	min	33	32	30	30	30
F_{ty} , ksi	L	28	30	28	25	26
	T	24	28	26	27	28
	min	18	21	21	21	21
F_{cy} , ksi	L	21	24	22	20	18
	T	20	25	23	21	20
	min	15	20	17	15	14
$e(2 \text{ in})$, percent	L	11	11	12	11	10
	T	17	14	17	13	11
	min	6	6	6	6	6

3.0214 Average mechanical properties of rolled rings produced from upset blanks, Table 3.0214.

TABLE 3.0214

Source	(9)				
Alloy	HM21A				
Form	Rolled Rings from Upset Blanks				
Condition	T5				
	Orientation	Rolling Reduction			
		20 Percent	40 Percent	60 Percent	
F_{tu} , ksi	Tang	35	39	40	
	Axial	34	34	36	
	Radial	34	36	36	
F_{ty} , ksi	Tang	29	33	34	
	Axial	14	18	23	
	Radial	13	14	17	
e , percent	Tang	9	7	8	
	Axial	10	11	9	
	Radial	14	15	12	
F_{cy} , ksi	Tang	16	18	21	
	Axial	15	15	15	
	Radial	15	18	22	

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- 3.0215 Average mechanical properties of rolled rings produced directly from cast blanks, Table 3.0215.

TABLE 3.0215

Source	(9)				
Alloy	HM21A				
Form	Rolled Rings from Cast Blanks				
Condition	T5				
	Orientation	Rolling Reduction			
		20 Percent	40 Percent	60 Percent	
F_{tu} , ksi	Tang	31	34	37	
	Axial	28	31	34	
	Radial	30	33	33	
F_{ty} , ksi	Tang	22	27	30	
	Axial	16	20	23	
	Radial	12	12	16	
e, percent	Tang	2	5	5	
	Axial	3	6	5	
	Radial	9	12	9	
F_{cy} , ksi	Tang	13	15	20	
	Axial	13	15	19	
	Radial	16	17	22	

- 3.0216 Effect of exposure to elevated temperature on tensile properties of sheet at room temperature, Figure 3.0216.
- 3.022 Compression, (See Tables 3.01, 3.0212, 3.0213, 3.0214 and 3.0215).
- 3.023 Impact.
- 3.0231 Charpy V Notch impact strength of T5 forgings at room temperature. 5.2 ft lbs, (Ref 2).
- 3.024 Bending.
- 3.025 Torsion and shear.
- 3.0251 Room temperature shear properties of T8 sheet and plate, Table 3.0251.

TABLE 3.0251

Source	(1)					
Alloy	HM21A					
Form	Sheet and Plate (a)					
Condition	T8					
Thickness, inches	0.016 to 0.250	0.250 to 0.500	0.500 to 1.000	1.000 to 2.000	2.000 to 3.000	
F_{su} , ksi	L	25	26	24	24	24
	T	24	27	26	26	27
	min	21	20	19	19	19

(a) Data given are typical and minimum properties are not guaranteed.

- 3.026 Bearing.
- 3.0261 Room temperature bearing properties of T8 sheet and plate, Table 3.0261.

- 3.027 Stress concentration.
- 3.0271 Notch properties.
- 3.0272 Fracture toughness.
- 3.028 Combined properties.

- 3.03 Mechanical Properties at Various Temperatures
- 3.031 Tension.
- 3.0311 Stress strain diagrams.
- 3.03111 Tensile stress strain curves for sheet in T8 condition, Figure 3.03111.
- 3.03112 Tensile stress strain curves for sheet in T81 condition, Figure 3.03112.
- 3.0312 Effect of test temperature on tensile properties of sheet in condition T8, Figure 3.0312.
- 3.0313 Effect of test temperature on tensile properties of plate in T8 condition, Figure 3.0313.
- 3.0314 Effect of test temperature on tensile properties of sheet and plate in the T81 condition, Figure 3.0314.
- 3.0315 Effect of test temperature on tensile properties of forgings, Figure 3.0315.
- 3.0316 Effects of test temperature and test direction on tensile properties of forgings, Figure 3.0316.
- 3.0317 Effects of forging temperature and test temperature on tensile properties, Figure 3.0317.
- 3.0318 Effect of strain rate on tensile properties of sheet at various test temperatures, Figure 3.0318.
- 3.032 Compression.
- 3.0321 Compressive stress-strain curves for sheet in T8 condition, Figure 3.0321.
- 3.0322 Effect of test temperature on compressive yield strength of sheet, Figure 3.0322.
- 3.0323 Effect of test temperature on compressive yield strength of plate, Figure 3.0323.
- 3.033 Impact.
- 3.034 Bending.
- 3.035 Torsion and shear.
- 3.0351 Effect of test temperature on shear strength of sheet in T8 condition, Figure 3.0351.
- 3.0352 Effect of test temperature on shear strength of plate in T8 condition, Figure 3.0352.
- 3.036 Bearing.
- 3.0361 Effect of test temperature on bearing properties of sheet in T8 condition, Figure 3.0361.
- 3.0362 Effect of test temperature on bearing properties of plate in T8 condition, Figure 3.0362.
- 3.037 Stress concentration.
- 3.0371 Notch properties.
- 3.0372 Fracture toughness.
- 3.038 Combined properties.

TABLE 3.0261

Source	(1)					
Alloy	HM21A					
Form	Sheet and Plate (a)					
Condition	T8					
Thickness, inches	0.016 to 0.250	0.250 to 0.500	0.500 to 1.000	1.000 to 2.000	2.000 to 3.000	
(e/d = 1.5)						
F_{bru} , ksi	L	55	57	53	52	52
	T	53	61	57	57	61
	min	47	45	43	43	43
F_{bry} , ksi	L	39	42	40	38	36
	T	38	43	41	39	38
	min	29	35	31	29	27
(e/d = 2.0)						
F_{bru} , ksi	L	65	67	63	61	61
	T	63	71	67	67	71
	min	56	54	52	52	52
F_{bry} , ksi	L	39	42	40	38	36
	T	38	43	41	39	38
	min	29	35	31	29	27

(a) Data given are typical and minimum properties are not guaranteed.

Mg
2 Th
0.8 Mn

HM 21 A

CODE 3504

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Mg
2 Th
0.8 Mn

HM 21 A

- 3.04 Creep and Creep Rupture Properties
3.041 100 hour creep and total strain data for sheet and forgings, Table 3.041.

TABLE 3.041

Source		(1)(2)(10)			
Condition	Test Direction	Test Temp F	100 Hr Strength, ksi		
			Creep 0.1 Percent	Total Strain 0.2 Percent	0.5 Percent
0.125 In Sheet					
T8	-	300	14.9	12.0	15.6
	-	400	13.3	11.4	13.5
	-	500	8.0	7.0	9.0
	-	600	5.0	5.0	6.0
	-	700	2.3	2.6	3.3
1 In Disk Forged at 700F					
T5	-	400	18.0	12.5	19.0
	-	500	12.0	9.5	13.5
	-	600	7.7	7.0	9.0
	-	700	3.7	3.8	5.4
1 In Disk Forged at 1000F					
T5	-	400	13.8	11.2	15.0
	-	500	12.0	9.0	13.5
	-	600	5.4	5.3	6.6
	-	700	2.6	2.6	2.9
Production Forgings					
T5	Axial (a)	400	11.0	9.5	12.0
		600	8.0	7.2	8.0
		700	3.1	3.1	3.3
	Trans (a)	400	11.0	9.4	12.0
		600	7.6	6.9	8.2
		700	3.5	3.5	3.9
	Radial (b)	400	13.0	11.0	15.0
		600	6.0	6.0	6.2
		700	3.4	3.2	3.6
		(a) Specimens taken from forged wheel. (b) Specimens taken from forged impeller fin.			

- 3.042 Stresses for 0.1 percent creep strain in 100 hours for sheet, Figure 3.042.
3.043 Isochronous stress strain curves.
3.0431 Isochronous stress strain curves for T8 sheet at 400 to 900F, Figure 3.0431.
3.0432 Isochronous stress strain curves for T81 sheet at 600F, Figure 3.0432.
3.0433 Isochronous stress strain curves for T81 sheet at 700F, Figure 3.0433.
3.0434 Isochronous stress strain curves for T81 sheet at 500F, Figure 3.0434.
3.0435 Isochronous stress strain curves for T81 sheet at 900F, Figure 3.0435.
3.0436 Isochronous stress strain curves for forgings at 400 to 700F, Figure 3.0436.
3.05 Fatigue Properties
3.051 S-N curves for sheet tested at room temperature, 400F and 600F, Figure 3.051.
3.052 S-N curves for smooth and notched specimens from forgings tested at room temperature, Figure 3.052.
3.053 S-N curves for smooth specimens from forgings tested at room temperature, 400F and 600F, Figure 3.053.
3.06 Elastic Properties
3.061 Poisson's Ratio. 0.35. (Ref 10).
3.062 Modulus of elasticity.
3.0621 Effect of test temperature on modulus of elasticity. Figure 3.0621.
3.063 Modulus of rigidity, 2400 ksi. (Ref 10).

4. FABRICATION

4.01 Formability

- 4.011 General. Magnesium alloys possess excellent formability at elevated temperatures and many operations requiring relatively mild deformation around generous radii (as in bending) can be done at room temperature for HM21A, no significant change in bending radius occurs from room temperature to 500F. Parts requiring bends sharper than can be made at room temperature should be bent at 600 to 800F. In drawing operations the sheet requires die temperatures of 700 to 750F with drawing speeds up to 12 inches per minute. Punch temperatures of 350 to 400F are recommended and generous radii on drawing dies should be employed, (Ref 10)(Ref 15).
4.012 Hot working temperature range. 650 to 800F, (Ref 16).
4.013 Die temperature of electrically heated dies for hot dimpling is 850F, provided that die contact with sheet does not exceed 5 seconds, (Ref 10).
4.014 Suggested bend factors, Figure 4.014.
4.015 Forging of alloy is usually done in closed dies and press forging is the preferred method, (Ref 10).

4.02 Machining and Grinding

- 4.021 HM21A has excellent machining characteristics. High speed tools are normally suitable but carbide tipped tools are preferred. Very good finish cuts are obtained with diamond tools. Tools must be kept sharp. Dry machining is recommended and compressed air is sometimes used for cooling. If liquid coolant is used, it should be mineral oil. (Ref 10).
4.022 Drilling. General purpose steel drills can be used for holes up to 5 times drill diameter. Speeds can vary from 300 to 2000 fpm with feeds from 0.005 to 0.050 inch per revolution. (Ref 10).
4.023 Milling Turning. Moderate feeds and depth of cut, high cutting speeds, large rake angles and ample chip clearance are desirable. (see reference 10 for more detailed information).
4.024 Grinding. Rough grinding should employ medium to coarse grain wheels. Dust collection systems (wet type) specifically recommended for magnesium must be used.

4.03 Welding

- 4.031 General. Alloy exhibits good weldability with practically no tendency toward weld cracking. EZ33A composition is recommended for arc welding. The alloy is also readily spot welded. Detailed information on weldability of this alloy is given in reference 11.

4.04 Heat Treatment

See AZ63A.

4.05 Surface Treatment

- 4.051 General. Surface treatments for magnesium alloys are many and are used in numerous combinations. They are applied for corrosion protection, electrical resistance or abrasion resistance. Excellent detailed discussions pertaining to surface treatment of magnesium alloys are given in references 6.7 and 10.

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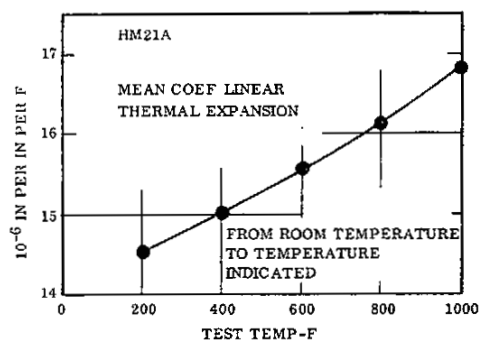


FIG. 2.014 THERMAL EXPANSION.

(8)

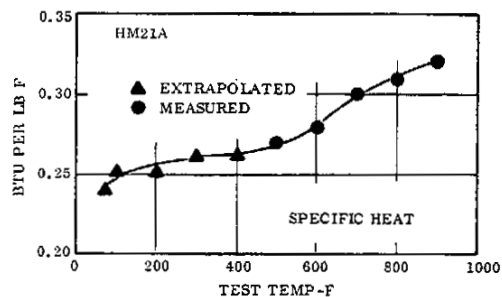


FIG. 2.015 SPECIFIC HEAT.

(10)

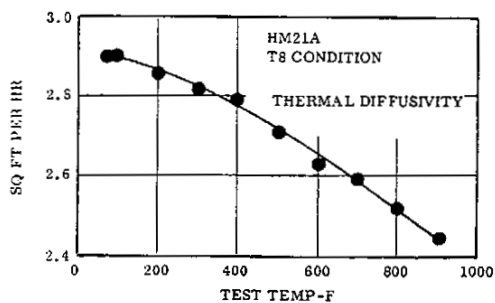


FIG. 2.016 DIFFUSIVITY (CALCULATED VALUES).

(10)

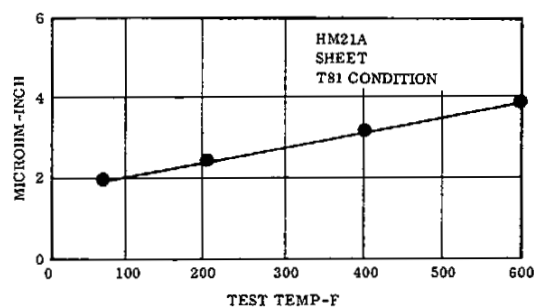


FIG. 2.022 ELECTRICAL RESISTIVITY.

(8)

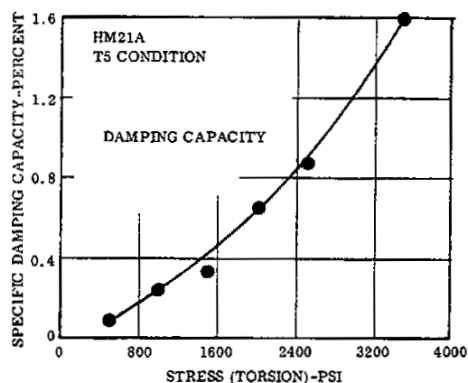


FIG. 2.025 DAMPING CAPACITY.

(14)

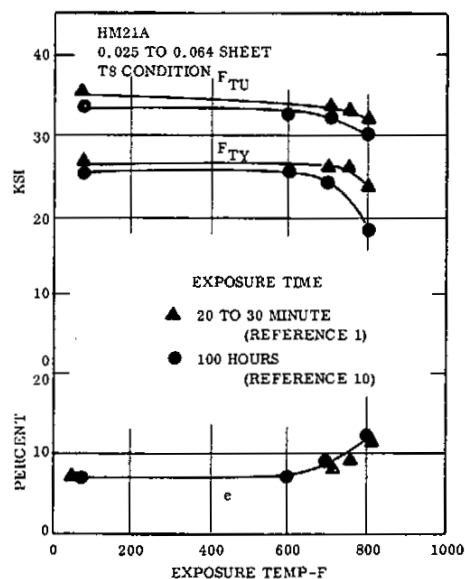


FIG. 3.0216 EFFECT OF EXPOSURE TO ELEVATED TEMPERATURE ON TENSILE PROPERTIES OF SHEET AT ROOM TEMPERATURE.

(1) (10)

Mg
2 Th
0.8 Mn
HM 21 A

	Mg
2	Th
0.8	Mn

HM 21 A

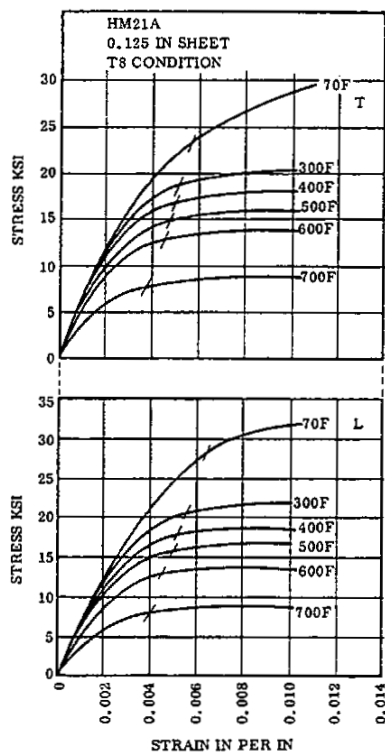


FIG. 3.03111 TENSILE STRESS STRAIN CURVES FOR SHEET IN T8 CONDITION.

(10)

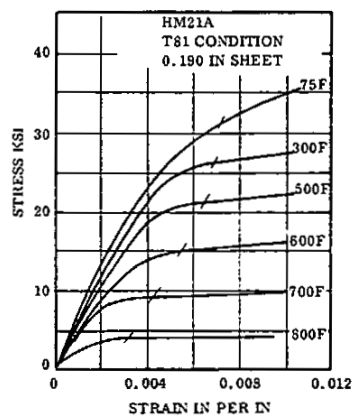


FIG. 3.03112 TENSILE STRESS STRAIN CURVES FOR SHEET IN T81 CONDITION.

(10)

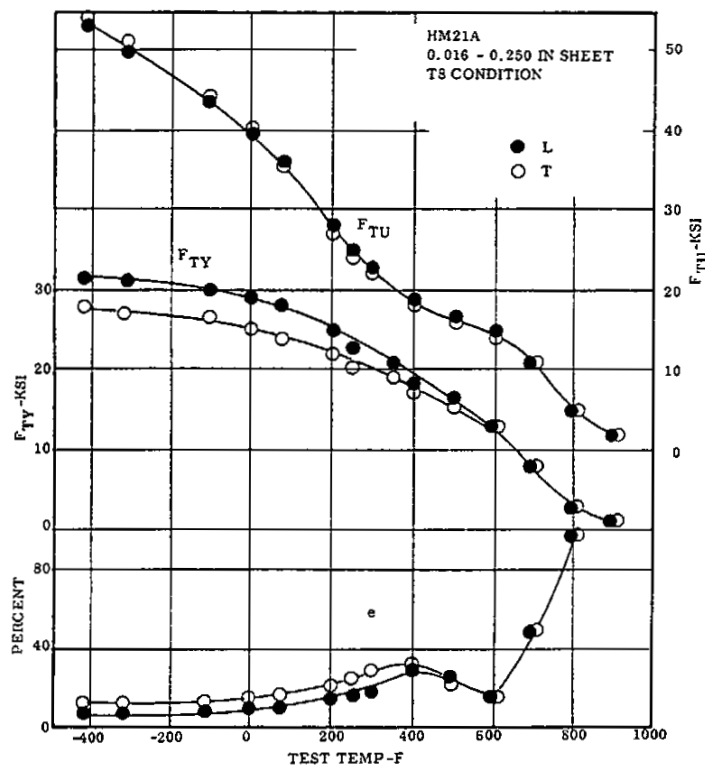


FIG. 3.0312 EFFECT OF TEST TEMPERATURE ON TENSILE PROPERTIES OF SHEET IN CONDITION T8.

(1)

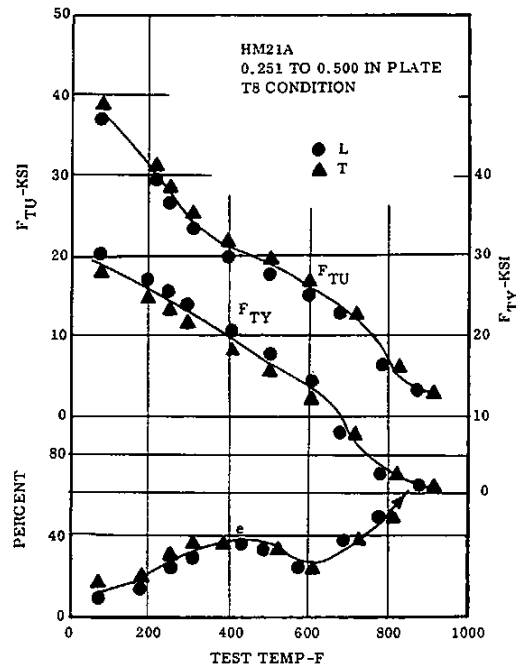


FIG. 3.0313 EFFECT OF TEST TEMPERATURE ON TENSILE PROPERTIES OF PLATE IN T8 CONDITION. (1)

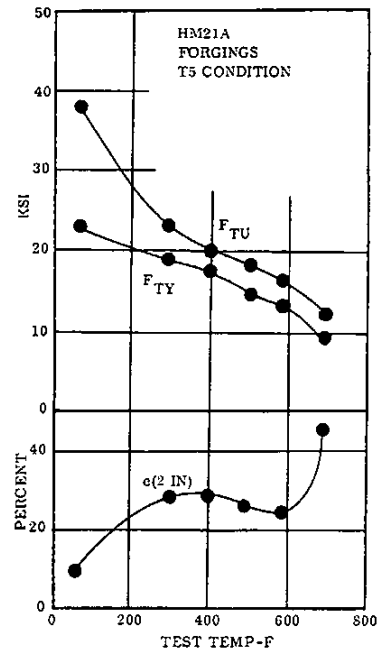


FIG. 3.0315 EFFECT OF TEST TEMPERATURE ON TENSILE PROPERTIES OF FORGINGS. (10)

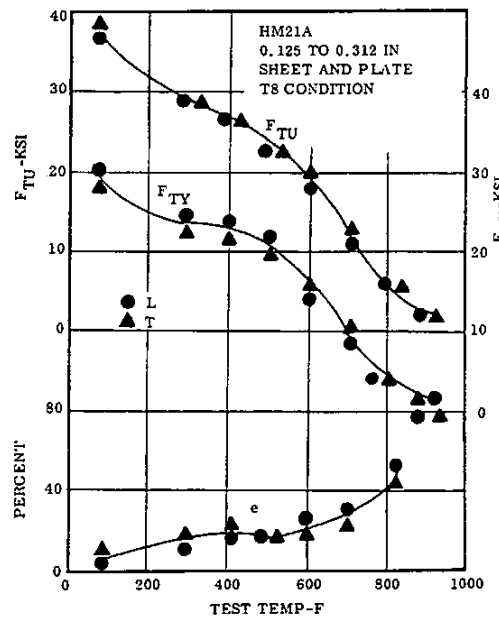


FIG. 3.0314 EFFECT OF TEST TEMPERATURE ON TENSILE PROPERTIES OF SHEET AND PLATE IN THE T81 CONDITION. (8)

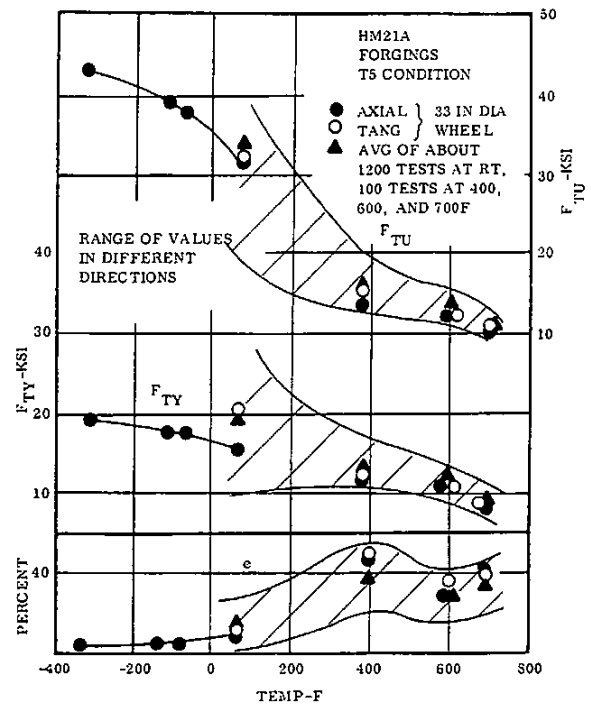


FIG. 3.0316 EFFECTS OF TEST TEMPERATURE AND TEST DIRECTION ON TENSILE PROPERTIES OF FORGINGS. (2)

Mg
2 Th
0.8 Mn

HM 21 A

Mg
2 Th
0.8 Mn
HM 21 A

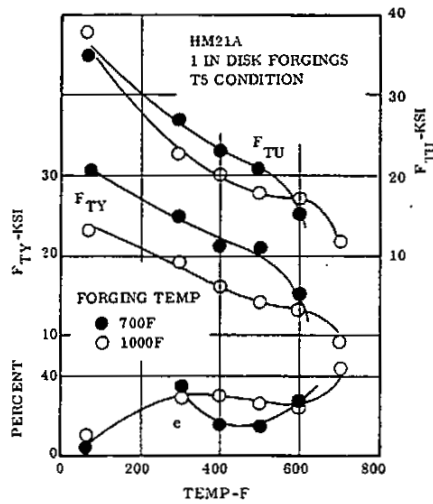


FIG. 3.0317 EFFECT OF FORGING TEMPERATURE AND TEST TEMPERATURES ON TENSILE PROPERTIES.

(2)

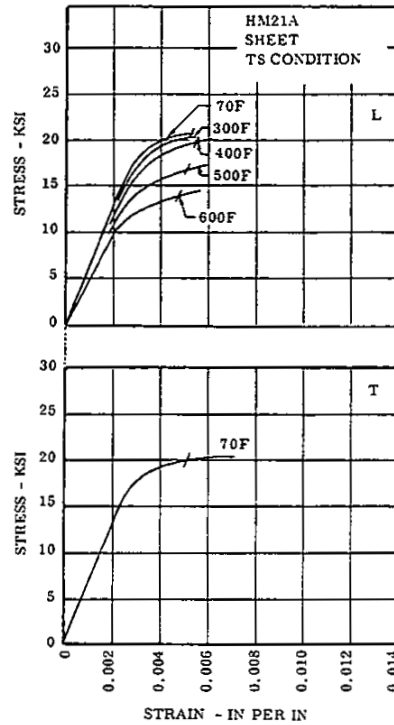


FIG. 3.0321 COMPRESSIVE STRESS-STRAIN CURVES FOR SHEET IN TS CONDITION.

(10)

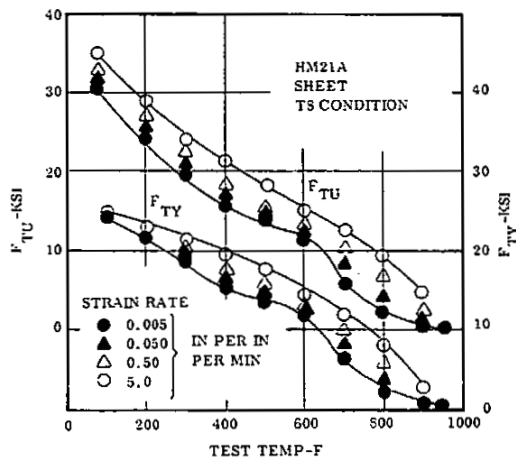


FIG. 3.0315 EFFECT OF STRAIN RATE ON TENSILE PROPERTIES OF SHEET AT VARIOUS TEST TEMPERATURES.

(10)

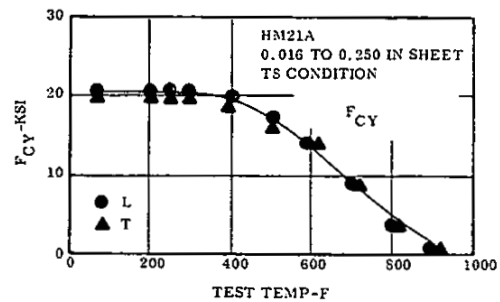


FIG. 3.0322 EFFECT OF TEST TEMPERATURE ON COMPRESSIVE YIELD STRENGTH OF SHEET.

(1)

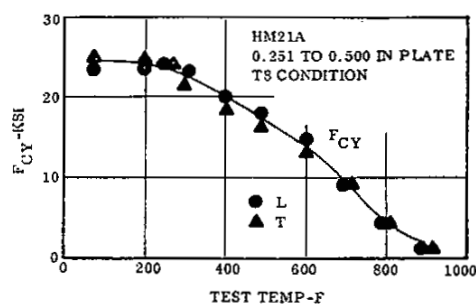


FIG. 3.0323 EFFECT OF TEST TEMPERATURE ON COMPRESSIVE YIELD STRENGTH OF PLATE.

(1)

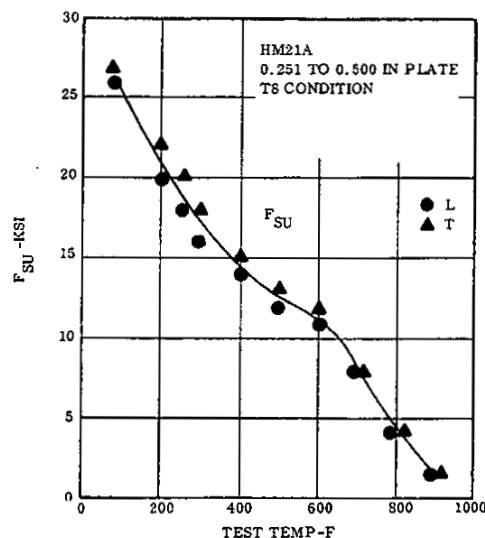


FIG. 3.0352 EFFECT OF TEST TEMPERATURE ON SHEAR STRENGTH OF PLATE IN T8 CONDITION.

(1)

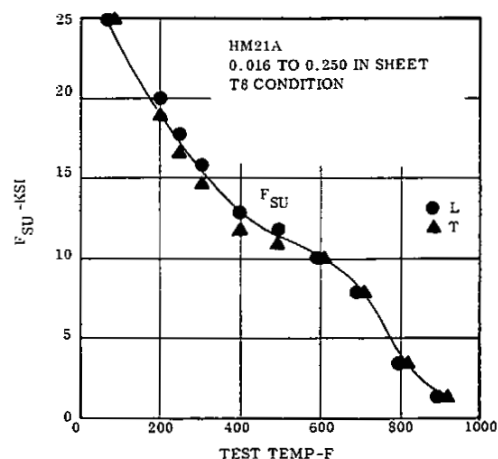


FIG. 3.0351 EFFECT OF TEST TEMPERATURE ON SHEAR STRENGTH OF SHEET IN T8 CONDITION.

(1)

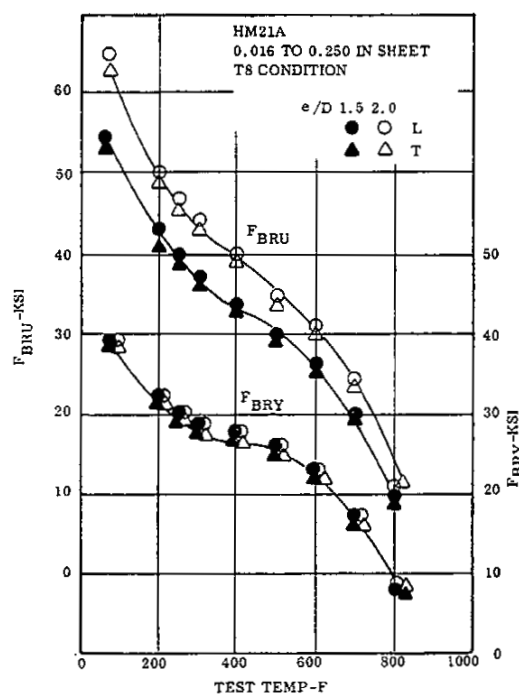


FIG. 3.0361 EFFECT OF TEST TEMPERATURE ON BEARING PROPERTIES OF SHEET IN T8 CONDITION.

(1)

Mg
2 Th
0.8 Mn
HM 21 A

Mg
2 Th
0.8 Mn
HM 21 A

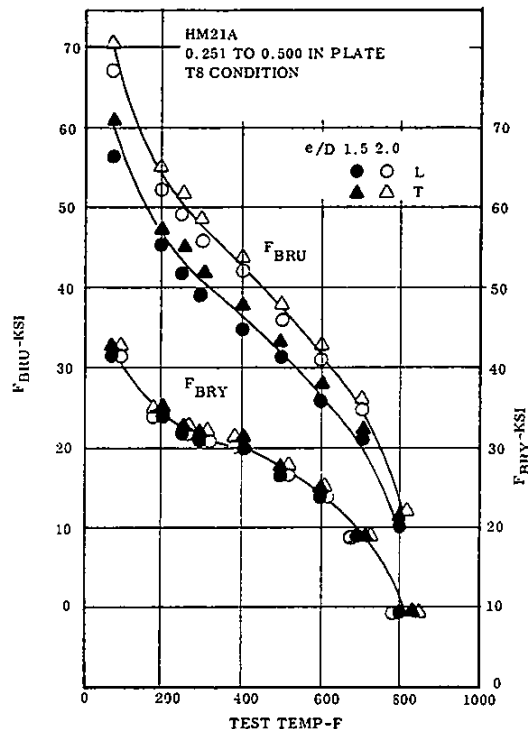


FIG. 3.0362 EFFECT OF TEST TEMPERATURE ON BEARING PROPERTIES OF PLATE IN T8 CONDITION.
(1)

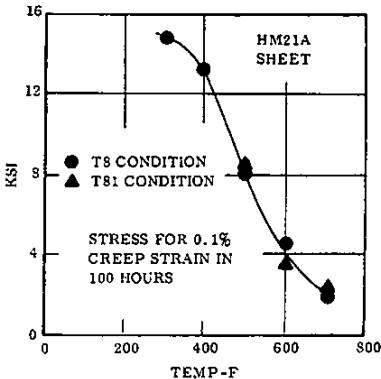


FIG. 3.042 STRESSES FOR 0.1 PERCENT CREEP STRAIN IN 100 HOURS FOR SHEET.
(7)

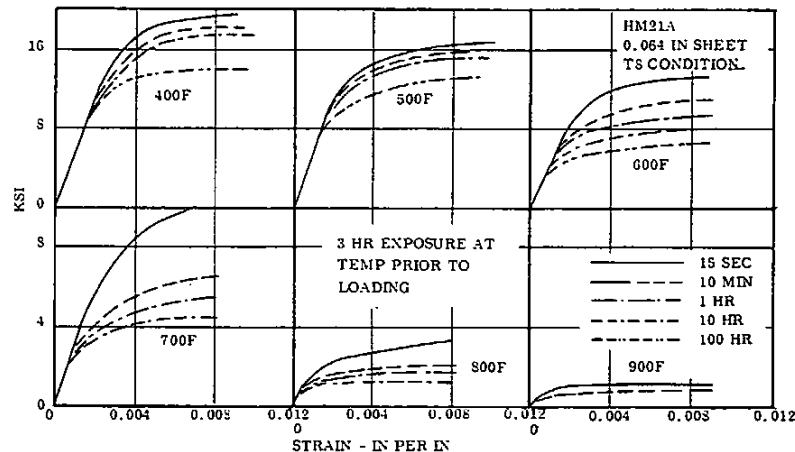


FIG. 3.0431 ISOCHRONOUS STRESS STRAIN CURVES FOR T8 SHEET AT 400 TO 900F.
(10)

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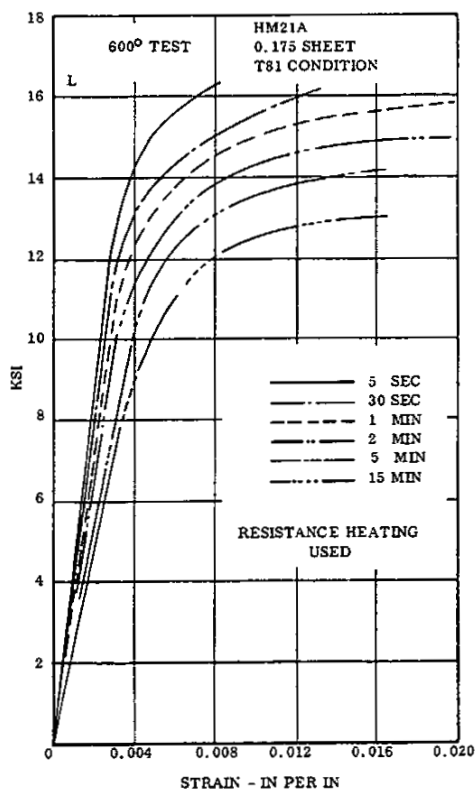


FIG. 3.0432 ISOCHRONOUS STRESS STRAIN CURVES FOR T81 SHEET AT 600F.

(8)

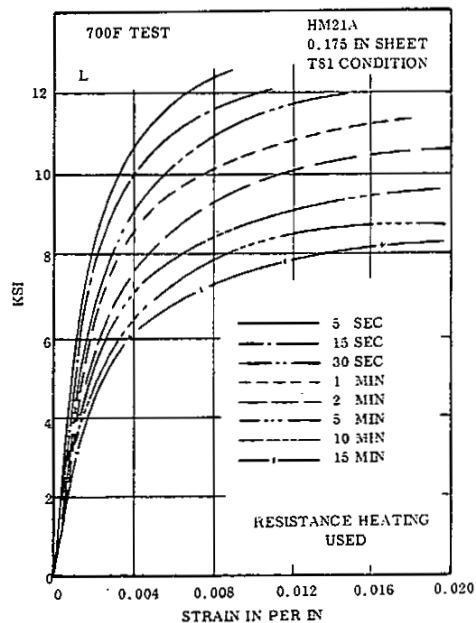


FIG. 3.0433 ISOCHRONOUS STRESS STRAIN CURVES FOR T81 SHEET AT 700F.

(8)

	Mg
2	Th
0.8	Mn

HM 21 A

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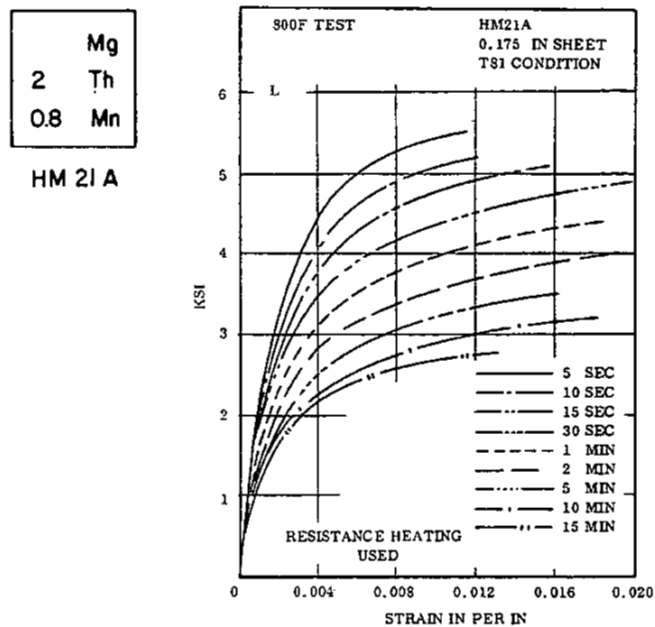


FIG. 3.034 ISOCHRONOUS STRESS STRAIN CURVES FOR
T81 SHEET AT 800F.

(8)

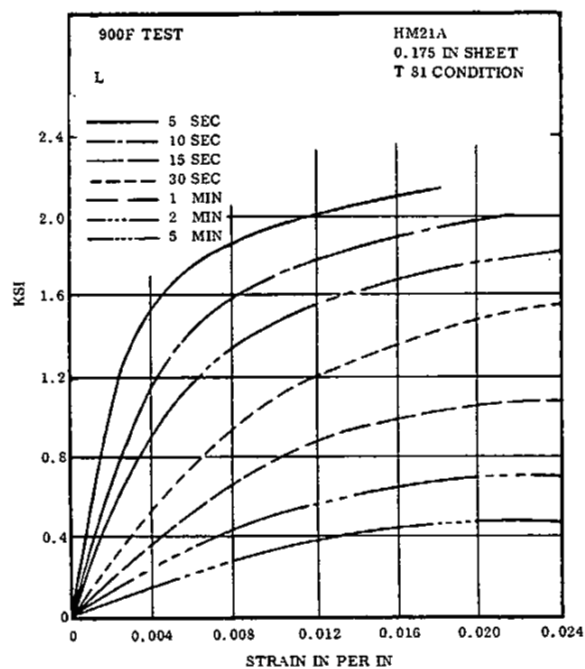


FIG. 3.0435 ISOCHRONOUS STRESS STRAIN CURVES FOR T81 SHEET
AT 900F.

(8)

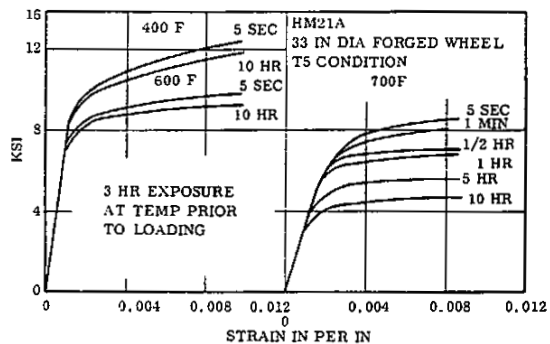


FIG. 3.0436 ISOCHRONOUS STRESS STRAIN CURVES FOR FORGINGS AT 400 TO 700F.

(10)

Mg
2 Th
0.8 Mn

HM 21 A

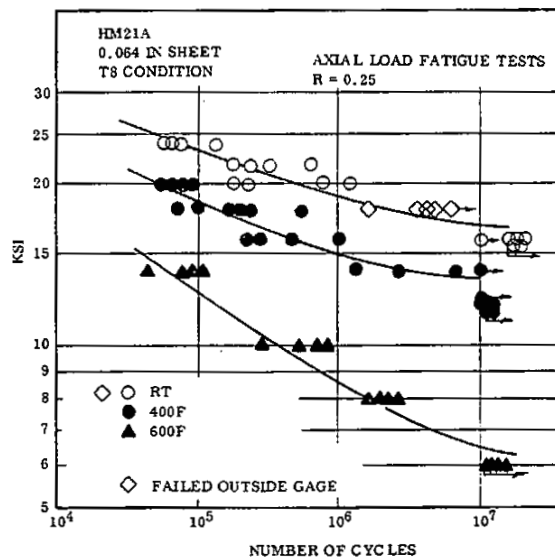


FIG. 3.051 S-N CURVES FOR SHEET TESTED AT ROOM TEMPERATURE, 400F AND 600F.

(1)

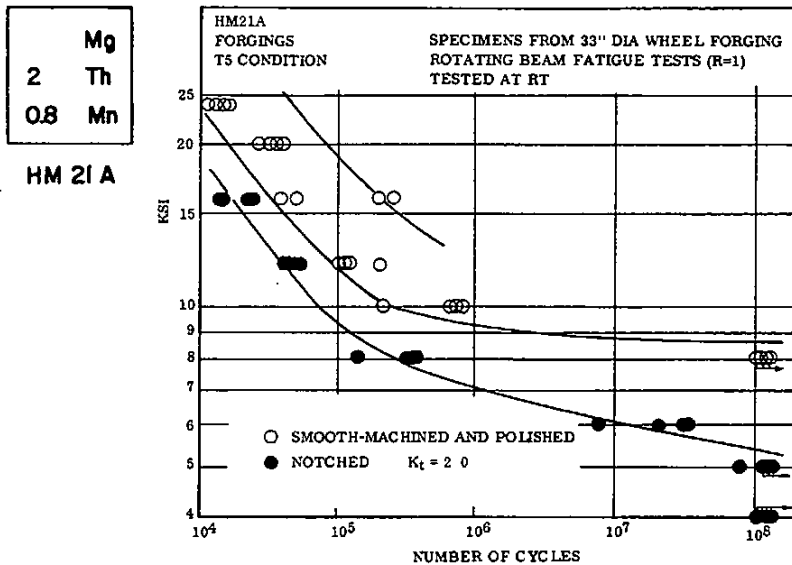


FIG. 3.052 S-N CURVES FOR SMOOTH AND NOTCHED SPECIMENS FROM FORGINGS TESTED AT ROOM TEMPERATURE.

(2)

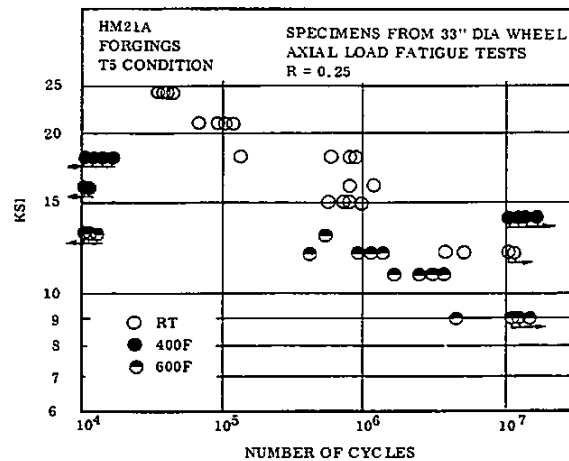


FIG. 3.053 S-N CURVES FOR SMOOTH SPECIMENS FROM FORGINGS TESTED AT ROOM TEMPERATURE, 400F AND 600F.

(2)

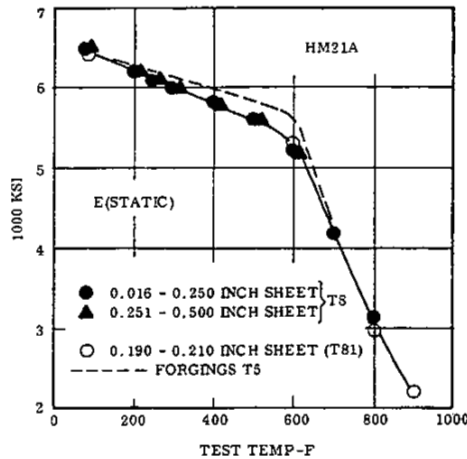


FIG. 3.0621 EFFECT OF TEST TEMPERATURE ON
MODULUS OF ELASTICITY.
(1)(2)(10)

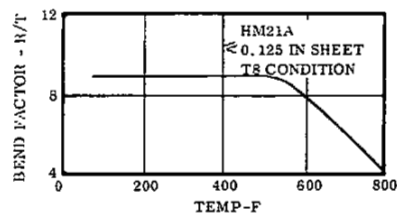


FIG. 4.014 SUGGESTED BEND FACTORS.
(10)

Mg
2 Th
0.8 Mn
HM 21 A

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2. The Dow Chemical Co., "Magnesium Forging Alloys for Elevated Temperature Service", (April 24, 1962)
3. Fenn, R.W. Jr., "Young's Modulus of Magnesium Alloys as a Function of Temperature and Metallurgical Variables", The Dow Chemical Co., (June 27, 1959)
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5. Department of Defense, "Index of Specifications and Standards", Part I, Alphabetical Listing, and Part II, Numerical Listing, (September 1964), Supplemented (March 31, 1965)
6. White, E. L. and Fink, F.W., "Corrosion Protection of Magnesium and Magnesium Alloys", DMIC Memorandum 205, Battelle Memorial Institute, (June 1, 1965)
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13. The Dow Chemical Co., "Shop Guide for Elevated Temperature Magnesium Alloys", Bulletin Number 141-204, (1960)
14. Brooks and Perkins, Inc., "Light Metals Data", (December 1962)
15. Alloy Digest, "Magnesium HM21A", Filing Code: Mg-46, Magnesium Alloy, Engineering Alloys Digest Inc., (April 1960)
16. Materials Engineering, Materials Selector Issue, Vol 66, No 5, (Mid-October 1967)

CODE 3504

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REVISED: SEPTEMBER 1971

NONFERROUS ALLOYS

AUTHOR: J. R. KATTUS

1. GENERAL
This heat treatable magnesium alloy is produced in the form of extrusions only. It is used primarily in the T5 condition (artificially aged), but is also sometimes used in the F condition (as extruded). At temperatures above 350 F, it has the highest strength - both short-time and long-time - of all magnesium extrusion alloys; at lower temperatures AZ80A-T5 and ZK60A-T5 are stronger. HM31A has good formability and excellent weldability. Its primary uses are in aerospace and missile applications that require strength in the range 350 to 800 F. Its corrosion resistance is similar to that of other magnesium alloys, surface coatings being needed for long-time protection.
- 1.01 Commercial Designation
HM31A
- 1.02 Alternate Designations
HM31XA (obsolete).
- 1.03 Specifications
AMS 4388B (F condition)
AMS 4389C (T5 condition)
MIL-M-8916A
- 1.04 Composition
Table 1.04.
- 1.05 Heat Treatment
1.051 T5 condition: Artificially age as extruded (F condition) at 415 to 435 F 16 hours, air cool (3).
1.052 O condition, full anneal: 850 F, 1 hour in furnace atmosphere containing 0.7 percent minimum SO₂ or 3 percent minimum CO₂, air cool (3).
1.053 Stress relief after forming and after welding: 800 F, 1 hour in furnace atmosphere containing 0.7 percent minimum SO₂ or 3 percent minimum CO₂, air cool (3).
- 1.06 Hardness
T5 condition: 63 Brinell hardness No. (4).
- 1.07 Forms and Conditions Available
Produced only in the form of extrusions mostly in the T5 condition (artificially aged) and to a limited extent in the F condition (as extruded). Forms in regular production are rod, bar, solid shapes, structural shapes, and precision extrusions. Tubing and other hollow and semi-hollow shapes can also be produced for special requirements (5).
- 1.08 Melting and Casting Practice
(see AZ31B, Code 3601, section 1.08)
- 1.09 Special Considerations
1.091 Exposures to temperatures through 600 F for periods of 1000 hours cause negligible change in short-time room and elevated temperature properties and cause very little drop in creep strength of HM31A-T5 (6).
1.092 Considerable data obtained on this alloy in the T5 condition show that both room and elevated temperature mechanical properties are sensitive to extrusion section size, strength decreasing with increasing size. This characteristic has not been thoroughly studied and documented in the F condition.
2. PHYSICAL AND CHEMICAL PROPERTIES
- 2.01 Thermal Properties
2.011 Melting range, 1121-1202 F (7).
2.012 Phase changes. In the as cast condition an unidentified compound forms a network at the grain boundaries. Mechanical working causes the network to break up, and high temperature treatment causes it to coalesce, but there is no metallographic evidence of solution and precipitation due to thermal treatments (8).
2.0121 Time-temperature-transformation diagrams.
2.013 Thermal conductivity, Figure 2.013.
- 2.014 Thermal expansion.
2.0141 Mean coefficient of thermal expansion from 68 to 392 F, 14.9×10^{-6} per F (5).
2.015 Specific heat, Figure 2.015.
2.016 Thermal diffusivity, Figure 2.016.
- 2.02 Other Physical Properties
2.021 Density, 0.0652 lb per cu in (7).
2.022 Electrical properties, Table 2.022.
2.023 Magnetic properties. Non-magnetic.
2.024 Emissance.
2.025 Damping capacity. At a stress equal to 0.1 F_{ty} the specific damping capacity of HM31A-F is 5.0, which is a medium level compared with other magnesium alloys (9).
- 2.03 Chemical Properties
2.031 Corrosion resistance.
2.0311 The galvanic and general corrosion characteristics of HM31A are similar to those of AZ31B, Code 3601, sections 2.0311 and 2.0312.
2.0312 The resistance of HM31A to stress corrosion is somewhat superior to that of AZ31B, Code 3601, section 2.0313.
2.032 Safety precautions should be directed to the prevention of fires, burns, and explosions (see HZ32A, Code 3408, section 2.032).
- 2.04 Nuclear Properties
2.041 Thorium is a radioactive metal. For comments on precautions required by this characteristic see HZ32A, Code 3408, sections 2.041 and 2.042.
2.042 The high nuclear cross section caused by the manganese content of this alloy make it unsuitable for applications where shielding is not wanted.
3. MECHANICAL PROPERTIES
- 3.01 Specified Mechanical Properties
Table 3.01.
- 3.02 Mechanical Properties at Room Temperature
3.021 Tension.
3.0211 Stress-strain diagrams (see Figures 3.03111, 3.03112, 3.03113).
3.0212 Tensile properties for T5 and F conditions, Table 3.0212.
3.0213 Effect of exposures at elevated temperatures on tensile properties at room temperature, Figure 3.0213.
3.022 Compression.
3.0221 Stress-strain diagrams (see Figure 3.03211 and 3.03212).
3.0222 Compressive strength for T5 and F conditions, Table 3.0222.
3.0223 Effect of exposures at elevated temperatures on compressive yield strength at room temperature, Figure 3.0223.
3.023 Impact (see Figure 3.0331).
3.024 Bending.
3.025 Torsion and shear.
3.0251 Shear strength of different section sizes, Table 3.0251.
3.026 Bearing.
3.0261 Bearing properties of different section sizes, Table 3.0261.
3.027 Stress concentration.
3.0271 Notch properties.
3.0272 Fracture toughness.
3.028 Combined properties.
- 3.03 Mechanical Properties at Various Temperatures
3.031 Tension.
3.0311 Stress-strain diagrams.
3.03111 Stress-strain curves at room and elevated temperatures for extrusions in T5 condition, Figure 3.03111.
3.03112 Stress-strain curves at room and elevated temperatures for extrusions in F condition, Figure 3.03112.
3.03113 Complete stress-strain curves at low temperatures for extrusions in F condition, Figure 3.03113.
3.0312 Effects of temperature on tensile properties, Figure 3.0312.

Mg
3 Th
1.5 Mn

HM31A

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3.0223 Effect of exposures at elevated temperatures on compressive yield strength at room temperature, Figure 3.0223.
3.023 Impact (see Figure 3.0331).
3.024 Bending.
3.025 Torsion and shear.
3.0251 Shear strength of different section sizes, Table 3.0251.
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3.0261 Bearing properties of different section sizes, Table 3.0261.
3.027 Stress concentration.
3.0271 Notch properties.
3.0272 Fracture toughness.
3.028 Combined properties.
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3.0311 Stress-strain diagrams.
3.03111 Stress-strain curves at room and elevated temperatures for extrusions in T5 condition, Figure 3.03111.
3.03112 Stress-strain curves at room and elevated temperatures for extrusions in F condition, Figure 3.03112.
3.03113 Complete stress-strain curves at low temperatures for extrusions in F condition, Figure 3.03113.
3.0312 Effects of temperature on tensile properties, Figure 3.0312.

	Mg
3	Th
1.5	Mn

HM31A

	Mg
3	Th
1.5	Mn

HM31A

- 3.0313 Elevated temperature tensile properties at various strain rates, Figure 3.0313.
 3.032 Compression.
 3.0321 Stress-strain diagrams.
 3.03211 Stress-strain curves in compression at room and elevated temperatures for extrusions in T5 condition, Figure 3.03211.
 3.03212 Stress-strain curves in compression at room and elevated temperatures for extrusions in F condition, Figure 3.03212.
 3.0322 Elevated temperature compressive yield strength of extrusions, Figure 3.0322.
 3.033 Impact.
 3.0331 Charpy V-notch impact properties at low temperatures, Figure 3.0331.
 3.034 Bending.
 3.035 Torsion and shear.
 3.0351 Effect of temperature on single-shear strength, Figure 3.0351.
 3.036 Bearing.
 3.0361 Effect of test temperature on bearing properties, Figure 3.0361.
 3.037 Stress concentration.
 3.0371 Notch properties.
 3.0372 Fracture toughness.
 3.038 Combined properties.

3.04 Creep and Creep Rupture Properties

- 3.041 Short-time isochronous stress-strain curves for extrusions in T5 condition after rapid heating to test temperatures of 500, 600, 700, and 800 F, Figure 3.041.
 3.042 Isochronous stress-strain curves for extrusions in F condition after 3 hours exposure at test temperatures of 500, 600, 700, and 800 F prior to loading, Figure 3.042.
 3.043 Isochronous stress-strain curves for extrusions in F condition after 3 hours exposure at test temperatures of 300 and 400 F prior to loading, Figure 3.043.
 3.044 Short-time isochronous stress-strain curves for extruded tubing in F condition after 5 seconds exposure at test temperatures of 500, 600, 700 and 800 F prior to loading, Figure 3.044.
 3.045 Effect of temperature on 100 hour creep strength for various extensions, Figure 3.045.

3.05 Fatigue Properties

- 3.051 Rotating beam fatigue properties, Figure 3.051.

3.06 Elastic Properties

- 3.061 Poisson's ratio, 0.35 (4)(5).
 3.062 Modulus of elasticity.
 3.0621 Effect of temperature on modulus of elasticity, Figure 3.0621.
 3.0622 Compressive tangent modulus curves at room and elevated temperatures, Figure 3.0622.
 3.0623 Compressive secant modulus curves at room and elevated temperatures, Figure 3.0623.
 3.063 Modulus of rigidity, 2.4×10^3 ksi (4).

4. FABRICATION4.01 Formability

- 4.011 HM31A can be formed by any of the processes commonly applied to extruded shapes. At room temperature the formability is limited, the minimum bend radius being about seven times the thickness. At the maximum recommended forming temperature of 800 F (1 hour maximum time at temperature), the formability is good, the minimum bend radius being 2.5 times the thickness. Stress relief in accordance with section 1.053 is recommended after severe forming operations (5)(13)(14).

4.02 Machining and Grinding

- 4.021 This alloy, like other magnesium alloys, has exceptionally good machinability, which enables it to be machined at high speeds and feeds. For further details, see HZ32A, Code 3408, sections 4.021 and 4.022.
 4.022 The alloy can be chem-milled with sulfuric, nitric, or hydrochloric acid of 5 percent strength or greater (15).

4.03 Welding

- 4.031 HM31A has excellent weldability by arc and electric-resistance methods. For arc welding EZ33A magnesium alloy filler metal is generally used except when joining to an aluminum containing magnesium alloy, in which instances AZ92A or AZ61A are suitable filler alloys. Stress relief in accordance with section 1.053 is recommended after welding. For further details see AZ31B, Code 3601, section 4.031(5)(17).
 4.032 Effect of temperature on tensile properties of extrusions, both unwelded and with transverse butt welds made by inert-gas-shielded tungsten-arc process, Figure 4.032.

4.04 Surface Treatment

- 4.041 The extrusions are normally oiled by the producer with a light corrosion inhibiting oil for protection during shipment and storage (1)(2).
 4.042 For a discussion of the various surface treatments that can be applied for corrosion protection, see HZ32A, Code 3408, sections 4.042 and 4.043.

TABLE 1.04

Alloy	HM31A	
Source	(1)(2)	
Element	Percent	
	Minimum	Maximum
Thorium	2.5	3.5
Manganese	1.2	-
Impurities, each	-	0.1
Impurities, total	-	0.3
Magnesium	Balance	

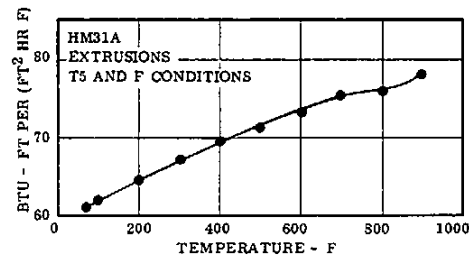


FIG. 2.013 THERMAL CONDUCTIVITY. (5)(7)

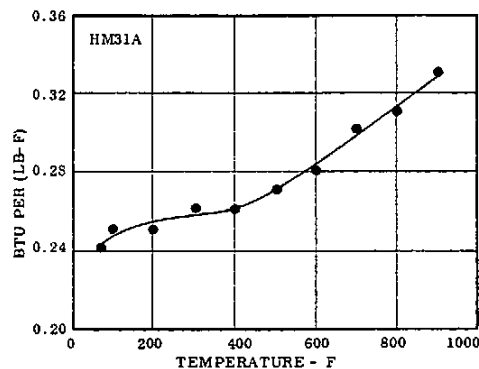


FIG. 2.015 SPECIFIC HEAT. (5)

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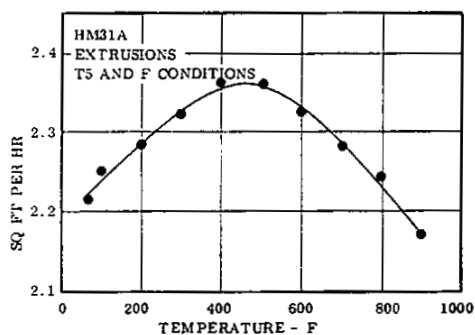


FIG. 2.016 THERMAL DIFFUSIVITY.

(5)(7)

TABLE 2.022						
Alloy	HM31A					
Source	(5)(7)					
Condition	Electrical Conductivity				Electrical Resistivity	
	percent IACS		megmhos per in ³		microhm - in	
Temp- F	F	TS	F	TS	F	TS
63	26.2	30.4	0.384	0.446	2.60	2.24
100	24.7	28.8	0.363	0.424	2.76	2.36
200	21.8	24.7	0.321	0.364	3.12	2.75
300	19.6	21.5	0.289	0.316	3.46	3.16
400	17.8	19.3	0.262	0.285	3.82	3.50
500	16.3	17.6	0.240	0.259	4.17	3.86

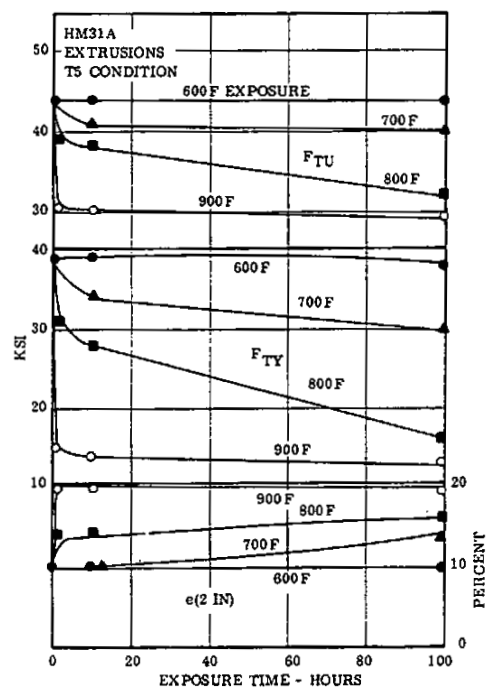


FIG. 3.0213 EFFECT OF EXPOSURES AT ELEVATED TEMPERATURES ON TENSILE PROPERTIES AT ROOM TEMPERATURE.

(5)

TABLE 3.01					
Alloy	HM31A				
Form	Extrusions				
Size	4 square inches, maximum cross section				
Condition	Source	F _{tu} - ksi min	F _{ty} - ksi min	e(2 in) min	F _{cy} * - ksi min
TS	(2)	37.0	26.0	4	19.0
F	(1)	37.0	26.0	4	-

* Compression specimens oriented in longitudinal direction.
Orientation of tensile specimens not specified.

TABLE 3.0212				
Alloy	HM31A			
Form	Extrusions			
Size	4 square inches, maximum cross section			
Condition	Source	F _{tu} - ksi	F _{ty} - ksi	e(2 in)
TS	(5)	44	39	10
F	(10)	42	33	10

TABLE 3.0222			
Alloy	HM31A		
Form	Extrusions		
Condition	Cross section sq in	Source	F _{cy} ksi
TS	1.000 max	(5)	27
TS	1.000-3.999	(5)	23
F	4.000 max	(10)	27

CODE 3505

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	Mg
3	Th
1.5	Mn

HM31A

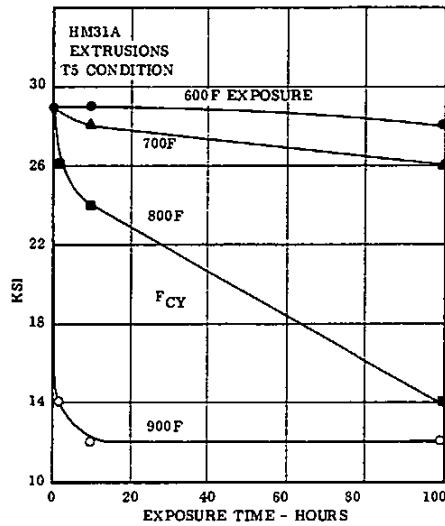


FIG. 3.0223 EFFECT OF EXPOSURES AT ELEVATED TEMPERATURES ON COMPRESSIVE YIELD STRENGTH AT ROOM TEMPERATURE. (5)

TABLE 3.0251

Alloy	HM31A
Condition	T5
Form	Extrusions
Source	(5)
Cross section, sq in	F_{su} - ksi
1.000 maximum	27
1.000-3.999	22

TABLE 3.0261

Alloy	HM31A	
Condition	T5	
Form	Extrusions	
Source	(5)	
Cross section, sq in	$F_{bru}^* - \text{ksi}$	$F_{bry}^* - \text{ksi}$
1.000 maximum	68	48
1.00-3.999	58	42
* $e/D = 2.5$		

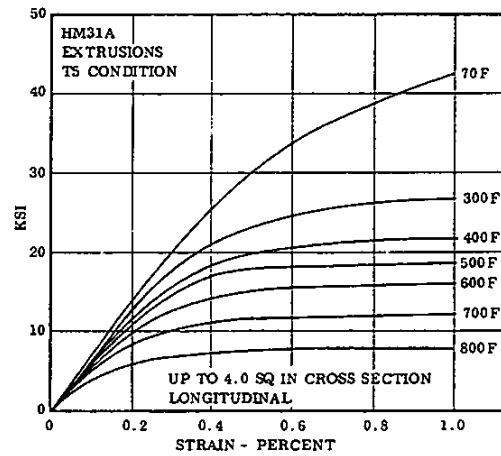


FIG. 3.03111 STRESS-STRAIN CURVES AT ROOM AND ELEVATED TEMPERATURES FOR EXTRUSIONS IN T5 CONDITION. (5)

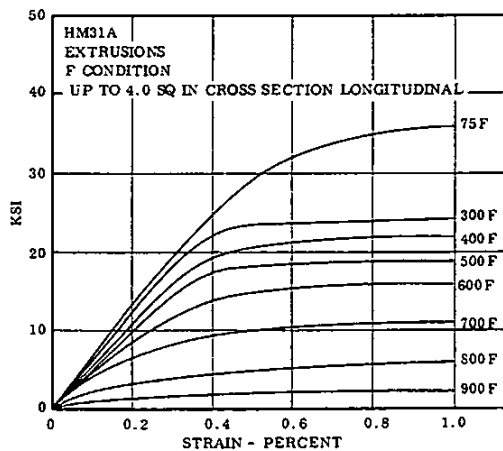


FIG. 3.03112 STRESS-STRAIN CURVES AT ROOM AND ELEVATED TEMPERATURES FOR EXTRUSIONS IN F CONDITION. (6)

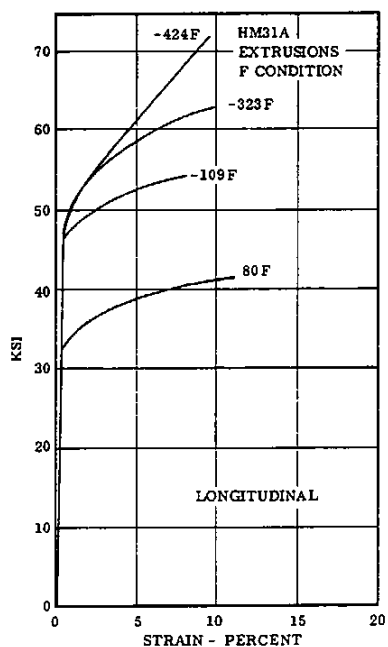


FIG. 3.03113 COMPLETE STRESS-STRAIN CURVES AT LOW TEMPERATURES FOR EXTRUSIONS IN F CONDITION. (11)

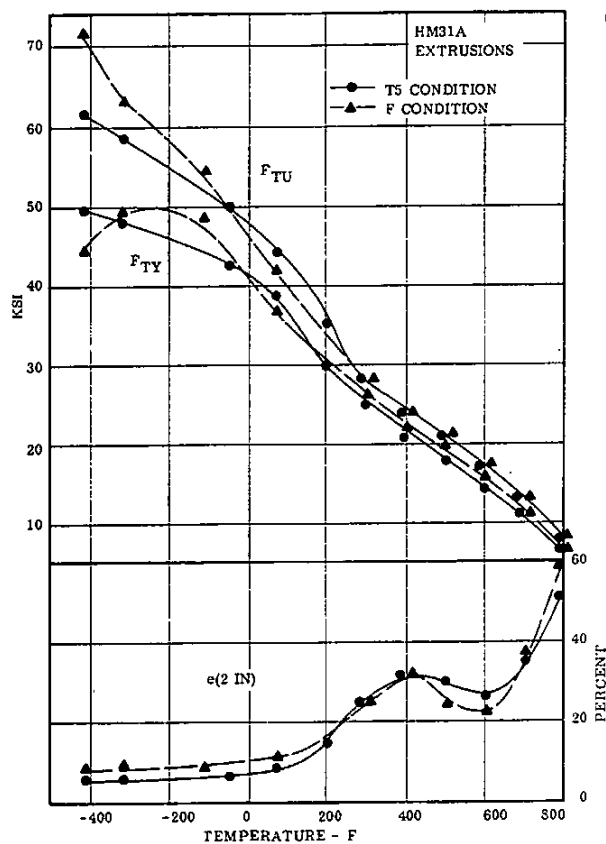


FIG. 3.0312 EFFECTS OF TEMPERATURE ON TENSILE PROPERTIES. (5)(11)(18)(19)

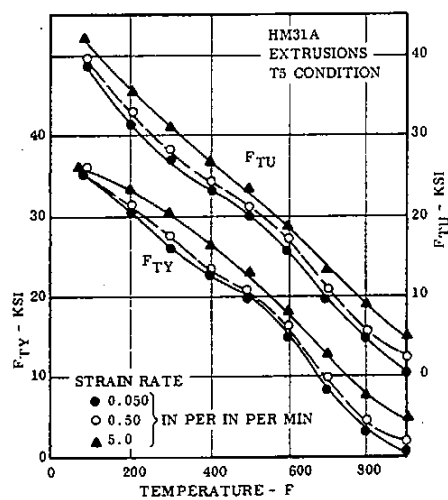


FIG. 3.0313 ELEVATED TEMPERATURE TENSILE PROPERTIES AT VARIOUS STRAIN RATES. (5)

Mg
3 Th
1.5 Mn

HM31A

	Mg
3	Th
1.5	Mn

HM31A

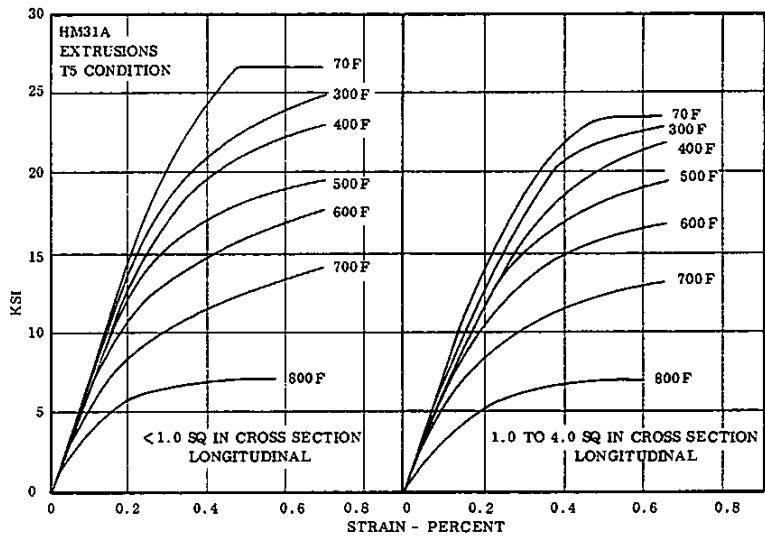


FIG. 3.03211 STRESS-STRAIN CURVES IN COMPRESSION AT ROOM AND ELEVATED TEMPERATURES FOR EXTRUSIONS IN T5 CONDITION. (5)

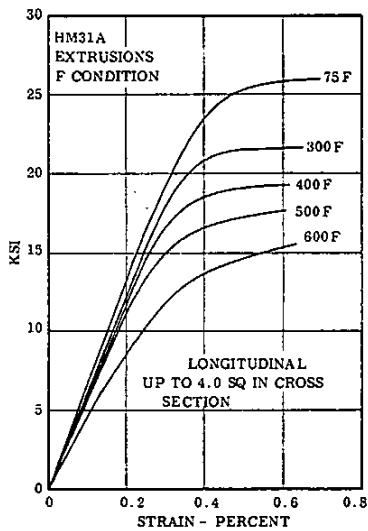


FIG. 3.03212 STRESS-STRAIN CURVES IN COMPRESSION AT ROOM AND ELEVATED TEMPERATURES FOR EXTRUSIONS IN F CONDITION. (6)

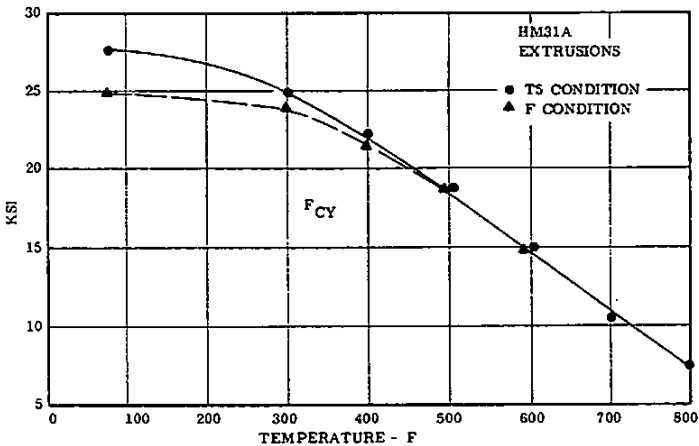


FIG. 3.0322 ELEVATED TEMPERATURE COMPRESSIVE YIELD STRENGTH OF EXTRUSIONS. (5)(6)

	Mg
3	Th
1.5	Mn

HM31A

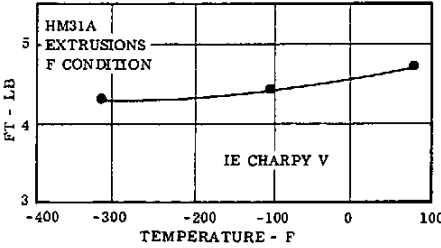


FIG. 3.0331 CHARPY V-NOTCH IMPACT PROPERTIES AT LOW TEMPERATURES. (11)

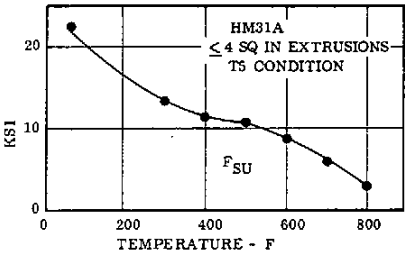


FIG. 3.0351 EFFECT OF TEMPERATURE ON SINGLE SHEAR STRENGTH. (6)

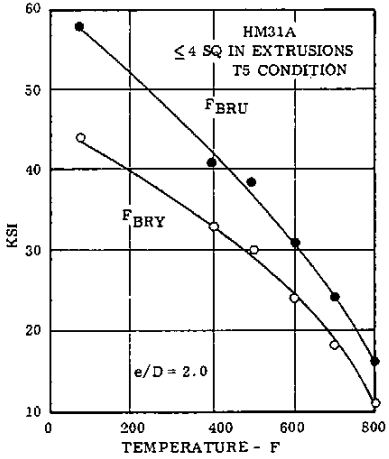


FIG. 3.0361 EFFECT OF TEMPERATURE ON BEARING PROPERTIES. (6)

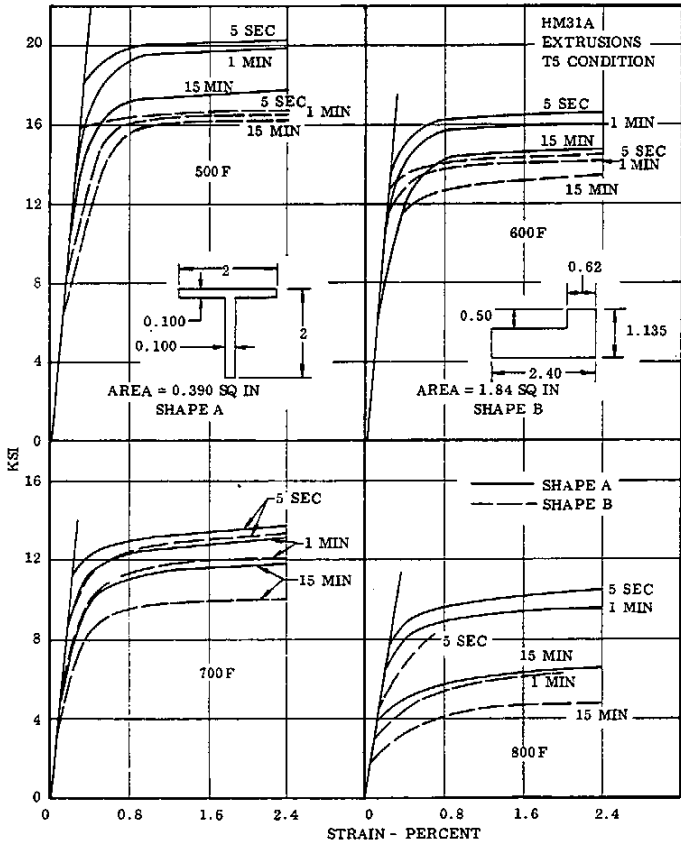


FIG. 3.041 SHORT-TIME ISOCHRONOUS STRESS-STRAIN CURVES FOR EXTRUSIONS IN T5 CONDITION AFTER RAPID HEATING TO TEST TEMPERATURES OF 500, 600, 700, AND 800 F. (5)

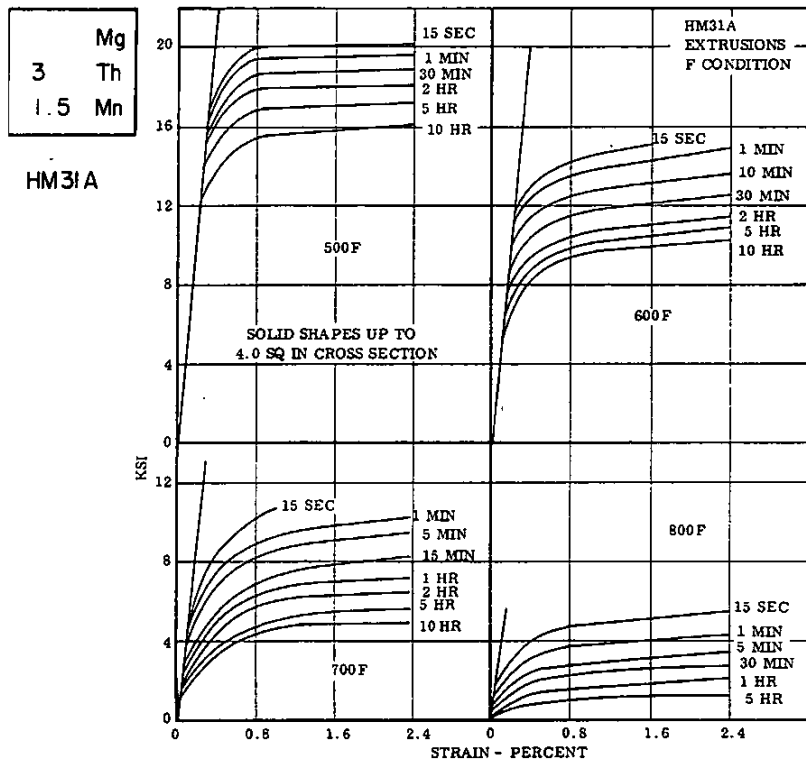


FIG. 3.042 ISOCHRONOUS STRESS-STRAIN CURVES FOR EXTRUSIONS IN F CONDITION AFTER 3 HOURS EXPOSURE AT TEST TEMPERATURES OF 500, 600, 700, AND 800 F PRIOR TO LOADING.

(6)

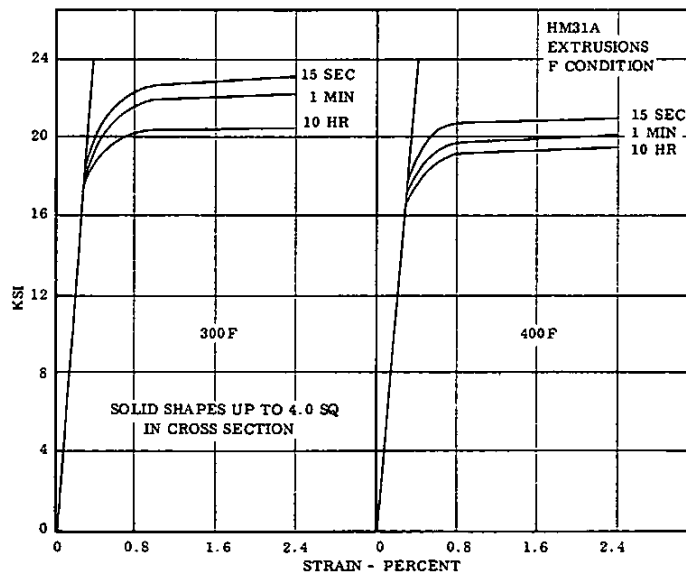


FIG. 3.043 ISOCHRONOUS STRESS-STRAIN CURVES FOR EXTRUSIONS IN F CONDITION AFTER 3 HOURS EXPOSURE AT TEST TEMPERATURES OF 300 AND 400 F PRIOR TO LOADING.

(6)

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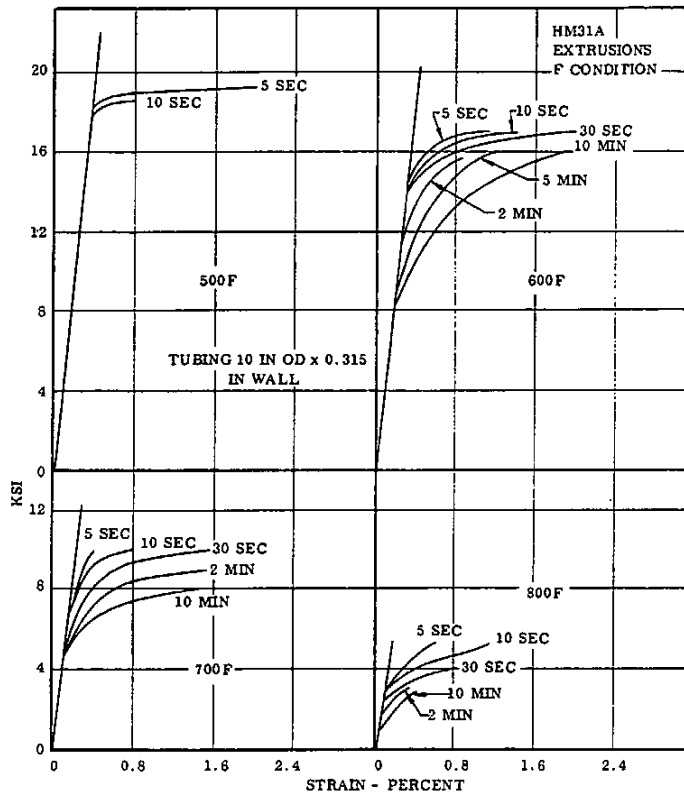


FIG. 3.044 SHORT-TIME ISOCHRONOUS STRESS-STRAIN CURVES FOR EXTRUDED TUBING IN F CONDITION AFTER 5 SECONDS EXPOSURE AT TEST TEMPERATURES OF 500, 600, 700, AND 800 F PRIOR TO LOADING. (6)

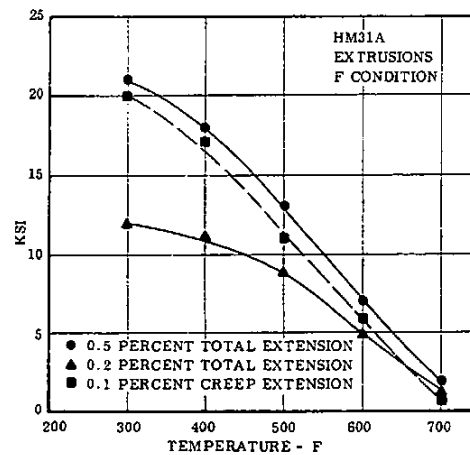


FIG. 3.045 EFFECT OF TEMPERATURE ON 100 HOUR CREEP STRENGTH FOR VARIOUS EXTENSIONS. (6)

	Mg
3	Th
1.5	Mn

HM31A

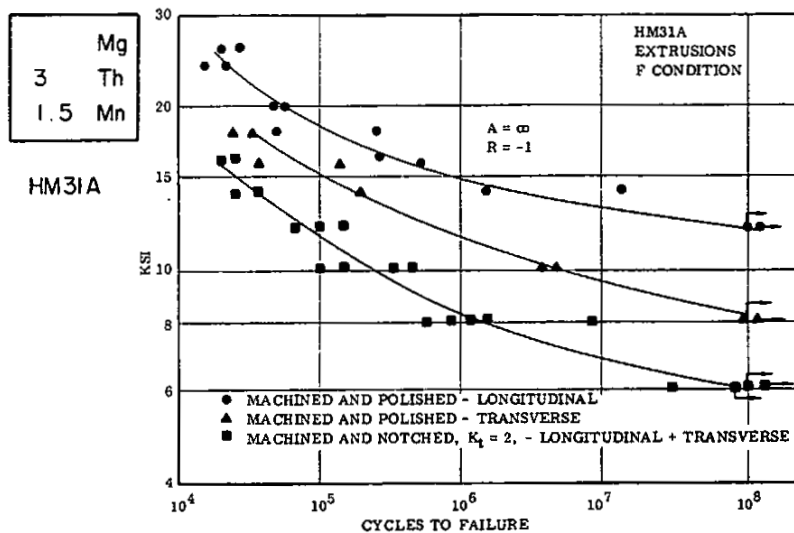


FIG. 3.051 ROTATING BEAM FATIGUE PROPERTIES.

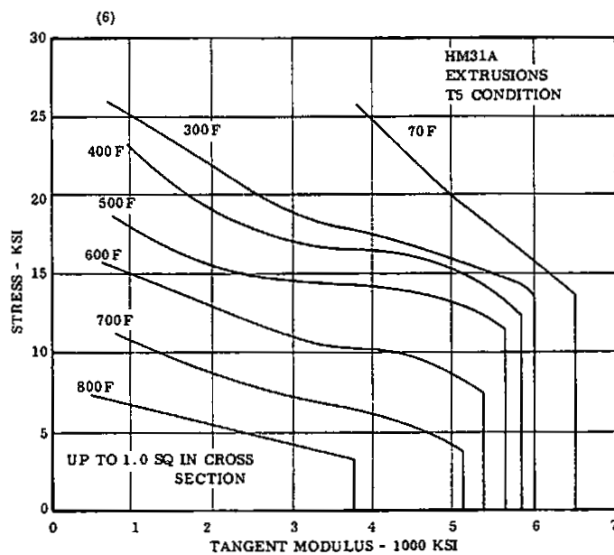


FIG. 3.0622 COMPRESSIVE TANGENT MODULUS CURVES AT ROOM AND ELEVATED TEMPERATURES. (5)

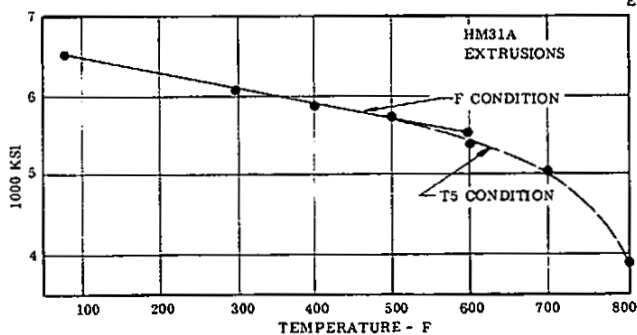


FIG. 3.0621 EFFECT OF TEMPERATURE ON MODULUS OF ELASTICITY. (5)(12)

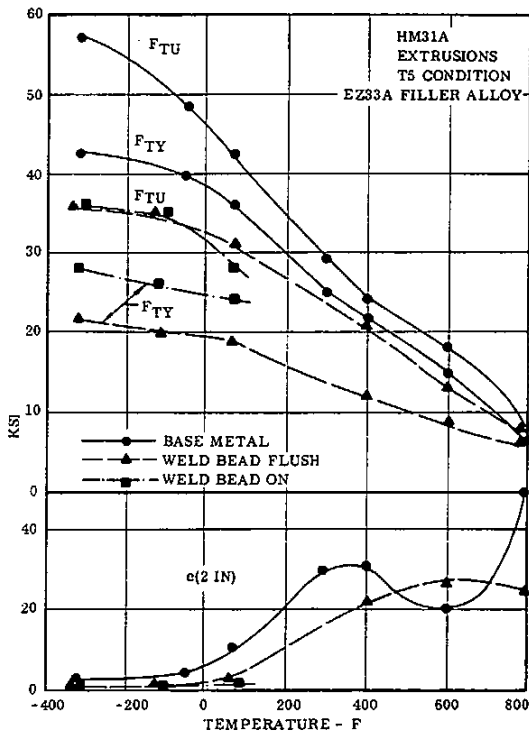


FIG. 4.032 EFFECT OF TEMPERATURE ON TENSILE PROPERTIES OF EXTRUSIONS, BOTH UNWELDED AND WITH TRANSVERSE BUTT WELDS MADE BY INERT-GAS-SHIELDED TUNGSTEN-ARC PROCESS. (5)(6)(16)

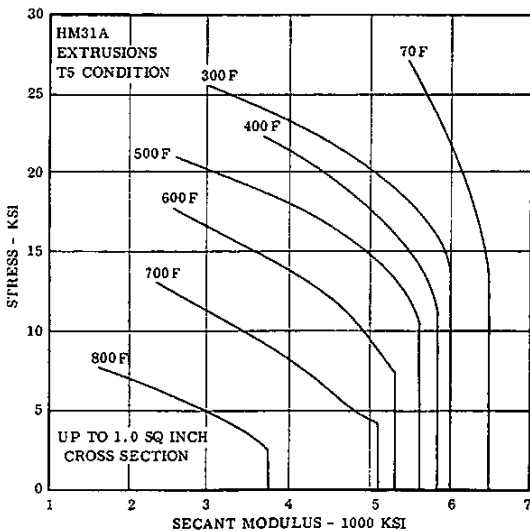


FIG. 3.0623 COMPRESSIVE SECANT-MODULUS CURVES AT ROOM AND ELEVATED TEMPERATURES. (5)

	Mg
3	Th
1.5	Mn

HM31A

REFERENCES

1. AMS 4385B, HM31A-F (May 1, 1968).
2. AMS 4389C, HM31A-T5 (May 1, 1968).
3. "Heat Treatment of Magnesium Alloys," ASM Metals Handbook, Volume 2, 8th Edition (1964) pp. 292-297.
4. "Design it with Magnesium Mill Products," Form No. 141-233-70, Dow Chemical Company, Midland, Michigan (1970).
5. "Magnesium in Design," Form No. 141-213-67, Dow Chemical Company, Midland, Michigan (1967).
6. "HM31XA Magnesium Alloy Extrusions," Bulletin No. 141-199, Dow Chemical Company, Midland, Michigan.
7. "Physical Properties of Magnesium and Magnesium Alloys," Code 2.51, Dow Chemical Company, Midland, Michigan (1967).
8. Leontis, T. E., "Properties of Magnesium-Thorium and Magnesium-Thorium-Cerium Alloys," Jr of Metals, Volume 4, (1952) pp. 287-294.
9. Jensen, J. W., "Damping Capacity - Cause and Effects," Light Metal Age, Volume 22 (December 1964) pp. 4-8.
10. "Shop Guide for Elevated Temperature Magnesium Alloys," Bulletin No. 141-204, Dow Chemical Company, Midland, Michigan (March 1959).
11. Reed, R. P., Mikesell, R. P. and Greeson, R. L., "Some Mechanical Properties of Magnesium Alloys at Low Temperature," ASTM STP 287, pp. 61-73 (1961).
12. Fenn, R. W. Jr., "Young's Modulus of Magnesium Alloys as a Function of Temperature and Metallurgical Variables," ASTM Proceeding, Volume 58, (1958) pp. 826-837.
13. "Forming Magnesium, Part 1," Form No. 141-305-65, Dow Chemical Company, Midland, Michigan (1965).
14. "Forming Magnesium, Part 3," Form No. 141-307-66, Dow Chemical Company, Midland, Michigan (1966).
15. "Design" Magnesium Electron Ltd., 1270 Avenue of the Americas, New York, New York 10020.
16. "Low Temperature Properties of Various Magnesium Alloys," Dow Chemical Company, Midland, Michigan (1958).
17. "Arc Welding Magnesium," Form 141-300-67, Dow Chemical Company, Midland, Michigan (1967).
18. Vorhees, H. R. and Freeman, J. W., "Elevated Temperature Properties of Aluminum and Magnesium Alloys," ASTM STP 291 (1960).
19. Hollowell, J. B. and Ogden, H. R., "An Introduction to Magnesium Alloys," DMIC Report 206, (August 26, 1964).

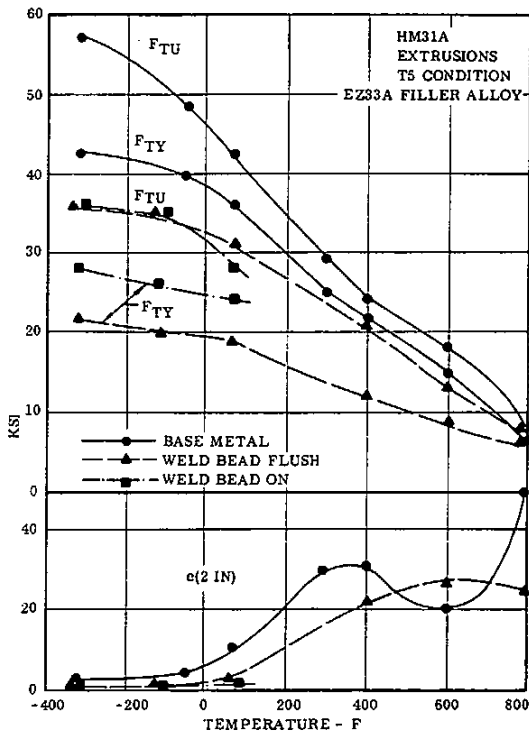


FIG. 4.032 EFFECT OF TEMPERATURE ON TENSILE PROPERTIES OF EXTRUSIONS, BOTH UNWELDED AND WITH TRANSVERSE BUTT WELDS MADE BY INERT-GAS-SHIELDED TUNGSTEN-ARC PROCESS. (5)(6)(16)

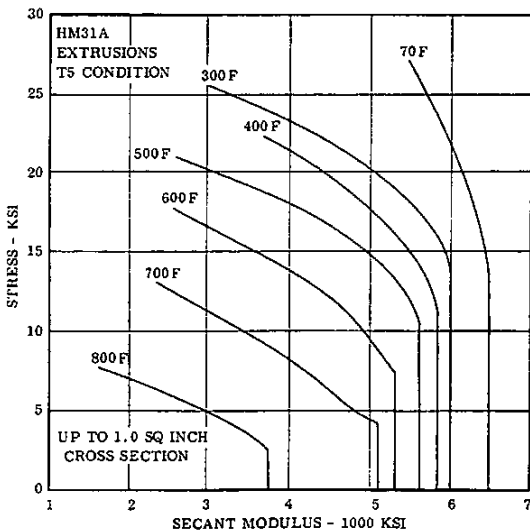


FIG. 3.0623 COMPRESSIVE SECANT-MODULUS CURVES AT ROOM AND ELEVATED TEMPERATURES. (5)

	Mg
3	Th
1.5	Mn

HM31A

REFERENCES

1. AMS 4385B, HM31A-F (May 1, 1968).
2. AMS 4389C, HM31A-T5 (May 1, 1968).
3. "Heat Treatment of Magnesium Alloys," ASM Metals Handbook, Volume 2, 8th Edition (1964) pp. 292-297.
4. "Design it with Magnesium Mill Products," Form No. 141-233-70, Dow Chemical Company, Midland, Michigan (1970).
5. "Magnesium in Design," Form No. 141-213-67, Dow Chemical Company, Midland, Michigan (1967).
6. "HM31XA Magnesium Alloy Extrusions," Bulletin No. 141-199, Dow Chemical Company, Midland, Michigan.
7. "Physical Properties of Magnesium and Magnesium Alloys," Code 2.51, Dow Chemical Company, Midland, Michigan (1967).
8. Leontis, T. E., "Properties of Magnesium-Thorium and Magnesium-Thorium-Cerium Alloys," Jr of Metals, Volume 4, (1952) pp. 287-294.
9. Jensen, J. W., "Damping Capacity - Cause and Effects," Light Metal Age, Volume 22 (December 1964) pp. 4-8.
10. "Shop Guide for Elevated Temperature Magnesium Alloys," Bulletin No. 141-204, Dow Chemical Company, Midland, Michigan (March 1959).
11. Reed, R. P., Mikesell, R. P. and Greeson, R. L., "Some Mechanical Properties of Magnesium Alloys at Low Temperature," ASTM STP 287, pp. 61-73 (1961).
12. Fenn, R. W. Jr., "Young's Modulus of Magnesium Alloys as a Function of Temperature and Metallurgical Variables," ASTM Proceeding, Volume 58, (1958) pp. 826-837.
13. "Forming Magnesium, Part 1," Form No. 141-305-65, Dow Chemical Company, Midland, Michigan (1965).
14. "Forming Magnesium, Part 3," Form No. 141-307-66, Dow Chemical Company, Midland, Michigan (1966).
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16. "Low Temperature Properties of Various Magnesium Alloys," Dow Chemical Company, Midland, Michigan (1958).
17. "Arc Welding Magnesium," Form 141-300-67, Dow Chemical Company, Midland, Michigan (1967).
18. Vorhees, H. R. and Freeman, J. W., "Elevated Temperature Properties of Aluminum and Magnesium Alloys," ASTM STP 291 (1960).
19. Hollowell, J. B. and Ogden, H. R., "An Introduction to Magnesium Alloys," DMIC Report 206, (August 26, 1964).

REVISED: DECEMBER 1969
AUTHOR: J. R. KATTUS

NONFERROUS ALLOYS

1.

GENERAL

HZ32A, which is a magnesium-base casting alloy used in the artificially aged (T5) condition, has reasonably good foundry characteristics and medium room temperature mechanical properties similar to those of HK31A. The relatively high thorium content (3.2 percent) in these two alloys gives them outstanding elevated temperature strength among the magnesium casting alloys. The addition of 2.1 percent zinc to HZ31A to produce HZ32A results in optimum creep resistance at temperatures of 500F and above, whereas HZ31A is somewhat superior at lower temperatures. HZ32A exhibits excellent long time stability at elevated temperatures, exposures of at least 1000 hours at 600F having no detrimental effect on room temperature mechanical properties. It has excellent machinability and reasonably good weldability. For long time use or even short time use under severe corrosive conditions, chemical treatment followed by painting is recommended. HZ32A-T5 should be considered for use in aerospace or any other applications where the prime requirement is a high strength-to-weight ratio primarily in the temperature range of 500 to 650F.

1.01

Commercial Designation
HZ32A

1.02

Alternate Designations
HZ32XA, ZT1 (British)

1.03

Specifications
AMS 4447B
ASTM B80-68
U. S. Federal QQ-M-56b (1)
U. S. Federal QQ-M-55b

1.04

Composition
Table 1.04.

TABLE 1.04

Alloy	HZ32A			
	Composition			
	AMS 4447B (20)		ASTM B80-68	
	Percent		Percent	
Source	Minimum	Maximum	Minimum	Maximum
Zinc	1.7	2.5	1.7	2.5
Thorium	2.5	4.0	2.5	4.0
Zirconium				
total	0.50	1.0	0.50	1.0
soluble*	0.50	-	-	-
Copper	-	0.10	-	0.10
Rare Earths	-	0.10	-	0.10
Nickel	-	0.01	-	0.01
Others	-	0.20	-	0.30
Magnesium	Balance		Balance	

* Soluble zirconium is that portion of the zirconium that is soluble in 1:4 hydrochloric acid held below its boiling point.

1.05

Heat Treatment

Cast plus artificially aged (T5) at 600F for 16 hours (1)(2).

1.06

Hardness

1.061

BHN 50-75 with 1000 kg load and 10 mm ball (AMS 4447B).

1.062

BHN 45-70 with 500 kg load and 10mm ball or 1000 kg load and 9/16 inch ball (AMS 4447B).

1.07

Forms and Conditions Available

Produced as castings and used in the T5 (artificially aged) condition.

1.08

Melting and Casting Practice

Melting practice for magnesium alloys containing zirconium is somewhat different from practices used for the alloys containing aluminum. A cast or fabricated and welded steel crucible is normally used for both melting and pouring, since transfer from a melting to a pouring crucible results in zirconium losses. Melting is carried out in gas- or oil-fired furnaces. The magnesium

is brought to a temperature of 1450 to 1500F for alloying under a crucible-flux cover, which normally consists of magnesium chloride with other chlorides and fluorides. This type of flux first melts to form a liquid cover; but after some time at 1400F or above, it gradually becomes more viscous and finally forms a dry scaly crust. Alloying additions are made by immersing them below the melt surface on a steel ladle and gently agitating. Metallic zinc, which is subject to little or no melting loss, is added first. Thorium is then introduced, as pellets made from compacted and sintered thorium powder or as a magnesium-thorium hardener alloy. As thorium oxidizes readily, care must be taken to avoid raising it to a high temperature in air. (Considerable loss of thorium occurs, which must be determined by experience for different foundry conditions.) Finally, zirconium is added in the form of a magnesium-zirconium hardener alloy containing 30 to 50 percent zirconium or in the form of zirconium fluoride or chloride in a fused-salt mixture. Because of the low solubility of zirconium, it is necessary to add about 3 to 5 times the required percentage. After the alloying additions have been made, the melt should be thoroughly stirred and skimmed, covered with additional crucible flux, and held for 20 minutes before pouring to allow separation of the flux from the metal and to allow undissolved zirconium to settle. The flux is skimmed from the surface just before pouring, and burning is prevented during pouring by dusting the melt surface with a mixture of sulfur and boric acid or a proprietary preparation. The metal is poured between 1350 and 1550F, depending upon the section size of the casting. A heel 2 to 3 inches deep should be left in the crucible to minimize the possibility of pouring into the mold a residue consisting of zirconium containing sludge and flux (2).

1.09

Special Considerations

1.091

HZ32A-T5 tends to shrink slightly with increasing exposure times at elevated temperatures.

1.092

Shrinkage due to exposures at elevated temperatures, Figure 1.092

1.093

Contaminations with more than 0.005 percent aluminum should be avoided because aluminum forms undesirable intermetallic compounds with zirconium (5).

1.094

The presence of 0.1 percent or more rare-earth metals causes loss in creep resistance (5).

2.

PHYSICAL AND CHEMICAL PROPERTIES

2.01

Thermal Properties

2.011

Melting range, 1026-1198F (2).

2.012

Phase changes. Magnesium-thorium-zinc compounds in acicular shape, which enhance creep resistance, form at the grain boundaries during artificial aging (4).

2.0121

Time-temperature-transformation diagrams.

2.013

Thermal conductivity, 63.2 Btu ft per (hr sq ft F) at 68F (2)(5).

2.014

Thermal expansion, 14.8×10^{-6} per °F from 68 to 392F (5)(6).

2.015

Specific heat, 0.23 Btu per (lb F) from 68 to 392F (5)(6).

2.016

Thermal diffusivity.

2.02

Other Physical Properties

2.021

Density, 1.83 g/cc (2)(5). 0.0657 lb/cu in (6).

2.022

Electrical properties.

2.0221

Electrical conductivity, 0.35 megmhos/inch³ at 68F (6). 26.5 percent IACS at 68F (5).

2.0222

Electrical resistivity, 2.56 microhm - inch at 68F (5).

2.023

Magnetic properties.

2.024

Emittance.

2.025

Damping capacity. At a stress equal to 0.1 F_{ty} the specific damping capacity is 5, which is an intermediate level compared with other magnesium alloys (7).

2.03

Chemical Properties

2.031

HZ32A is subject to general and pitting-type corrosion when exposed to most natural environments. When properly surface treated and painted, it will perform satisfactorily in all of these environments except immersed in

	Mg
3.2	Th
2.1	Zn
0.7	Zr

HZ32A

CODE 3408

PAGE 1

Mg
3.2 Th
2.1 Zn
0.7 Zr

HZ32A

2.032

water (19). For a discussion of galvanic corrosion, see AZ31B, Code 3601, Section 2.0312.

Safety precautions should be directed to the prevention of fires, burns, and explosions. The hazards of the molten metal coming into contact with moisture or water are similar to those of other magnesium alloys and greater than with other metals, since molten magnesium reacts violently with water. The ignition point of HZ32A in air, as for other magnesium alloys, is 800F or above. The ease of combustion depends upon the size and shape of the material. Finely divided material, such as dust and powders, ignite readily and may explode when mixed with air. Machining and sawing operations generate particles that are generally too large to form an explosive mixture. The fire hazard is less than with powder, but shavings burn readily once they are heated above the ignition point. Large sections burn only after prolonged heating. Graphite powder, sodium-chloride base salts, and cast iron chips are the recommended materials for extinguishing fires. Wet dust collector systems conforming to NFPA Bulletin No. 48 (21) are recommended for grinding and welding operations. During heat treatment, a minimum of one percent sulfur dioxide or three percent carbon dioxide should be maintained in the furnace atmosphere to minimize the possibility of fire (1)(2)(3).

2.04

2.041

Nuclear Properties

Thorium is a radioactive metal, but at the concentration in this alloy it constitutes little or no hazard in normal storage, handling, and use. Since the fumes given off during melting and welding are slightly radioactive, adequate ventilation should be provided. Thorium-magnesium hardener alloys and thorium pellets used in the manufacture of HZ32A, as well as sludge left from melting operations, are radioactive and should be handled in accordance with the regulations of the Atomic Energy Commission or local codes, whichever are stricter (2).

2.042 No interference in the sending or receiving of radio or radar signals is caused by the slight radioactivity of the alloy (8).

3. MECHANICAL PROPERTIES

3.01 Specified Mechanical Properties
Table 3.01.

TABLE 3.01

Alloy		HZ32A					
Form		Sand-Cast					
Condition		T5					
Specification		AMS 4447B (20)			ASTM B30-68		
Specimen	Temp F	F _{tu} min ksi	F _{ty} min ksi	e(2 in) min	F _{tu} min ksi	F _{ty} min ksi	e(2 in) min
Cut from casting							
single	75.0	-	10.5	-	19.0	10.5	-
average of 4 or more	75.0	23.0	11.7	2.0	23.0	11.7	1.0
single	500.0	-	-	-	10.0	6.0	-
Separately cast	75.0	27.0	13.0	4.0	27.0	13.0	4.0

3.02 Mechanical Properties at Room Temperature

3.021 Tension, typical: F_{tu} = 30.0 ksi, F_{ty} = 14.0 ksi, and e(2 inches) = 7 percent (2)(3)(5).

3.0211 Stress-strain diagrams (see Figure 3.0311)

3.0212 Effect of end chill on tensile properties of cast plates of two thicknesses, Figure 3.0212.

3.0213 Effect of elevated-temperature exposure on tensile strength, Table 3.0213.

TABLE 3.0213

Source		(10)
Alloy		HZ32A
Form		Sand Castings
Condition		T5
Exposure		F _{tu} , ksi
None		29.0
1000 hours at 400F		32.0
1000 hours at 500F		34.0

3.022 Compression, typical F_{cy} = 14.0 ksi (10).

3.0221 Stress-strain diagrams.

3.023 Impact.

3.024 Bending.

3.025 Torsion and shear.

3.0251 Typical shear, F_{su} = 20.0 ksi (10).

3.026 Bearing, typical for separately sand-cast specimens with e/D=2.5: F_{bru} = 60.0 ksi, F_{bry} = 37.0 ksi (3)(10).

3.027 Stress concentration.

3.0271 Notch properties.

3.0273 Fracture toughness.

3.028 Combined properties.

3.03 Mechanical Properties at Various Temperatures

3.031 Tension.

3.0311 Stress-strain diagrams.

3.03111 Tensile stress-strain curves, Figure 3.03111.

3.0312 Effect of elevated temperatures on tensile properties, Figure 3.0312.

3.0313 Effect of variations in strain rate on tensile properties at different temperatures, Figure 3.0313.

3.032 Compression.

3.0321 Stress-strain diagrams.

3.033 Impact.

3.034 Bending.

3.035 Torsion and shear.

3.036 Bearing.

3.037 Stress concentration.

3.0371 Notch properties.

3.0372 Fracture toughness.

3.038 Combined properties.

3.04 Creep and Creep Rupture Properties

3.041 Effect of temperature and stress on the time to 0.1 percent creep extension, Figure 3.041.

3.042 Effect of temperature and stress on the time to 0.2 percent creep extension, Figure 3.042.

3.043 Effect of temperature and stress on the time to 0.5 percent creep extension, Figure 3.043.

3.05 Fatigue Properties

3.051 Room temperature fatigue strength, Table 3.051.

TABLE 3.051

Alloy		HZ32A			
Form		Sand-Cast Specimens			
Condition		T5			
Type Test	Surface Condition	Source	Cycles to Failure	ksi	
Reverse Bend	Smooth Machined	(14)	5 X 10 ⁷	10.08	
Reverse Bend	Notched*	(14)	5 X 10 ⁷	10.08	
R. R. Moore	Smooth Machined	(2)	10 ⁸	10.0	
Rotating Beam	Smooth Machined	(15)	10 ⁶	13.0	
Rotating Beam	Notched*	(15)	10 ⁶	10.0	
Reverse Bend	As Cast	(15)	10 ⁶	7.0	
Reverse Bend	Smooth Machined	(15)	10 ⁶	15.0	

* Stress-concentration factor of 2.

3.052 Effect of temperature on fatigue strength of smooth, machined specimens at 10⁷ and 10⁸ cycles to failure, Figure 3.052.

3.06 Elastic Properties

3.061 Poisson's ratio, 0.3 (5).

3.062 Modulus of elasticity.

3.0621 Effect of temperature on tension modulus, Figure 3.0621.

3.063 Modulus of rigidity, 2.5 X 10³ ksi (5).

4. FABRICATION

4.01 Formability4.02 Machining and Grinding

4.021 This alloy, like other magnesium alloys, has exceptionally good machinability, which enables it to be machined at high speeds and feeds. It can usually be machined dry;

but occasionally a cutting fluid is desirable for cooling the work, minimizing the possibility of distortion and reducing the chances of ignition of fine chips. Cutting fluids should always be mineral oils, since animal or vegetable oils are not suitable for use on magnesium alloys. Similarly, water-soluble oils, oil-water emulsions, or water solutions of any kind must not be used because they would severely intensify a fire in the chips if one should start. Chips wet with these coolants present a serious hazard in storage and have little scrap value (17). The alloy can be chemically milled with sulfuric, nitric, or hydrochloric acid of 5 percent strength or greater (6).

Welding

The alloy can be arc welded with helium or argon shielding and HZ32A or EZ33A welding rods. After welding, the artificial aging treatment (16 hours at 600F) should be applied (1)(3)(5).

HZ32A should not be gas welded because of probable loss of zirconium (6).

Surface Treatment

The producing foundries normally chrome pickle the castings prior to shipment to protect them from corrosion and tarnish during shipment and storage (20)(ASTM B80-68). A suitable alternative is to oil with a light corrosion-inhibiting oil (20).

The following surface treatments, which have been developed for magnesium alloys, can be applied successfully to HZ32A to provide a good paint base as well as some degree of corrosion resistance (12) (18):

Chrome pickle, MIL-M-3171A-Type 1

Galvanic anodize, MIL-M-3171A-Type 4

Sealed chrome pickle, MIL-M-3171A-Type 2

Anodize, MIL-M-45202

Dilute chromic acid, MIL-M-3171B

Stannate immersion

HAE anodize, MIL-M-45202 (ORD)

For elevated temperature applications, the anodize treatment (MIL-M-45202) is preferred because it is stable to the melting point of the alloy. The best paints for service at 500 to 600F are the straight silicone resins followed by the silicone-modified epoxies or epoxy phenolic systems. In the 400 to 500F range, other promising resins are epoxy esters and various combinations of phenolics and epoxies (15).

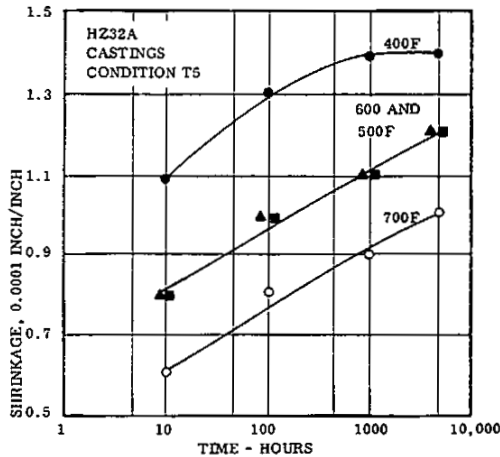


FIG. 1.092 SHRINKAGE DUE TO EXPOSURES AT ELEVATED TEMPERATURES. (1)

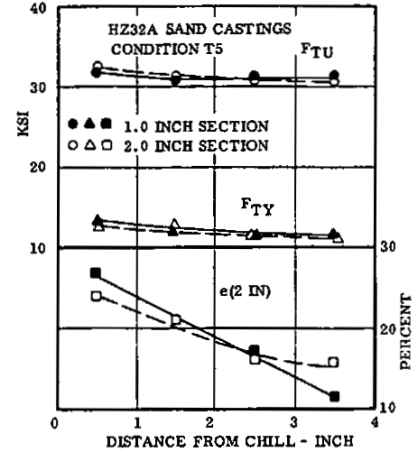


FIG. 3.0212 EFFECT OF END CHILL ON TENSILE PROPERTIES OF CAST PLATES OF TWO THICKNESSES. (9)

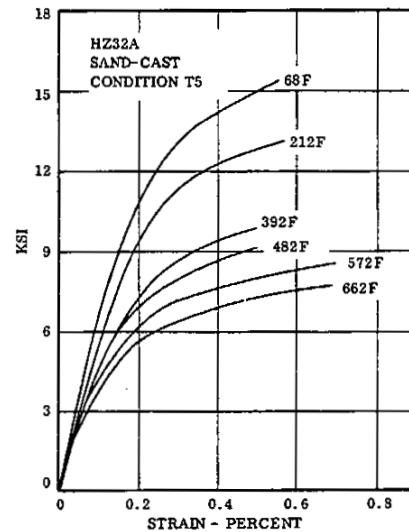


FIG. 3.03111 TENSILE STRESS-STRAIN CURVES. (6)

Mg
3.2 Th
2.1 Zn
0.7 Zr

HZ32A

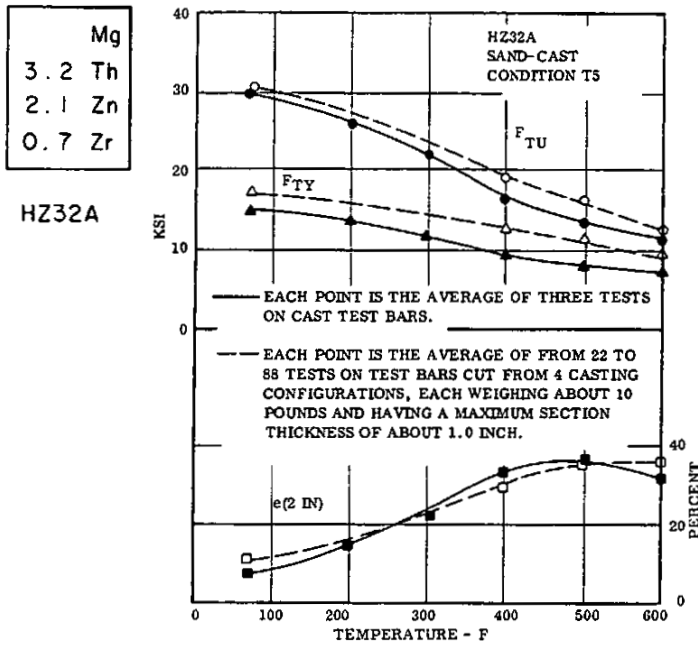


FIG. 3.0312 EFFECT OF ELEVATED TEMPERATURES ON TENSILE PROPERTIES. (10)(11)(12)

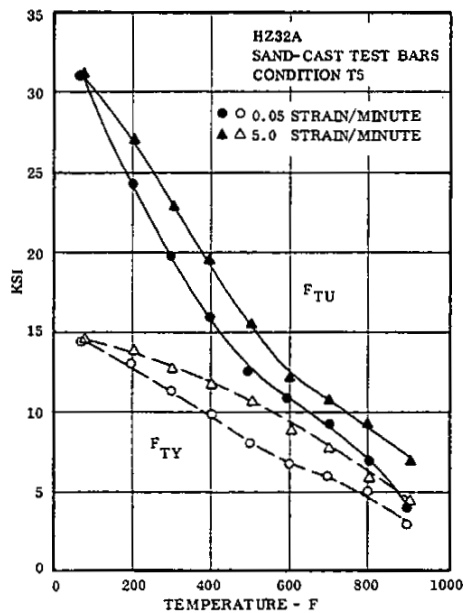


FIG. 3.0313 EFFECT OF VARIATIONS IN STRAIN RATE ON TENSILE PROPERTIES AT DIFFERENT TEMPERATURES. (13)

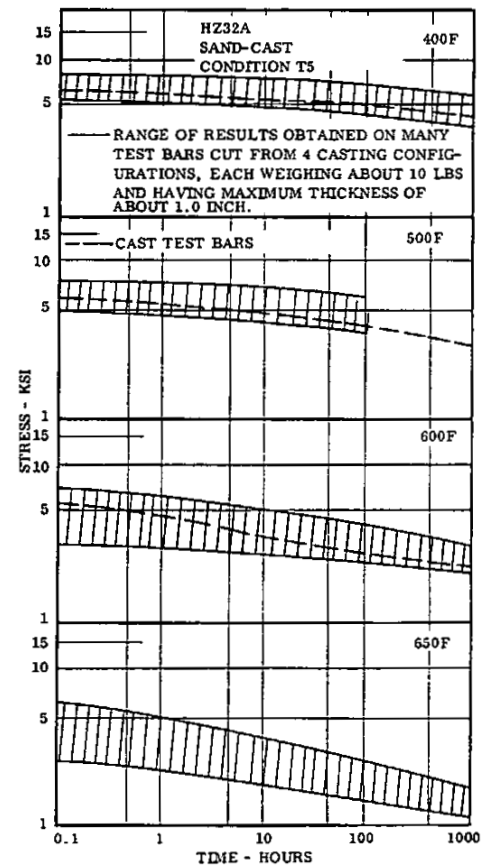


FIG. 3.041 EFFECT OF TEMPERATURE AND STRESS ON THE TIME TO 0.1 PERCENT CREEP EXTENSION. (12)

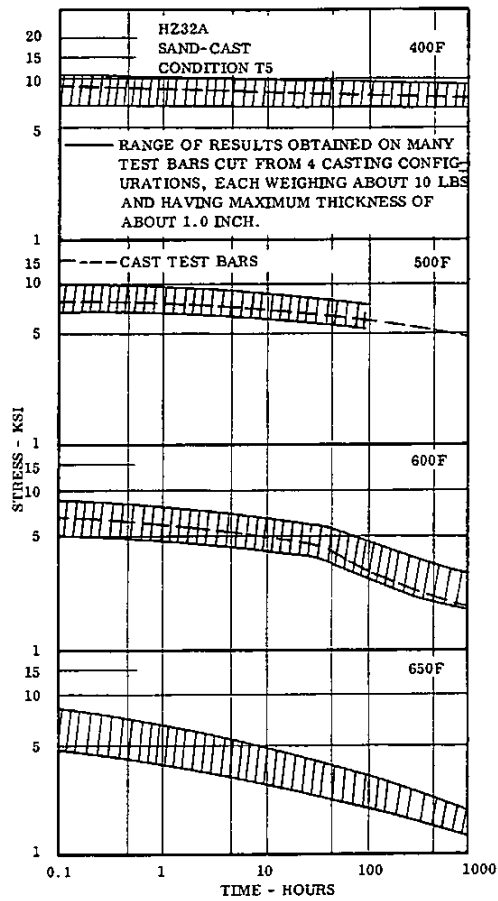


FIG. 3.042 EFFECT OF TEMPERATURE AND STRESS ON THE TIME TO 0.2 PERCENT CREEP EXTENSION. (12)

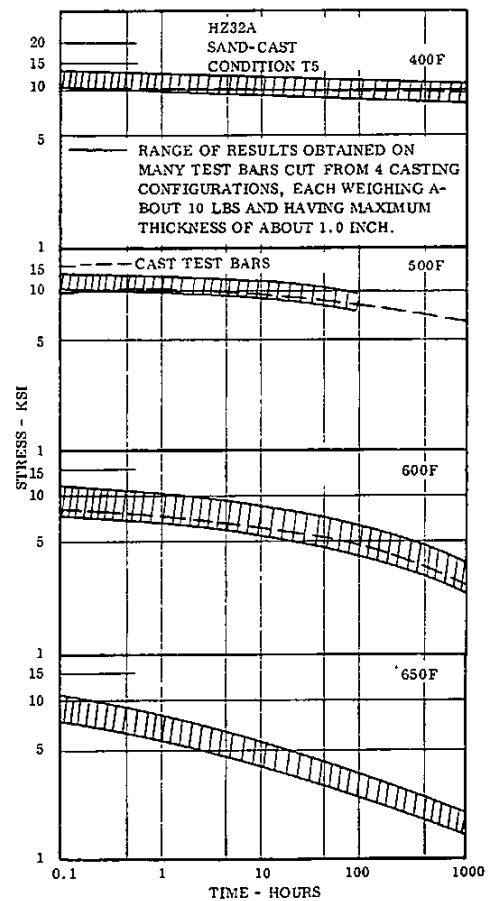


FIG. 3.043 EFFECT OF TEMPERATURE AND STRESS ON THE TIME TO 0.5 PERCENT CREEP EXTENSION. (12)

	Mg
3.2	Th
2.1	Zn
0.7	Zr

HZ32A

Mg
3.2 Th
2.1 Zn
0.7 Zr

HZ32A

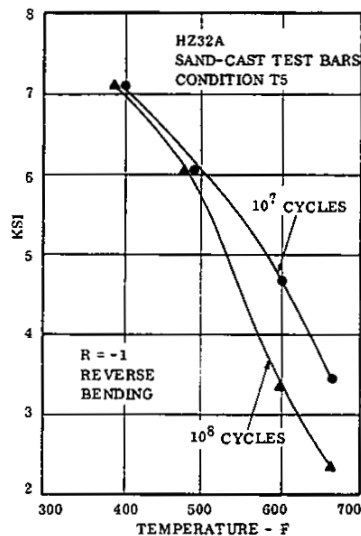


FIG. 3.052 EFFECT OF TEMPERATURE ON FATIGUE STRENGTH OF SMOOTH MACHINED SPECIMENS AT 10^7 AND 10^8 CYCLES TO FAILURE. (14)

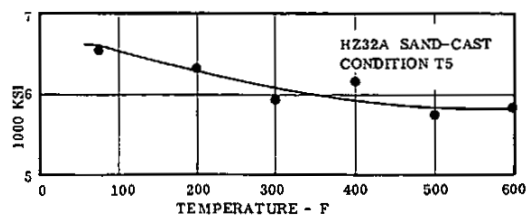


FIG. 3.0621 EFFECT OF TEMPERATURE ON TENSION MODULUS. (16)

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REVISED: DECEMBER 1969
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NONFERROUS ALLOYS

1. GENERAL

The lower lithium content of LA91A, as compared with its sister alloy LA141A, results in a two-phase structure of hexagonal-close-packed alpha in a matrix of body-centered cubic beta. When the alpha phase is thoroughly broken up and distributed throughout the beta matrix, primarily by hot work, the strength of LA91A equals or exceeds that of LA141A. In addition, LA91A exhibits somewhat better ductility, and has considerably better stability when exposed to an elevated temperature of 200F. The LA91A alloy, however, is slightly more dense than LA141A (1).

Although it has been reported that LA91A can be significantly strengthened by heat treatment (2), available data do not support this claim. The as-hot-rolled material retains relatively stable properties during aging for 48 hours at 200F (1) (see Table 3.0212). Cold rolling up to 50 percent reduction produces increases in strength of about 10 percent, but further cold working appears to be detrimental.

LA91A is readily formable by most commercial processes both at room temperature and at elevated temperatures, and may be readily joined by the various fusion welding techniques. The atmospheric corrosion resistance of the alloy is comparable to that of most commercial magnesium alloys. Suitable coatings are recommended for humid, salt-spray, and marine environments.

LA91A should be considered for applications similar to those associated with LA141A (aerospace structures, meteorite shields, instrument housing, and armor plate) particularly where temperatures above room temperature might be involved.

1.01 Commercial Designation LA91A.

1.02 Alternate Designations LA91, LA91XA.

1.03 Specifications None.

1.04 Composition Table 1.04

TABLE 1.04

Composition*	Percent	
	Minimum	Maximum
Aluminum	1.00	1.50
Copper	-	0.04
Iron	-	0.005
Lithium	8.0	10.0
Manganese	-	0.15
Nickel	-	0.005
Silicon	-	0.10
Sodium	-	0.005
Total, other impurities	-	0.30
Magnesium	Balance	

* Composition limits of elements other than Lithium taken from AMS 4386 for LA 141A

1.041 Since no specification has been published, the composition limits for LA141A in AMS 4386 (3) are used as a guide in defining the composition limits for LA91A in Table 1.04.

1.05 Heat Treatment None.

1.051 Available data indicate that there is little or no improvement in properties gained through solution treatment as compared with as-hot-worked properties (1)(4). Aging of the solution treated material at

200F results in a marked decrease in strength and increase in ductility of the solution treated material but has little effect on the as-hot-worked material (1) (see Table 3.0214).

1.052 No data are available on the effects of stabilizing treatment at 350F as is specified for LA141A in AMS 4386 (3).

1.06 Hardness 55 to 75 RE

1.07 Forms and Conditions Available Commercially, none.

1.071 The alloy has been made experimentally in the form of sheet, plate, forging, extrusion, and casting (1).

1.08 Melting and Casting Practice

1.081 Because the alloy reacts readily with oxygen and nitrogen in the temperature range 1200 to 1400F required for melting, it must be protected from oxygen by one of several methods during melting.

1.0811 A technique applicable to small heats is the use of a molten-flux cover. One such flux consists of 3:1 LiCl-LiF in an amount equivalent to about one third of the metal weight. A late addition of LiBr may be made to improve the separation of the flux from the metal (2).

Another flux that has been used is 12.5 percent LiF-37.5 percent LiCl-50 percent KCl, its weight being about one-tenth the weight of the metal (5).

1.0812 A better technique is the use of an inert atmosphere, normally argon, to protect the molten metal (2).

1.0813 Finally, vacuum melting and casting is an effective technique to prevent oxidation of LA91A during melting (2). An effective variation of this technique is to melt under a small partial pressure of argon (1).

1.082 Because of excessive reactivity, LA91A should not be melted in conventional ceramic or graphite crucibles. Steel crucibles are recommended (1).

1.083 Steel or graphite molds are normally used to produce ingots or other cast shapes (1)(6).

1.09 Special Considerations

1.091 The attainment of optimum strength in LA91A is highly dependent upon sufficient hot work to break up the coarse as-cast structure of alpha and beta phases into a fine dispersion of alpha in a beta matrix. In hot rolling, a reduction ratio of 40:1 is ample for this purpose. Although similar figures have not been established for extrusion and forging, it is known that a 24:1 extrusion ratio is insufficient and 75 percent upset reduction by forging is insufficient (1).

2. PHYSICAL AND CHEMICAL PROPERTIES

2.01 Thermal Properties

2.011 Melting range. Approximately 1060 - 1070F.

2.012 Phase changes. There is some indication that a third phase, theta (identified as Mg Li₂ Al), and perhaps additional phases precipitate during aging, but these reactions have not been clearly established (2)(7).

2.0121 Time-temperature-transformation diagrams.

2.013 Thermal conductivity. 32.3 Btu ft per (hr sq ft F) (50 to 300F) (1)(8).

2.014 Thermal expansion. 18×10^{-6} inch per inch degree F (68 to 200F) (1.)

2.015 Specific heat, Figure 2.015.

2.016 Thermal diffusivity.

2.02 Other Physical Properties

2.021 Density. 0.0523 lb per cu in (8).
1.52 gr per cu cm (1)

2.022 Electrical properties.

2.023 Magnetic properties.

2.024 Emissance, Figure 2.024.

2.025 Damping capacity.

2.03 Chemical Properties

	Mg
9	Li
1	Al

LA91A

CODE 3508

PAGE 1

Mg
9 Li
1 Al

LA91A

2.031 Corrosion. In humid atmospheres the corrosion resistance of LA91A is equivalent to most other magnesium alloys, but in salt water or salt spray it corrodes at somewhat faster rates than most of the other alloys (9). In a vacuum of 1 to 2×10^{-6} mm of Hg it loses no weight at temperatures up to 600°F; at 800°F it loses weight at a rate of 1.1×10^{-2} $\mu\text{g}/\text{cm}^2/\text{sec}$ (1). In general, the corrosion products on LA91A are less adherent than those on most commercial alloys. Over long exposure periods the corrosion rates for the commercial alloys decrease with time; those for magnesium-lithium alloys are more likely to remain constant or to decrease much more slowly (9). LA91A is sufficiently resistant to normal atmospheric corrosion for only limited structural service. Protective coatings are necessary for most applications, especially when prolonged periods of time are involved.

2.04 Nuclear Properties

3. MECHANICAL PROPERTIES

3.01 Specified Mechanical Properties

3.02 Mechanical Properties at Room Temperature

3.021 Tension.

3.0211 Stress-strain diagrams.

3.0212 Typical tensile properties as-hot-rolled and after 48 hours exposure to 200°F, Table 3.0212.

TABLE 3.0212

Source	(1)					
Alloy	LA91A					
Form	0.063 Inch Sheet					
Data	Room Temperature Tensile					
Condition	As-Hot-Rolled			After 48 Hours Anneal at 200°F		
Composition	Ru Ksi	Fty Ksi	e(2 In)	Ftu Ksi	Fty Ksi	e(2 In)
Mg-9Li-1.0Al	27.8	21.8	34	26.2	20.3	38
Mg-9Li-1.5Al	28.0	21.4	38	26.4	20.6	36

3.0213 Effect of fabrication procedure, Table 3.0213.

3.0214 Effect of heat treatment, Table 3.0214.

TABLE 3.0214

Source	(1)					
Alloy	LA91A					
Form	0.063 Inch Sheet					
	Solution Treat		Age Treat		Ftu, ksi	Fty, ksi
	Time, hr	Temp, F	Time, hr	Temp, F	e (2 in)	
As-extruded and hot-rolled	1/2	650	-	-	28.1	24.0
	1/2	650	24	200	27.9	22.1
As-forged and hot-rolled	1/2	650	-	-	29.5	20.2
	1/2	650	24	200	27.8	23.2

3.0215 Effect of cold rolling at 75°F and -100°F on tensile properties of sheet previously hot rolled at 450°F, Figure 3.0215.

3.022 Compression.

3.0221 Stress-strain diagrams.

3.023 Impact.

3.024 Bending.

3.0241 Bend radius for sheet, 1T to 3T (1).

3.025 Torsion and shear.

3.026 Bearing.

3.027 Stress concentration.

3.0271 Notch properties.

3.0272 Fracture toughness.

3.028 Combined properties.

3.03 Mechanical Properties at Various Temperatures

3.031 Tension. Effect of temperature on tensile properties. Figure 3.031.

3.0311 Stress-strain diagrams.

3.032 Compression.

3.0321 Stress-strain diagrams.

3.033 Impact.

3.034 Bending.

3.035 Torsion and shear.

3.036 Bearing.

3.037 Stress concentration.

3.0371 Notch properties.

3.0372 Fracture toughness.

3.038 Combined properties.

3.04 Creep and Creep Rupture Properties

3.05 Fatigue Properties

3.06 Elastic Properties

3.061 Poisson's ratio.

3.062 Modulus of elasticity: 6.6×10^3 ksi (S).

3.063 Modulus of rigidity.

TABLE 3.0213

Source	(1)				
Alloy	LA91A				
Condition	As-Hot-Worked				
Method of Fabrication	Fabrication Procedure	Reduction Ratio	Ftu, ksi	Fty, ksi	e(2 In)
As-extruded	0.187 x 2 x 2 inch, T-section extruded from 4 7/16 - inch diameter billet at 500°F	24:1	21.0	18.1	30
As-extruded and rolled	0.187 x 2 - inch flange of T-section rolled at 450°F to 0.063 - inch thick sheet	40:1	28.1	24.0	18
As-forged	Bar stock hammer forged at 550°F from cast ingot	4:1	23.6	20.8	39
As-forged and rolled	Forged bar rolled at 450°F to 0.063 inch thick sheet	40:1	29.5	20.2	34
As-rolled	As-cast ingot rolled at 450°F to 0.063 inch thick steel	40:1	30.8	24.9	15

4. FABRICATION

4.01 Formability

4.011 General. LA91A, like LA141A and in contrast to most commercial magnesium alloys, is easily fabricated and formed, even at room temperature. Primarily, the excellent forming characteristics of LA91A are a result of its body centered cubic matrix structure, whereas most magnesium alloys have hexagonal close packed structures, which are much more difficult to form.

4.012 Parts can be produced by all methods of fabrication. For severe forming, such as deep drawing, impact extruding, spinning, hammer forging, and large rolling reductions, elevated temperatures (normally in the range 350 to 500F) should be used. The needed temperature depends upon the severity of forming (2)(9).

4.02 Machining and Grinding

4.021 General. LA91A is easily machined, cut, sawed, or chemically milled. In machinability it is comparable to other magnesium alloys and aluminum. The same precautions used in magnesium machining must be observed. Where a machining coolant or lubricant is desired, a mineral oil (non water soluble) is recommended. For cutting or sawing, mineral oil or paraffin may be used (2)(9).

4.022 Chemical milling. The alloy can be chemically milled in phosphoric or sulfuric acid solutions. Acid strength and temperature vary depending upon the physical size of parts and the amount of material to be removed, so that convenient etching rates can be selected. Masking techniques similar to those used for aluminum can be used (9).

4.03 Welding

4.031 General. LA91A can be readily fusion welded. Joint efficiencies are high and weld cracking difficulties are rare. Both GTA and GMA processes, with manual or automatic techniques, are applicable. The use of helium gas maintains a cleaner appearance of the liquid pool; however, weldments with 100 percent joint efficiency have been obtained with the use of argon. Backside shielding is required to reduce underside oxidation. Prior to welding, the material must be cleaned by abrasion with aluminum oxide or with stainless steel or aluminum wire brushes. No preheating is necessary, but a postweld stress relief at 250 to 350F is recommended. The alloy can also be resistance spot welded on equipment conventionally used for other magnesium alloys (2).

4.032 Filler metals. Welding wires of LA141A, EZ33A AZ92A, and AZ61A have been used successfully. As with the base metal, it is necessary to use freshly cleaned welding wire, which can be cleaned by passing through stainless steel wool (2).

4.033 Tensile properties of LA91A sheet TIG welded with EZ33A filler wire, Table 4.033.

TABLE 4.033

Source	(2)				
Alloy	LA91A				
Form	0.090 Inch Sheet				
Condition	GTA Welded with EZ 33 A Filler Wire				
Temp, F	F _{tu} Ksi	F _{ty} Ksi	ϵ (2 In)	Fracture Location	
75	23.7	21.2	6	Base Metal	
75	23.7	21.8	6	Base Metal	
75	23.4	21.4	6	Base Metal	
-320	30.4	25.7	7	Base Metal	
-320	30.2	-	12	Base Metal	
-423	43.3	-	6	Fusion Zone	
-423	35.1	-	1	Fusion Zone	
-423	39.4	-	3	Fusion Zone	

4.04 Surface Treatment

4.041 General. Several treatments developed originally for commercial magnesium alloys have been applied with fair success to LA91A. These are Dow 17, HAE, fluoride anodize, and stannate treatments. All of them require subsequent paint coatings, preferably baking or room temperature curing resins, for protection in outdoor, salt-air, or humid environments (2)(5)(9).

4.042 Metallic coatings. There are three accepted methods for applying metallic coatings to commercial magnesium alloys; immersion zinc plating, electroless (immersion) nickel plating, and direct electroplating of nickel. On LA91A the first two are much more effective than the third. In each case, other metals that can be electroplated can be deposited by standard methods over the initial layer of zinc or nickel (2) (9).

	Mg
9	Li
1	Al

LA91A

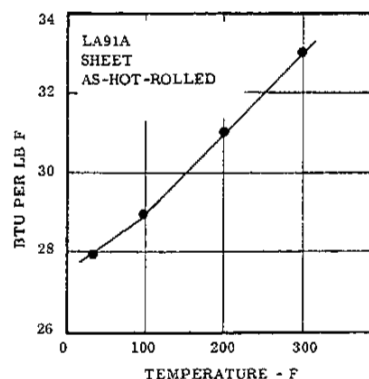


FIG. 2.015 SPECIFIC HEAT. (1)

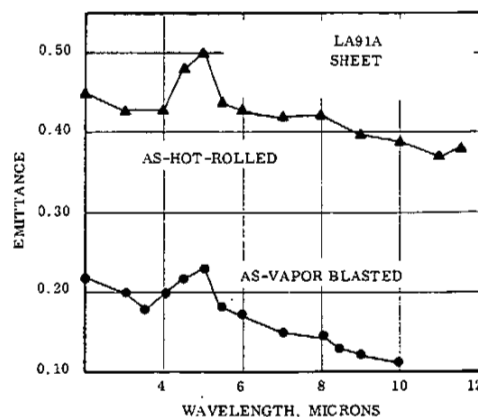


FIG. 2.024 NORMAL SPECTRAL EMITTANCE AT 360° K. (1)

	Mg
9	Li
1	Al

LA91A

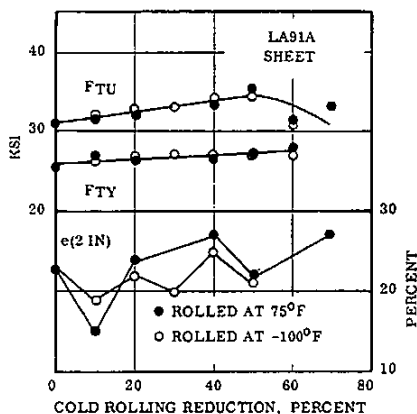


FIG. 3.0215 EFFECT OF COLD ROLLING AT 75°F AND -100°F ON TENSILE PROPERTIES OF SHEET PREVIOUSLY HOT-ROLLED AT 450°F. (1)

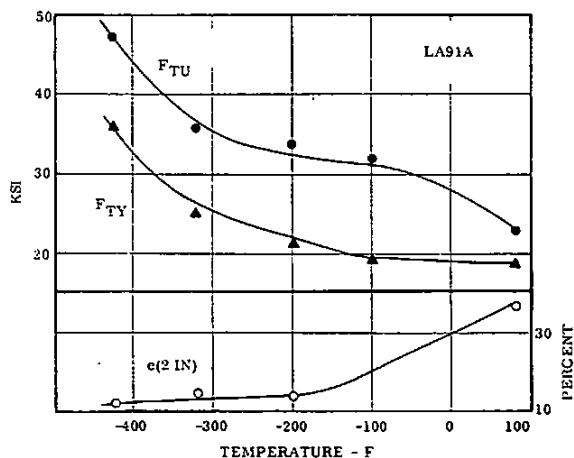


FIG. 3.031 TENSION EFFECT OF TEMPERATURE ON TENSILE PROPERTIES.

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REVISED: JUNE 1971
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NONFERROUS ALLOYS

1. **GENERAL**
This magnesium alloy, which is normally used in the T6 condition (solution treated and artificially aged), is produced primarily in the form of castings, but it is also suitable for at least limited applications as forgings. It combines good mechanical properties with excellent foundry characteristics, that is, fluidity with little tendency toward porosity and hot cracking. At room temperature its strength is slightly lower than that of ZK61A, but at elevated temperatures up to 540 F, its tensile strength is superior to that of any other magnesium casting alloy. Above 540 F, HK31A is somewhat stronger. It has good creep properties at temperatures up to 400 F, but long time strength and stability are not good at higher temperatures. The alloy is weldable by inert-gas-arc techniques. It should be considered for any aerospace or other applications where good short time mechanical properties are required up to 540 F and good creep properties up to 400 F (5)(6).

- 1.01 Commercial Designation
QE22A

- 1.02 Alternate Designations
QE22, MSR

- 1.03 Specifications
Table 1.03.

TABLE 1.03

Alloy	QE22A
Forms	Specifications
Sand Castings	AMS 4418C ASTM B80 MIL-M-46062 (MR) Federal QQ-M-56b (1)
Permanent Mold Casting	ASTM B199 MIL-M-46062A Federal QQ-M-46062A
Investment Castings	ASTM B403

- 1.04 Composition
Table 1.04.

TABLE 1.04

Alloy		QE22A			
Source	(1)		(2)(3)(4)		
Composition	Percent		Percent		
	Minimum	Maximum	Minimum	Maximum	
Silver	2.0	3.0	2.0	3.0	
Didymium (a)	1.75	2.5	1.8	2.5	
Zirconium, total	0.40	1.0	0.40	1.0	
Zirconium, soluble (b)	0.40	-	-	-	
Copper	-	0.10	-	0.10	
Nickel	-	0.01	-	0.01	
Others, total	-	0.30	-	0.30	
Magnesium	Balance		Balance		
(a) A rare-earth alloy consisting of 85 percent neodymium and 15 percent praseodymium.					
(b) Soluble zirconium is that portion of the zirconium that is soluble in 1:4 hydrochloric acid held below its boiling point.					

- 1.05 Heat Treatment(7)
1.051 Solution treatment: 970 to 980 F, 8 hours in furnace atmosphere containing 1 percent SO₂ minimum, quench in water at 140 F minimum within maximum delay time of 30 seconds.
1.052 Artificially age to T6 condition: 400 F, 8 hours, air cool.
1.06 Hardness (1)
T6 condition: BHN 62-85 with 500 kg load and 10 mm ball or 1000 kg load and 9/16 inch ball; BHN 67-90 with 1000 kg load and 10 mm ball.
1.07 Forms and Conditions Available
Produced primarily as castings; limited production of roll-forged rings. Used in the T6 (solution treated and artificially aged) condition.

- 1.08 Melting and Casting Practice
QE22A is melted and cast similarly to other zirconium containing magnesium casting alloys (see HZ32A, Code 3408, Section 1.08). The silver, which is added as pure metal, and didymium, which is added as a magnesium-didymium hardener, are handled in the same manner as zinc. Zinc and silver losses are negligible for each melting cycle, but a loss of one fourth percent (of total melt weight) of rare earths (didymium) for each melt cycle is typical although this will vary with local foundry conditions (8).

- 1.09 Special Considerations
1.091 It is essential that contamination with aluminum, iron, manganese, and silicon be prevented, as these elements prevent zirconium from performing its desired grain refining function (9).
1.092 This alloy has relatively low section sensitivity, that is, with good foundry practice, its mechanical properties are not drastically reduced with increasing section size (see Figure 3.0213)(10).
1.093 Rate of quenching from the solution treatment temperature is critical, and castings should be quenched in hot water within 30 seconds of their removal from the furnace (6).

2. PHYSICAL AND CHEMICAL PROPERTIES

- 2.01 Thermal Properties
2.011 Melting range. 1020-1190 F (8).
2.012 Phase changes. Solution treatment results in partial solution of the magnesium-rare earth compounds that normally appear at the grain boundaries in the as-cast condition. Very finely divided precipitates form within the grains during artificial aging. These precipitates have not been fully identified, but are believed to be silver-rare earth magnesium compounds and also possibly zirconium compounds (6)(11).
2.0121 Time-temperature-transformation diagrams.
2.013 Thermal conductivity.
2.0131 T6 condition: 59.5 Btu ft per (ft² hr F)(12) - 65.34 Btu ft per (ft² hr F)(6).
2.0132 F condition (as forged): 55.6 Btu ft per (ft² hr F) at 68 F (12).
2.014 Thermal expansion. 14.85 x 10⁻⁶ per F from 68 F to 392 F (13).
2.015 Specific heat. 0.245 Btu per (lb F).
2.016 Thermal diffusivity.
2.02 Other Physical Properties
2.021 Density. 0.066 lb per cu in (8).
2.022 Electrical properties, Table 2.022.

TABLE 2.022

Alloy	QE22A		
Condition	T6		
Source	(14)		
Temperature - F	Electrical Conductivity		Electrical Resistivity microhm - in
	Percent IACS	Megmhos per in ³	
68	27.0	0.397	2.52
113	25.2	0.370	2.70
212	22.3	0.328	3.05

- 2.023 Magnetic properties. Nonmagnetic.
2.024 Emissance.
2.025 Damping capacity.
2.03 Chemical Properties
2.031 Corrosion resistance.
2.0311 QE22A, like other magnesium alloys, is subject to general and pitting corrosion in industrial, marine, and moist environments. With suitable surface treatment and painting, it performs satisfactorily in all types of natural environments with the exception of continuous immersion in water (15).

	Mg
2.5	Ag
2.0	Di
0.4	Zr

QE22A

REVISED: JUNE 1971
AUTHOR: J.R. KATTUS

NONFERROUS ALLOYS

1. **GENERAL**
This magnesium alloy, which is normally used in the T6 condition (solution treated and artificially aged), is produced primarily in the form of castings, but it is also suitable for at least limited applications as forgings. It combines good mechanical properties with excellent foundry characteristics, that is, fluidity with little tendency toward porosity and hot cracking. At room temperature its strength is slightly lower than that of ZK61A, but at elevated temperatures up to 540 F, its tensile strength is superior to that of any other magnesium casting alloy. Above 540 F, HK31A is somewhat stronger. It has good creep properties at temperatures up to 400 F, but long time strength and stability are not good at higher temperatures. The alloy is weldable by inert-gas-arc techniques. It should be considered for any aerospace or other applications where good short time mechanical properties are required up to 540 F and good creep properties up to 400 F (5)(6).

- 1.01 Commercial Designation
QE22A

- 1.02 Alternate Designations
QE22, MSR

- 1.03 Specifications
Table 1.03.

TABLE 1.03

Alloy	QE22A
Forms	Specifications
Sand Castings	AMS 4418C ASTM B80 MIL-M-46062 (MR) Federal QQ-M-56b (1)
Permanent Mold Casting	ASTM B199 MIL-M-46062A Federal QQ-M-46062A
Investment Castings	ASTM B403

- 1.04 Composition
Table 1.04.

TABLE 1.04

Alloy	QE22A			
Source	(1)		(2)(3)(4)	
	Percent		Percent	
Composition	Minimum	Maximum	Minimum	Maximum
Silver	2.0	3.0	2.0	3.0
Didymium (a)	1.75	2.5	1.8	2.5
Zirconium, total	0.40	1.0	0.40	1.0
Zirconium, soluble (b)	0.40	-	-	-
Copper	-	0.10	-	0.10
Nickel	-	0.01	-	0.01
Others, total	-	0.30	-	0.30
Magnesium	Balance		Balance	
(a) A rare-earth alloy consisting of 85 percent neodymium and 15 percent praseodymium.				
(b) Soluble zirconium is that portion of the zirconium that is soluble in 1:4 hydrochloric acid held below its boiling point.				

- 1.05 Heat Treatment(7)
1.051 Solution treatment: 970 to 980 F, 8 hours in furnace atmosphere containing 1 percent SO₂ minimum, quench in water at 140 F minimum within maximum delay time of 30 seconds.
1.052 Artificially age to T6 condition: 400 F, 8 hours, air cool.
1.06 Hardness (1)
T6 condition: BHN 62-85 with 500 kg load and 10 mm ball or 1000 kg load and 9/16 inch ball; BHN 67-90 with 1000 kg load and 10 mm ball.
1.07 Forms and Conditions Available
Produced primarily as castings; limited production of roll-forged rings. Used in the T6 (solution treated and artificially aged) condition.

- 1.08 Melting and Casting Practice
QE22A is melted and cast similarly to other zirconium containing magnesium casting alloys (see HZ32A, Code 3408, Section 1.08). The silver, which is added as pure metal, and didymium, which is added as a magnesium-didymium hardener, are handled in the same manner as zinc. Zinc and silver losses are negligible for each melting cycle, but a loss of one fourth percent (of total melt weight) of rare earths (didymium) for each melt cycle is typical although this will vary with local foundry conditions (8).

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1.091 It is essential that contamination with aluminum, iron, manganese, and silicon be prevented, as these elements prevent zirconium from performing its desired grain refining function (9).
1.092 This alloy has relatively low section sensitivity, that is, with good foundry practice, its mechanical properties are not drastically reduced with increasing section size (see Figure 3.0213)(10).
1.093 Rate of quenching from the solution treatment temperature is critical, and castings should be quenched in hot water within 30 seconds of their removal from the furnace (6).

2. PHYSICAL AND CHEMICAL PROPERTIES

- 2.01 Thermal Properties
2.011 Melting range. 1020-1190 F (8).
2.012 Phase changes. Solution treatment results in partial solution of the magnesium-rare earth compounds that normally appear at the grain boundaries in the as-cast condition. Very finely divided precipitates form within the grains during artificial aging. These precipitates have not been fully identified, but are believed to be silver-rare earth magnesium compounds and also possibly zirconium compounds (6)(11).
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2.0131 T6 condition: 59.5 Btu ft per (ft² hr F)(12) - 65.34 Btu ft per (ft² hr F)(6).
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2.02 Other Physical Properties
2.021 Density. 0.066 lb per cu in (8).
2.022 Electrical properties, Table 2.022.

TABLE 2.022

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Condition	T6		
Source	(14)		
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	Percent IACS	Megmhos per in ³	
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- 2.023 Magnetic properties. Nonmagnetic.
2.024 Emissance.
2.025 Damping capacity.
2.03 Chemical Properties
2.031 Corrosion resistance.
2.0311 QE22A, like other magnesium alloys, is subject to general and pitting corrosion in industrial, marine, and moist environments. With suitable surface treatment and painting, it performs satisfactorily in all types of natural environments with the exception of continuous immersion in water (15).

Mg
2.5 Ag
2.0 Di
0.4 Zr

QE22A

Mg
2.5 Ag
2.0 Di
0.4 Zr

QE 22 A

- 2.0312 This alloy has low susceptibility to stress corrosion cracking (6).
 2.0313 For a discussion of galvanic corrosion, see AZ31B, Code 3601, Section 2.0312.
 2.032 Safety precautions should be directed to the prevention of fires, burns, and explosions (see H232A, Code 3408, Section 2.032).

2.04 Nuclear Properties3. MECHANICAL PROPERTIES3.01 Specified Mechanical Properties

3.011 AMS and ASTM specifications, Table 3.011.

TABLE 3.011

Alloy	QE22A								
Condition	T6								
Source	(20)								
Type Casting	Sand			Permanent Mold			Investment		
Specimen	Temp F	F _{tu} ksi	F _{ty} ksi	e(2 in) min	F _{tu} ksi	F _{ty} ksi	e(2 in) min	F _{tu} ksi	F _{ty} ksi
Separately cast	75 600	35 11.5	25 9.0	2 -	35 -	25 -	2 -	35 -	25 -
Out from casting single average 4 or more single	75 600	28 10	20 8	1 -	- -	- -	- -	- -	- -

3.012 MIL-M-46062 (MR) specifications, Table 3.012.

TABLE 3.012

Alloy	QE22A		
Condition	T6		
Form	Castings		
Source	(17)		
Section *	Tensile Properties in Designated Sections of Castings		
	F _{tu} - ksi Minimum	F _{ty} - ksi Minimum	e(2 in) Minimum
1	40	28	4
2	37	26	2
3	33	23	2
X	28	20	2

* Sections 1, 2, and 3 are designated critical sections of castings and would be specified for the particular casting in question; section X covers unspecified sections.

- 3.02 Mechanical Properties at Room Temperature
 3.021 Tension. Typical for sand-cast test bars in T6 condition F_{tu} = 40.0 ksi F_{ty} = 30.0 ksi e(2 in) = 4 percent (7) (8) (16).
 3.0211 Stress-strain diagrams (see Figure 3.0311).
 3.0212 Effect of end chill on tensile properties of cast plates of two thicknesses, Figure 3.0212.
 3.0213 Effect of section thickness on tensile properties, Figure 3.0213.
 3.0214 Effect of overaging on tensile properties, Figure 3.0214.
 3.0215 Effect of cold work on tensile properties, Figure 3.0215.

- 3.0216 Effect of orientation and forging reduction on tensile properties of roll-forged rings, Table 3.0216.

TABLE 3.0216

Alloy	QE22A			
Condition	T6*			
Form	Roll Forged			
Source	(20)			
Specimen Orientation	Forging Reduction percent	F _{tu} ksi	F _{ty} ksi	e(2 in) percent
Tangential	20	43	33	8
	40	45	36	6
	60	44	37	6
Axial	20	40	27	11
	40	40	29	10
	60	40	30	9
Radial	20	40	26	9

* Heat treated after roll forging.

- 3.022 Compression. Typical for sand-cast test bars in T6 condition. F_{cy} = 30 ksi (7).
 3.0221 Stress-strain diagrams.
 3.0222 Effect of orientation and forging reduction on compressive properties of roll-forged rings, Table 3.0222.

TABLE 3.0222

Alloy	QE22A	
Condition	T6*	
Form	Roll Forged	
Source	(20)	
Specimen Orientation	Forging Reduction percent	F _{cy} ksi
Tangential	20	26
	40	26
	60	25
Axial	20	26
	40	26
	60	25
Radial	20	28
	40	28
	60	28

* Heat treated after roll forging.

- 3.023 Impact (see Figure 3.0331).
 3.024 Bending.
 3.025 Torsion and shear. Typical shear strength for sand-cast test bars in T6 condition. F_{su} = 21.5 ksi (7)(16).
 3.026 Bearing.
 3.027 Stress concentration.
 3.0271 Notch properties.
 3.02711 Effect of crack length on breaking load of fatigue cracked specimens as percent of breaking load of uncracked specimen, Figure 3.02711.
 3.02712 Effect of fatigue crack size on total stress to fracture in bending, Figure 3.02712.
 3.0272 Fracture toughness. A small amount of data on cracked specimens appears in Reference 22. However the specimen is not sufficiently well described to make the information useful for the purposes of this Handbook.
 3.028 Combined properties.

3.03 Mechanical Properties at Various Temperatures

- 3.031 Tension.
 3.0311 Stress-strain diagrams, Figure 3.0311.
 3.0312 Effect of temperature on tensile properties of castings, Figure 3.0312.
 3.0313 Elevated temperature tensile properties of roll forgings, Figure 3.0313.
 3.032 Compression.
 3.0321 Stress-strain diagrams.
 3.033 Impact.
 3.0331 Effect of temperature on notched and unnotched Charpy impact properties, Figure 3.0331.
 3.034 Bending.
 3.035 Torsion and shear.
 3.0351 Effect of temperature on shear strength, Figure 3.0351.
 3.036 Bearing.

- 3.037 Stress concentration.
 3.0371 Notch properties.
 3.0372 Fracture toughness.
 3.038 Combined properties.
- 3.04 Creep and Creep Rupture Properties
 3.041 Effects of temperature and stress on the times to various amounts of creep extension, Figure 3.041.
 3.042 Creep rupture time at 392 F, Figure 3.042.
- 3.05 Fatigue Properties
 3.051 S-N fatigue curves at room and elevated temperatures, Figure 3.051.
- 3.06 Elastic Properties
 3.061 Poisson's ratio. 0.35 (13).
 3.062 Modulus of elasticity, Figure 3.062.
 3.063 Modulus of rigidity. 2.4×10^3 ksi (13).
4. FABRICATION
- 4.01 Formability
- 4.02 Machining and Grinding
 4.021 This alloy, like other magnesium alloys, has exceptionally good machinability, which enables it to be machined at high speeds and feeds. For further details, see HZ32A, Code 3408, Section 4.021.
 4.022 The alloy can be chem milled with sulfuric, nitric, or hydrochloric acid of 5 percent strength or greater (13).
- 4.03 Welding
 4.031 QE22A is weldable by gas tungsten-arc and gas metal-arc techniques with either helium or argon gas shielding. EZ33A filler metal should be used when welded joints will be used at high temperatures, whereas AZ92A and AZ61A filler metals are satisfactory for room-temperature service. Preheating to about 500 F is recommended if needed to minimize distortion or prevent cracking. If possible, the welded part should be fully heat treated to the T6 condition after welding (6)(23).
- 4.04 Surface Treatment
 See HZ32A, Code 3408, Sections 4.041, 4.042, and 4.043.

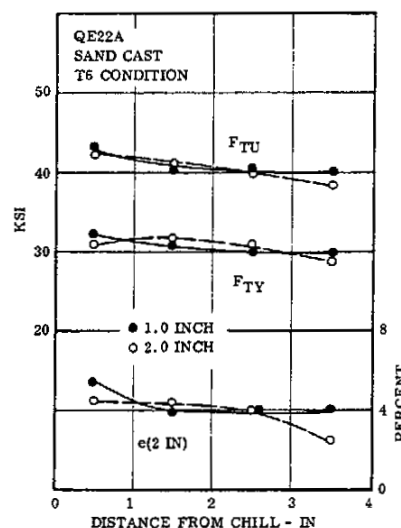


FIG. 3.0212 EFFECT OF END CHILL ON TENSILE PROPERTIES OF CAST PLATES OF TWO THICKNESSES. (18)

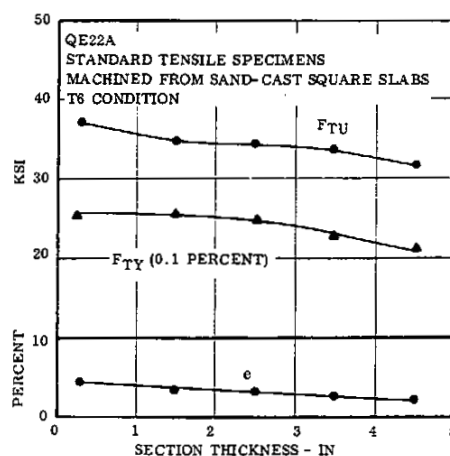


FIG. 3.0213 EFFECT OF SECTION THICKNESS ON TENSILE PROPERTIES. (6)

Mg
 2.5 Ag
 2.0 Di
 0.4 Zr
 QE 22 A

	Mg
2.5	Ag
2.0	Di
0.4	Zr

QE 22 A

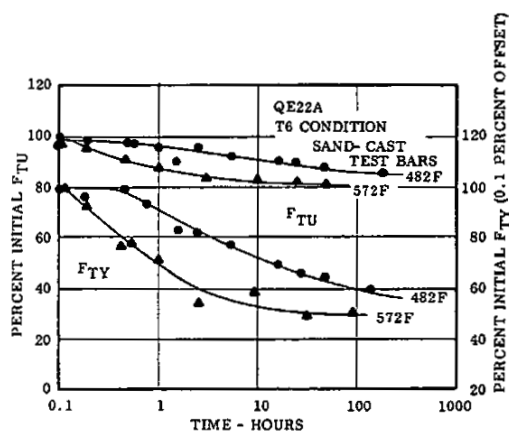


FIG. 3.0214 EFFECT OF OVERAGING ON TENSILE PROPERTIES. (6)

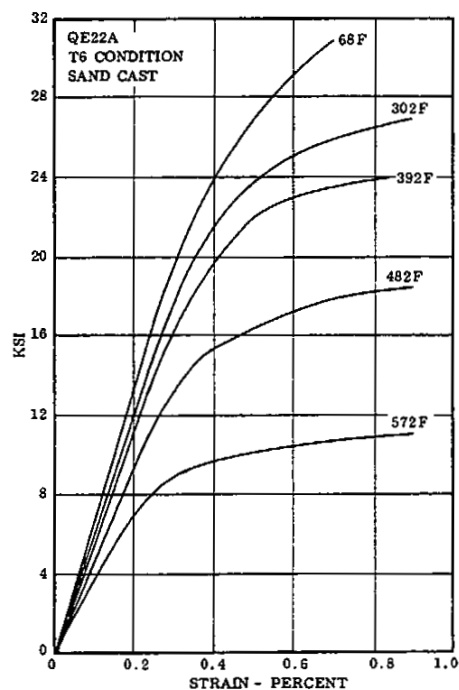


FIG. 3.0311 STRESS-STRAIN DIAGRAMS. (13)

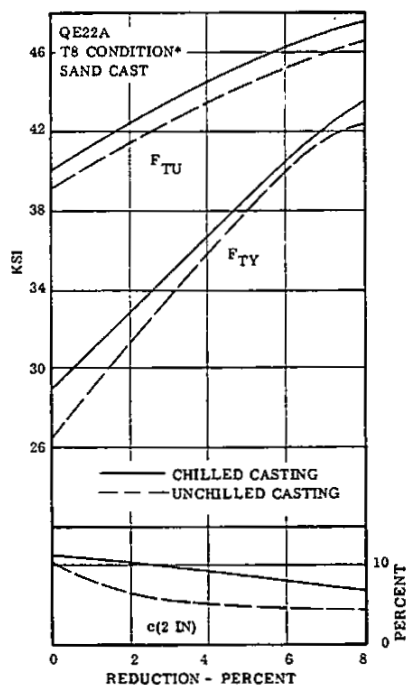


FIG. 3.0215 EFFECT OF COLD WORK ON TENSILE PROPERTIES. (19)

* T8 condition in this case means that the metal was cold worked the given amount between the solution and aging treatments specified for the T6 condition.

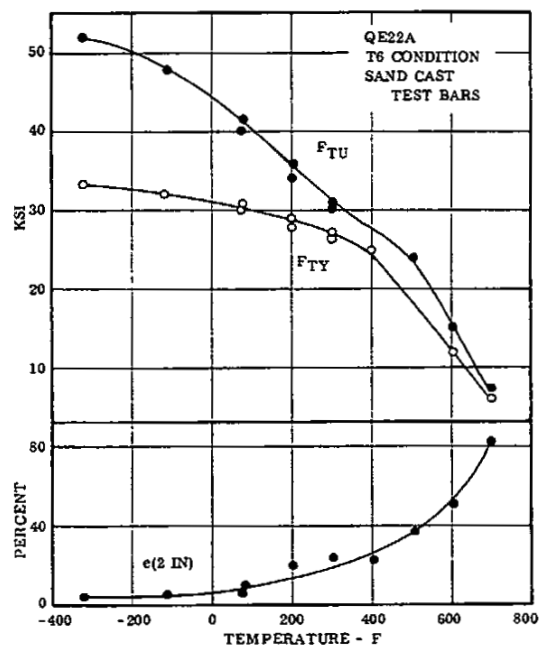


FIG. 3.0312 EFFECT OF TEMPERATURE ON TENSILE PROPERTIES OF CASTINGS. (12)

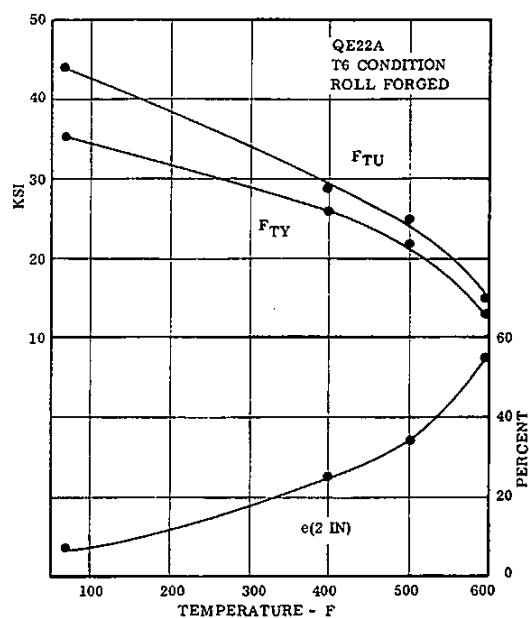


FIG. 3.0313 ELEVATED TEMPERATURE TENSILE PROPERTIES OF ROLL FORGINGS. (20)

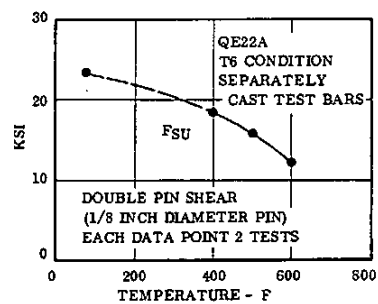


FIG. 3.0351 EFFECT OF TEMPERATURE ON SHEAR STRENGTH. (6)

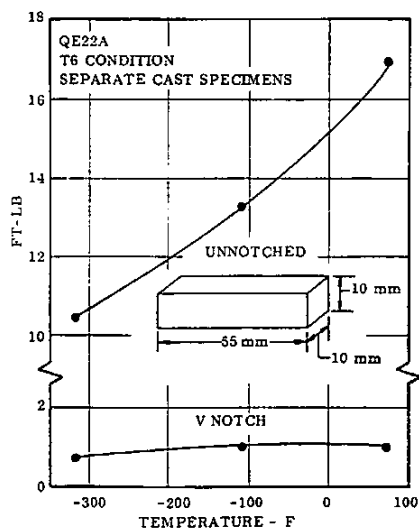


FIG. 3.0331 EFFECT OF TEMPERATURE ON NOTCHED AND UNNOTCHED CHARPY IMPACT PROPERTIES. (21)

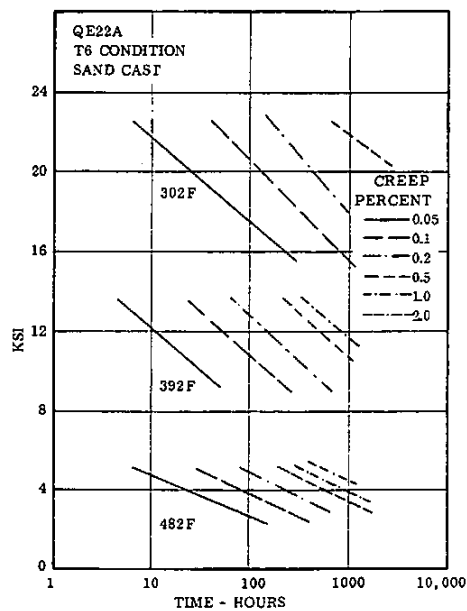


FIG. 3.041 EFFECTS OF TEMPERATURE AND STRESS ON THE TIMES TO VARIOUS AMOUNTS OF CREEP EXTENSION. (6)

Mg
2.5 Ag
2.0 Di
0.4 Zr
QE22A

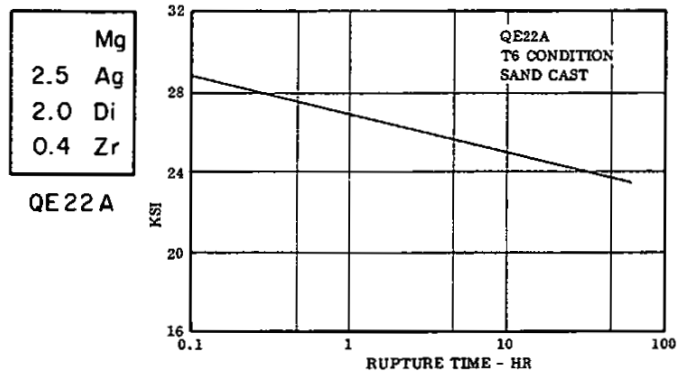


FIG. 3.042 CREEP RUPTURE TIME AT 392F. (5)

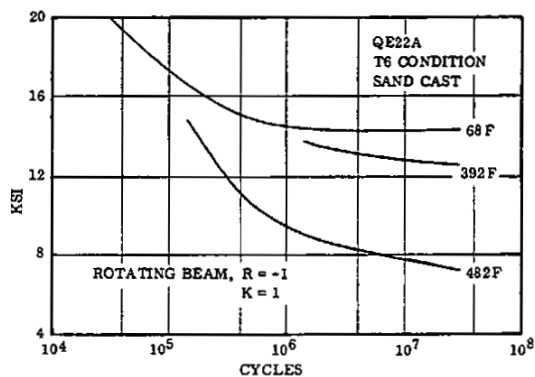


FIG. 3.051 S-N FATIGUE CURVES AT ROOM AND ELEVATED TEMPERATURES. (5)

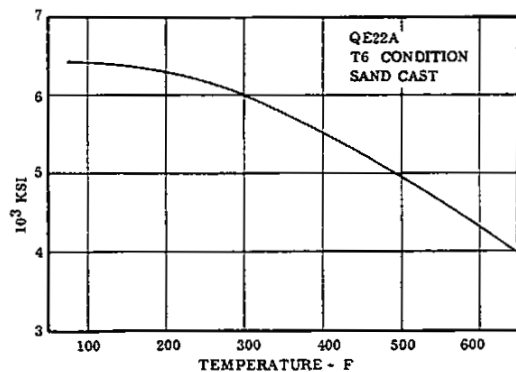


FIG. 3.062 MODULUS OF ELASTICITY. (13)

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22. Marrien, M., "Recent Developments in Magnesium Casting Alloys for Aircraft Structures," Transactions AFS, Volume 75 (1967) p. 376.
23. Arc Welding Magnesium, Form 141-300-67, Dow Metal Products Department, Midland, Michigan (1967).

RELEASED: DECEMBER 1969
AUTHOR: J.R. KATTUS

NONFERROUS ALLOYS

1. GENERAL
- ZH62A is a magnesium-base casting alloy which combines a reasonable degree of castability with excellent strength up to 300F. Its strength properties drop sharply at temperatures above 300F. Its castability is rated above that of ZK51A and ZK61A but below that of QE22A, which are other high-strength magnesium casting alloys; however, the ductility of ZH62A is considerably better than that of QE22A. ZH62A has excellent weldability and machinability. Like other magnesium alloys, coatings are recommended to prevent corrosion in humid, salt-spray, and marine environments. It is used only in the artificially aged (T-5) condition and should be considered for any aerospace or other applications requiring a high strength-to-weight ratio at temperatures up to 300F.

- 1.01 Commercial Designation
ZH62A

- 1.02 Alternate Designations
ZH62XA, TZ6 (British)

- 1.03 Specifications
AMS 4438B
ASTM B80-68
U.S. Federal QQ-M-56b (1)
SAE 508
MIL-M-46062A

- 1.04 Composition
Table 1.04.

TABLE 1.04

Alloy	ZH62A			
	Composition			
	AMS 4438B (18)		ASTM B80-68	
	Percent		Percent	
Source	Minimum	Maximum	Minimum	Maximum
Zinc	5.2	6.2	5.2	6.2
Thorium	1.4	2.2	1.4	2.2
Zirconium				
total	0.50	1.0	0.50	1.0
soluble*	0.50			
Copper		0.10		0.10
Nickel		0.01		0.01
Others		0.30		0.30
Magnesium	Balance		Balance	

* Soluble zirconium is that portion of the zirconium that is soluble in 1:4 hydrochloric acid held below its boiling point.

- 1.05 Heat Treatment
Artificially age 470 to 490F, 12 to 16 hours, AC to Condition T-5 (1).
- 1.051 Alternative age treatment for Condition T-5, 615 to 635F 2 hours, AC, plus 340 to 360F, 16 hours (1)(2).

- 1.06 Hardness
1.061 BHN 65-80 with 1000 kg load and 10 mm ball (18).
1.062 BHN 60-75 with 500 kg load and 10 mm ball or 1000 kg load and 9/16 inch ball (18).

- 1.07 Forms and Conditions Available
Produced as castings and used in the T-5 (artificially aged) condition.

- 1.08 Melting and Casting Practice (2)
(see HZ32A cast magnesium alloy)

- 1.09 Special Considerations
1.091 Contamination of the alloy with more than 0.005 percent aluminum should be avoided to prevent the formation of aluminum-zirconium compounds, which are detrimental to mechanical properties (5).
1.092 The alloy has excellent dimensional stability at service temperatures up to at least 300F (6).

2. PHYSICAL AND CHEMICAL PROPERTIES

- 2.01 Thermal Properties
2.011 Melting range.
2.0111 The liquidus temperature is 1169F (2).
2.012 Phase changes. One or more zinc-zirconium phases are formed during artificial aging. Optimum mechanical properties are dependent upon a uniform distribution of these phases in finely divided form (4).
2.0121 Time-temperature-transformation diagrams.
2.013 Thermal conductivity. 63.0 Btu ft per (hr sq ft F) at 68F (2)(5).
2.014 Thermal expansion. 15.1×10^{-6} per F from 68 to 392F (5)(6).
2.015 Specific heat. 0.23 Btu per (lb F) from 68 to 212F (5)(6).
2.016 Thermal diffusivity.

- 2.02 Other Physical Properties
2.021 Density. 1.86 g/cc (2)(5). 0.0675 lb/cubic inch (6).
2.022 Electrical properties.
2.0221 Electrical conductivity. 0.39 megmhos/in³ at 68F (6). 25.5 percent IACS at 68F (5).
2.0222 Electrical resistivity. 2.56 microhm-inch at 68F (5).
2.023 Magnetic properties.
2.024 Emission.
2.025 Damping capacity. At a stress equal to 0.1 F_{ty} the specific damping capacity is 0.14, which is relatively low in comparison with most other magnesium alloys (7).

- 2.03 Chemical Properties
2.031 ZH62A, like other magnesium alloys, will corrode in industrial, marine, and moist environments. With suitable surface treatment and painting, it will perform satisfactorily in all types of natural environments, with the exception of continuous immersion in water (17). For a discussion of galvanic corrosion see Code 3601, Section 2.0312.
2.032 Safety precautions should be directed to the prevention of fires, burns, and explosions. See HZ32A, Code 3408, Section 2.032.

- 2.04 Nuclear Properties
2.041 Thorium metal is radioactive, but the amount contained in this alloy is not sufficient to constitute a hazard in normal handling. For precautions during melting and welding, see HZ32A, Code 3408, Section 2.041.
2.042 The slight radioactivity of the alloy causes no interference in the sending and receiving of radar and radio signals (8).

3. MECHANICAL PROPERTIES

- 3.01 Specified Mechanical Properties
Table 3.01.

TABLE 3.01

Alloy	ZH62A						
	Sand Cast						
	T-5						
	AMS 4438B (18)		ASTM B80-68				
Specification	Temp	F_{tu} min	F_{ty} min	e(2 in) min	F_{tu} min	F_{ty} min	e(2 in) min
Specimen	F 1	ksi	ksi	ksi	ksi	ksi	ksi
Cut from casting (single)	75	28.0	17.5	1.0	26.5	15.5	-
(average of 4 or more)	75	31.5	19.5	2.0	31.5	17.5	1.25
Separately cast	75	35.0	22.0	5.0	35.0	22.0	5.0

- 3.02 Mechanical Properties at Room Temperature
3.021 Tension. Typical. F_{tu} = 40.0 ksi, F_{ty} = 25.0 ksi, and e(2 inches) = 6 percent.
3.0211 Stress-strain diagrams (see Figure 3.0311).
3.0212 Effect of section thickness on tensile properties. Figure 3.0212.
3.0213 Effect of end chill on tensile properties of cast plates of two thicknesses. Figure 3.0213.

Mg
1.5 Th
5.7 Zn
0.7 Zr

ZH62A

Mg
1.5 Th
5.7 Zn
0.7 Zr

ZH62A

- 3.022 Compression Typical $F_{CY} = 25.0$ ksi (11).
 3.0221 Stress-strain diagrams.
 3.023 Impact. Notched Izod - 2.5 ft-lbs (5).
 3.024 Bending.
 3.025 Torsion and shear.
 3.0251 Typical shear, $F_{su} = 24.0$ ksi (11).
 3.026 Bearing. Typical for separately sand-cast test specimens with $e/D=2.5$ (3)(11). $F_{bru} = 72.0$ ksi, $F_{bry} = 49.0$ ksi.
 3.027 Stress concentration.
 3.0271 Notch properties.
 3.0273 Fracture toughness.
 3.028 Combined properties.

Mechanical Properties at Various Temperatures

- 3.03 Tension.
 3.031 Stress strain diagrams.
 3.0311 Complete tensile stress strain curves at various temperatures, Figure 3.0314.
 3.0312 Effect of elevated temperatures on tensile properties, Figure 3.0312.
 3.0313 Effect of subzero temperatures on tensile properties, Figure 3.0313.
 3.0314 Effect of strain rate on tensile properties at different temperatures, Figure 3.0314.
 3.032 Compression.
 3.0321 Stress-strain diagrams.
 3.033 Impact.
 3.0331 Effect of subzero temperatures on Charpy impact strength, Figure 3.0331.
 3.034 Bending.
 3.035 Torsion and shear.
 3.036 Bearing.
 3.037 Stress concentration.
 3.0371 Notch properties.
 3.0372 Fracture toughness.
 3.038 Combined properties.

Creep and Creep Rupture Properties

- 3.04 Effect of temperature and stress on time to various amounts of creep extension, Figure 3.041.

Fatigue Properties

- 3.05 Wohler fatigue strength at 300F, sand-cast, smooth machined specimens: 10^7 cycles, 8.5 ksi; 5×10^7 cycles, 7.6 ksi (6).

Elastic Properties

- 3.06 Poisson's ratio, 0.3 (5).
 3.061 Modulus of elasticity.
 3.062 Effect of temperature on tension modulus, Figure 3.0621.
 3.063 Modulus of rigidity, 2.5×10^5 ksi (5).

4. FABRICATION

4.01 Formability

4.02 Machining and Grinding

- 4.021 This alloy, like other magnesium alloys, has exceptionally good machinability, which enables it to be machined at high speeds and feeds. For further details, see HZ32A, Code 3408, Section 4.021.
 4.022 The alloy can be chemically milled with sulfuric, nitric, or hydrochloric acid of 5 percent strength or greater (6).

4.03 Welding

- 4.031 The alloy can be arc welded with helium or argon shielding and ZH62A or EZ33A electrodes. One of the artificial aging treatments (Section 1.05 or 1.051) should be applied after welding (1)(3)(5).
 4.032 ZH62A should not be gas welded because of probable losses of zirconium (6).

4.04 Surface Treatment

(See HZ32A, Code 3408, Sections 4.041 and 4.042)

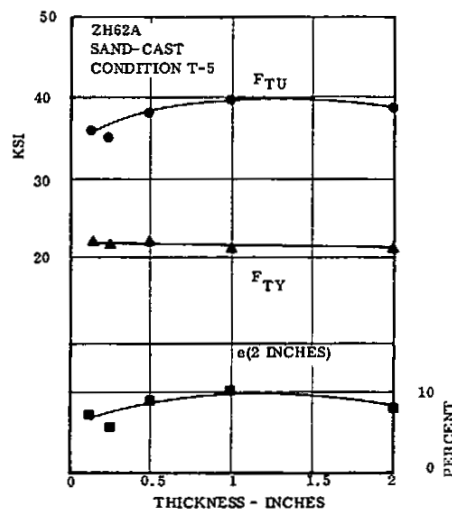


FIG. 3.0212 EFFECT OF SECTION THICKNESS ON TENSILE PROPERTIES (10).

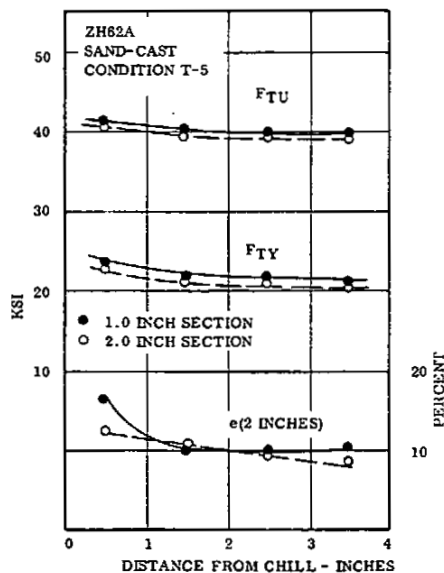


FIG. 3.0213 EFFECT OF END CHILL ON TENSILE PROPERTIES OF CAST PLATES OF TWO THICKNESSES (10).

CODE 3407

PAGE 2

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NONFERROUS ALLOYS

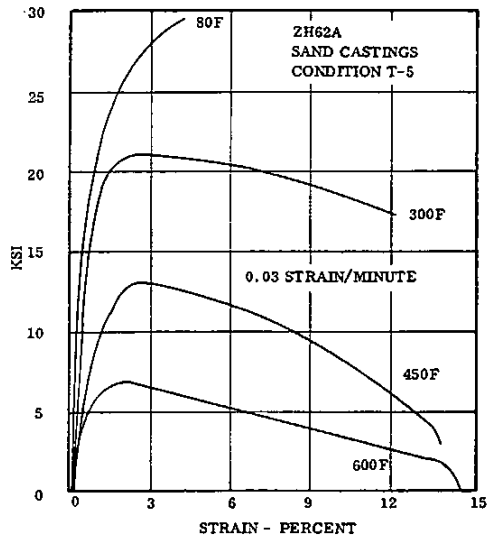


FIG. 3.03111 COMPLETE TENSILE STRESS-STRAIN CURVES AT VARIOUS TEMPERATURES (9).

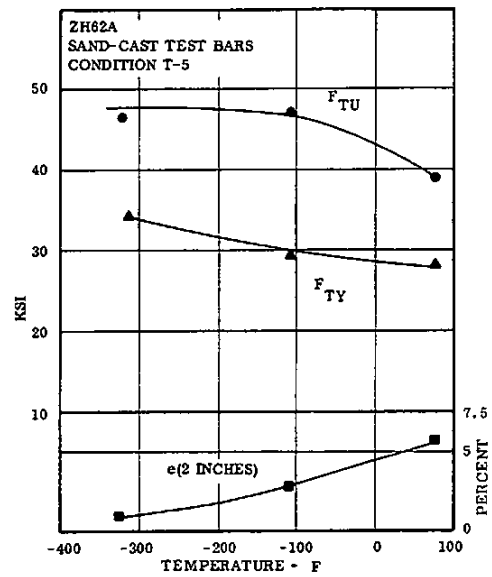


FIG. 3.0313 EFFECT OF SUBZERO TEMPERATURES ON TENSILE PROPERTIES (11).

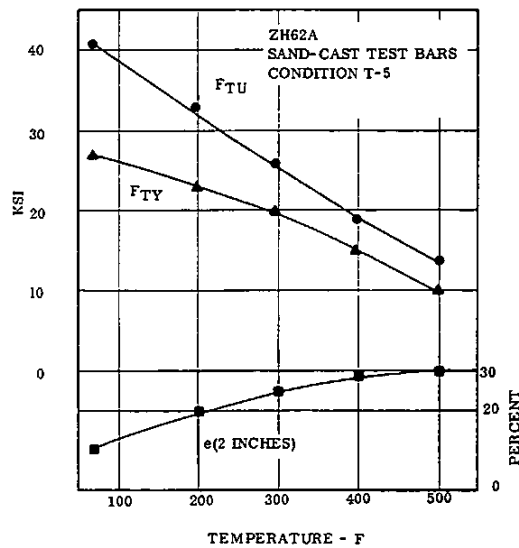


FIG. 3.0312 EFFECT OF ELEVATED TEMPERATURES ON TENSILE PROPERTIES (12).

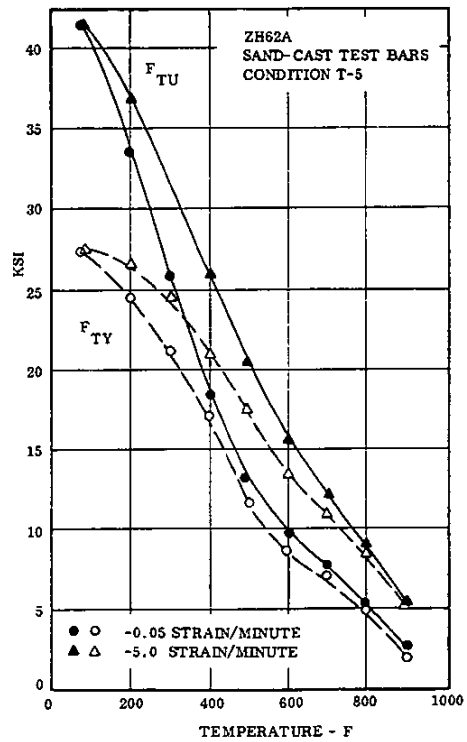


FIG. 3.0314 EFFECT OF STRAIN RATE ON TENSILE PROPERTIES AT DIFFERENT TEMPERATURES (13).

Mg
1.5 Th
5.7 Zn
0.7 Zr

ZH62A

REVISED MARCH 1963

NONFERROUS ALLOYS

1. **GENERAL**
This non-heat treatable magnesium alloy containing zinc and rare earth is a recent development for room temperature service. It is available in the form of sheet and plate. In either the 0 or H24 Condition, this alloy possesses the best ductility of all magnesium sheet alloys. It also exhibits good weldability and needs no postweld stress relief anneal.

- 1.01 **Commercial Designation.** ZE 10 A.
1.02 **Alternate Designations.** None.
1.03 **Specifications.** AMS specification pending.
1.04 **Composition.** Table 1.04.

Source	(1)	
	Min	Max
Zinc	1.0	1.5
Rare Earths	0.12	0.22
Impurities, Total	-	0.30
Magnesium	Balance	

- 1.05 **Heat Treatment**
1.051 **Anneal** to 0 Condition for maximum formability. 500 F, 1 hr.
1.052 **Hot roll** and partial anneal to H24 Condition by supplier.
1.06 **Hardenability.** This alloy can be hardened only by cold work.
1.07 **Forms and Conditions Available.** Sheet and plate are available in thicknesses from 0.016 to 0.500 in in 0 Condition, and from 0.016 to 0.250 in in H24 Condition.
1.08 **Melting and Casting Practice.** See AZ 31 B.
1.09 **Special Considerations**
1.091 **When welding** sheet and plate of this alloy to magnesium alloy extrusions, an extrusion alloy which does not require post weld stress relief is recommended.

2. **PHYSICAL AND CHEMICAL PROPERTIES**

- 2.01 **Thermal Properties**
2.011 **Melting range.** 1100 to 1195 F.
2.012 **Phase changes.** None.
2.013 **Thermal conductivity.** 0 Condition, 79.7 Btu ft (hr sq ft F). H24 Condition, 76.7 Btu ft (hr sq ft F).
2.014 **Thermal expansion.** See AZ 31 B.
2.015 **Specific heat.** 0.25 Btu per (lb F).
2.016 **Diffusivity.** 0 Condition, 3.04 sq ft per hr. H24 Condition, 2.95 sq ft per hr.
2.02 **Other Physical Properties**
2.021 **Density.** 0.0634 lb per cu in. 1.758 gr per cu cm.
2.022 **Electrical resistivity.** 0 Condition, 1.97 microhm-in. H24 Condition, 2.05 microhm-in.
2.023 **Magnetic properties.** Alloy is nonmagnetic.
2.03 **Chemical Properties**
2.031 **Corrosion resistance.** General corrosion resistance of the alloy is similar to AZ 31 B.
2.0311 **Alloy is more susceptible to pitting** than AZ 31 B.
2.0312 **Alloy is free from stress corrosion cracking.**
2.032 **Oxidation resistance.** See AZ 31 B.

- 2.04 **Nuclear Properties.** See EZ 33 A.

3. **MECHANICAL PROPERTIES**3.01 **Specified Mechanical Properties**

- 3.011 **Producers' specified mechanical properties, Table 3.011.**

Source	(1)					
	Sheet, Plate			H24		
Condition	0			H24		
Thickness - in	0.016 to 0.060	0.061 to 0.250	0.251 to 0.500	0.016 to 0.125	0.126 to 0.188	0.189 to 0.250
F_{tu} , min - ksi	30	30	29	36	34	31
F_{ty} , min - ksi	-	-	-	-	-	-
F_{cy} , min - ksi	-	-	-	-	-	-
$e(2 in)$ min-percent	15	15	12	4	4	4

- 3.02 **Mechanical Properties at Room Temperature**
3.021 **Typical mechanical properties, Table 3.021.**

Source	(1)					
	Sheet, Plate			H24		
Condition	0			H24		
Thickness - in	0.016 to 0.060	0.061 to 0.250	0.251 to 0.500	0.016 to 0.125	0.126 to 0.188	0.189 to 0.250
F_{tu} - ksi	33	33	31	38	37	34
F_{ty} - ksi	23	20	16	28	25	19
F_{cy} - ksi	16	16	12	26	24	16
$e(2 in)$ - percent	23	23	18	12	12	8

- 3.022 **Stress strain curves in tension** for sheet in 0 and H24 Conditions, Fig. 3.022.
3.023 **Stress strain curves in compression** for sheet in 0 and H24 Conditions, Fig. 3.023.
3.03 **Mechanical Properties at Various Temperatures**
3.04 **Creep and Creep Rupture Properties**
3.05 **Fatigue Properties.** Table 3.05.

Source	(1)						
Form	0.064 to 0.190 in Sheet						
Condition	-						
Temp F	Method	Stress Ratio		Stress Concen- tration	Fatigue Strength-ksi at Cycles		
		A	B		10 ⁵	10 ⁶	10 ⁷
RT	Direct Stress	1	0	Smooth K=1	19	16	15
		0.33	0.5		25	23	22

- 3.06 **Elastic Properties**
3.061 **Modulus of elasticity** at room and elevated temperatures, Fig. 3.061.
3.062 **Modulus of rigidity.** 2,400 ksi.
3.063 **Poisson's ratio.** 0.34.

4. **FABRICATION.** Similar to AZ 31 B. Complementary and different information is listed below.

- 4.01 **Forming**
4.011 **Hot forming** of 0 Condition is performed at 500 F maximum, with the maximum time at temperature being limited to 1 hr.
4.012 **Hot forming** of H24 Condition is performed at 275 F maximum, with the time at temperature being limited to 1 hr.
4.013 **Bending.** Suggested bend factors, Fig. 4.013.
4.03 **Welding.** This alloy possesses good weldability. For fusion welding, AZ 92 A, AZ 61 A or EZ 33 A welding rod can be used. It may be necessary to provide back up plates if AZ 92 A or AZ 61 A rod is used. No corrosion cracking

Mg
1 Zn
0.2 RE
ZE 10 A

Mg
1 Zn
0.2 RE

ZE 10 A

4.031 will occur with these welding rod materials if the alloy is welded to itself, and no stress relief is required.
Tensile properties of 0.063 in welded sheet, Table 4.031.

TABLE 4.031									
(1)									
Source	Sheet 0.063 in								
Form	Sheet 0.063 in								
Condition	O				H24				
	Base Metal	Welded with Rod AZ 61A	AZ 92A	BZ 33A	Base Metal	Welded with Rod AZ 61A	AZ 92A	BZ 33A	
F_u - ksi	34	31	30	29	39	32	32	31	
F_y - ksi	26	17	16	17	30	16	18	18	
e (in) - percent	29	8	6	6	12	4	4	4	
Weld Efficiency, Percent	-	91	88	85	-	82	82	80	

4.032 Fatigue properties of welded sheet, Table 4.032.

TABLE 4.032									
(1)									
Source	0.064 to 0.190 in Sheet								
Form	Welded with AZ92A Rod								
Condition	Welded with AZ92A Rod								
Temp F	Method	Stress Ratio		Stress Concentration	Fatigue Strength - ksi at Cycles				
		A	R		10^5	10^6	10^7		
RT	Direct Stress	0.33	0.50	K = 1	8.5	6	5.5		
					13	9	8		

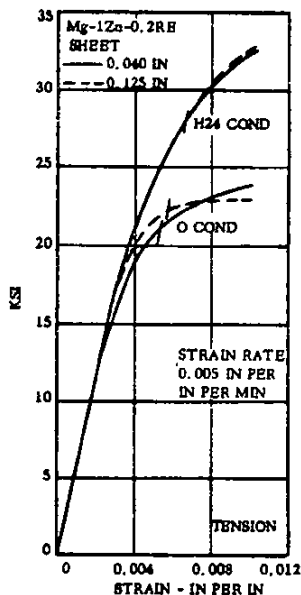


FIG. 3.022 STRESS STRAIN CURVES IN TENSION FOR SHEET IN O AND H24 CONDITIONS (2)

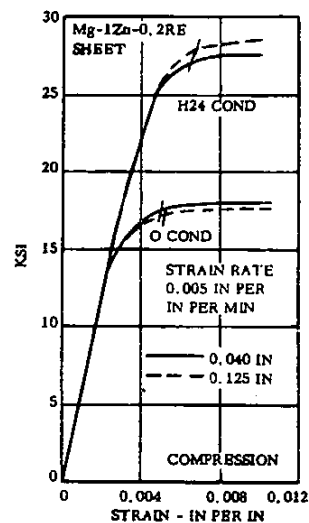


FIG. 3.023 STRESS STRAIN CURVES IN COMPRESSION FOR SHEET IN O AND H24 CONDITIONS (2)

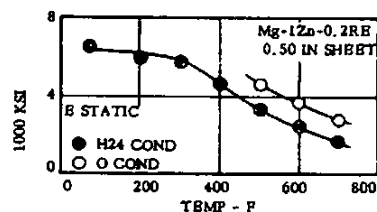


FIG. 3.061 MODULUS OF ELASTICITY AT ROOM AND ELEVATED TEMPERATURES (3)

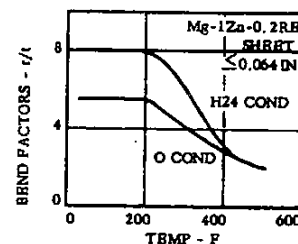


FIG. 4.013 SUGGESTED BEND FACTORS (1)

REFERENCES

- 1 The Dow Chemical Co., "ZE 10 A Magnesium Alloy Sheet and Plate", (1958)
- 2 The Dow Chemical Co., "Stress-Strain Curves for ZE 10 A (Sheet)", (Feb. 16, 1959)
- 3 Fenn, R. W., Jr., "Young's Modulus of Magnesium Alloys as a Function of Temperature and Metallurgical Variables", The Dow Chemical Co., (June 22-27, 1959)

RELEASED: DECEMBER 1969
AUTHOR: J.R. KATTUS

NONFERROUS ALLOYS

1. GENERAL
ZH62A is a magnesium-base casting alloy which combines a reasonable degree of castability with excellent strength up to 300F. Its strength properties drop sharply at temperatures above 300F. Its castability is rated above that of ZK51A and ZK61A but below that of QE22A, which are other high-strength magnesium casting alloys; however, the ductility of ZH62A is considerably better than that of QE22A. ZH62A has excellent weldability and machinability. Like other magnesium alloys, coatings are recommended to prevent corrosion in humid, salt-spray, and marine environments. It is used only in the artificially aged (T-5) condition and should be considered for any aerospace or other applications requiring a high strength-to-weight ratio at temperatures up to 300F.

1.01 Commercial Designation
ZH62A

1.02 Alternate Designations
ZH62XA, TZ6 (British)

1.03 Specifications
AMS 4438B
ASTM B80-68
U.S. Federal QQ-M-56b (1)
SAE 508
MIL-M-46062A

1.04 Composition
Table 1.04.

TABLE 1.04

Alloy	ZH62A			
	Composition			
	AMS 4438B (18)		ASTM B80-68	
	Percent		Percent	
Source	Minimum	Maximum	Minimum	Maximum
Zinc	5.2	6.2	5.2	6.2
Thorium	1.4	2.2	1.4	2.2
Zirconium				
total	0.50	1.0	0.50	1.0
soluble*	0.50			
Copper		0.10		0.10
Nickel		0.01		0.01
Others		0.30		0.30
Magnesium	Balance		Balance	

* Soluble zirconium is that portion of the zirconium that is soluble in 1:4 hydrochloric acid held below its boiling point.

- 1.05 Heat Treatment
Artificially age 470 to 490F, 12 to 16 hours, AC to Condition T-5 (1).
- 1.051 Alternative age treatment for Condition T-5, 615 to 635F 2 hours, AC, plus 340 to 360F, 16 hours (1)(2).
- 1.06 Hardness
1.061 BHN 65-80 with 1000 kg load and 10 mm ball (18).
1.062 BHN 60-75 with 500 kg load and 10 mm ball or 1000 kg load and 9/16 inch ball (18).
- 1.07 Forms and Conditions Available
Produced as castings and used in the T-5 (artificially aged) condition.
- 1.08 Melting and Casting Practice (2)
(see HZ32A cast magnesium alloy)
- 1.09 Special Considerations
1.091 Contamination of the alloy with more than 0.005 percent aluminum should be avoided to prevent the formation of aluminum-zirconium compounds, which are detrimental to mechanical properties (5).
1.092 The alloy has excellent dimensional stability at service temperatures up to at least 300F (6).

2. PHYSICAL AND CHEMICAL PROPERTIES

- 2.01 Thermal Properties
2.011 Melting range.
2.0111 The liquidus temperature is 1169F (2).
2.012 Phase changes. One or more zinc-zirconium phases are formed during artificial aging. Optimum mechanical properties are dependent upon a uniform distribution of these phases in finely divided form (4).
2.0121 Time-temperature-transformation diagrams.
2.013 Thermal conductivity. 63.0 Btu ft per (hr sq ft F) at 68F (2)(5).
2.014 Thermal expansion. 15.1×10^{-6} per F from 68 to 392F (5)(6).
2.015 Specific heat. 0.23 Btu per (lb F) from 68 to 212F (5)(6).
2.016 Thermal diffusivity.

- 2.02 Other Physical Properties
2.021 Density. 1.86 g/cc (2)(5). 0.0675 lb/cubic inch (6).
2.022 Electrical properties.
2.0221 Electrical conductivity. 0.39 megmhos/in³ at 68F (6). 25.5 percent IACS at 68F (5).
2.0222 Electrical resistivity. 2.56 microhm-inch at 68F (5).
2.023 Magnetic properties.
2.024 Emission.
2.025 Damping capacity. At a stress equal to 0.1 F_{ty} the specific damping capacity is 0.14, which is relatively low in comparison with most other magnesium alloys (7).

- 2.03 Chemical Properties
2.031 ZH62A, like other magnesium alloys, will corrode in industrial, marine, and moist environments. With suitable surface treatment and painting, it will perform satisfactorily in all types of natural environments, with the exception of continuous immersion in water (17). For a discussion of galvanic corrosion see Code 3601, Section 2.0312.
2.032 Safety precautions should be directed to the prevention of fires, burns, and explosions. See HZ32A, Code 3408, Section 2.032.
2.04 Nuclear Properties
2.041 Thorium metal is radioactive, but the amount contained in this alloy is not sufficient to constitute a hazard in normal handling. For precautions during melting and welding, see HZ32A, Code 3408, Section 2.041.
2.042 The slight radioactivity of the alloy causes no interference in the sending and receiving of radar and radio signals (8).

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Cut from casting (single)	75	28.0	17.5	1.0	26.5	15.5	-
(average of 4 or more)	75	31.5	19.5	2.0	31.5	17.5	1.25
Separately cast	75	35.0	22.0	5.0	35.0	22.0	5.0

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3.021 Tension. Typical. F_{tu} = 40.0 ksi, F_{ty} = 25.0 ksi, and $e(2 \text{ inches})$ = 6 percent.
3.0211 Stress-strain diagrams (see Figure 3.0311).
3.0212 Effect of section thickness on tensile properties. Figure 3.0212.
3.0213 Effect of end chill on tensile properties of cast plates of two thicknesses. Figure 3.0213.

Mg
1.5 Th
5.7 Zn
0.7 Zr

ZH62A

Mg
1.5 Th
5.7 Zn
0.7 Zr

ZH62A

- 3.022 Compression Typical $F_{CY} = 25.0$ ksi (11).
 3.0221 Stress-strain diagrams.
 3.023 Impact. Notched Izod - 2.5 ft-lbs (5).
 3.024 Bending.
 3.025 Torsion and shear.
 3.0251 Typical shear, $F_{su} = 24.0$ ksi (11).
 3.026 Bearing. Typical for separately sand-cast test specimens with $e/D = 2.5$ (3)(11). $F_{bru} = 72.0$ ksi, $F_{bry} = 49.0$ ksi.
 3.027 Stress concentration.
 3.0271 Notch properties.
 3.0273 Fracture toughness.
 3.028 Combined properties.

Mechanical Properties at Various Temperatures

- 3.03 Tension.
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 3.0311 Complete tensile stress strain curves at various temperatures, Figure 3.0314.
 3.0312 Effect of elevated temperatures on tensile properties, Figure 3.0312.
 3.0313 Effect of subzero temperatures on tensile properties, Figure 3.0313.
 3.0314 Effect of strain rate on tensile properties at different temperatures, Figure 3.0314.
 3.032 Compression.
 3.0321 Stress-strain diagrams.
 3.033 Impact.
 3.0331 Effect of subzero temperatures on Charpy impact strength, Figure 3.0331.
 3.034 Bending.
 3.035 Torsion and shear.
 3.036 Bearing.
 3.037 Stress concentration.
 3.0371 Notch properties.
 3.0372 Fracture toughness.
 3.038 Combined properties.

Creep and Creep Rupture Properties

- 3.04 Effect of temperature and stress on time to various amounts of creep extension, Figure 3.041.

Fatigue Properties

- 3.05 Wohler fatigue strength at 300F, sand-cast, smooth machined specimens: 10^7 cycles, 8.5 ksi; 5×10^7 cycles, 7.6 ksi (6).

Elastic Properties

- 3.06 Poisson's ratio, 0.3 (5).
 3.061 Modulus of elasticity.
 3.062 Effect of temperature on tension modulus, Figure 3.0621.
 3.063 Modulus of rigidity, 2.5×10^5 ksi (5).

4. FABRICATION

4.01 Formability4.02 Machining and Grinding

- 4.021 This alloy, like other magnesium alloys, has exceptionally good machinability, which enables it to be machined at high speeds and feeds. For further details, see HZ32A, Code 3408, Section 4.021.
 4.022 The alloy can be chemically milled with sulfuric, nitric, or hydrochloric acid of 5 percent strength or greater (6).

4.03 Welding

- 4.031 The alloy can be arc welded with helium or argon shielding and ZH62A or EZ33A electrodes. One of the artificial aging treatments (Section 1.05 or 1.051) should be applied after welding (1)(3)(5).
 4.032 ZH62A should not be gas welded because of probable losses of zirconium (6).

4.04 Surface Treatment

(See HZ32A, Code 3408, Sections 4.041 and 4.042)

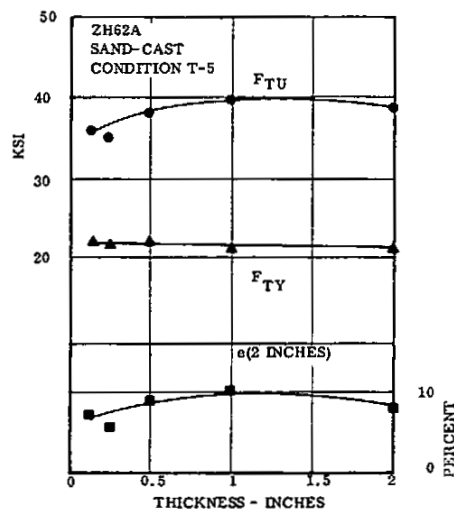


FIG. 3.0212 EFFECT OF SECTION THICKNESS ON TENSILE PROPERTIES (10).

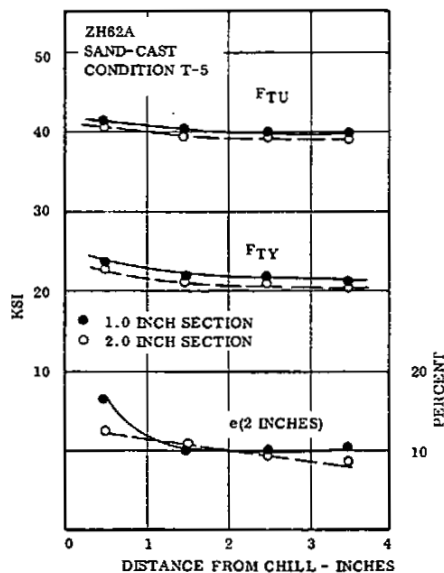


FIG. 3.0213 EFFECT OF END CHILL ON TENSILE PROPERTIES OF CAST PLATES OF TWO THICKNESSES (10).

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NONFERROUS ALLOYS

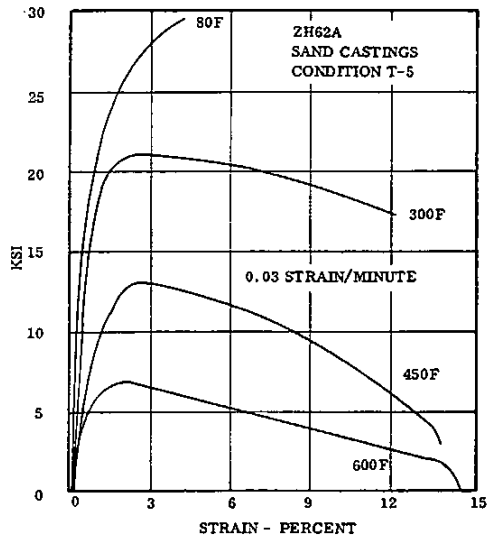


FIG. 3.03111 COMPLETE TENSILE STRESS-STRAIN CURVES AT VARIOUS TEMPERATURES (9).

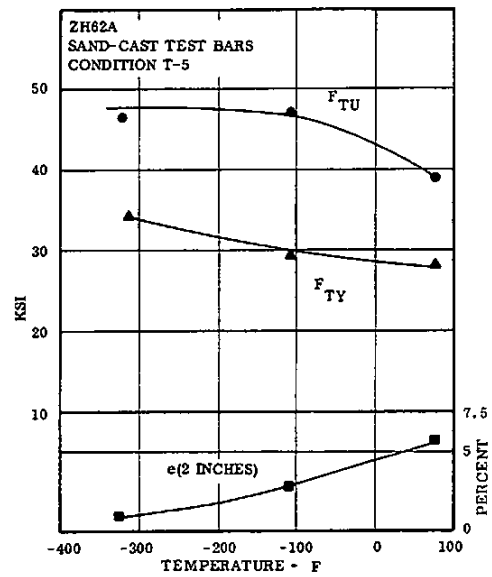


FIG. 3.0313 EFFECT OF SUBZERO TEMPERATURES ON TENSILE PROPERTIES (11).

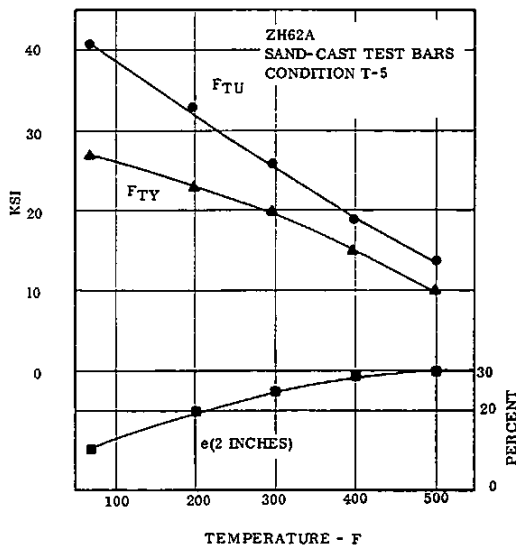


FIG. 3.0312 EFFECT OF ELEVATED TEMPERATURES ON TENSILE PROPERTIES (12).

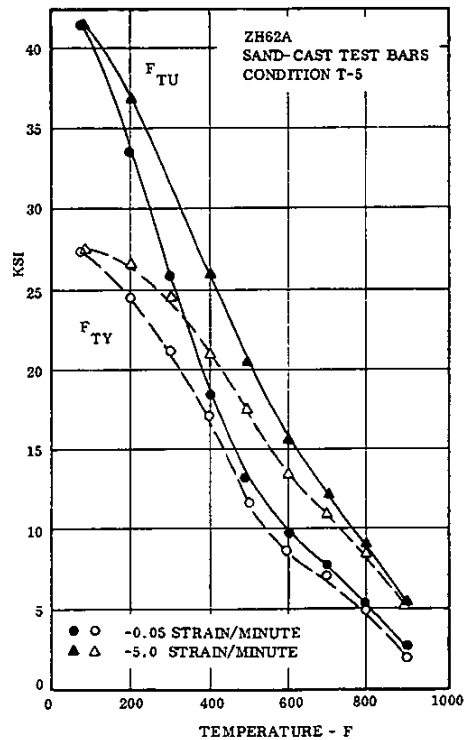
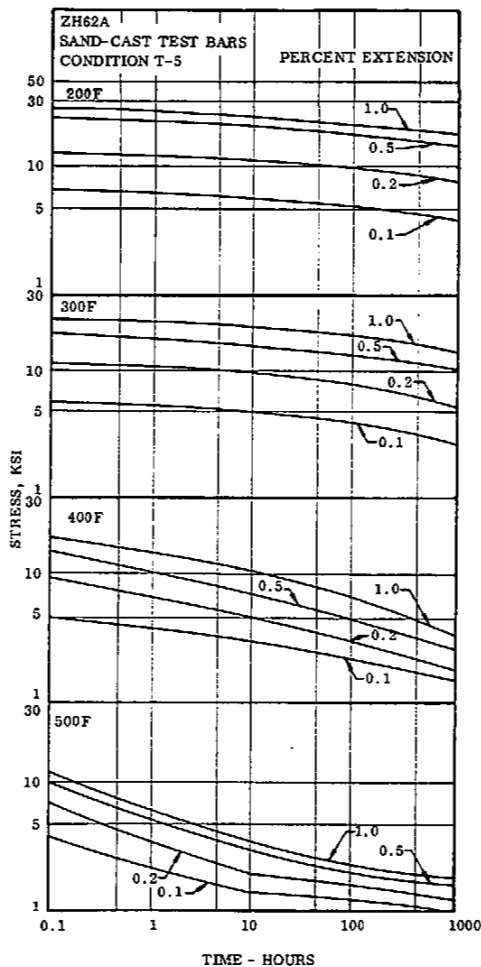
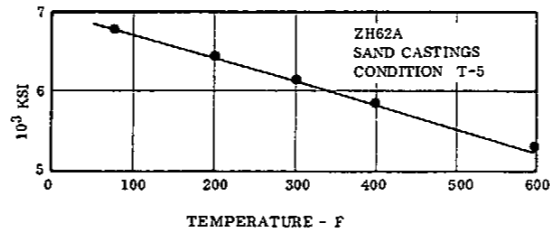
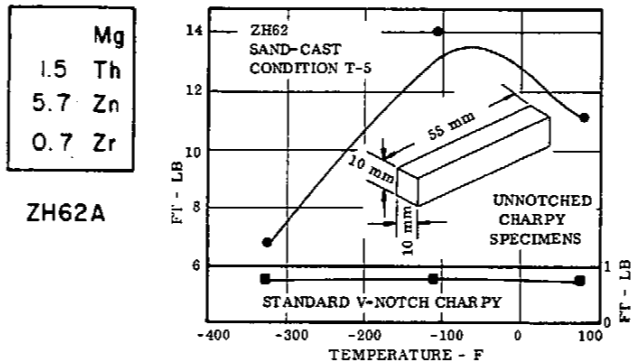


FIG. 3.0314 EFFECT OF STRAIN RATE ON TENSILE PROPERTIES AT DIFFERENT TEMPERATURES (13).

Mg
1.5 Th
5.7 Zn
0.7 Zr

ZH62A



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NONFERROUS ALLOYS

1. GENERAL

ZK 51 A is used for sand castings possessing high strength and good ductility. It is recommended for small or relatively simple, highly stressed parts of uniform cross section. This alloy is used in the T5 Condition which requires only a low temperature artificial aging. It has limited weldability, (3, p. 1102).

1.01 Commercial Designation. ZK 51 A.1.02 Alternate Designation1.03 Specifications. Table 1.03.

TABLE 1.03

AMS	Form	Federal	ASTM
4443 A	Castings, sand	QQ-M-56(a)	B80-56T

1.04 Composition. Table 1.04.

TABLE 1.04

Source	AMS (1)	
	Min	Max
Copper	-	0.10
Nickel	-	0.01
Zinc	3.60	5.50
Zirconium, total *	0.50	1.00
Zirconium, soluble	0.50	-
Other impurities, total	-	0.30
Magnesium	Balance	

*0.05 to 0.10 percent insoluble Zr normal (2)

1.05 Heat Treatment

1.051 Age. From as-cast to T5 Condition. 12 hr at 340 to 360 F, (3, p. 1103).

1.06 Hardenability1.07 Forms and Conditions Available.

1.071 Sand castings in T5 Condition.

1.08 Melting and Casting Practice.

1.081 This alloy requires special handling and procedures. Use sufficient flux to control oxidation, (3, p. 1103). Casting temperature 1300 to 1550 F.

1.09 Special Considerations.

1.091 Avoid contamination with aluminum during melting.

2. PHYSICAL AND CHEMICAL PROPERTIES

2.01 Thermal Properties

2.011 Melting range. Solidus temperature 1020 F. Liquidus temperature 1125 F, (3, p. 1103).

2.012 Phase changes. None.

2.013 Thermal conductivity, Fig. 2.013.

2.014 Thermal expansion. At 68 F, 14.5×10^{-6} in per in per F, (3, p. 1102).

2.015 Specific heat. At 68 F, 0.244 Btu per lb F, (3, p. 1102).

2.016 Latent heat of fusion, 76 Cal per gr or 137 Btu per lb, (3, p. 1102).

2.017 Effect of test temperature on emissivity of magnesium alloys, Fig. 2.017.

2.02 Other Physical Properties

2.021 Density. At 68 F, 0.0656 lb per cu in. 1.81 gr per cu cm, (3, p. 1102).

2.022 Electrical resistivity, Fig. 2.022.

2.023 Magnetic properties. Nonmagnetic.

2.03 Chemical Properties

2.031 Corrosion resistance, same as AZ 31 B.

2.032 Oxidation resistance, same as AZ 31 B.

2.04 Nuclear Properties

3. MECHANICAL PROPERTIES

3.01 Specified Mechanical Properties

3.011 AMS specified minimum mechanical properties, Table 3.011.

Mg
4.5 Zn
0.7 Zr

ZK 51 A

TABLE 3.011

Source	AMS (1)		
Alloy	Mg-4.5Zn-0.7Zr		
Form	Sand casting (a)	Sand casting (b)	Sand test bars
Condition	T5		
F _u , min-ksi	29	24	34
F _y , min-ksi	17	14	20
ε(2 in) typ-percent	2	-	5(d)
Hardness, BHN - min	55(c)	55(c)	-

(a) Specimens from castings, AMS recommends not less than 4 and preferably 10 specimens, values are averages.

(b) Individual specimens from castings.

(c) 500 kg load and 10 mm ball.

(d) ε(2 in).

3.02 Mechanical Properties at Room Temperature

3.021 Typical mechanical properties, Table 3.021

TABLE 3.021

Source	(4, p. 23)
Alloy	Mg-4.5Zn-0.7Zr
Condition	T5
F _u , typ - ksi	40
F _y , typ - ksi	26
ε(2 in) typ-percent	8
F _{cy} , typ - ksi	26
F _{su} , typ - ksi	22
F _{br} , typ - ksi	72
F _{br} , typ - ksi	47
Hardness	
BHN, typ	65
RE, typ	77

3.03 Mechanical Properties at Various Temperatures

3.031 Elevated temperature tensile properties

3.0311 Effect of elevated temperature on tensile properties of alloy in T5 Condition, Fig. 3.0311.

3.0312 Effects of test temperature and strain rate on tensile properties of sand cast test bars in T5 Condition, Fig. 3.0312.

3.04 Creep and Creep Rupture Properties

3.041 Total strain curves for alloy in T5 Condition at 200 and 400F, Fig. 3.041.

3.042 Total strain curves for alloy in T5 Condition at 300 F, Fig. 3.042.

3.05 Fatigue Properties3.05 Elastic Properties

3.051 Modulus of elasticity, 6,500 ksi, (5, p. 4.107).

3.0511 Static compression modulus, 6,500 ksi, (5, p. 4.107).

3.0512 Modulus of rigidity, 2,400 ksi, (5, p. 4.107).

3.052 Poisson's ratio, 0.35, (4, p. 26).

4. FABRICATION

4.01 Forming and Casting

4.011 Casting temperature, 1300 to 1550 F, (3, p. 1103).

4.012 Casting design. When this alloy is used for highly stressed parts, casting design should be simple, with uniform cross sections, (4, p. 53).

CODE 3405

PAGE 1

Mg
4.5 Zn
0.7 Zr

ZK 51A

- 4.02 Machining
 4.021 Magnesium and Magnesium alloys have excellent machinability and can be machined at higher speeds and greater economy than most common metals, (3, p. 1084)(4, p. 7).
- 4.03 Welding
 4.031 This alloy has limited weldability. Where welding must be performed, use Helium or Argon gas methods with EZ 33 A or ZK 51 A welding rod and stress relieve, (3, p. 1103).
- 4.04 Heating and Heat Treating
- 4.05 Surface Treating. See AZ 63 A.

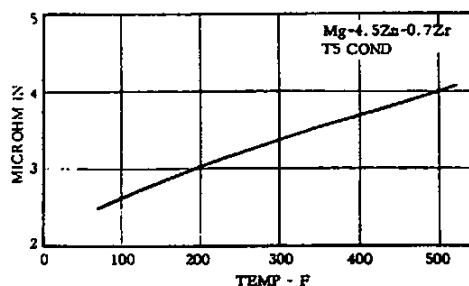


FIG. 2.022 ELECTRICAL RESISTIVITY

(6, tbl. IV)

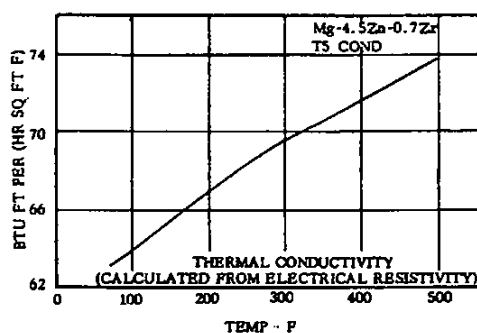


FIG. 2.013 THERMAL CONDUCTIVITY

(6, tbl. V)

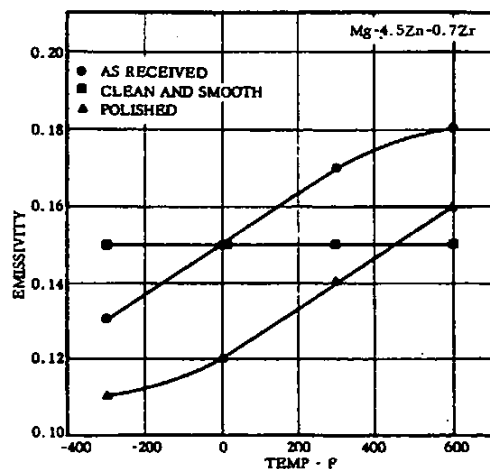


FIG. 2.017 EFFECT OF TEST TEMPERATURE ON EMISSIVITY OF MAGNESIUM ALLOYS

(8, Exhibit A)

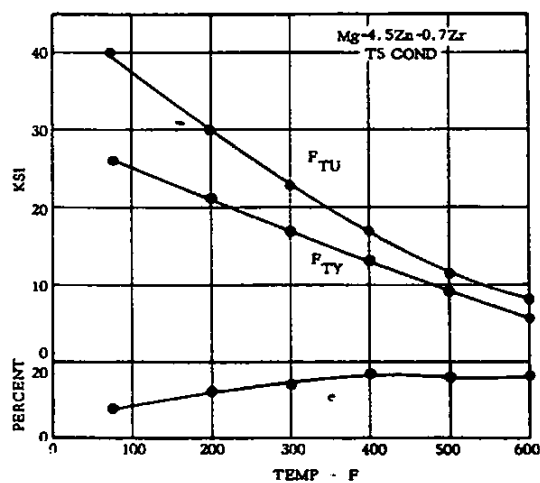


FIG. 3.0311 EFFECT OF ELEVATED TEMPERATURE ON TENSILE PROPERTIES OF ALLOY IN TS CONDITION

(3, p. 1103)

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NONFERROUS ALLOYS

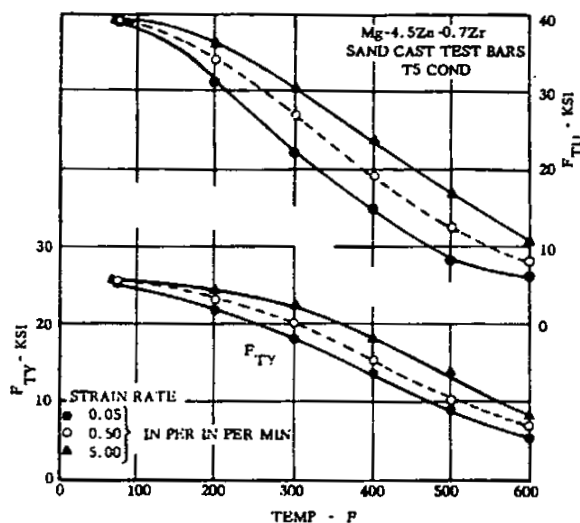


FIG. 3.0312 EFFECT OF TEST TEMPERATURE AND STRAIN RATE ON TENSILE PROPERTIES OF SAND CAST TEST BARS IN T5 CONDITION (7, tbl. IV)

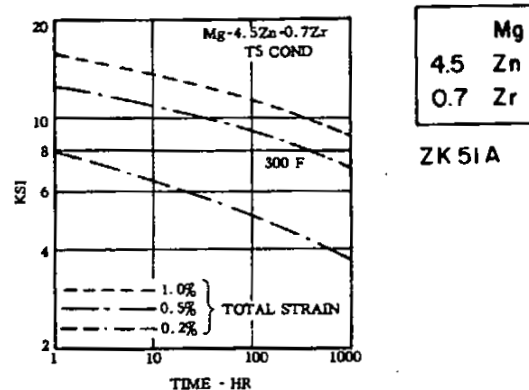


FIG. 3.042 TOTAL STRAIN CURVES FOR ALLOY IN T5 CONDITION AT 300 F (3, p. 1103)

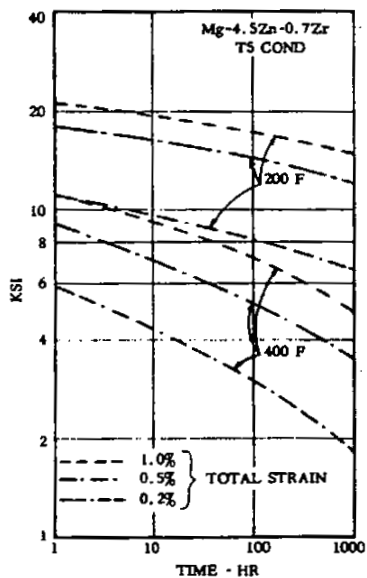


FIG. 3.041 TOTAL STRAIN CURVES FOR ALLOY IN T5 CONDITION AT 200 AND 400 F (3, p. 1103)

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REVISED: MARCH 1972
AUTHOR: J.R. KATTUS

NONFERROUS ALLOYS

- | | |
|-----|----|
| | Mg |
| 5.5 | Zn |
| 0.5 | Zr |
- ZK60A
1. GENERAL
This heat treatable magnesium alloy, which is usually used in either the T5 (artificially aged) or the T6 (solution treated and aged) condition is produced in the form of extrusions and forgings. It has similar high strength properties to AZ80A, and its ductility and toughness are superior to those of any other magnesium extrusion and forging alloys. At temperatures above 300 F, its strength falls below that of the thorium containing alloy, HM31A. ZK60A has poor arc-weldability, but reasonably good resistance-weldability. This alloy is used for highly stressed parts, primarily in aerospace and military applications at temperatures up to 300 F. A variation of this alloy, designated (P)ZK60B, was formerly made by extruding atomized ZK60A alloy into structural shapes. It was used commercially to a very limited extent but is now obsolete and no longer produced.
 - 1.01 Commercial Designation
ZK60A.
 - 1.02 Alternate Designations
ZK60 and ZW6(British).
 - 1.03 Specifications
Table 1.03
 - 1.04 Composition
Table 1.04.
 - 1.05 Heat Treatment
 - 1.051 T5 condition: age as-forged (F condition) material at 290 to 310 F 24 hours, air cool (6).
 - 1.052 T6 condition: Solution treat at 925 to 935 F 2 hours in furnace atmosphere containing 1.0 percent minimum SO₂ or 5.0 percent minimum CO₂, air cool, age at 290 to 310 F 24 hours, air cool (6)(7).
 - 1.053 O condition, full anneal: 550 F 1 hour, air cool (6).
 - 1.054 Stress relief after forming or welding: for material in F condition 500 F 15 minutes, air cool; for material in T5 or T6 condition 300 F 1 hour, air cool (6)(8).
 - 1.06 Hardness
Table 1.06.
 - 1.07 Forms and Conditions Available
Table 1.07.
 - 1.08 Melting and Casting Practice
(See AZ31B, Code 3601, Section 1.08.)
 - 1.09 Special Considerations
 - 1.091 In the T5 and T6 conditions, ZK60A loses room temperature strength rapidly as a result of exposures to temperatures above 300 F.
 2. PHYSICAL AND CHEMICAL PROPERTIES
 - 2.01 Thermal Properties
 - 2.011 Melting range. 970 to 1175 F (10).
 - 2.012 Phase changes. In the F condition, this alloy contains magnesium-zinc and zirconium-zinc compounds within an alpha magnesium matrix. T5 (artificial aging) treatment of the F material causes finely divided precipitation of more of these compounds. Solution treatment (930 F) causes most of the compounds to dissolve in the matrix, and artificial aging (about 300 F) causes them to reprecipitate in finely divided form. Prolonged aging at higher temperatures causes coagulation and growth of the precipitates resulting in deterioration of strength.
 - 2.0121 Time-temperature-transformation diagrams.
 - 2.013 Thermal conductivity, Figure 2.013.
 - 2.014 Thermal expansion. $15.0-15.1 \times 10^{-6}$ per F from 65 to 392 F (10).
 - 2.015 Specific heat, Figure 2.015.
 - 2.016 Thermal diffusivity. T5 condition, 2.59 sq ft per hr at 68 F (10).
 - 2.02 Other Physical Properties
 - 2.021 Density. 0.0660 lb per cu in (10).
 - 2.022 Electrical properties, Table 2.022.
 - 2.023 Magnetic properties, non-magnetic.
 - 2.024 Emissance.
 - 2.0241 Effect of temperature on normal total emissance of magnesium alloys in general, Figure 2.0241.
 - 2.025 Damping capacity. At a stress equal to 0.1 F_{ty} the specific damping capacity of ZK60A in both the F and T5 conditions is 0.2, which is a low level compared with other magnesium alloys (13).
 - 2.03 Chemical Properties
 - 2.031 Corrosion resistance.
 - 2.0311 ZK60A, like other magnesium alloys, is subject to stress corrosion and to general and pitting corrosion in industrial, marine, and moist environments. With suitable surface treatment and painting, it performs satisfactorily in all types of natural environments with the exception of continuous immersion in water (14).
 - 2.0312 Effect of stress on time to stress corrosion failure of specimens exposed to atmosphere in Washington, D.C., Figure 2.0312.
 - 2.0313 For a discussion of galvanic corrosion, see AZ31B, Code 3601, Section 2.0312.
 - 2.032 Safety precautions should be directed to the prevention of fires, burns, and explosions (see HZ32A, Code 3408, Section 2.032).
 - 2.04 Nuclear Properties
 3. MECHANICAL PROPERTIES
 - 3.01 Specified Mechanical Properties
Table 3.01.
 - 3.02 Mechanical Properties at Room Temperature
 - 3.021 Tension.
 - 3.0211 Stress-strain diagrams.
 - 3.02111 Stress-strain curves at room temperature for extrusions in different conditions, orientation, and sections sizes, Figure 3.02111.
 - 3.0212 Tensile properties of extrusions and forgings in various conditions and sizes, Table 3.0212.
 - 3.0213 Effect of exposures at elevated temperatures on tensile properties of extrusions at room temperature, Figure 3.0213.
 - 3.0214 Tensile properties in various sections of aircraft wheel forging, Table 3.0214.
 - 3.0215 Effect of rolling reduction and orientation on the tensile properties of roll forged rings produced directly from cast blanks, Figure 3.0215.
 - 3.0216 Effect of rolling reduction and orientation on the tensile properties of roll forged rings produced from upset blanks, Table 3.0216.
 - 3.022 Compression.
 - 3.0221 Stress-strain diagrams.
 - 3.02211 Compressive stress-strain curves at room temperature for extrusions in different conditions, orientations, and sections sizes, Figure 3.02211.
 - 3.0222 Compressive yield strength of extrusions and forgings in various conditions and sizes, Table 3.0222.
 - 3.0223 Effect of exposures at elevated temperatures on compressive yield strength at room temperature, Figure 3.0223.
 - 3.0224 Effect of rolling reduction and orientation on the compressive yield strength of roll forged rings produced directly from cast blanks, Figure 3.0224.
 - 3.0225 Effect of rolling reduction and orientation on the compressive yield strength of roll forged rings produced from upset blanks, Table 3.0225.
 - 3.023 Impact (see Figure 3.0331).
 - 3.024 Bending.
 - 3.025 Torsion and shear.
 - 3.0251 Shear strengths of extrusions and forgings in various conditions and sizes, Table 3.0251.
 - 3.026 Bearing.
 - 3.0261 Bearing properties of extrusions and forgings in various conditions and sizes, Table 3.0261.

Mg
5.5 Zn
0.5 Zr

ZK60A

- 3.027 Stress concentration.
3.0271 Notch properties (see Figure 3.03711).
3.0272 Fracture toughness.
3.028 Combined properties.
- 3.03 Mechanical Properties at Various Temperatures
3.031 Tension.
3.0311 Stress-strain diagrams.
3.03111 Stress-strain curves at room and elevated temperatures for forgings, forged at 600 F from extruded material, Figure 3.03111.
3.03112 Stress-strain curves at room and elevated temperatures for forgings, forged at 800 F from cast material, Figure 3.03112.
3.03113 Stress-strain curves at room and low temperatures for extrusions, Figure 3.03113.
3.0312 Effect of temperature on tensile properties of extrusions, Figure 3.0312.
3.0313 Effect of temperature on tensile properties of forgings, Figure 3.0313.
3.0314 Effect of temperature on tensile properties of extrusions after various exposure times at test temperature, Figure 3.0314.
3.0315 Effect of temperature and strain rate on tensile properties of extrusions in F condition, Figure 3.0315.
3.0316 Effect of temperature and strain rate on tensile properties of extrusions in T5 condition, Figure 3.0316.
3.032 Compression.
3.0321 Stress-strain diagrams.
3.0322 Effect of temperature on compressive yield strength of extrusions, Figure 3.0322.
3.033 Impact.
3.0331 Effect of low temperatures on impact strength of both smooth and notched Charpy bars, Figure 3.0331.
3.034 Bending.
3.035 Torsion and shear.
3.036 Bearing.
3.037 Stress concentration.
3.0371 Notch properties.
3.03711 Effect of low temperatures on notched tensile strength, Figure 3.03711.
3.0372 Fracture toughness.
3.038 Combined properties.
- 3.04 Creep and Creep Rupture Properties
3.041 Isochronous stress-strain curves for forgings in T5 condition, Figure 3.041.
3.042 Isochronous stress-strain curves for forgings in T6 condition, Figure 3.042.
3.043 Total creep strain curves for extrusions, Figure 3.043.
3.044 100 hour creep strength of forgings, Table 3.044.
- 3.05 Fatigue Properties
3.051 Fatigue properties of extrusions, Figure 3.051.
3.052 Fatigue properties of forgings, Figure 3.052.
- 3.06 Elastic Properties
3.061 Poisson's ratio. 0.35 (9).
3.062 Modulus of elasticity.
3.0621 Effect of temperature on static modulus of elasticity, Figure 3.0621.
3.0622 Compressive tangent modulus curves for extrusions of various section sizes in T5 condition, Figure 3.0622.
3.0623 Compressive tangent modulus curves for extrusions of various section sizes in F condition, Figure 3.0623.
3.0624 Compressive secant modulus curves for extrusions of various section sizes in T5 condition, Figure 3.0624.
3.0625 Compressive secant modulus curves for extrusions of various section sizes in F condition, Figure 3.0625.
3.063 Modulus of rigidity. 2.4×10^3 ksi (9).

4. FABRICATION

- 4.01 Formability
4.011 ZK60A, which can be formed by the usual methods and equipment used in the forming of other metals, has good formability at elevated temperatures but relatively poor formability at room temperature.

- 4.012 Formability limits for extrusions, Table 4.012.
4.013 Although it is not normally necessary after hot forming, stress relief in accordance with section 1.054 will minimize chances of stress corrosion after severe forming at temperatures appreciably below the maximum recommended forming temperatures.
4.014 ZK60A has excellent forgeability in the range 750 to 500 F. Overheating must be avoided to prevent grain growth, which can cause cracking during forging. When reheating during forging is required, it is desirable to reduce the starting temperature by about 50 F for each reheat cycle. A minimum section reduction of 20 percent after the final reheat is recommended to insure a fine grain structure. (23).

4.02 Machining and Grinding

- 4.021 This alloy, like other magnesium alloys, has exceptionally good machinability, which enables it to be machined at high speeds and feeds. For further details see HZ32A Code 3408, Section 4.021.
4.022 The alloy can be chem milled with sulfuric, nitric, or hydrochloric acid of 5 percent strength or greater (24).

4.03 Welding

- 4.031 Because of a tendency to hot cracking, ZK60A has poor weldability by the gas-shielded arc processes applied to many other magnesium alloys. Although arc welding is not recommended because the results are inconsistent, AZ92A filler metal should be used if welding is necessary. Stress relief in accordance with section 1.054 will minimize the danger of stress corrosion cracking in welded joints. Gas welding is not recommended (17).
4.032 ZK60A can be satisfactorily resistance welded, spot welding being used to the greatest extent. Spot welds have good static strength (shear and tension), but poor fatigue strength (9)(17).

4.04 Surface Treatment

- For a discussion of various surface treatments that can be applied for corrosion protection see HZ32A, Code 3408, Sections 4.041, 4.042, and 4.043.

TABLE 1.03

Alloy	ZK60A
Source	(1)
Forms	Specifications
Extruded rods, bars, and shapes	AMS 4352D ASTM B107-69 Federal QQ-M-31b(1) SAE 524
Forgings	AMS 4362B ASTM B91-68 Federal QQ-M-40b(1) SAE 524
Extruded tubes	AMS 4352D ASTM B107-69 Federal WW-T-825a SAE 524

TABLE 1.04

Alloy	ZK60A	
Source	(2)(3)(4)(5)	
	Percent	
Element	Minimum	Maximum
Zinc	4.8	6.2
Zirconium	0.45	-
Impurities (total)	-	0.30
Magnesium	Balance	

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TABLE 1.06

Alloy	ZK60A	
Source	(9)	
Form	Condition	Brinell Hardness
Extrusions	F	75
	T5	82
Forgings	T5	65
	T6	75

TABLE 1.07

Alloy	ZK60A	
Source	(9)	
Forms	Condition	
Extrusions: rods, bars, solid shapes, tubes, semi-hollow and hollow shapes	F and T5	
Forgings: die forgings, hand forgings, and roll forged rings	T5 and T6	

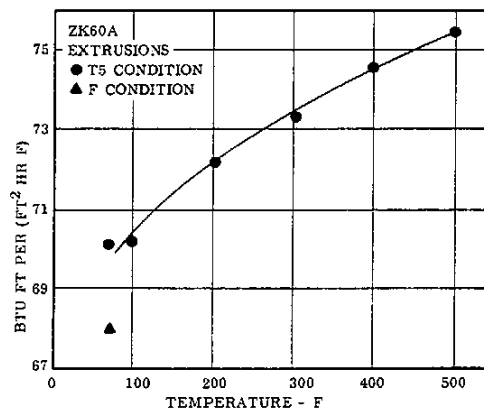


FIG. 2.013 THERMAL CONDUCTIVITY. (10)(11)

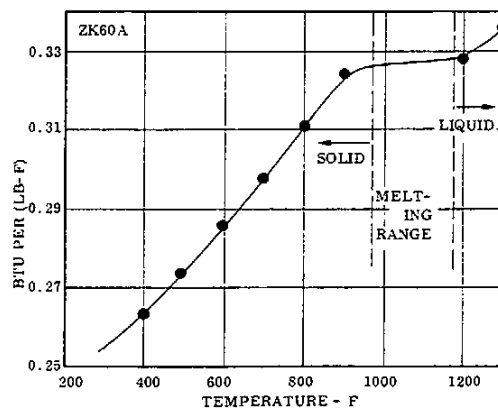


FIG. 2.015 SPECIFIC HEAT. (10)

TABLE 2.022

Alloy	ZK60A		
Condition	T5		
Source	(10)		
Temperature F	Electrical Conductivity		Electrical Resistivity microhm-in
	Percent LACS	Megmhos per in ³	
68	30.4	0.447	2.24
100	28.8	0.424	2.36
200	24.6	0.362	2.76
300	21.5	0.316	3.16
400	19.2	0.282	3.55
500	17.4	0.256	3.90

Mg
5.5 Zn
0.5 Zr
ZK60A

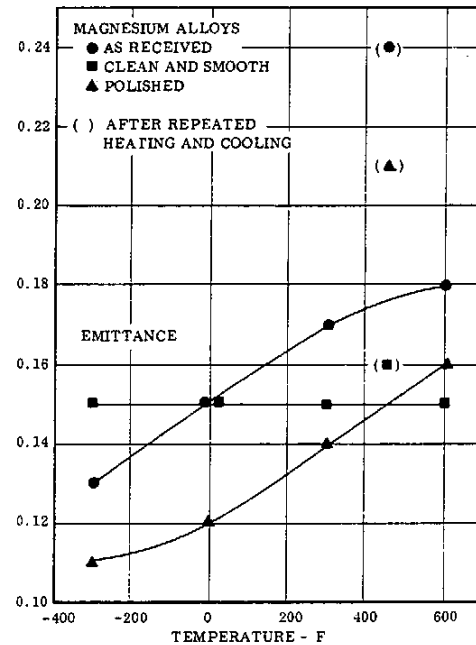


FIG. 2.0241 EFFECT OF TEMPERATURE ON NORMAL TOTAL EMITTANCE OF MAGNESIUM ALLOYS IN GENERAL (11)(12)

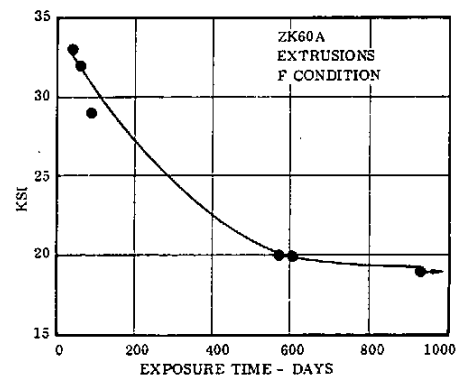


FIG. 2.0312 EFFECT OF STRESS ON TIME TO STRESS CORROSION FAILURE OF SPECIMENS EXPOSED TO ATMOSPHERE IN WASHINGTON D.C. (15)

TABLE 3.01

Alloy		ZK60A						
Form		Extrusions						
Condition		T5						
Shapes	Source	Cross sectional area - in ²	Outside diameter in	Section thickness in	F _{tu} ksi min	F _{ty} ksi min	c (2 in) min	F _{cy} ksi min
Bars, rods, and solid shapes	(2)	up to 2	-	-	45.0	36.0	4	30.0
		2 to 3	-	-	45.0	36.0	4	28.0
		3 to 5	-	-	45.0	36.0	4	25.0
		5 to 10	-	-	45.0	34.0	6	23.0
		10 to 25	-	-	45.0	34.0	6	22.0
		25 to 40	-	-	43.0	31.0	6	20.0
Tubing	(2)	-	up to 3	0.028-0.250	46.0	38.0	4	26.0
		-	3 to 8.5	0.094-1.188	44.0	33.0	4	21.0
Hollow shapes	(2)	all	-	all	46.0	38.0	4	26.0
Bars, rods, and shapes	(5)	up to 5	-	-	45.0	36.0	4	-
Tubing	(5)	-	up to 3	0.028-0.250	46.0	38.0	4	-
		-	3 to 8.5	0.094-1.188	44.0	33.0	4	-
Hollow shapes	(5)	all	-	all	46.0	38.0	4	-
Form		Extrusions						
Condition		F						
Bars, rods, and shapes	(5)	up to 5	-	-	43.0	31.0	5	-
		5 to 40	-	-	43.0	31.0	4	-
Tubing	(5)	-	up to 3	0.028-0.750	40.0	28.0	5	-
Hollow shapes	(5)	all	-	all	40.0	28.0	5	-
Form		Forgings						
Condition		T5						
Die Forgings	(3)(4)	-	-	up to 3	42.0	26.0	7	-
Hand Forgings	(3)	-	-	up to 6	38.0	20.0	7	-

Note: Test specimens oriented in the direction of maximum flow.

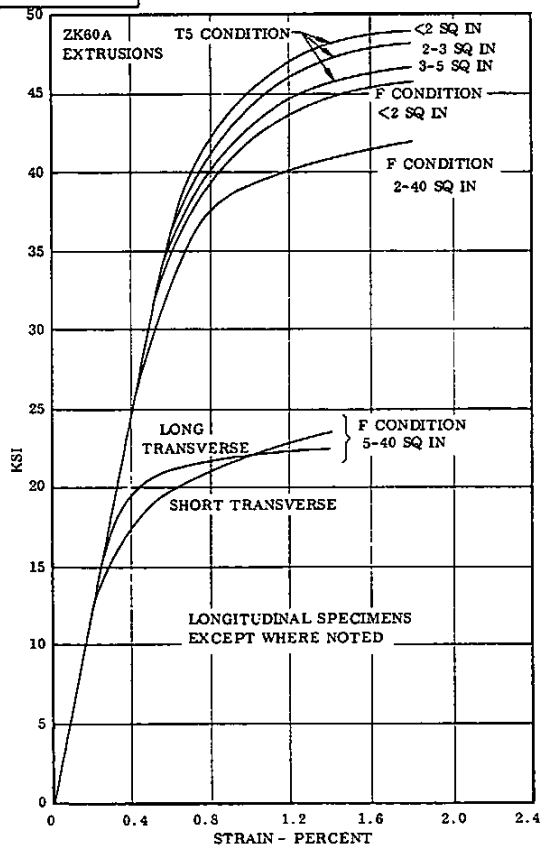


FIG. 3.02111 STRESS-STRAIN CURVES AT ROOM TEMPERATURE FOR EXTRUSIONS IN DIFFERENT CONDITIONS, ORIENTATIONS, AND SECTION SIZES. (9)

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TABLE 3.0212					
ZK60A					
Alloy Source	(9)				
Condition	Form	Cross Sectional Area - sq in	F _{tu} ksi	F _{ty} ksi	e(2 in)
T5	Extruded rods, bars, and shapes	under 2.000	53	44	11
		2.000-2.999	52	43	12
		3.000-4.999	51	42	14
F	Extruded rods, bars, and shapes	under 2.000	49	38	14
		2.000-2.999	49	37	14
		3.000-4.999	49	36	14
T5	Extruded tubes	Dimensions-in			
		3.0 max OD and 0.028-0.250 wall	50	40	11
		3.0-8.5 OD and 0.094-1.188 wall	49	39	12
T5	Extruded hollow shapes	limits not established	50	40	11
T5	Forgings	limits not given	44	30	16
T6			47	39	11

Note: All properties apply to longitudinal orientation.

TABLE 3.0214				
ZK60A				
Alloy Form	Aircraft Wheel Forging			
Source	(25)			
Condition	Test Location	F _{tu} - ksi	F _{ty} - ksi	e(2 in)
T5	A. Rim Vertical	36.0	19.5	10.5
	B. Web Tangential	43.5	32.5	18.5
	C. Center Vertical	39.5	24.0	15.0
	D. Center Vertical	39.5	23.0	16.5
	E. Web Radial	41.5	25.0	16.5
	F. Rim Vertical	42.0	24.0	12.0
	G. Rim Tangential	45.0	36.5	22.0
T6	A. Rim Vertical	43.0	34.0	10.5
	B. Web Tangential	45.5	38.0	11.0
	C. Center Vertical	43.0	34.0	10.5
	D. Center Vertical	43.0	34.0	10.5
	E. Web Radial	42.5	35.0	15.5
	F. Rim Vertical	43.0	34.0	10.5
	G. Rim Tangential	45.5	38.0	11.0

Mg
5.5 Zn
0.5 Zr
ZK60A

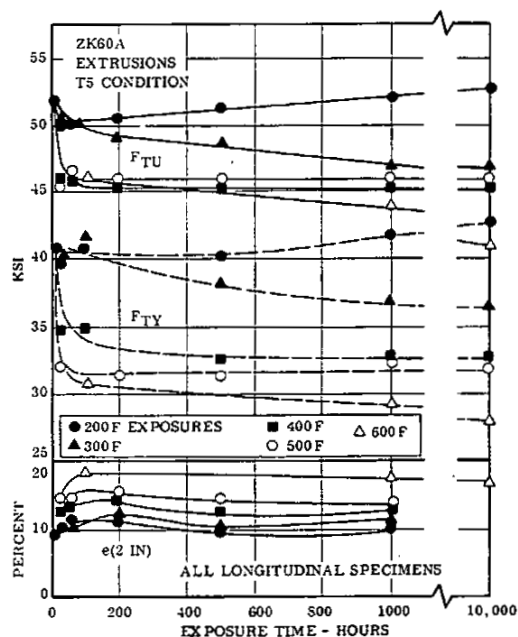
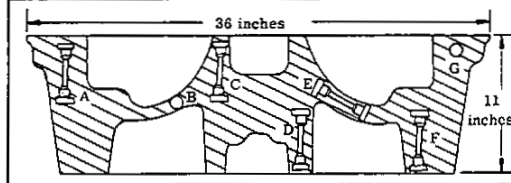


FIG. 3.0213 EFFECT OF EXPOSURES AT ELEVATED TEMPERATURES ON TENSILE PROPERTIES OF EXTRUSIONS AT ROOM TEMPERATURE. (9)(16)

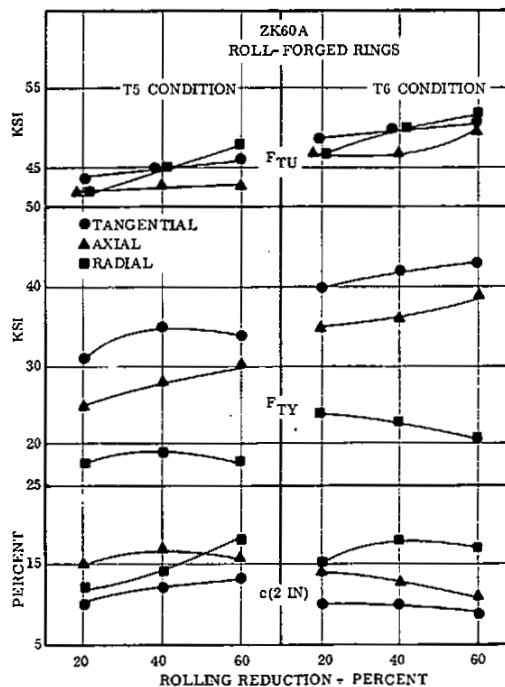


FIG. 3.0215 EFFECT OF ROLLING REDUCTION AND ORIENTATION ON THE TENSILE PROPERTIES OF ROLL-FORGED RINGS PRODUCED DIRECTLY FROM CAST BLANKS. (18)

Mg
5.5 Zn
0.5 Zr

ZK60A

TABLE 3.0216

ZK60A						
Form	Roll Forged Rings					
Source	(18)					
Condition	Orientation	Rolling Reduction Percent	F _{tu} ksi	F _{ty} ksi	e (2 in)	
T5	Tangential	40	49	39	13	
		60	51	42	12	
	Axial	40	45	26	14	
		60	45	28	14	
	Radial	40	44	21	20	
		60	45	23	15	
T6	Tangential	40	54	47	10	
		60	51	43	9	
	Axial	40	47	32	11	
		60	46	33	9	
	Radial	40	49	25	22	
		60	50	21	14	

TABLE 3.0222

ZK60A			
Alloy Source	(9)		
Condition	Form	Cross Sectional Area - sq in	F _{cy} - ksi
T5	Extruded rods, bars, and shapes	under 2.000	36
		2.000-2.999	31
		3.000-4.999	30
F	Extruded rods, bars, and shapes	under 2.000	33
		2.000-2.999	28
		3.000-4.999	27
T5	Extruded tubes	Dimensions - in	
		3.0 max OD and 0.094-1.188 wall	30
		3.0-8.5 OD and 0.094-1.188 wall	26
T5	Extruded hollow shapes	limits not established	29
F	Forgings	limits not given	25

Note: All properties apply to longitudinal orientation.

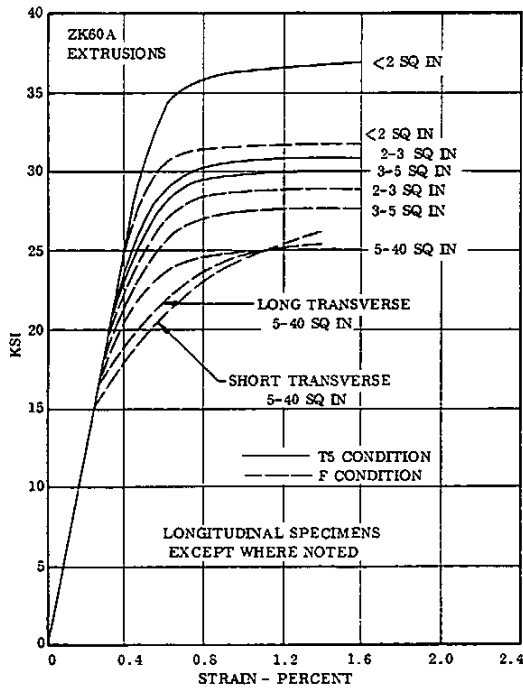


FIG. 3.02211 COMPRESSIVE STRESS-STRAIN CURVES AT ROOM TEMPERATURE FOR EXTRUSIONS IN DIFFERENT CONDITIONS, ORIENTATIONS, AND SECTION SIZES. (9)

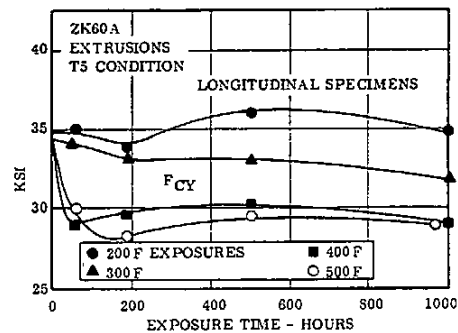


FIG. 3.0223 EFFECT OF EXPOSURES AT ELEVATED TEMPERATURES ON COMPRESSIVE YIELD STRENGTH AT ROOM TEMPERATURE. (9)

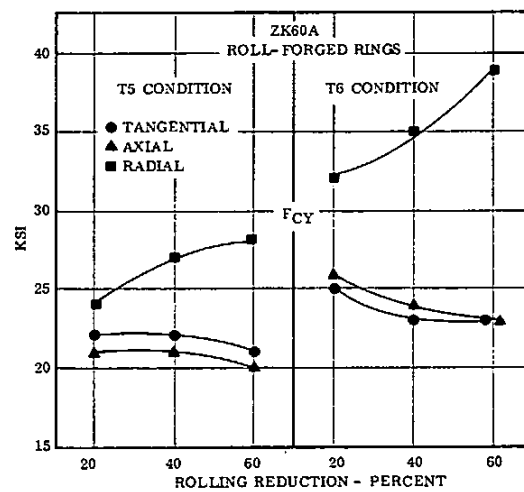


FIG. 3.0224 EFFECT OF ROLLING REDUCTION AND ORIENTATION ON THE COMPRESSIVE YIELD STRENGTH OF ROLL-FORGED RINGS PRODUCED DIRECTLY FROM CAST BLANKS. (15)

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TABLE 3.0225

Alloy	ZK60A		
Form	Roll Forged Rings		
Source	(18)		
Condition	Orientation	Rolling Reduction Percent	F _{cy} - ksi
T5	Tangential	40	25
		60	27
	Axial	40	22
		60	25
T6	Radial	40	26
		60	30
	Tangential	40	27
		60	24
T6	Axial	40	27
		60	22
	Radial	40	35
		60	37

TABLE 3.0251

Alloy	ZK60A		
Source	(9)		
Condition	Form	Cross Sectional Area - sq in	F _{su} - ksi
T5	Extruded rods, bars, and shapes	under 2.000	26
		2.000 - 2.999	26
		3.000 - 4.999	25
F	Extruded rods, bars, and shapes	under 2.000	24
		2.000 - 2.999	24
		3.000 - 4.999	24
		5.000 - 39.999	24
T5	Forgings	limits not given	24
F			25

Note: All properties apply to longitudinal orientation.

TABLE 3.0261

Alloy	ZK60A			
Source	(9)			
Condition	Form	Cross sectional area - sq in	F _{bru} * ksi	F _{bry} * ksi
T5	Extruded rods, bars, and shapes	under 2.000	79	59
		2.000-2.999	75	53
		3.000-4.999	77	52
F	Extruded rods, bars, and shapes	under 2.000	76	56
		2.000-2.999	76	50
		3.000-4.999	76	49
		5.000-39.999	75	44
T5	Forgings	limits not given	55	42
F			65	46

* edge-distance-to-hole-diameter-ratio of 2.

Note: All properties apply to longitudinal orientation.

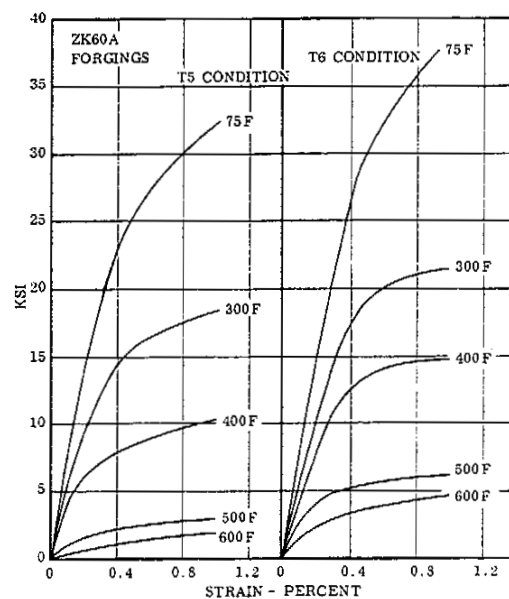


FIG. 3.03111 STRESS-STRAIN CURVES AT ROOM AND ELEVATED TEMPERATURES FOR FORGING, FORGED AT 600 F FROM EXTRUDED MATERIAL. (17)

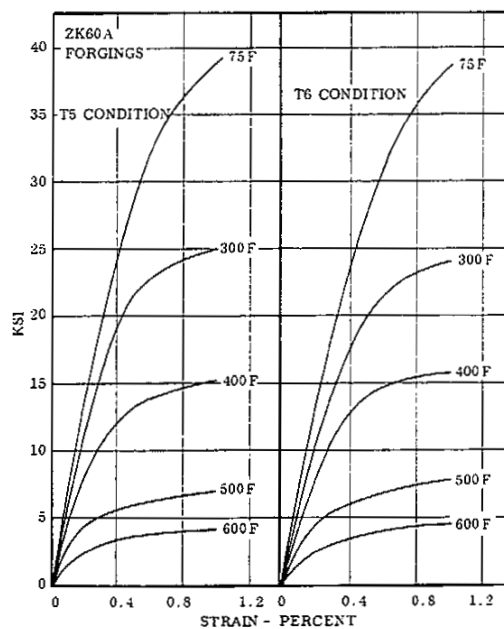


FIG. 3.03112 STRESS-STRAIN CURVES AT ROOM AND ELEVATED TEMPERATURES FOR FORGINGS, FORGED AT 500 F FROM CAST MATERIAL. (17)

Mg
5.5 Zn
0.5 Zr
ZK60A

Mg
5.5 Zn
0.5 Zr
ZK60A

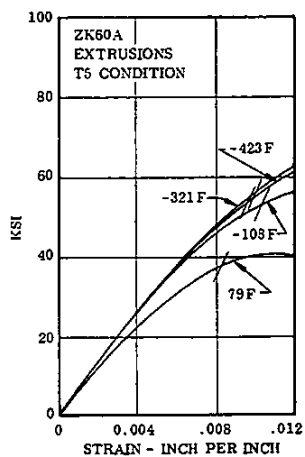


FIG. 3.03113 STRESS-STRAIN CURVES AT ROOM AND LOW TEMPERATURES FOR EXTRUSIONS. (19)

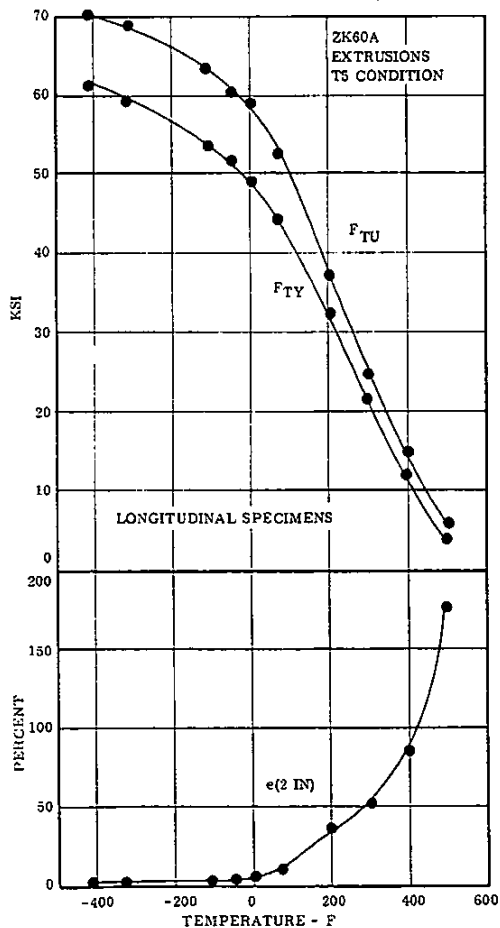


FIG. 3.0312 EFFECT OF TEMPERATURE ON TENSILE PROPERTIES OF EXTRUSIONS. (9)(12)

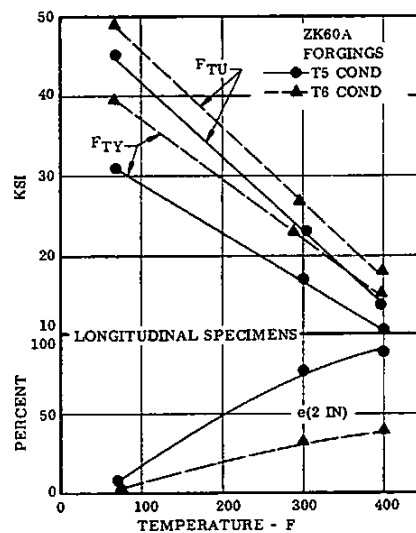


FIG. 3.0313 EFFECT OF TEMPERATURE ON TENSILE PROPERTIES OF FORGINGS. (9)

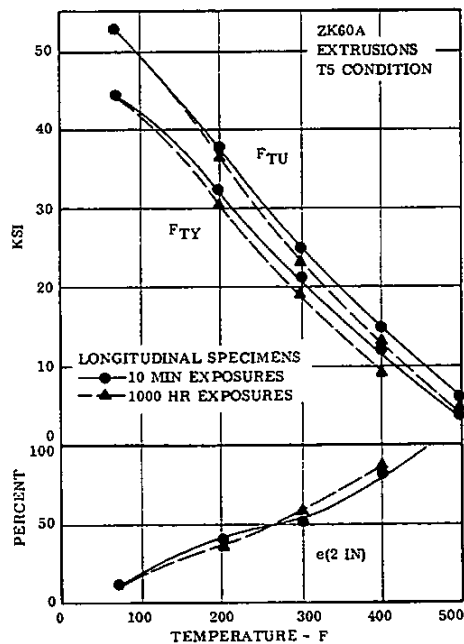


FIG. 3.0314 EFFECT OF TEMPERATURE ON TENSILE PROPERTIES OF EXTRUSIONS AFTER VARIOUS EXPOSURE TIMES AT TEST TEMPERATURE. (9)(20)

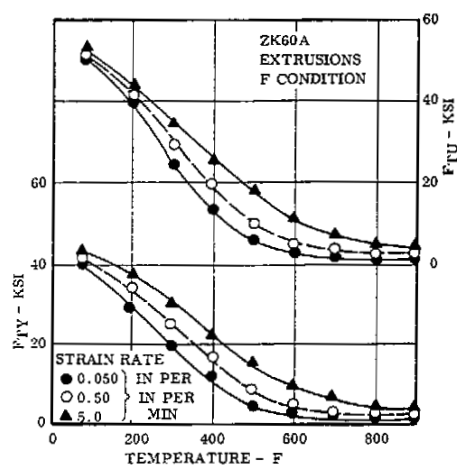


FIG. 3.0315 EFFECT OF TEMPERATURE AND STRAIN RATE ON TENSILE PROPERTIES OF EXTRUSIONS IN F CONDITION. (9)

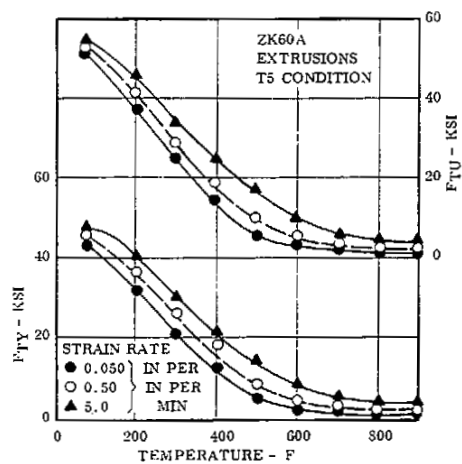


FIG. 3.0316 EFFECT OF TEMPERATURE AND STRAIN RATE ON TENSILE PROPERTIES OF EXTRUSIONS IN T5 CONDITION. (9)

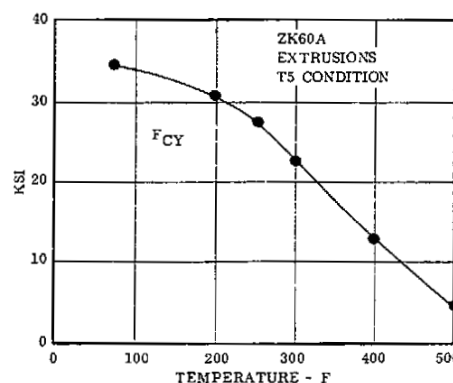


FIG. 3.0322 EFFECT OF TEMPERATURE ON COMPRESSIVE YIELD STRENGTH OF EXTRUSIONS. (9)

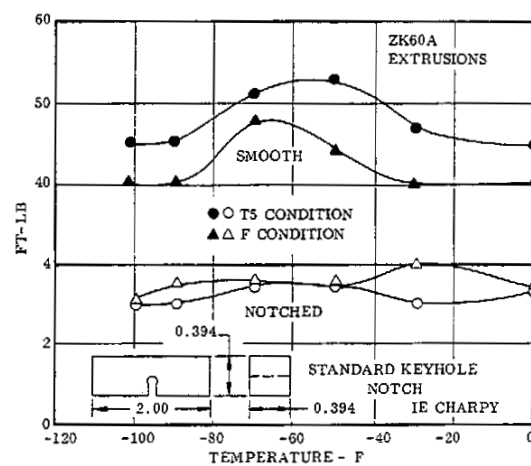


FIG. 3.0331 EFFECTS OF LOW TEMPERATURES ON IMPACT STRENGTH OF BOTH SMOOTH AND NOTCHED CHARPY BARS. (12)

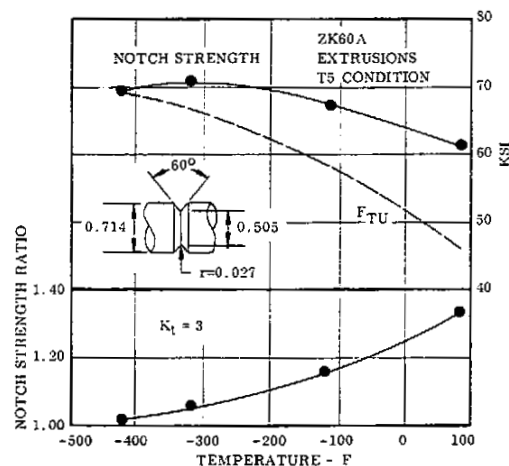


FIG. 3.0371 EFFECT OF LOW TEMPERATURES ON NOTCHED TENSILE STRENGTH. (19)

Mg
5.5 Zn
0.5 Zr
ZK60A

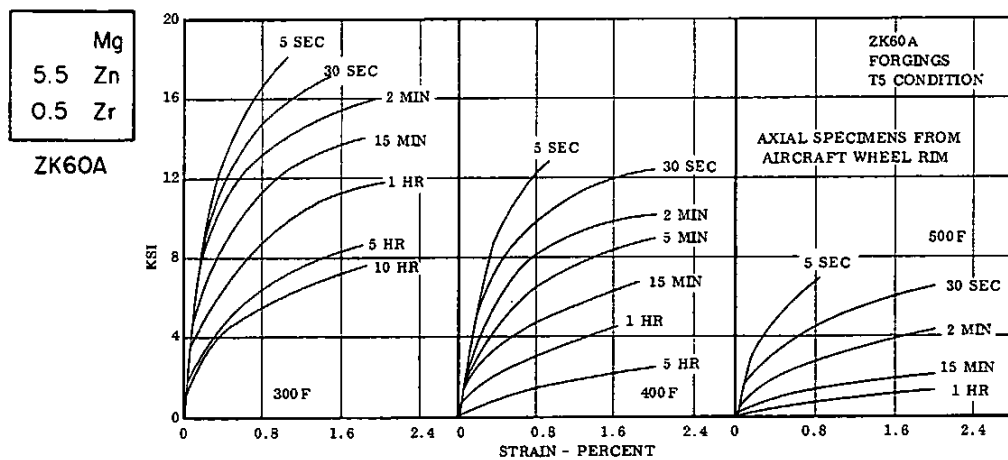


FIG. 3.041 ISOCHRONOUS STRESS-STRAIN CURVES FOR FORGINGS IN T5 CONDITION.

(9)

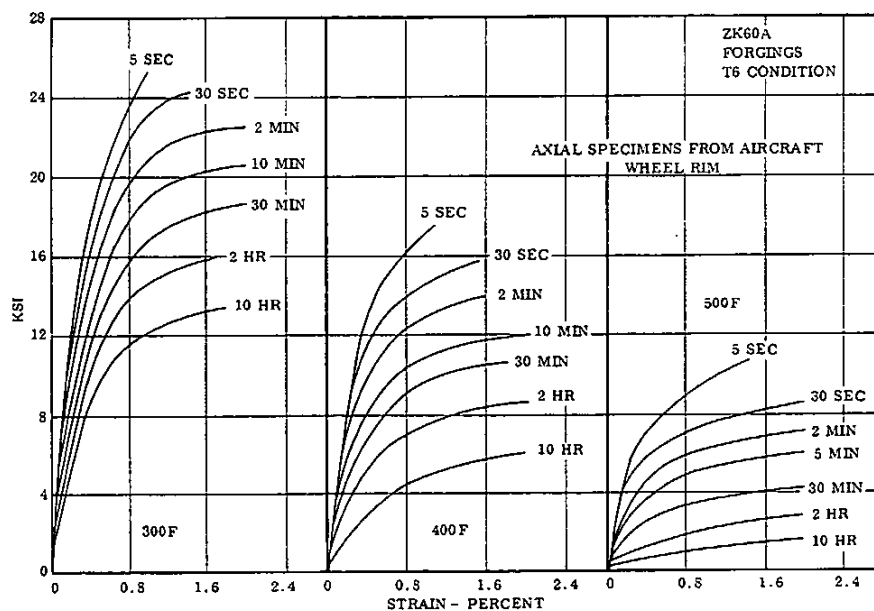


FIG. 3.042 ISOCHRONOUS STRESS-STRAIN CURVES FOR FORGINGS IN T6 CONDITION.

(9)

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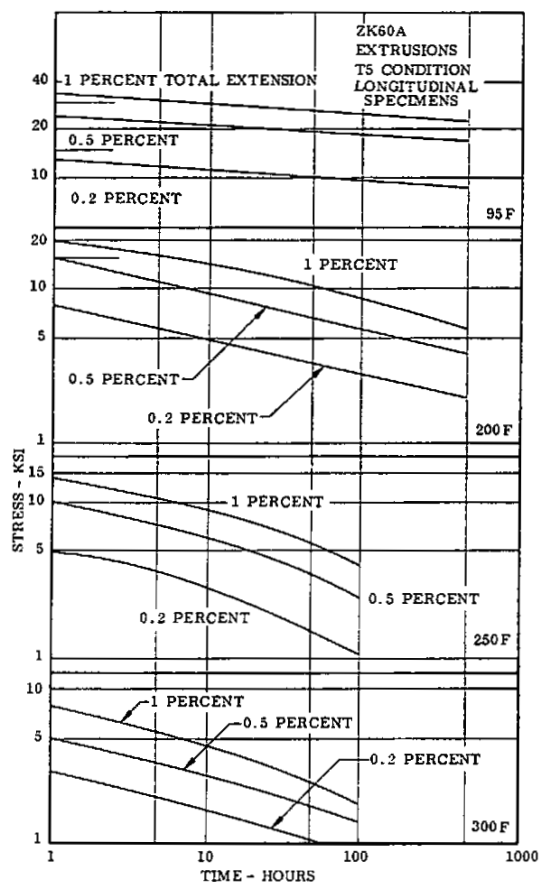
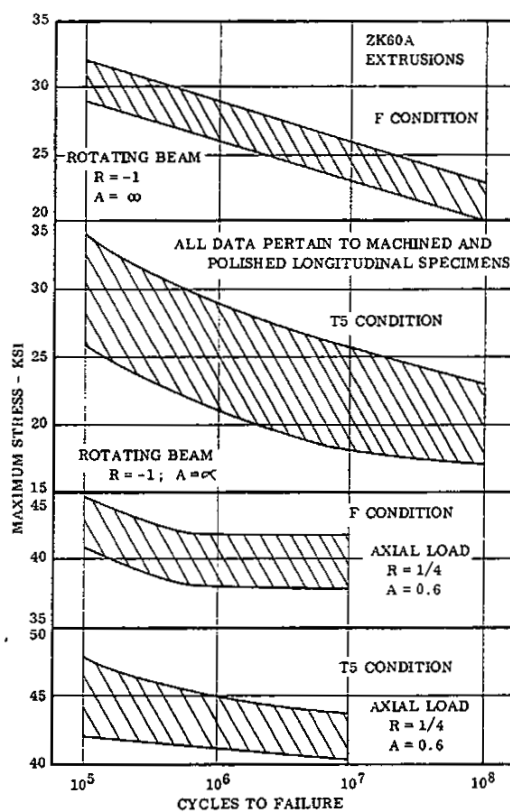
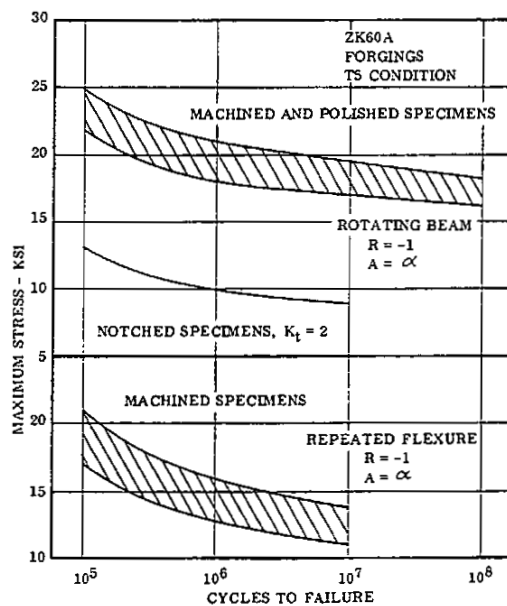
FIG. 3.043 TOTAL CREEP STRAIN CURVES FOR EXTRUSIONS.
(9)(20)

TABLE 3.044				
ZK60A				
(9)				
Condition	Temp	100 hour creep strength - ksi		
		0.1 percent creep extension	0.2 percent total extension	0.5 percent total extension
T5	300	0.9	1.3	2.3
	400	0.2	0.3	0.5
T6	300	3.3	3.8	6.2
	400	1.2	1.5	2.3

FIG. 3.051 FATIGUE PROPERTIES OF EXTRUSIONS.
(9)FIG. 3.052 FATIGUE PROPERTIES OF FORGINGS.
(9)(21)

Mg
5.5 Zn
0.5 Zr
ZK60A

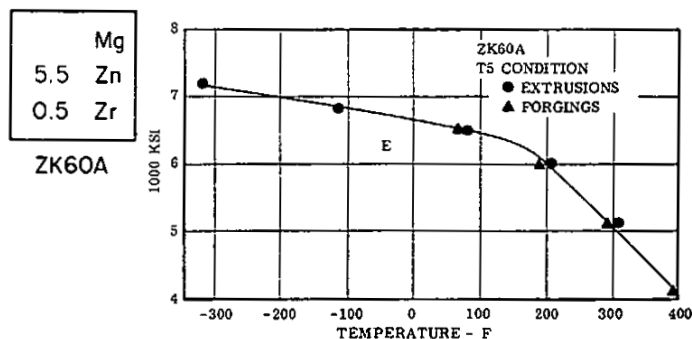


FIG. 3.0621 EFFECT OF TEMPERATURE ON STATIC MODULUS OF ELASTICITY. (9)(19)

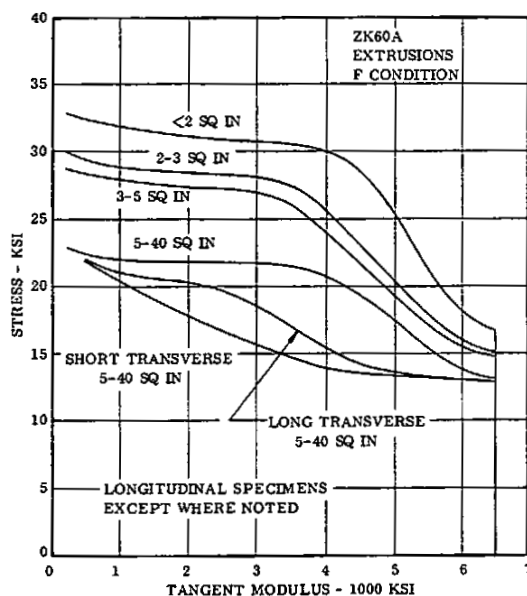


FIG. 3.0623 COMPRESSIVE TANGENT MODULUS CURVES FOR EXTRUSIONS OF VARIOUS SECTION SIZES IN F CONDITION. (9)

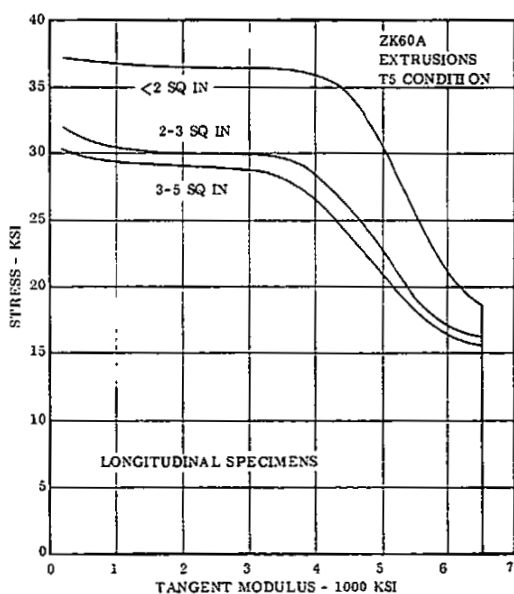


FIG. 3.0622 COMPRESSIVE TANGENT MODULUS CURVES FOR EXTRUSIONS OF VARIOUS SECTION SIZES IN T5 CONDITION. (9)

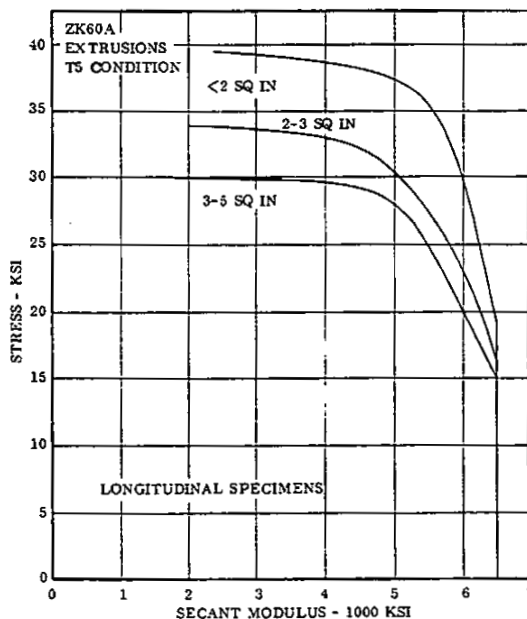


FIG. 3.0624 COMPRESSIVE SECANT MODULUS CURVES FOR EXTRUSIONS OF VARIOUS SECTION SIZES IN T5 CONDITION. (9)

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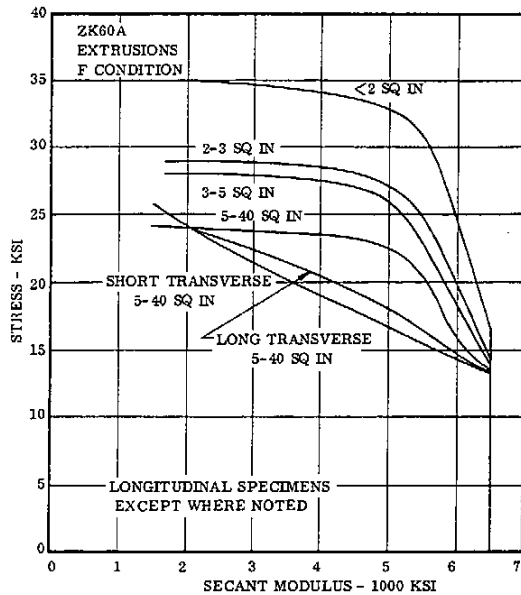


FIG. 3.0625 COMPRESSIVE SECANT MODULUS CURVES FOR EXTRUSIONS OF VARIOUS SECTION SIZES IN F CONDITION. (9)

Mg
5.5 Zn
0.5 Zr
ZK60A

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- AMS 4352D, Extrusions (May 1, 1968).
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- "Arc Welding Magnesium," Dow Chemical Company, Metal Products Department, Form No. 141-300-67 (1967).
- "Magnesium in Design," Dow Chemical Company, Metal Products Department, Form No. 141-213-67 (1967).
- "Physical Properties of Magnesium and Magnesium Alloys," Dow Chemical Company, Metal Products Department, Code 2.51 (April 10, 1967).
- "Heat Transfer Characteristics of Magnesium Alloys," Dow Chemical Company, Metal Products Department, Code 2.46, Appendix A (February 24, 1959).
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- "Forming Magnesium," Dow Chemical Company, Metal Products Department, Form No. 141-93-55 (1958).
- "Design," booklet published by Magnesium Elektron Ltd., 1270 Avenue of the Americas, New York City 10020.
- "The Selection and Application of Magnesium and Magnesium Alloys," ASM Metals Handbook, Volume 1, 8th Edition, pp. 1067-1086 (1961).

TABLE 4.012

Alloy				
Source				
ZK60A				
(22)				
Form	Condition	Min bend rad at 75 F	Hot forming limits	
			Time and Temp	Min bend rad
Solid extrusions	F	12t	1/2 hr at 550 F	2t
	T5	12t	1/2 hr at 400 F	6.6t
Tubing	F	5D	-	-

Note: t = thickness; D = tube OD

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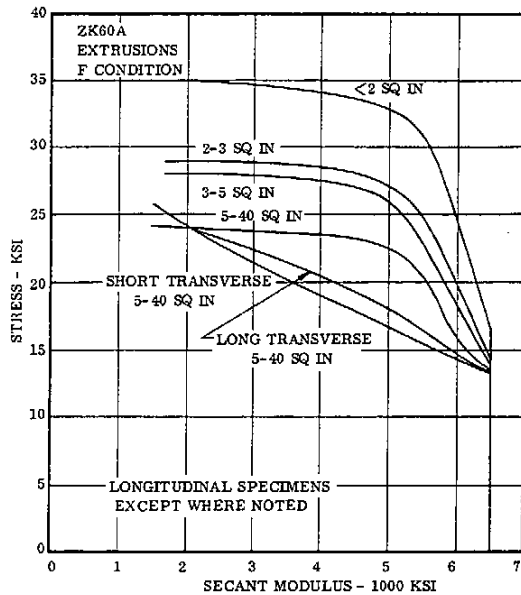


FIG. 3.0625 COMPRESSIVE SECANT MODULUS CURVES FOR EXTRUSIONS OF VARIOUS SECTION SIZES IN F CONDITION. (9)

Mg
5.5 Zn
0.5 Zr
ZK60A

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- "Digest of Specifications for Magnesium Products - 1970" Form No. 141-138-70, The Dow Chemical Company, Midland, Michigan (1970).
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- AMS 4362B, Forgings (May 1, 1968).
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- "Forming Magnesium," Dow Chemical Company, Metal Products Department, Form No. 141-215-64 (1964).
- "Forming Magnesium," Dow Chemical Company, Metal Products Department, Form No. 141-93-55 (1958).
- "Design," booklet published by Magnesium Elektron Ltd., 1270 Avenue of the Americas, New York City 10020.
- "The Selection and Application of Magnesium and Magnesium Alloys," ASM Metals Handbook, Volume 1, 8th Edition, pp. 1067-1086 (1961).

TABLE 4.012

Alloy				
Source				
ZK60A				
(22)				
Form	Condition	Min bend rad at 75 F	Hot forming limits	
			Time and Temp	Min bend rad
Solid extrusions	F	12t	1/2 hr at 550 F	2t
	T5	12t	1/2 hr at 400 F	6.6t
Tubing	F	5D	-	-

Note: t = thickness; D = tube OD

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RELEASED: SEPTEMBER 1970
AUTHOR: J. R. KATTUS

NONFERROUS ALLOYS

1. GENERAL
ZK61A is a magnesium sand-casting and investment-casting alloy, which has an outstanding combination of strength and ductility in the age-hardened condition. It was developed to provide castings with a very high strength-to-weight ratio for use in aerospace applications at temperatures up to about 350F (1). The achievement of this goal resulted in somewhat poorer foundry characteristics--fluidity, microporosity, hot-cracking tendency--than most of the other magnesium alloys. This alloy has excellent machinability but poor weldability. Its corrosion resistance is similar to that of most other magnesium alloys; for long-time exposures to marine or industrial environments, chemical treatment followed by painting is recommended.

- 1.01 Commercial Designation
ZK61A

- 1.02 Alternate Designations
ZK61

- 1.03 Specifications
AMS 4444A
ASTM B80-68, B403-67
Federal QQ-M-56b (1)
MIL-M-46062A
SAE 513

- 1.04 Composition
Table 1.04.

TABLE 1.04

ZK61A				
Source AMS 4444 A(2), ASTM B80-68, B403-67				
Element	Percent		Percent	
	Minimum	Maximum	Minimum	Maximum
Zinc	5.5	6.5	5.5	6.5
Zirconium (total)	0.6	1.0	0.6	1.0
Zirconium (soluble)*	0.6	-	-	-
Copper	-	0.10	-	0.10
Nickel	-	0.01	-	0.01
Others (total)	-	0.30	-	0.30
Magnesium	Remainder		Remainder	

* Soluble zirconium is that portion of the zirconium that is soluble in 1:4 hydrochloric acid held below its boiling point.

- 1.05 Heat Treatment
Table 1.05.

TABLE 1.05

ZK61A					
Source (3) (4) (5)					
Treatment	Solution			Age	
	Temp F	Time hr	Cool	Temp F	Time hr
T4 Solution(a)	930	5	a.b. (b)		
T5 Artificial Age				300	48
T6 As Cast + Solution(a) + Artificial Age	930	5	a.b. (b)	265	48

(a) Alternate solution: 900F, 10 hr.

(b) a.b. - air blast

- 1.051 Effects of variations in heat-treating conditions (solution time, cooling method, and aging time) on the tensile properties of chilled casting, Figure 1.051.
- 1.052 ZK61A - F (as cast) also age hardens at room temperature, 10 months' aging resulting in properties equivalent to those produced by the T5 heat treatment (6).

- 1.06 Hardness

- 1.061 Hardness of sand castings in different heat-treated conditions, Table 1.061.

TABLE 1.061

ZK61A		
Sand Cast		
Source (1)		
Condition	BHN	RE
F*	58-65	65-70
T5	65-70	75-80
T6	65-75	75-82

* As-cast

- 1.062 Effect of temperature on hardness, Figure 1.062.

- 1.07 Forms and Conditions Available

Produced primarily as sand castings; has been used to a small extent as investment castings; used in the T4 (solution-treated), T5 (artificially aged), and T6 (solution-treated and artificially aged) conditions.

- 1.08 Melting and Casting Practice (7)(8)(9)

ZK61A is melted in gas-fired or oil-fired crucible-type furnaces. The same steel container should be used for both melting and pouring because of the excessive losses of zirconium if the molten metal is transferred from a melting crucible to a casting crucible. Since losses of zirconium are greater when pre-alloyed ingots are melted, most foundries start with primary magnesium and add zinc and zirconium at about 1450F by plunging them below the surface of the melt. Zinc is added as pure metal and zirconium as a magnesium-zirconium master alloy containing 30-50 percent zirconium or as zirconium tetrachloride salt. Zinc losses are negligible, but zirconium recovery is only about 10-50 percent, depending upon the foundry conditions. About 3 pounds of crucible flux per 100 pounds of metal is used to prevent burning and to trap impurities. This flux is a mixture of magnesium chloride with various other chlorides and fluorides. Since zirconium is an extremely effective grain refiner, no further grain refining treatments are necessary. For pouring, the flux is skimmed from the melt, and a mixture of sulfur and boric acid is dusted onto the surface to prevent burning. The normal pouring temperature is about 1425F. When the molten metal is held below 1400F, zirconium settles out as an insoluble material; above 1500F, however, the alloy tends to absorb iron, which is a detrimental impurity, from the crucible. During melting, therefore, the metal should be brought to 1400F as quickly as possible and held between 1425 and 1475F until poured.

- 1.09 Special Considerations

- 1.091 The attainment of fine grain size and associated optimum strength is highly dependent upon the amount of soluble zirconium in the alloy as illustrated in Figure 1.091. This type of zirconium is in solid solution in the alloy rather than distributed in metallic-particle form. The maximum attainable soluble zirconium content is 0.85 percent and the minimum for acceptable properties is about 0.60 percent (1). Good melting practice and temperature control as discussed in Section 1.08 are essential for the production of the proper soluble zirconium content.

- 1.092 It is essential in producing this alloy that all equipment and scrap metal be controlled to prevent contamination with aluminum, iron, manganese, and silicon. These elements remove zirconium from the melt.

2. PHYSICAL AND CHEMICAL PROPERTIES

- 2.01 Thermal Properties

- 2.011 Melting range. 985-1175F (8).

- 2.012 Phase changes. In the as-cast (F) condition, massive magnesium-zinc compounds occur at the grain

Mg
6 Zn
0.8 Zr

ZK61A

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PAGE 1

Mg
6 Zn
0.8 Zr

ZK61A

2.0121
2.013

boundaries, and smaller magnesium-zinc and zirconium-zinc compounds form within the alpha magnesium grains. During solution treatment, most of the compounds go into solution in the alpha magnesium, and they reprecipitate in finely dispersed form during aging (11). If heat-treated ZK61A is held at 250F and above for extended periods, over-aging occurs, during which the precipitates coagulate and grow causing a deterioration of mechanical properties.

Time-temperature-transformation diagrams.

Thermal conductivity. Table 2.013.

TABLE 2.013			
ZK61A			
Form			
Castings			
Source			
(8) (12)			
Condition	Temperature, F	Thermal Conductivity Btu ft per (ft ² hr F)	
T6	68	63	
All	212-570	51	

- 2.014 Thermal expansion. 14.5×10^{-6} per F from 68 to 212F (8).
- 2.015 Specific heat. 0.25 Btu per (lb F) (approximate) at 78F (13).
- 2.016 Thermal diffusivity.

- 2.02 Other Physical Properties
- 2.021 Density. 0.066 lb per in³ (8).
- 2.022 Electrical properties.
- 2.0221 Electrical conductivity. T6 condition: 27 percent IACS conductivity.
- 2.0222 Electrical resistivity. T6 condition: 2.52 microhm - inch at 68F (8).
- 2.023 Magnetic properties.
- 2.024 Emissance.
- 2.025 Damping capacity.

- 2.03 Chemical Properties
- ZK61A, like other magnesium alloys, corrodes in industrial, marine, and moist environments. For long-time applications under these conditions, therefore, suitable surface coating is recommended to protect the metal and to insulate contact surfaces from galvanic corrosion. Coated parts are suitable for exposure to all natural environments except continuous immersion in water (14)(15). For a discussion of galvanic corrosion, see Code 3601, Section 2.0312.
- 2.031 Safety precautions should be directed to the prevention of fires, burns, and explosions. (see H232A, Code 3408, Section 2.032)

2.04 Nuclear Properties

3. MECHANICAL PROPERTIES

- 3.01 Specified Mechanical Properties
Table 3.01.

TABLE 3.01						
ZK61A						
Form						
Castings						
Specification	Type	Cond	Specimen	F _{tu} ksi	F _{ty} ksi	e min (2 in)
AMS 4444 A (2)	Sand	T5	Separate cast (single)	39	26	5
			Cut from casting (average 4 or more)	34	24	3
			Cut from casting (single)	30	21	2
ASTM B40- 68	Sand	T6	Separate Cast (single)	39	26	5
ASTM B403- 67	Invest- ment	T6	Separate cast (single)	40	25	5

- 3.02 Mechanical Properties at Room Temperature
- 3.021 Tension.
- 3.0211 Stress-strain diagrams, Figure 3.0211.
- 3.0212 Typical tensile properties, Table 3.0212.

TABLE 3.0212						
ZK61A						
Form						
Castings						
Source						
(6)(16)(17)						
Type	Condition	Specimen	F _{tu} ksi	F _{ty} ksi	e (2 in)	
Sand	F	Separate cast	40	21	11	
	T5	Separate cast	41.5	28.5	6.5	
	T6	Separate cast	46	30	10	
	T6	Cut from castings	41	29	5	
Investment	T6	Separate cast	44	29	10	

- 3.0213 Effect of section thickness on tensile properties, Figure 3.0213.
- 3.0214 Effect of end chill on tensile properties of cast plates of two thicknesses, Figure 3.0214.
- 3.022 Compression
- 3.0221 Stress-strain diagrams.
- 3.0222 Compressive yield strength of castings in different heat-treated conditions, Table 3.0222.

TABLE 3.0222			
ZK61A			
Form			
Sand Cast			
Source			
(1)			
Condition	Specimen	F _{cy} -ksi	
F	Separate cast	18	
T5		25.1	
T6		29.2	

- 3.023 Impact.
- 3.0231 Impact strength of castings in different heat-treated conditions, Table 3.0231.

TABLE 3.0231				
ZK61A				
Form				
Sand Cast				
Source				
(1)				
Charpy Impact, ft lb				
Condition	Specimen	V notch	No notch	
F	Separate cast	3.5	20	
T5		2.5	14	
T6		3.5	15	

- 3.024 Bending.
- 3.025 Torsion and shear.
- 3.0251 Shear strength for separate sand-cast test specimens (1).
- F condition: F_{su} = 24.5 ksi
- T5 condition: F_{su} = 24.8 ksi
- T6 condition: F_{su} = 26.5 ksi
- 3.026 Bearing.
- 3.027 Stress concentration.
- 3.0271 Notch properties.
- 3.0272 Fracture toughness.
- 3.028 Combined properties.

- 3.03 Mechanical Properties at Various Temperatures
- 3.031 Tension.
- 3.0311 Stress-strain diagrams.
- 3.0312 Effect of temperature on tensile properties, Figure 3.0312.
- 3.032 Compression.
- 3.0321 Stress-strain diagrams.
- 3.033 Impact.
- 3.034 Bending.
- 3.035 Torsion and shear.
- 3.036 Bearing.
- 3.037 Stress concentration.
- 3.0371 Notch properties.
- 3.0372 Fracture toughness.
- 3.038 Combined properties.

3.04 Creep and Creep Rupture Properties
 3.041 Effect of temperature on stresses to cause 0.2 percent and 0.5 percent creep in 100 hours, Figure 3.041.

3.05 Fatigue Properties
 3.051 Rotating beam fatigue strength of notched and smooth specimens, Figure 3.051.

3.06 Elastic Properties
 3.061 Poisson's ratio.
 3.062 Modulus of elasticity. All conditions: 6500 ksi (14).
 3.063 Modulus of rigidity.

4. FABRICATION

4.01 Formability

4.02 Machining and Grinding
 4.021 This alloy, like other magnesium alloys, has exceptionally good machinability, which enables it to be machined at high speeds and feeds (8)(14)(19)(see also HZ32A, Code 3406, Section 4.021).

4.03 Welding
 ZK61A has poor weldability in comparison with most other magnesium alloys and is not recommended for use in applications requiring appreciable welding. When welding is required, helium-or argon-gas shielded arc techniques with tungsten or consumable electrode and EZ33A filler metal should be used. A Stress-relieving treatment of 500 F for 5 hours is recommended after welding (8)(13)(14)(20).

4.04 Surface Treatment
 (see AM100A, Code 3509, Section 4.041 through 4.044)

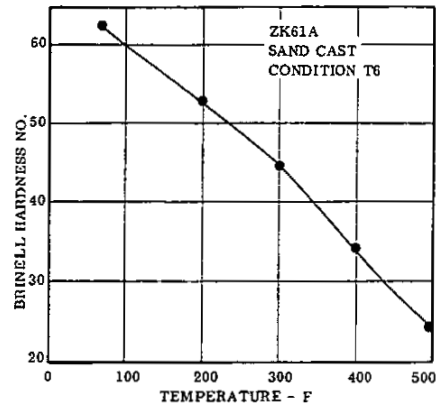


FIG. 1.062 EFFECT OF TEMPERATURE ON HARDNESS. (18)

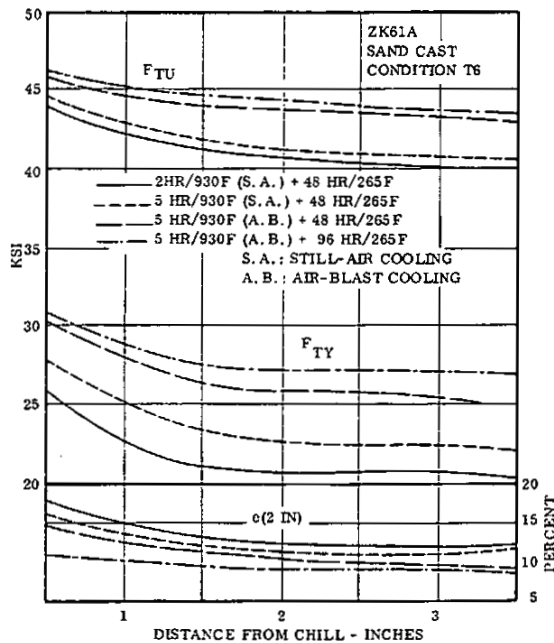


FIG. 1.051 EFFECT OF VARIATIONS IN HEAT TREATING CONDITIONS (SOLUTION TIME, COOLING METHOD, AND AGING TIME) ON THE TENSILE PROPERTIES OF CHILLED CASTING. (4)

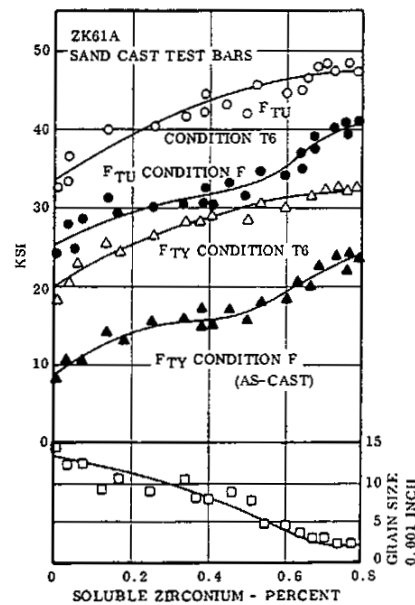


FIG. 1.091 EFFECT OF SOLUBLE ZIRCONIUM CONTENT ON TENSILE STRENGTH AND GRAIN SIZE. (1)(6)(10)

	Mg
6	Zn
0.8	Zr

ZK61A

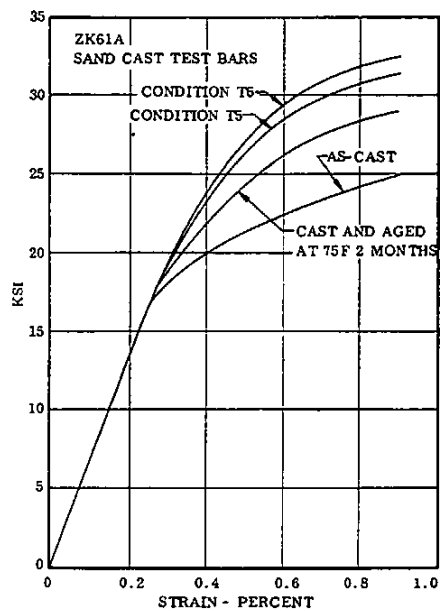


FIG. 3.0211 STRESS-STRAIN DIAGRAMS. (6)

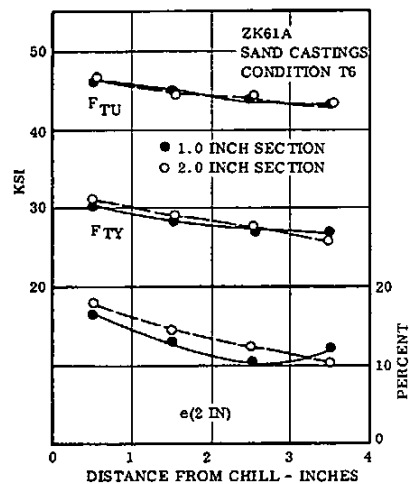


FIG. 3.0214 EFFECT OF END CHILL ON TENSILE PROPERTIES OF CAST PLATES OF TWO THICKNESSES. (4)

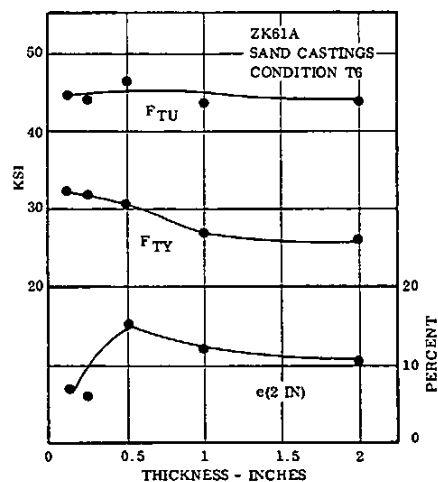


FIG. 3.0213 EFFECT OF SECTION THICKNESS ON TENSILE PROPERTIES. (4)

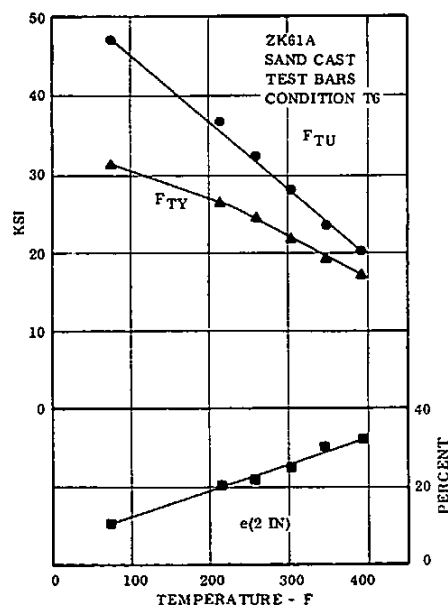


FIG. 3.0312 EFFECT OF TEMPERATURE ON TENSILE PROPERTIES. (1)

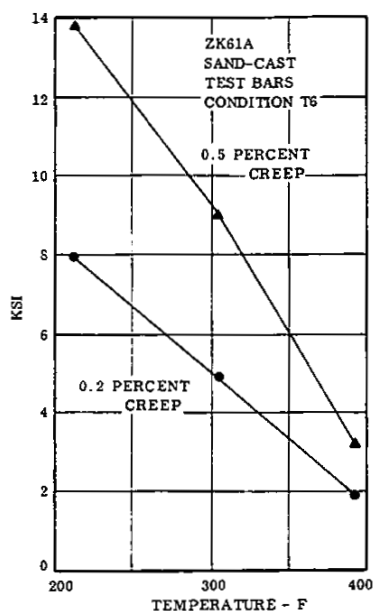


FIG. 3.041 EFFECT OF TEMPERATURE ON STRESSES TO CAUSE 0.2 PERCENT AND 0.5 PERCENT CREEP IN 100 HOURS. (1)

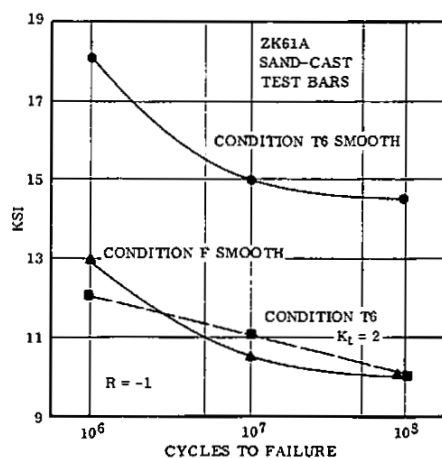


FIG. 3.051 ROTATING BEAM FATIGUE STRENGTH OF NOTCHED AND SMOOTH SPECIMENS. (1)

	Mg
6	Zn
0.8	Zr

ZK61A

REFERENCES

- Meier, J. W., "Characteristics of High-Strength Magnesium Casting Alloy ZK61," Transactions AFS, Volume 61 (1953) pp. 719-723.
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- Nelson, K. E., "New Specifications for High-Strength Magnesium Castings," Foundry, Volume 91 (December 1963) pp. 58-62.
- Pellegrini, C. J., "Investment Cast Zirconium-Bearing Magnesium-Base Alloys," Transactions AFS, Volume 70 (1962) pp. 1229-1234.
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- Arc Welding Magnesium, Form No. 141-400-67 (revised), The Dow Chemical Company, Metal Product Department, (1965).

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3.04 Creep and Creep Rupture Properties
 3.041 Effect of temperature on stresses to cause 0.2 percent and 0.5 percent creep in 100 hours, Figure 3.041.

3.05 Fatigue Properties
 3.051 Rotating beam fatigue strength of notched and smooth specimens, Figure 3.051.

3.06 Elastic Properties
 3.061 Poisson's ratio.
 3.062 Modulus of elasticity. All conditions: 6500 ksi (14).
 3.063 Modulus of rigidity.

4. FABRICATION

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4.04 Surface Treatment
 (see AM100A, Code 3509, Section 4.041 through 4.044)

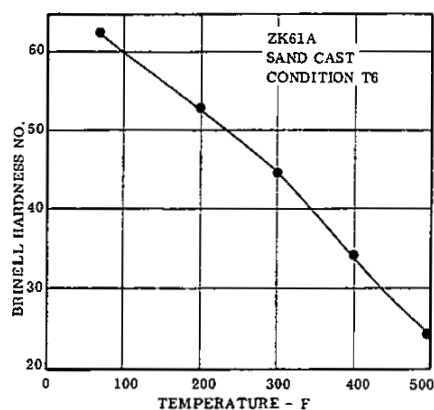


FIG. 1.062 EFFECT OF TEMPERATURE ON HARDNESS.
 (18)

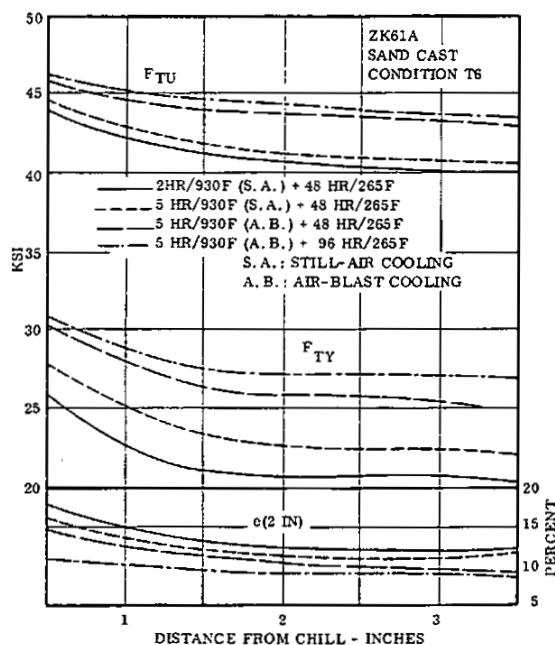


FIG. 1.051 EFFECT OF VARIATIONS IN HEAT TREATING CONDITIONS (SOLUTION TIME, COOLING METHOD, AND AGING TIME) ON THE TENSILE PROPERTIES OF CHILLED CASTING. (4)

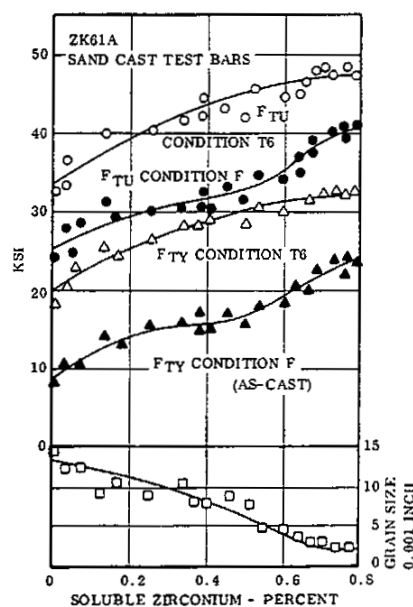


FIG. 1.091 EFFECT OF SOLUBLE ZIRCONIUM CONTENT ON TENSILE STRENGTH AND GRAIN SIZE.
 (1)(6)(10)

	Mg
6	Zn
0.8	Zr

ZK61A

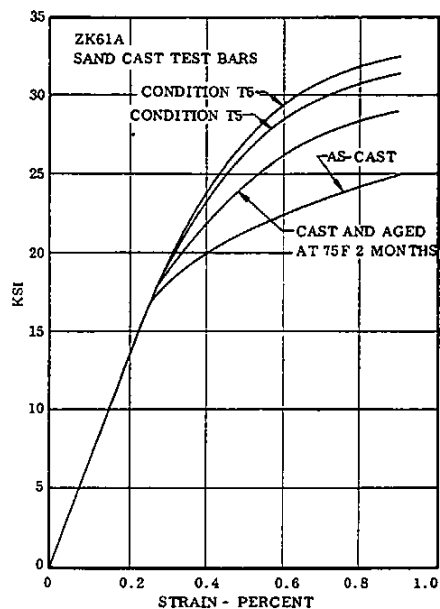


FIG. 3.0211 STRESS-STRAIN DIAGRAMS. (6)

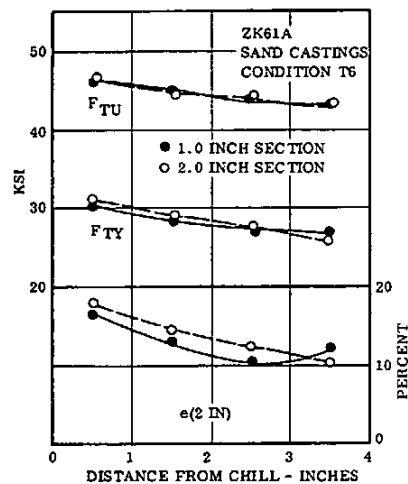


FIG. 3.0214 EFFECT OF END CHILL ON TENSILE PROPERTIES OF CAST PLATES OF TWO THICKNESSES. (4)

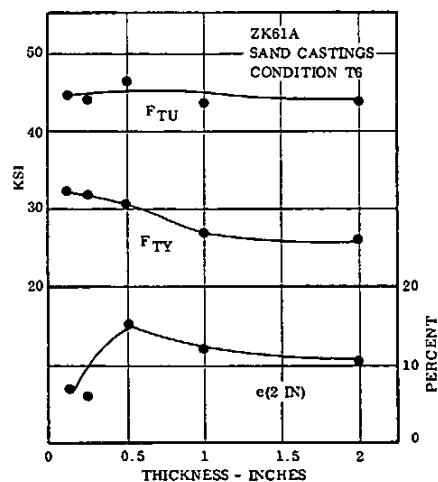


FIG. 3.0213 EFFECT OF SECTION THICKNESS ON TENSILE PROPERTIES. (4)

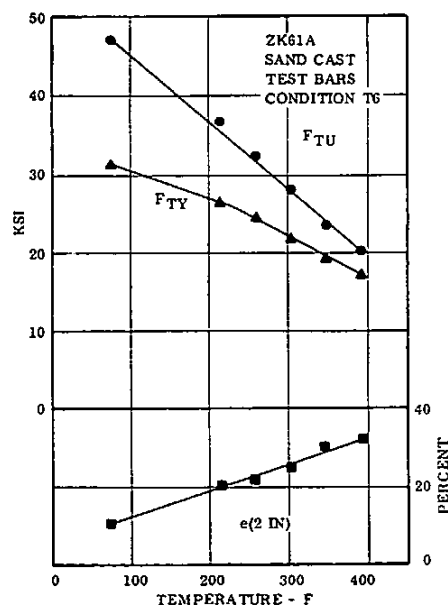


FIG. 3.0312 EFFECT OF TEMPERATURE ON TENSILE PROPERTIES. (1)

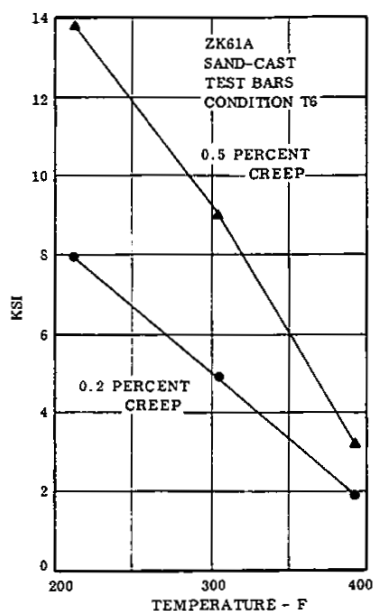


FIG. 3.041 EFFECT OF TEMPERATURE ON STRESSES TO CAUSE 0.2 PERCENT AND 0.5 PERCENT CREEP IN 100 HOURS. (1)

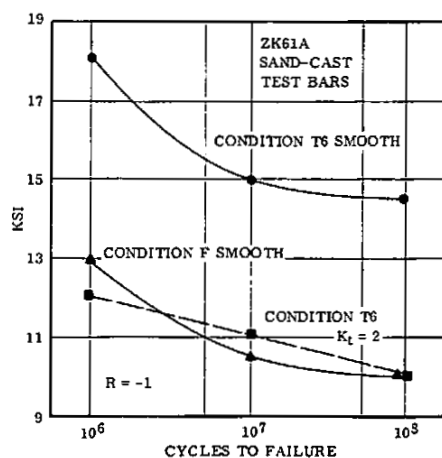


FIG. 3.051 ROTATING BEAM FATIGUE STRENGTH OF NOTCHED AND SMOOTH SPECIMENS. (1)

	Mg
6	Zn
0.8	Zr

ZK61A

REFERENCES

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- Leontis, T. E., "The Room and Elevated-Temperature Properties of Some Sand Cast Magnesium-Base Alloys Containing Zinc," Transactions ADME, Volume 180 (1949) pp. 287-321.
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- Arc Welding Magnesium, Form No. 141-400-67 (revised), The Dow Chemical Company, Metal Product Department, (1965).

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RELEASED: JUNE 1970
AUTHOR: J. R. KATTUS

NONFERROUS ALLOYS

1. GENERAL

AM 100 A is an age-hardenable magnesium-base alloy, which is used primarily for permanent-mold castings because it has outstanding resistance to hot cracking. It is also produced as investment castings. In the age-hardened condition, it has medium strength and ductility at room temperature. Its maximum use temperature should be limited to 350 F since its strength deteriorates rapidly at elevated temperatures. AM 100 A has desirable foundry characteristics including excellent fluidity and little tendency toward microporosity. It has very good machinability and weldability. Like other magnesium alloys, it should be protected from corrosion by chemical treatment followed by painting when it is to be used for long times in industrial environments or even for short times in marine environments. It is recommended for casting configurations that can be economically produced in permanent molds -- normally relatively high production of simple shapes. It is also a desirable alloy for applications requiring pressure tightness or X-ray inspection. Specific aerospace applications have included landing wheels, magneto housings, rocker-box covers, and jet compressor cases (1).

1.01 Commercial Designation
AM 100 A1.02 Alternate Designations
A10, G.1.03 Specifications
AMS 4455A, 4483A
ASTM B80-68, B199-68, B403-67
Federal QQ-M-55b
MIL-M-46062A
SAE 5021.04 Composition
Table 1.04.

TABLE 1.04		
Alloy	AM 100 A	
Source	Composition	
	AMS 4455A(2), 4483A(3); ASTM B80-68; B199-68; B403-67	
Element	Percent	
	Minimum	Maximum
Aluminum	9.3	10.7
Manganese	0.10	-
Zinc	-	0.30
Silicon	-	0.30
Copper	-	0.10
Nickel	-	0.01
Others (total)	-	0.30
Magnesium	Remainder	

1.05 Heat Treatment
Table 1.05.

1.051 Effect on tensile properties of aging time at various temperatures after solution treatment, Figure 1.051.

TABLE 1.05					
Alloy	AM 100 A				
Source	Heat Treatments				
Treatment	(4)(5)				
	Solution			Age	
	Temp F	Time hr	Cool (b)	Temp F	Time hr
T4 Solution (a)	775	18	a.b.	-	-
T5 Artificial Age	-	-	-	450	5
T6 Solution + artificial age	775	18	a.b.	450	5
T61 Solution + overage	775	18	a.b.	400	24
(a) Alternate solution to prevent excessive grain growth: 775 F 6 hr, furnace cool to 665 F, hold 2 hr, reheat to 775 F, hold 10 hr, cool in air blast.					
(b) a.b. -- Air Blast					

1.06

Hardness

Hardness for permanent-mold and investment castings,
Table 1.06.

TABLE 1.06			
Alloy	AM 100 A		
Source	(2) (6)		
Form	Condition	Hardness	
		BHN	RE
Permanent-mold castings	F(as cast)	53	64
Permanent-mold castings	T4	52	62
Permanent-mold castings	T6	60	72
Permanent-mold castings	T61	70	81
Investment Castings	T6	-	70-95

1.07

Forms and Conditions Available

Produced mostly as permanent-mold castings and to a lesser extent as investment castings; used in the T4 (solution-treated), T5 (artificially aged), and T6 (solution treated and artificially aged) conditions. The as-cast condition is designated as F.

1.08

Melting and Casting Practice (7)(8)

Melting practice for AM 100 A is the same as that for magnesium-aluminum-zinc casting alloys. Gas-fired or oil-fired crucible-type furnaces and steel melting containers and casting containers are used. When separate melting and casting crucibles are used, the metal is melted under "open-pot" flux, which is used in quantities of about 2 lb per 100 lb of metal in both crucibles.

When the melting is done in the casting crucible, "crucible" flux is used in quantities of about 3 lb per 100 lb of metal. Both fluxes are magnesium chloride mixed with various types and quantities of other chlorides and fluorides. The flux prevents burning and also traps impurities and settles them out of the melt in the form of sludge. Foundries usually buy AM 100 A in prealloyed ingot form, but an alternate method is to melt commercially pure magnesium and add the aluminum and manganese by immersing the pure metals in the melt until dissolved. Melting losses are negligible. Harmful gases, particularly hydrogen, can be removed from the melt by chlorination. Chlorination can be effected either by bubbling chlorine through the melt for from 5 to 15 minutes at about 1350 F, or plunging tablets of hexachloroethane or hexachlorobenzene into the melt at about 1450 F.

These tablets serve the additional function of grain refinement, which is very important for the attainment of optimum properties. Alternate methods of grain refinement are superheating to 1675 F and rapid cooling to the pouring temperature, or plunging of lampblack into the melt at 1450 F. For pouring, the flux should be skimmed from the surface of the melt and burning prevented by dusting on a mixture of sulfur and boric acid. The pouring temperature is normally about 1450 F.

1.09

Special Considerations

AM 100 A is subject to germination, which is the growth of large crystals in some locally stressed areas during solution heat treatment. Germination is very detrimental to mechanical properties, reducing strength by as much as 50 percent. The conditions favoring germination are very fine as-cast grains, internal stresses such as occur in chilled areas, complete solution of grain-boundary constituents, and a solution temperature above 730 F. The usual method for preventing germination is an interrupted solution shown as the alternate solution treatment in Table 1.05. This treatment relaxes the internal stresses (8) (9).

1.092

Special care should be taken in the preparation of AM 100 A to avoid contamination with zirconium-containing alloys, since such contamination inhibits response to grain-refining treatments (7).

Mg
Al
Q.I
Mn

AM 100 A

RELEASED: JUNE 1970
AUTHOR: J. R. KATTUS

NONFERROUS ALLOYS

1. GENERAL

AM 100 A is an age-hardenable magnesium-base alloy, which is used primarily for permanent-mold castings because it has outstanding resistance to hot cracking. It is also produced as investment castings. In the age-hardened condition, it has medium strength and ductility at room temperature. Its maximum use temperature should be limited to 350 F since its strength deteriorates rapidly at elevated temperatures. AM 100 A has desirable foundry characteristics including excellent fluidity and little tendency toward microporosity. It has very good machinability and weldability. Like other magnesium alloys, it should be protected from corrosion by chemical treatment followed by painting when it is to be used for long times in industrial environments or even for short times in marine environments. It is recommended for casting configurations that can be economically produced in permanent molds -- normally relatively high production of simple shapes. It is also a desirable alloy for applications requiring pressure tightness or X-ray inspection. Specific aerospace applications have included landing wheels, magneto housings, rocker-box covers, and jet compressor cases (1).

1.01 Commercial Designation

AM 100 A

1.02 Alternate Designations

A10, G.

1.03 Specifications

AMS 4455A, 4483A
ASTM B80-68, B199-68, B403-67
Federal QQ-M-55b
MIL-M-46062A
SAE 502

1.04 Composition

Table 1.04.

TABLE 1.04		
Alloy	AM 100 A	
Source	Composition	
	AMS 4455A(2), 4483A(3); ASTM B80-68; B199-68; B403-67	
Element	Percent	
	Minimum	Maximum
Aluminum	9.3	10.7
Manganese	0.10	-
Zinc	-	0.30
Silicon	-	0.30
Copper	-	0.10
Nickel	-	0.01
Others (total)	-	0.30
Magnesium	Remainder	

1.05 Heat Treatment

Table 1.05.

1.051 Effect on tensile properties of aging time at various temperatures after solution treatment, Figure 1.051.

TABLE 1.05					
Alloy	AM 100 A				
Source	Heat Treatments				
Treatment	(4)(5)				
	Solution			Age	
	Temp F	Time hr	Cool (b)	Temp F	Time hr
T4 Solution (a)	775	18	a.b.	-	-
T5 Artificial Age	-	-	-	450	5
T6 Solution + artificial age	775	18	a.b.	450	5
T61 Solution + overage	775	18	a.b.	400	24
(a) Alternate solution to prevent excessive grain growth: 775 F 6 hr, furnace cool to 665 F, hold 2 hr, reheat to 775 F, hold 10 hr, cool in air blast.					
(b) a.b. -- Air Blast					

1.06

Hardness

Hardness for permanent-mold and investment castings, Table 1.06.

TABLE 1.06			
Alloy	AM 100 A		
Source	(2) (6)		
Form	Condition	Hardness	
		BHN	RE
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Investment Castings	T6	-	70-95

1.07

Forms and Conditions Available

Produced mostly as permanent-mold castings and to a lesser extent as investment castings; used in the T4 (solution-treated), T5 (artificially aged), and T6 (solution treated and artificially aged) conditions. The as-cast condition is designated as F.

1.08

Melting and Casting Practice (7)(8)

Melting practice for AM 100 A is the same as that for magnesium-aluminum-zinc casting alloys. Gas-fired or oil-fired crucible-type furnaces and steel melting containers and casting containers are used. When separate melting and casting crucibles are used, the metal is melted under "open-pot" flux, which is used in quantities of about 2 lb per 100 lb of metal in both crucibles.

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1.09

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1.092

Special care should be taken in the preparation of AM 100 A to avoid contamination with zirconium-containing alloys, since such contamination inhibits response to grain-refining treatments (7).

Mg
Al
Q.I
Mn

AM 100 A

2.	Mg
2.01	Al
2.011	Mn
2.012	
AM 100 A	

PHYSICAL AND CHEMICAL PROPERTIES

Thermal Properties

Melting range, 867-1100F (8).

Phase changes. An eutectic network of $Mg_{17}Al_{12}$ compound and the alpha magnesium-aluminum solid solution forms at the grain boundaries in as-cast AM 100 A, which has matrix of alpha solid solution. Solution heat treatment dissolves the $Mg_{17}Al_{12}$ in the alpha phase. During aging heat treatment $Mg_{17}Al_{12}$ compound precipitates in a finely divided state, which can form a "pearlite" or a fine Widmanstätten type of structure (10)(11). Because of over-aging, during which the $Mg_{17}Al_{12}$ precipitate coagulates and grows, the mechanical properties of heat-treated AM 100 A deteriorate when the alloy is exposed to temperatures of 300F and above for long periods (13).

Time-temperature-transformation diagrams.

Thermal conductivity.

Table 2.013.

TABLE 2.013

Alloy	AM 100 A		
Form	Castings		
Source	(8) (12) (13)		
Condition	Temperature F	Thermal Conductivity Btu-ft per (ft ² -hr-F)	
F (as cast)	68	29	
T4	65	24	
T6	68	34	
T61	68	26	
All	212-570	41	

2.014 Thermal expansion. T6 and T61 conditions: 14.5×10^{-6} in per in per F from 68 to 212F (8) (5).

2.015 Specific heat. 0.25 Btu per (lb-F) at 78F (14).

2.016 Thermal diffusivity.

Other Physical Properties

2.021 Density. 0.065 lb per in³ (8).

2.022 Electrical properties.

2.0221 Electrical conductivity.

Table 2.0221.

TABLE 2.0221

Alloy	AM 100 A		
Form	Castings		
Source	(8) (15)		
Condition	Temperature F	Percent LACS	Megmhos per inch ³
F	68	12	0.176
T4	68	10	0.148
T6	68	13	0.204
T61	65	15	0.221

2.0222 Electrical resistivity (8)(15).

F condition: 5.64 microhm - in at 68F

T4 condition: 6.77 microhm - in at 68F

T6 condition: 4.90 microhm - in at 68F

T61 condition: 4.53 microhm - in at 68F

2.023 Magnetic properties.

2.024 Emission.

2.025 Damping Capacity. At a stress equal to 0.1 F_{ty} , the specific damping capacity of AM 100 A - F (as-cast) is 4.0, which is a medium level in comparison with other magnesium alloys (16).

Chemical Properties

2.03 In industrial environments, AM 100 A corrodes at a rate equivalent to most of the other commercial magnesium alloys. Its resistance to corrosion in marine environments, however, is generally the poorest of all the commercial magnesium alloys (18). The resistance to marine environments can be markedly improved by controlling impurity contents to the following maximum levels: iron 0.002 percent, nickel 0.0013 percent, and copper 0.05 percent (17). However, these low impurity levels are normally not practical under production conditions. With proper surface coating, the alloy can be

used in all natural environments except continuous immersion in water (15)(19). For a discussion of galvanic corrosion, see Code 3601, Section 2.0312.

2.032 Safety precautions should be directed to the prevention of fires, burns, and explosions. (see H232A, Code 3408, Section 2.032)

2.04 Nuclear Properties

3. MECHANICAL PROPERTIES

3.01 Specified Mechanical Properties

Table 3.01.

TABLE 3.01

Alloy	AM 100 A					
Form	Castings					
Specification	Type Casting	Cond	Specimen	F_{tu} ksi	F_{ty} ksi	e min (2 in)
AMS 4483A(3)	Perm Mold	T6	Separate cast (single) Cut from casting (avg 4 or more) Cut from casting (single)	34 25.5 17	15 13.5 10	2 1 -
AMS 4455A(2)	Investment	T6	Separate cast (single) Cut from casting (avg 4 or more) Cut from casting (single)	34 25.5 17	20 11.5 9.5	4 1 -
ASTM B199-68	Perm Mold	F T4 T6 T61	Separate cast (single)	20 34 34 34	10 10 15 17	- 6 2 -
ASTM B403-67	Investment	F T4 T6 T7	Separate cast (single)	20 34 34 34	10 10 15 17	- 6 2 -
ASTM B80-68	Sand	T6	Separate cast (single)	35	17	-

3.02 Mechanical Properties at Room Temperature

3.021 Tension.

3.0211 Stress-strain diagrams.

3.0212 Tensile properties of permanent-mold castings, Table 3.0212.

TABLE 3.0212

Alloy	AM 100 A				
Form	Castings				
Source	(18) (13) (14) (5)				
Type Castings	Condition	Specimen	F _{tu} ksi	F _{ty} ksi	e (2 in)
Permanent mold	F	Separate Cast	24	16	1
	T4		39	14	10
	T6		39	20	2
	T61		39	22	1
Permanent mold	F	Cut from castings	20	11	2
	T4		35	12	9
	T6		35	16	4
	T61		36	19	1
	T5		22	16	2

3.022 Compression.

3.0221 Stress-strain diagrams.

3.0222 Compressive strength of permanent-mold castings, Table 3.0222.

TABLE 3.0222

Alloy	AM 100 A	
Form	Permanent Mold Cast	
Source	(1) (13) (14) (5)	
Condition	Specimen	F_{cy} , ksi
F	Cut from castings	11
T4		12
T6		16
T61		19
T5		16
F	Separate cast	12
T4		13
T6		16
T61		22

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NONFERROUS ALLOYS

- 3.023 Impact.
3.0231 Impact strength of permanent-mold castings, Table 3.0231.

TABLE 3.0231			
Alloy AM 100 A			
Form Permanent Mold Cast			
Source (1) (13) (18)			
Condition	Specimen	Charpy Impact - ft lb	
		Keyhole Notch	No Notch
T4	Separate cast	2.0	-
F	Cut from casting	0.6	2.6
T4		2.0	17.2
T6		1.0	4.6
T61		0.7	-

- 3.024 Bending.
3.025 Torsion and shear.
3.0251 Shear strength of permanent-mold castings, Table 3.0251.

TABLE 3.0251		
Alloy AM 100 A		
Form Permanent Mold Cast		
Source (1) (13) (5)		
Condition	Specimen	F_{su} - ksi
F	Cut from castings	18
T4		20
T6		21
T61		22
F	Separate cast	17
T4		19
T6		21
T61		22

- 3.026 Bearing.
3.0261 Bearing strength of permanent-mold castings, Table 3.0261.

TABLE 3.0261			
Alloy AM 100 A			
Form Permanent Mold Cast			
Source (14)			
Condition	Specimen	(e/D = 2.5)	
		F_{bru} , ksi	F_{bry} , ksi
T4	Cut from casting	69	45
T61		81	68

- 3.027 Stress concentration.
3.0271 Notch properties.
3.0273 Fracture toughness.
3.028 Combined properties.

3.03 Mechanical Properties at Various Temperatures
3.031 Tension.
3.0311 Stress-strain diagrams.
3.0312 Effect of temperature on tensile properties in T4 (solution-treated) condition, Figure 3.0312.
3.0313 Effect of temperature on tensile properties in T6 (solution-treated and aged) condition, Figure 3.0313.
3.032 Compression.
3.0321 Stress-strain diagrams.
3.033 Impact.
3.0331 Effect of low temperatures on Charpy V-notch impact energy, Figure 3.0331.
3.034 Bending.
3.035 Torsion and shear.
3.036 Bearing.
3.037 Stress concentration.
3.0371 Notch properties.
3.0372 Fracture toughness.
3.038 Combined properties.

3.04 Creep and Creep Rupture Properties3.05 Fatigue Properties

- 3.051 Fatigue strength for permanent-mold castings, Table 3.051.

TABLE 3.051					
Source (18)					
Alloy AM 100 A					
Form Permanent Mold Cast					
Method	Stress Ratio		Stress Concentration	Condition	Fatigue Strength-ksi at Cycles
	A	R			
Rotating Bending	∞	-1	Smooth $K_t = 1$	F	16
				T4	18
				T6	16
			Notched $K_t = 2$	F	10
				T4	12
				T6	11

- 3.06 Elastic Properties
3.061 Poisson's ratio, all conditions: 0.35 (14).
3.062 Modulus of elasticity, all conditions: 6500 ksi (14).
3.063 Modulus of rigidity, all conditions: 2400 ksi (14).

4. FABRICATION4.01 Formability4.02 Machining and Grinding

- 4.021 This alloy, like other magnesium alloys, has exceptionally good machinability, which enables it to be machined at high speeds and feeds (6)(8)(15). (see HZ32A, Code 3408, Section 4.021)

4.03 Welding

This alloy can be readily joined by gas-shielded (helium or argon) arc-welding techniques with either tungsten or consumable electrodes. Recommended filler metals are AZ61A or AZ92A. A post-weld stress relief of 500F for 60 minutes followed by air cooling is required to prevent possible stress-corrosion cracking in the weld area. The use of rigid jigs is sometimes necessary during stress relief to prevent warpage of the welded parts. The stress-relief treatment will not develop maximum joint strength. For maximum strength, solution-and-age treatment given in Table 1.05 is necessary except that solution time should be reduced to 1/2 hour at 725F in order to prevent germination of the weld metal (4)(8)(15)(21)(22). The alloy can also be resistance welded, but resistance welding is generally not suitable for joints that are critically stressed or subject to vibration or fatigue. Gas welding is not recommended (15)(23).

4.04 Surface Treatment

- 4.041 The producing foundries normally chrome pickle the castings prior to shipment to protect them from corrosion and tarnish during shipment and storage (2)(3) (ASTM B60-68, B199-68, B403-67). A suitable alternative is to oil with a light corrosion-inhibiting oil (2)(3). The following surface treatments, which have been developed for magnesium alloys, can be applied to AM 100 A to provide a good paint base as well as some degree of corrosion resistance (15)(24):
1. Chrome pickle, MIL-M-3171A - Type 1
 2. Dichromate, MIL-M-3171A - Type 3
 3. Galvanic anodize, MIL-M-3171A - Type 4
 4. Sealed chrome pickle, MIL-M-3171A - Type 2
 5. Anodize, MIL-M-45202
 6. Dilute chromic acid, MIL-M-3171B
 7. Stannate immersion
 8. HAE anodize, MIL-M-45202 (ORD)
 9. Fluoride anodize
 10. Iridite No. 15
- The anodize and HAE processes are foremost in adherence, abrasion resistance, corrosion resistance, and heat resistance; they form an excellent base for paints and are stable to the melting point of magnesium. For optimum corrosion resistance, the above surface treatments should be followed by painting. The paint should have good resistance to alkali, since highly

Mg
Al
O.I Mn
AM 100 A

	Mg
10	Al
0.1	Mn

AM 100 A 4.044

alkaline environments are produced at the cathode during corrosion. One of the best paint systems is an epoxy-polyamide primer with a topcoat of polyurethane. Vinyl paints are available that are superior to phenolics for coating magnesium. However, the epoxies are more highly favored because of their excellent resistance to alkalis (15)(24).

With suitable surface pretreatments, high-quality electrodeposits of most metals can be applied. Two pretreatments--zinc-immersion and electroless-nickel processes--are used. The zinc-immersion process deposits a thin layer of zinc suitable for a copper flash, after which any type of electroplate can be applied. The electroless-nickel process deposits nickel to serve as finish surface or as undercoat for other types of electroplate (15)(24).

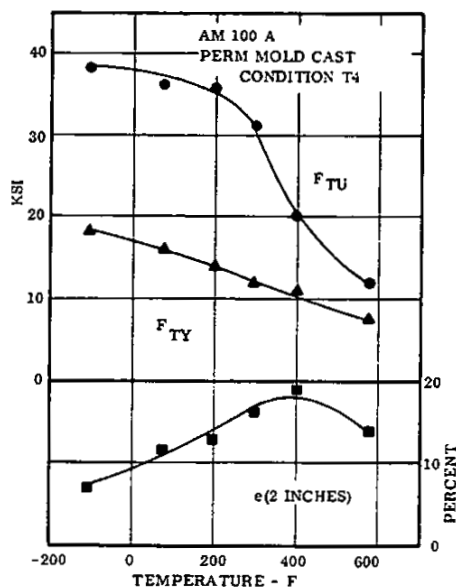


FIG. 3.0312 EFFECT OF TEMPERATURE ON TENSILE PROPERTIES IN CONDITION T4 (SOLUTION-TREATED). (13)

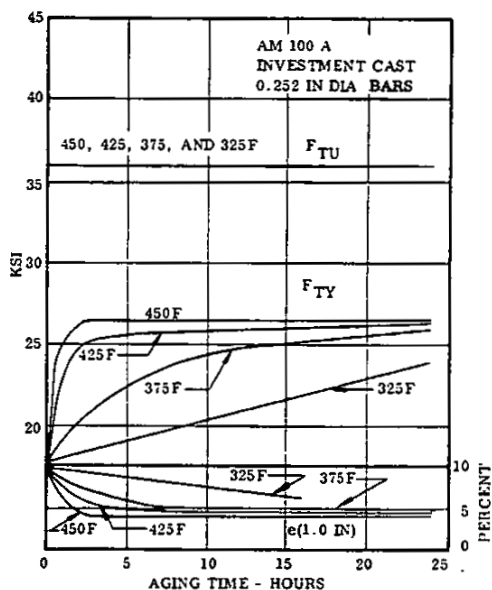


FIG. 1.051 EFFECT ON TENSILE PROPERTIES OF AGING TIME AT VARIOUS TEMPERATURES AFTER SOLUTION TREATMENT. (20)

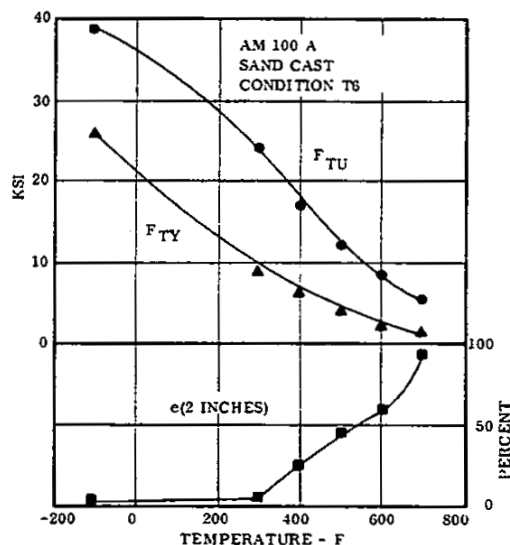


FIG. 3.0313 EFFECT OF TEMPERATURE ON TENSILE PROPERTIES IN CONDITION T6 (SOLUTION-TREATED AND AGED). (14)

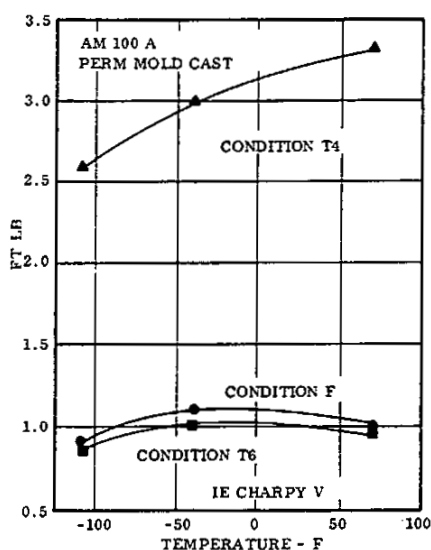


FIG. 3.0331 EFFECT OF LOW TEMPERATURES ON CHARPY V-NOTCH IMPACT ENERGY. (13)

	Mg
IO	Al
Q.I	Mn

AM 100 A

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REVISED: JUNE 1971
AUTHOR: J. R. KATTUS

NONFERROUS ALLOYS

1. **GENERAL**
This nonheat treatable magnesium alloy is widely produced and used in wrought form because it has good mechanical properties along with excellent formability. Its strength deteriorates rapidly with increasing temperatures; 350 F is the maximum temperature at which it should be used. It has good weldability by inert-gas-shielded-arc techniques and also by resistance spot welding.

- 1.01 Commercial Designation
AZ31B.

- 1.02 Alternate Designation
AZ31

- 1.03 Specifications
Table 1.03.

TABLE 1.03	
Alloy	AZ31B
Forms	Specifications
Sheet and plate	AMS 4375 F (O Condition) AMS 4377 D (H24 Condition) AMS 4376 C (H26 Condition) ASTM B90 MIL-F-46048 (Tread plate) MIL-T-38749 (Tooling plate) Federal QQ-M-44b SAE 510
Extrusions	ASTM B107 Federal QQ-M-31b (rods, bars, shapes) Federal WW-T-825a (tubes) SAE 510
Forgings	ASTM B91 Federal QQ-M-40b (1)

- 1.04 Composition
Table 1.04.

TABLE 1.04				
Alloy	AZ31B			
Source	(1)(2)(3)		(4)(5)(6)	
Element	Percent		Percent	
	Minimum	Maximum	Minimum	Maximum
Aluminum	2.5	3.5	2.5	3.5
Zinc	0.7	1.3	0.6	1.4
Manganese	0.20	-	0.20	-
Silicon	-	0.10	-	0.10
Copper	-	0.05	-	0.05
Calcium	-	0.04	-	0.04
Nickel	-	0.005	-	0.005
Iron	-	0.005	-	0.005
Others, total	-	0.30	-	0.30
Magnesium	Balance		Balance	

- 1.05 Heat Treatment(7)
Full anneal, O condition: 650 F 1 hr, air cool.
1.051 Partial anneal after strain hardening to H24 or H26 conditions, H26 indicating a slightly higher degree of cold work: 300 F, 1 hr, air cool.
1.052 Stress relief after welding and after forming: for material in O and F conditions, 500 F 15 min, air cool; for material in H24 and H26 conditions, 300 F 1 hr, air cool.
1.053
1.06 Hardness (8)
1.061 Extrusions, F condition: BHN 49
1.062 Forgings, F condition: BHN 55

- 1.07 Forms and Conditions Available
Table 1.07.

TABLE 1.07		
Alloy	AZ31B	
Source	(9)	
Form	Condition	Thickness - inches
Flat sheet and plate	O (fully annealed)	0.010 to 3.000
Flat sheet and plate	H24 (strain hardened and partially annealed)	0.010 to 3.000
Flat sheet and plate	H26 (strain hardened and partially annealed)	0.016 to 2.000
Coiled sheet	O	0.032 to 0.250
Coiled sheet	H24	0.032 to 0.250
Tooling plate	-	0.250 to 6.000
Extrusions	F (as extruded)	-
Forgings	F (as forged)	-

Mg
3 Al
1 Zn
AZ31B

- 1.08 Melting and Casting Practice
AZ31B, as well as other magnesium alloys for wrought products, are normally melted and alloyed in steel crucibles under flux in gas-fired or oil-fired furnaces and cast into ingot molds up to about 28 inches in diameter.

- 1.09 Special Considerations
1.091 Material in the H24 and H26 conditions loses room temperature strength as a result of exposures to temperatures above 300 F, the time required for strength deterioration decreasing with increasing temperature. The maximum exposure times at various temperatures without deterioration of room temperature properties are shown in Table 1.091.

TABLE 1.091	
Alloy	AZ31B
Condition	H24
Source	(10)
Maximum Time minutes	Temperature F
0.3	500
1	435
2	410
3	395
4	385
5	370
10	360
30	345
60	325

2. **PHYSICAL AND CHEMICAL PROPERTIES**

- 2.01 Thermal Properties
2.011 Melting range: 1120-1170 F (11).
2.012 Phase changes: None.
2.0121 Time-temperature-transformation diagrams.
2.013 Thermal conductivity, Figure 2.013.
2.014 Thermal expansion, Figure 2.014.
2.015 Specific heat, Figure 2.015.
2.016 Thermal diffusivity, Figure 2.016.

- 2.02 Other Physical Properties
2.021 Density, 0.0642 lb per cu in (9).
2.022 Electrical properties, Table 2.022.

TABLE 2.022			
Alloy	AZ31B		
Condition	F, H24, O		
Source	(9)		
Temperature - F	Electrical Conductivity		Electrical Resistivity
	percent IACS	megmhos per in ³	microhm in
68	18.8	0.276	3.62
100	18.2	0.268	3.74
200	16.5	0.247	4.06
300	15.5	0.232	4.31
400	14.4	0.212	4.73
500	13.3	0.197	5.09

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PAGE 1

	Mg
3	Al
1	Zn

AZ 31B

- 2.023 Magnetic properties, nonmagnetic.
 2.024 Emission, Figure 2.024.
 2.025 Damping capacity. At a stress equal to 0.1 F_{ty} the specific damping capacity is 6.5, which is a medium level compared with other magnesium alloys (15).

Chemical Properties

- 2.03 Corrosion resistance.
 2.031 AZ31B, like other magnesium alloys, is subject to corrosion (Figure 2.0311) and associated loss of strength (Table 2.0311) in industrial, marine, and moist environments. With suitable surface treatment and painting, it performs satisfactorily in all types of natural environments with the exception of continuous immersion in water (17).
 2.0311

TABLE 2.0311

Alloy Source	AZ31B (17)				
	Surface Treatment	Original Properties		Percent change after 4 years in industrial atmosphere	
		F_{tu} ksi	e(2 in) percent	F_{tu}	e(2 in)
F	none	51.6	11.8	-15	-16
O	none	36.0	22.2	-19	-15
H24	none	41.3	27.2	-13	-25
H26	none	44.1	12.7	-17	-45
H26	chrome pickle	45.2	9.5	-17	-37

- b. Suitable protective treatments are applied.
 c. A device is used to increase the resistance of the galvanic cell.
 d. The galvanic cell is inhibited by chemical means.

Generally, the copper containing aluminum alloys are not compatible with magnesium nor are those containing high amounts of iron impurity. Mild steel, stainless steel, titanium, copper, monel, and similar materials are not compatible and will corrode magnesium alloys galvanically. Some dissimilar metals considered to be compatible with magnesium alloys are high purity aluminum and alloys 5052, 5053, 5056, 6061, and 6063 (8)(17). AZ31B and other magnesium alloys are subject to stress corrosion in air, fresh water, sea water, and many other salt solutions. The threshold stress, rate of crack growth, and time to failure vary widely with the environment. AZ31B sheet in the H24 and H26 conditions are more resistant than the annealed material. Stress relief after forming and welding is very important in minimizing stress-corrosion cracking (18)(19). Safety precautions should be directed to the prevention of fires, burns, and explosions (see HZ32A, Code 3408, Section 2.032).

2.0313

2.032

2.04

Nuclear Properties

3.

MECHANICAL PROPERTIES

3.01

Specified Mechanical Properties

Table 3.01.

TABLE 3.01

Alloy		AZ31B						
Condition	Form	Source	Thickness or Diameter - in	Specimen Orientation	F_{tu} ksi	F_{ty} -ksi min	e(2 in) min	F_{cy} -ksi min
O	sheet and plate	(1)	0.016-0.060	tension not specified, compression longitudinal	32-40	18	12	-
			0.060-0.500		32-40	15	12	-
			0.063-0.249		-	-	-	12
			0.249-2.000		-	-	-	10
			0.500-2.000		32-40	15	10	-
H24	sheet and plate	(3)	2.000-3.000	tension not specified, compression longitudinal	32-40	15	9	8
			0.016-0.249		F_{tu} -ksi min			
			0.063-0.249		39	29	6	-
			0.249-0.374		-	-	-	24
			0.374-0.500		38	26	8	20
			0.500-1.000		37	24	8	16
			1.000-2.000		36	22	8	13
			2.000-3.000		34	20	8	10
H26	sheet and plate	(2)	0.016-0.249	tension not specified, compression longitudinal	34	18	8	9
			0.250-0.374		39	27	6	22
			0.374-0.438		-	-	-	21
			0.438-0.500		-	-	-	18
			0.500-0.750		38	26	6	-
			0.750-1.000		37	25	6	17
			1.000-1.500		37	23	6	16
			1.500-2.000		35	22	6	15
F	extruded bars, rods, and shapes	(6)	up to 0.249	longitudinal	35	21	7	-
			0.250-1.499		35	22	7	-
			1.500-2.499		34	22	7	-
	extruded tubes and hollow shapes	(6)	2.500-4.999	longitudinal	32	20	7	-
			0.028-0.250		32	16	8	-
	forgings	(7)	0.251-0.750	longitudinal	32	16	4	-
			all		34	19	6	-

- 2.0312 Magnesium alloys, in general, have the highest electro-negative potential of the common structural metals, and they exhibit only a slight tendency to polarize anodically in salt solutions. As a result, AZ31B as well as other magnesium alloys in electrical contact with other metals can suffer severe galvanic corrosion in moist environments unless one or more of the following preventive measures are taken:

- a. A dissimilar metal with galvanic compatibility with magnesium is selected.

- 3.02 Mechanical Properties at Room Temperature
 3.021 Tension.
 3.0211 Stress-strain diagrams (see Figures 3.03111, 3.03112, and 3.03113).
 3.0212 Effect of thickness on tensile properties of sheet and plate, Figure 3.0212.
 3.0213 Effect of exposures at elevated temperatures on tensile properties at room temperature of sheet in H24 condition, Figure 3.0213.
 3.0214 Effect of rolling temperature on the tensile properties of sheet rolled to 20 percent reduction, Figure 3.0214.

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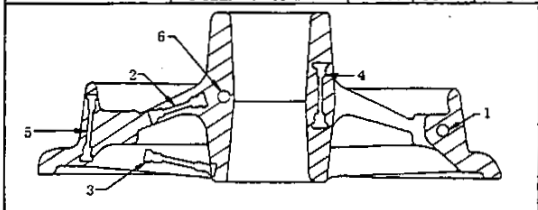
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- 3.0215 Effect of rolling temperature on the tensile properties of sheet rolled to 40 percent reduction, Figure 3.0215.
- 3.0216 Typical tensile properties of extrusions in F condition in section sizes up to 5.0 inches
 $F_{tu} = 38.0$ ksi $F_{ty} = 28.5$ ksi $e(2 \text{ in}) = 14.5$ (9).
- 3.0217 Typical tensile properties of forgings in F condition
 $F_{tu} = 38.0$ ksi $F_{ty} = 28.0$ ksi $e(2 \text{ in}) = 9.0$ (9).
- 3.0218 Tensile properties at various locations in brake wheel forging in different conditions, Table 3.0218.

TABLE 3.0218

Alloy	AZ31B			
Form	20.5 lb Brake Wheel Forging			
Source	(21)			
Condition	Test Location	F_{ty} -ksi	F_{tu} -ksi	$e(2 \text{ in})$
As hot forged	1 Rim Tangential	25.9	39.3	18.0
	6 Center Tangential	23.7	38.1	18.4
	2 Radial	21.1	37.8	18.0
	3 Radial	24.5	38.2	16.6
	4 Center Vertical	14.8	35.9	18.0
Hot forged and cold finished	5 Rim Vertical	17.1	36.2	11.6
	1 Rim Tangential	29.0	40.6	16.6
	6 Center Tangential	27.2	41.4	17.6
	2 Radial	28.4	40.5	18.0
	3 Radial	23.3	38.8	15.2
Hot forged and aged 48 hours at 300F	4 Center Vertical	21.7	37.2	12.2
	5 Rim Vertical	17.9	36.3	9.2
	1 Rim Tangential	30.0	39.7	14.0
	6 Center Tangential	24.8	38.7	16.0
	2 Radial	23.8	38.3	13.0
Hot forged, cold finished, and aged 48 hours at 300F	3 Radial	25.9	36.7	9.0
	4 Center Vertical	15.1	36.7	15.0
	5 Rim Vertical	20.4	34.6	14.0
	1 Rim Tangential	28.5	39.9	15.0
	6 Center Tangential	29.8	39.7	15.0
	2 Radial	28.1	40.3	15.0
	3 Radial	26.7	37.7	8.0
	4 Center Vertical	20.4	36.1	14.0
	5 Rim Vertical	18.0	34.0	8.0



- 3.0219 Effect of orientation and forging reduction on tensile properties of roll forged rings, Table 3.0219.

TABLE 3.0219

Alloy	AZ31B			
Condition	F			
Form	Roll Forged			
Source	(22)			
Specimen Orientation	Forging Reduction percent	F_{tu} - ksi	F_{ty} - ksi	$e(2 \text{ in})$ percent
Tangential	20	32	24	9
	40	36	26	11
	60	37	27	11
Axial	20	34	15	12
	40	34	20	12
	60	36	23	12
Radial	20	32	9	11
	40	36	9	13
	60	39	12	15

- 3.022 Compression.
- 3.0221 Stress-strain diagrams (see Figures 3.03211 and 3.03212).
- 3.0222 Effect of thickness on compressive yield strength of sheet and plate, Figure 3.0222.
- 3.0223 Effect of exposures at elevated temperatures on compressive yield strength at room temperature of sheet in H24 condition, Figure 3.0223.
- 3.0224 Typical compressive strength of extrusions in F condition in section sizes up to 5.0 inches
 $F_{cy} = 14.2$ ksi (9).
- 3.0225 Typical compressive strength of forgings in F condition
 $F_{cy} = 12$ ksi (9).
- 3.0226 Effect of orientation and forging reduction on compressive strength of roll forged rings, Table 3.0226.

TABLE 3.0226

Alloy	AZ31B	
Condition	F	
Form	Roll Forged	
Source	(22)	
Specimen Orientation	Forging Reduction - percent	F_{cy} ksi
Tangential	20	12
	40	12
	60	12
Axial	20	11
	40	11
	60	11
Radial	20	14
	40	14
	60	18

- 3.023 Impact (see Figure 3.0331).
- 3.024 Bending.
- 3.025 Torsion and shear.
- 3.0251 Effect of thickness on shear strength of sheet and plate, Figure 3.0251.
- 3.0252 Typical shear strength of extrusions in F condition in sections up to 5.0 inches: $F_{su} = 19$ ksi (9).
- 3.0253 Typical shear strength of forgings in F condition: $F_{su} = 19$ ksi (9).
- 3.026 Bearing.
- 3.0261 Effect of thickness on bearing properties of sheet and plate, Figure 3.0261.
- 3.0262 Typical bearing ($e/d = 2.5$) properties of extrusions in F condition in sections up to 5.0 inches: $F_{bru} = 56$ ksi $F_{bry} = 34$ ksi (9).
- 3.0263 Typical bearing ($e/d = 2.5$) properties of forgings in F condition: $F_{bru} = 70$ ksi $F_{bry} = 36$ ksi (9).
- 3.027 Stress concentration.
- 3.0271 Notch properties.
- 3.0272 Fracture toughness.
- 3.028 Combined properties.

Mechanical Properties at Various Temperatures

- 3.03 Tension.
- 3.031 Stress-strain diagrams.
- 3.0311 Effects of elevated temperature exposure on stress-strain curves for sheet in O condition, Figure 3.03111.
- 3.03112 Effects of elevated temperature exposure on stress-strain curves for sheet in H24 condition, Figure 3.03112.
- 3.03113 Complete stress-strain curves at low temperatures, Figure 3.03113.
- 3.0312 Elevated temperature tensile properties of sheet in H24 condition after various exposure times from one half to 1000 hours at temperature, Figure 3.0312.
- 3.0313 Low temperature properties of sheet tensile specimens in H24 condition, both unwelded and with gas tungsten arc butt welds transverse to the gage length, Figure 3.0313.
- 3.0314 Effects of temperature on tensile properties of sheet in H24 condition at rapid strain rates after rapid heating and short holding times at temperature, Figure 3.0314.
- 3.0315 Effects of strain rate on tensile properties of sheet in H24 condition at various temperatures, Figure 3.0315.
- 3.0316 Effects of strain rate on tensile properties of sheet in O condition at various temperatures, Figure 3.0316.

	Mg
3	Al
1	Zn

AZ31B

	Mg
3	Al
1	Zn

AZ31B

- 3.0317 Effects of strain rate on tensile properties of extrusions in F condition at various temperatures, Figure 3.0317.
- 3.0318 Low temperature tensile properties of extrusions and sheet, Figure 3.0318.
- 3.0319 Elevated temperature tensile strength of extrusions, Figure 3.0319.
- 3.032 Compression.
- 3.0321 Stress-strain diagrams.
- 3.03211 Effect of elevated temperature exposure on stress-strain curves in compression for sheet in O condition, Figure 3.03211.
- 3.03212 Effect of elevated temperature exposure on stress-strain curves in compression for sheet in H24 condition, Figure 3.03212.
- 3.0322 Elevated temperature compressive yield strength, Figure 3.0322.
- 3.033 Impact.
- 3.0331 Charpy impact properties at low temperatures, Figure 3.0331.
- 3.034 Bending.
- 3.035 Torsion and shear.
- 3.0351 Effect of temperature and exposure time on shear strength, Figure 3.0351.
- 3.036 Bearing.
- 3.0361 Effects of temperature and exposure time on bearing properties, Figure 3.0361.
- 3.037 Stress concentration.
- 3.0371 Notch properties.
- 3.0372 Fracture toughness.
- 3.038 Combined properties.
- 3.04 Creep and Creep Rupture Properties
- 3.041 Total creep strain curves for sheet in O condition, Figure 3.041.
- 3.042 Total creep strain curves for sheet in H24 condition, Figure 3.042.
- 3.043 Total creep strain curves for extrusions in F condition, Figure 3.043.
- 3.044 Short time total strain curves at 300 to 600F for sheet in H24 condition, Figure 3.044.
- 3.05 Fatigue Properties
- 3.051 Fatigue strength of extrusions and sheet, Table 3.051.

TABLE 3.051

Source		(32)									
Form		(a) Extrusions (b) Sheet									
Condition	Temp F	Method	Stress Ratio		Stress Concentration	Fatigue Strength - ksi at Cycles					
			A	R		10 ⁵	10 ⁶	10 ⁷	10 ⁸		
(a) F	RT	Rot beam	∞	-1	Smooth K _t = 1	23 to 29	21 to 26	19 to 23	17 to 21	-	
(b) O		Rev bend	∞	-1	As rolled	18 to 22	15 to 17	14 to 16	-	-	
(b) H24						19 to 25	16 to 20	14 to 17	-	-	
(a) F	RT	Direct stress	0.60	0.25	Smooth K _t = 1	23 to 28	22 to 25	20 to 24	-	-	
(b) O					As rolled	20 to 24	19 to 22	18 to 21	-	-	
(b) H24					As rolled	22 to 27	20 to 24	19 to 23	-	-	
Source		(33)									
(a) H24	RT	Rot beam	∞	-1	Smooth	24.3	22	19	-	-	
	-320 F				K _t = 1	32.7	28	25	-	-	
	RT				Notched	14	10	8	-	-	
	-320 F				K _t = 3.4	16.5	12	10	-	-	

- 3.052 Stress-range diagrams for sheet in the O and H24 conditions, Figure 3.052.
- 3.053 Stress range diagram for forgings at 90 percent survival level, Figure 3.053.

- 3.06 Elastic Properties
- 3.061 Poisson's ratio. 0.35 (9).
- 3.062 Modulus of elasticity, Figure 3.062.
- 3.063 Modulus of rigidity. 2.4×10^3 ksi.
- 3.064 Tangent modulus curves in compression for sheet in O condition, Figure 3.064.
- 3.065 Tangent modulus curves in compression for sheet in H24 condition, Figure 3.065.

4. FABRICATION

- 4.01 Formability.
- 4.011 AZ31B is one of the most formable of the magnesium alloys. The methods and equipment used are the same type commonly used for other metals. Like other magnesium alloys, the room temperature formability of AZ31B is limited to relatively mild deformation around generous radii. It becomes very workable at elevated temperatures, optimum formability being achieved at temperatures above 400F. The formability at 400 to 600F is so improved that more severe working is possible in this temperature range, in most operations, than in most other metals at room temperature. In order to prevent deterioration in strength during hot forming operations, it is important not to exceed established temperature limits as given in Table 4.011. Stress relieving, as given in section 1.053, is recommended to reduce residual stresses induced by cold and hot forming (7)(9)(10)(37)(38).

TABLE 4.011

Alloy		AZ31B		
Source		(37)(10)		
Condition	Form	Max Forming Temp - F	Max Time at Temp - hr	
H24	Sheet and plate	300*	1	
O	Sheet and plate	550	1	
F	Extrusions	550	1	

* Higher temperatures may be used with shorter maximum times at temperature as shown in Table 1.091

- 4.02 Machining and Grinding
- 4.021 This alloy, like other magnesium alloys has exceptionally good machinability, which enables it to be machined at high speeds and feeds. For further details, see HZ32A, Code 3408, Section 4.021.
- 4.022 The alloy can be chem-milled with sulfuric, nitric, or by hydrochloric acid of 5 percent strength or greater (39).
- 4.03 Welding
- 4.031 AZ31B has excellent weldability by arc and electric-resistance methods. In arc welding the arc should be shielded with argon or helium gas, and either tungsten or consumable electrodes may be used. AZ32A and AZ61 magnesium alloys are suitable filler metals. Electric-resistance welding methods that may be used include spot, seam, and flash welding. Spot welding is used to the greatest extent. Joining methods other than spot welding should be used in applications that involve vibrating stresses. Fusion welded, riveted, bolted, and adhesive bonded joints all have fatigue strength superior to spot welded joints. Welded parts should be stress relieved in accordance with the procedure in section 1.053 for the following reasons: (9)(40)
- to prevent stress corrosion cracking
 - to obtain a stress-free assembly
 - to facilitate sizing and straightening
 - to provide dimensional stability
- Some properties of welded joints are shown in Figure 3.0313.

- 4.04 Surface Treatment
- 4.041 The various wrought products are normally oiled by the producer with a light corrosion inhibiting oil for protection during shipment and storage (1)(2)(3).
- 4.042 See HZ32A, Code 3408, section 4.042 and 4.043.

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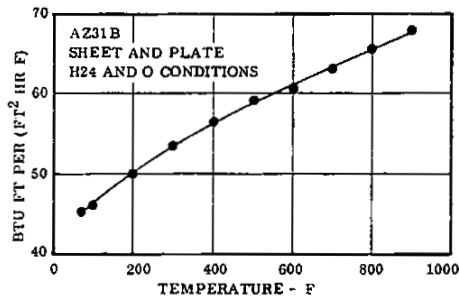


FIG. 2.013 THERMAL CONDUCTIVITY.

(9)

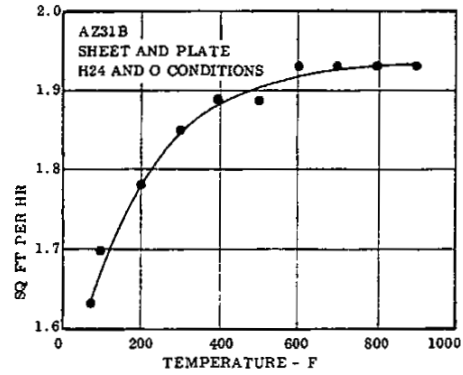


FIG. 2.016 THERMAL DIFFUSIVITY.

(9)

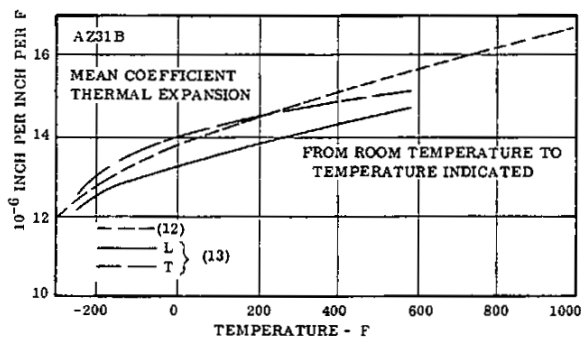


FIG. 2.014 THERMAL EXPANSION.

(12)(13)

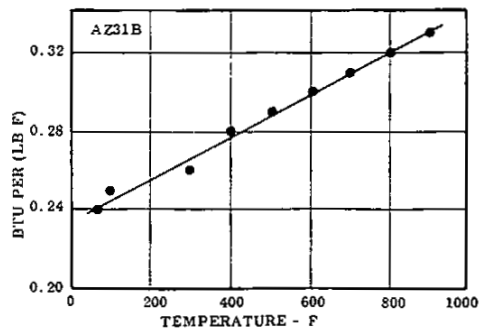


FIG. 2.015 SPECIFIC HEAT.

(9)

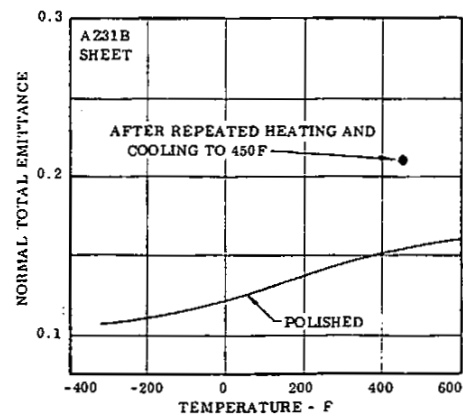


FIG. 2.024 TOTAL NORMAL EMITTANCE.

(14)

	Mg
3	Al
1	Zn

AZ 31B

	Mg
3	Al
1	Zn

AZ 31B

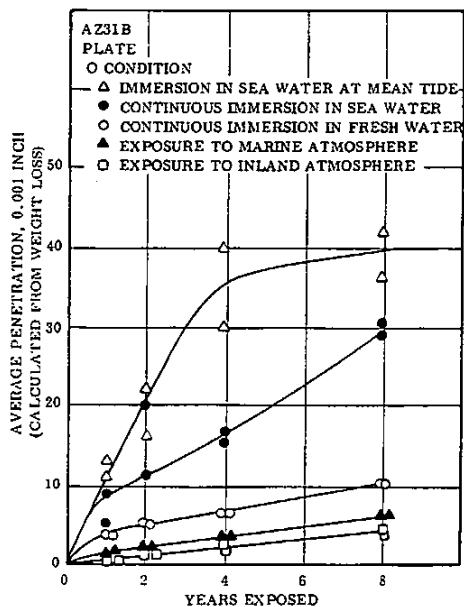


FIG. 2.0311 CORROSION IN VARIOUS ENVIRONMENTS. (16)

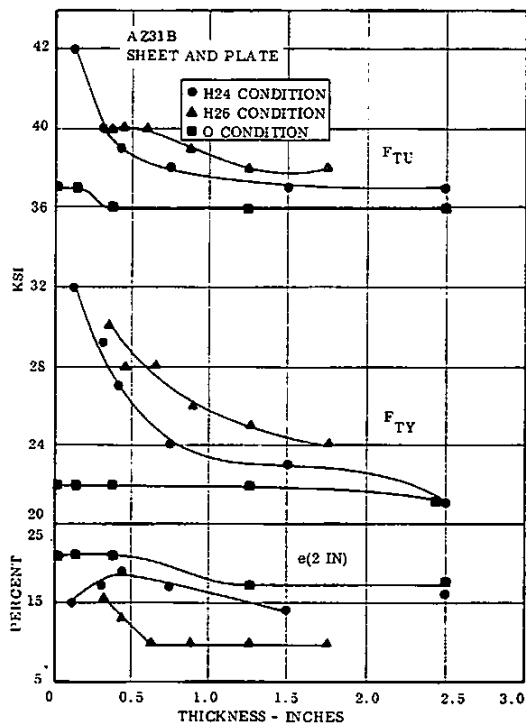


FIG. 3.0212 EFFECT OF THICKNESS ON TENSILE PROPERTIES OF SHEET AND PLATE. (9)

NOTE: Data are based on the lowest strength orientation whether longitudinal or transverse.

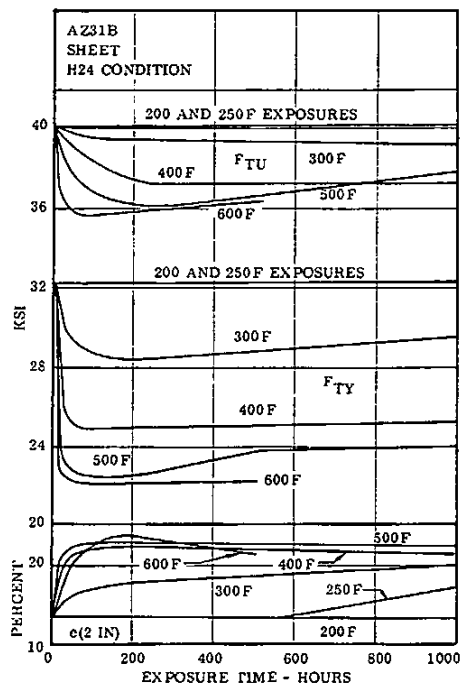


FIG. 3.0213 EFFECT OF EXPOSURES AT ELEVATED TEMPERATURES ON TENSILE PROPERTIES AT ROOM TEMPERATURE OF SHEET IN H24 CONDITION. (9)

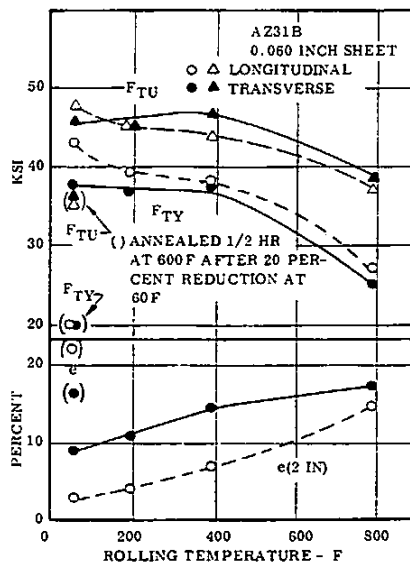


FIG. 3.0214 EFFECT OF ROLLING TEMPERATURE ON THE TENSILE PROPERTIES OF SHEET ROLLED TO 20 PERCENT REDUCTION. (20)

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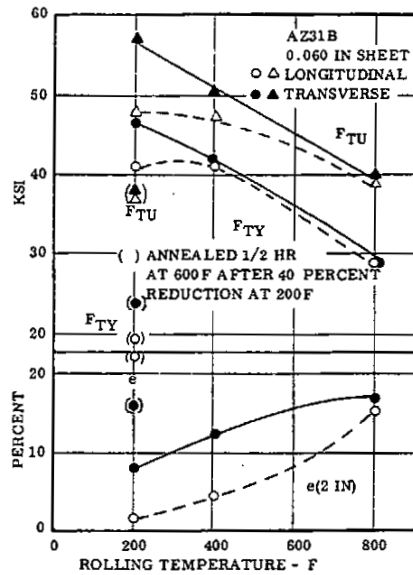


FIG. 3.0215 EFFECT OF ROLLING TEMPERATURE ON THE TENSILE PROPERTIES OF SHEET ROLLED TO 40 PERCENT REDUCTION. (20)

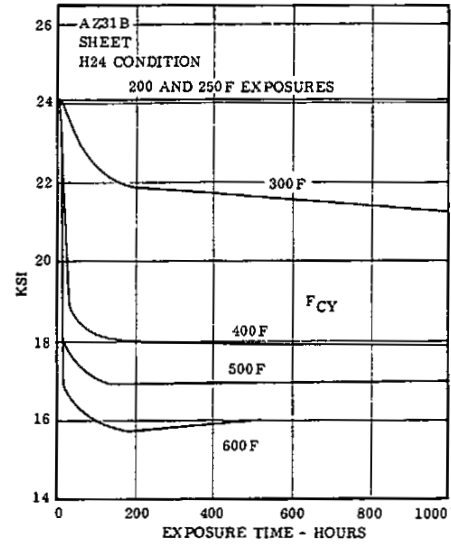


FIG. 3.0223 EFFECT OF EXPOSURES AT ELEVATED TEMPERATURES ON COMPRESSIVE YIELD STRENGTH AT ROOM TEMPERATURE OF SHEET IN H24 CONDITION. (9)

	Mg
3	Al
1	Zn
AZ 31B	

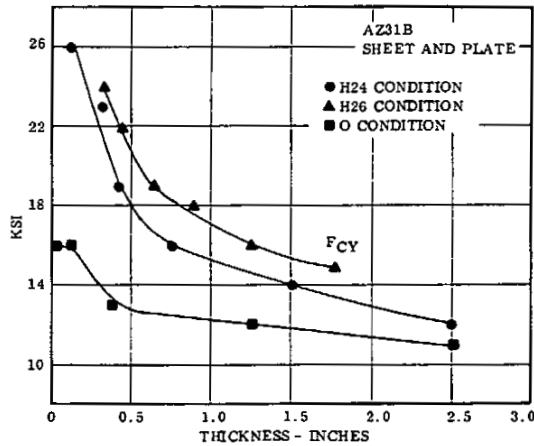


FIG. 3.0222 EFFECT OF THICKNESS ON COMPRESSIVE YIELD STRENGTH OF SHEET AND PLATE. (9)

NOTE: Data are based on the lower strength orientation whether longitudinal or transverse.

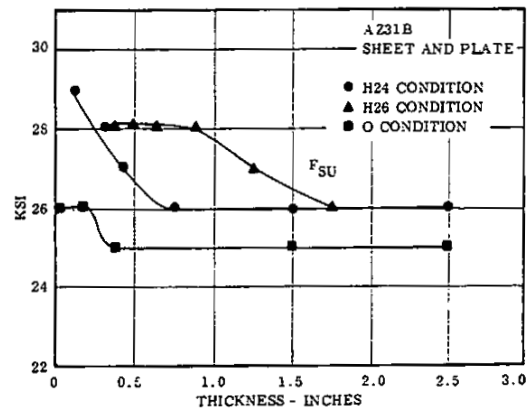


FIG. 3.0251 EFFECT OF THICKNESS ON SHEAR STRENGTH OF SHEET AND PLATE. (9)

NOTE: Data are based on the lower strength orientation whether longitudinal or transverse.

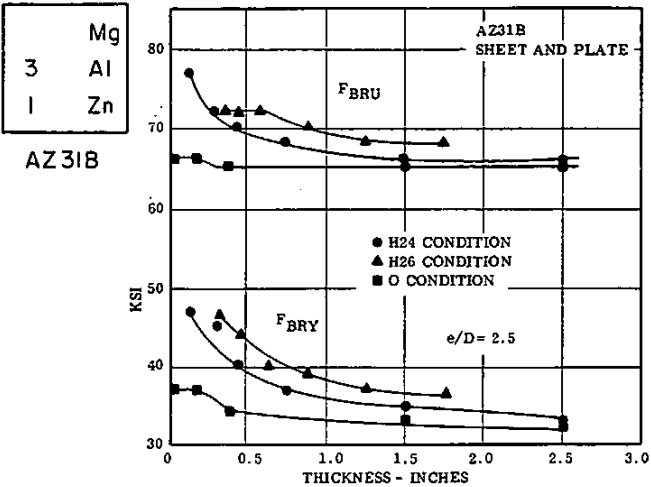


FIG. 3.0261 EFFECT OF THICKNESS ON BEARING PROPERTIES OF SHEET AND PLATE. (9)

NOTE: Data are based on the lower strength orientation whether longitudinal or transverse.

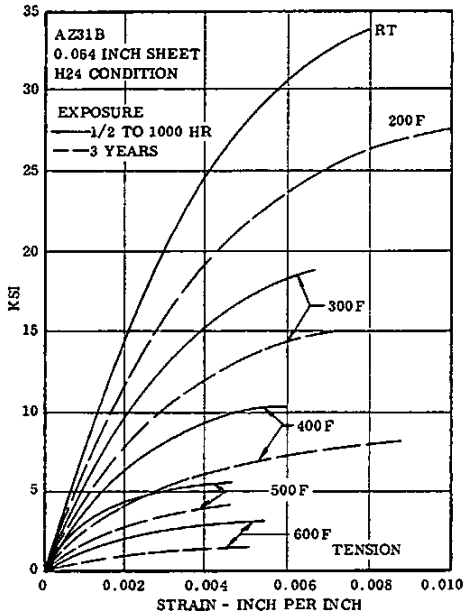


FIG. 3.03112 EFFECT OF ELEVATED TEMPERATURE EXPOSURE ON STRESS-STRAIN CURVES FOR SHEET IN H24 CONDITION. (24)(25)

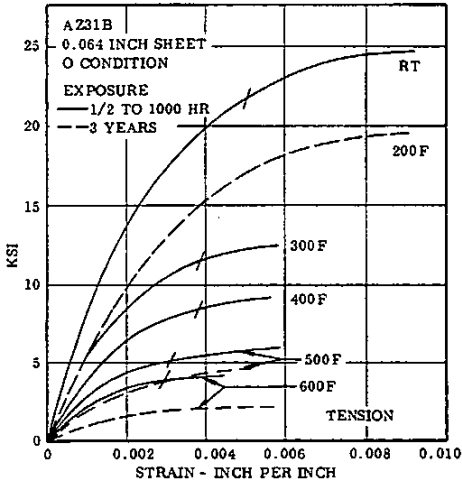


FIG. 3.03111 EFFECT OF ELEVATED TEMPERATURE EXPOSURE ON STRESS-STRAIN CURVES FOR SHEET IN O CONDITION. (23)(24)

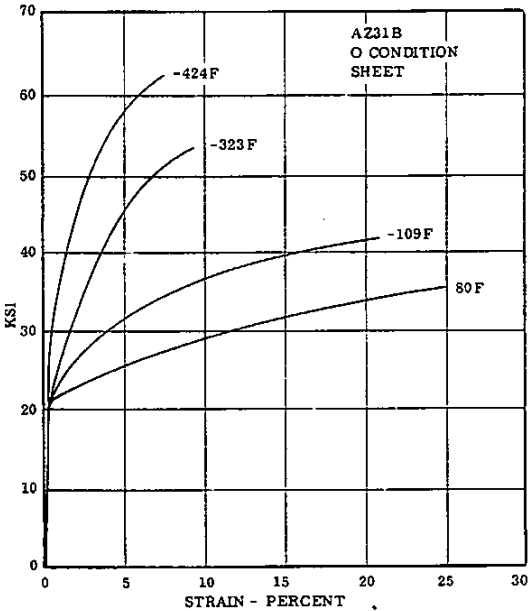


FIG. 3.03113 COMPLETE STRESS-STRAIN CURVES AT LOW TEMPERATURES. (26)

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	Mg
3	Al
1	Zn

AZ 31B

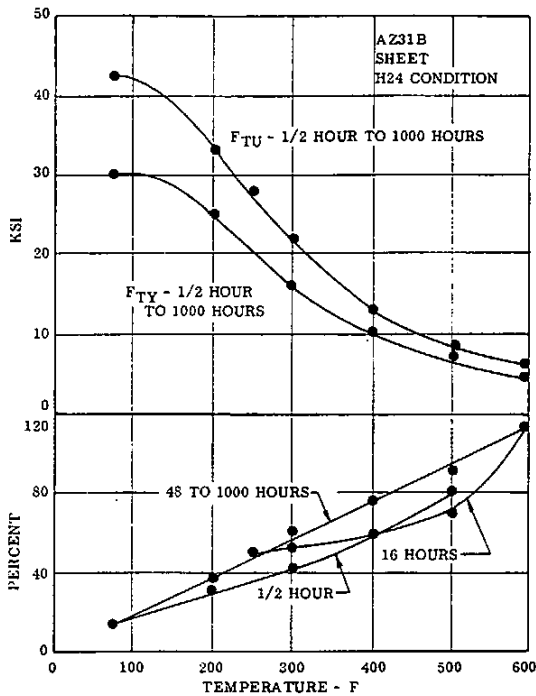


FIG. 3.0312 ELEVATED TEMPERATURE TENSILE PROPERTIES OF SHEET IN H24 CONDITION AFTER VARIOUS EXPOSURE TIMES FROM ONE HALF TO 1000 HOURS AT TEMPERATURE. (9)(27)

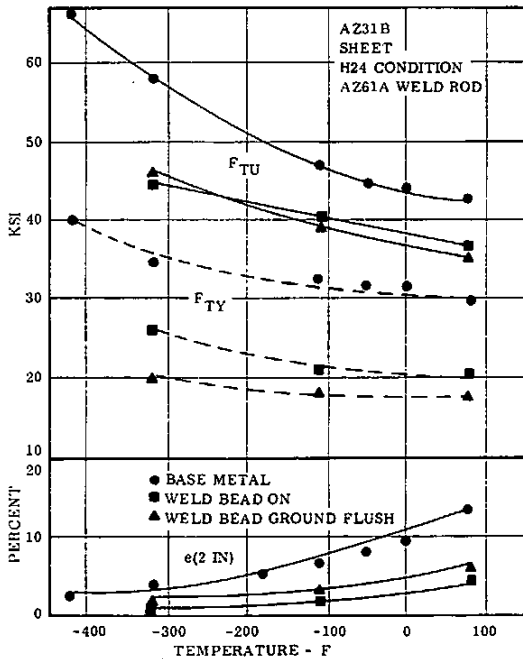


FIG. 3.0313 LOW TEMPERATURE PROPERTIES OF SHEET TENSILE SPECIMENS IN H24 CONDITION, BOTH UNWELDED AND WITH GAS TUNGSTEN-ARC BUTT WELDS TRANSVERSE TO THE GAGE LENGTH. (9)(27)

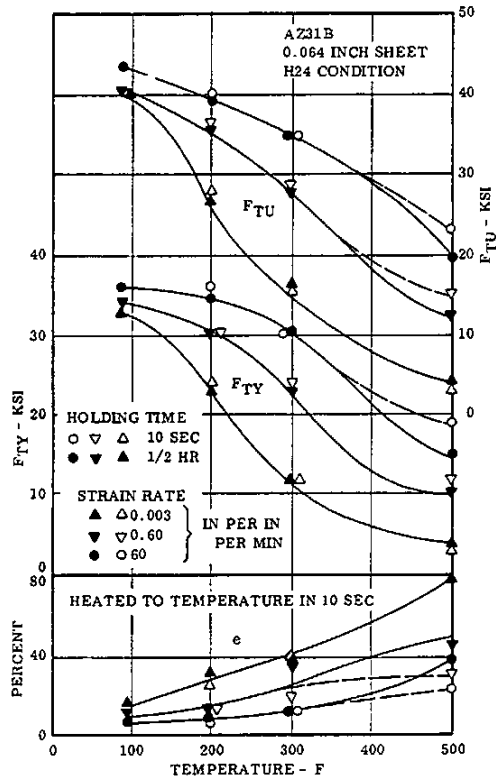


FIG. 3.0314 EFFECTS OF TEMPERATURE ON TENSILE PROPERTIES OF SHEET IN H24 CONDITION AT RAPID STRAIN RATES AFTER RAPID HEATING AND SHORT HOLDING TIMES AT TEMPERATURE. (28)

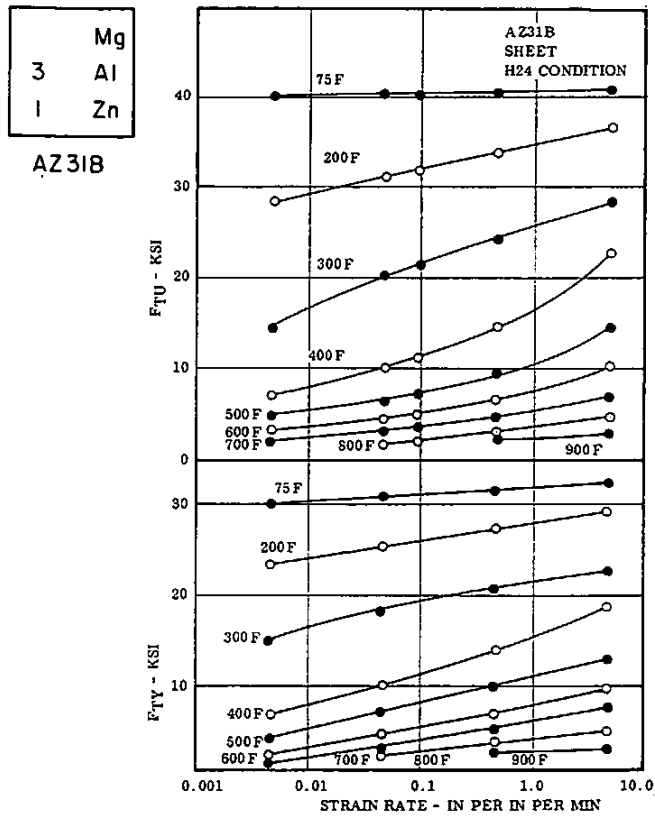


FIG. 3.0315 EFFECTS OF STRAIN RATE ON TENSILE PROPERTIES OF SHEET IN H24 CONDITION AT VARIOUS TEMPERATURES. (9)

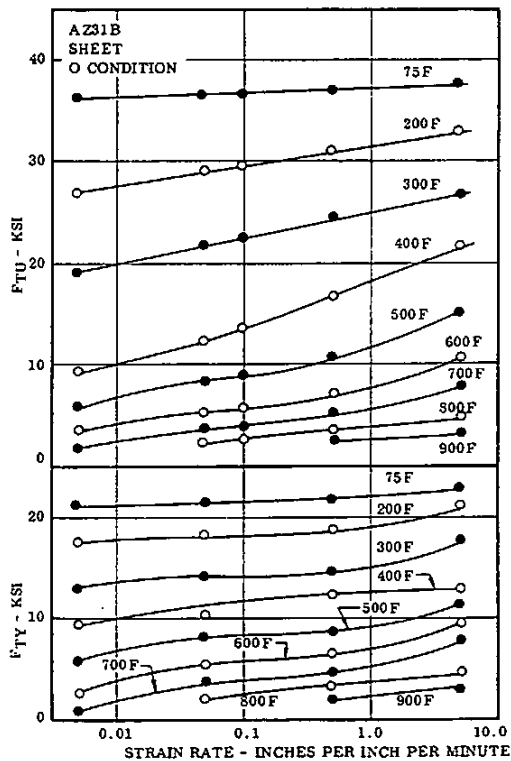


FIG. 3.0316 EFFECTS OF STRAIN RATE ON TENSILE PROPERTIES OF SHEET IN O CONDITION AT VARIOUS TEMPERATURES. (9)

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NONFERROUS ALLOYS

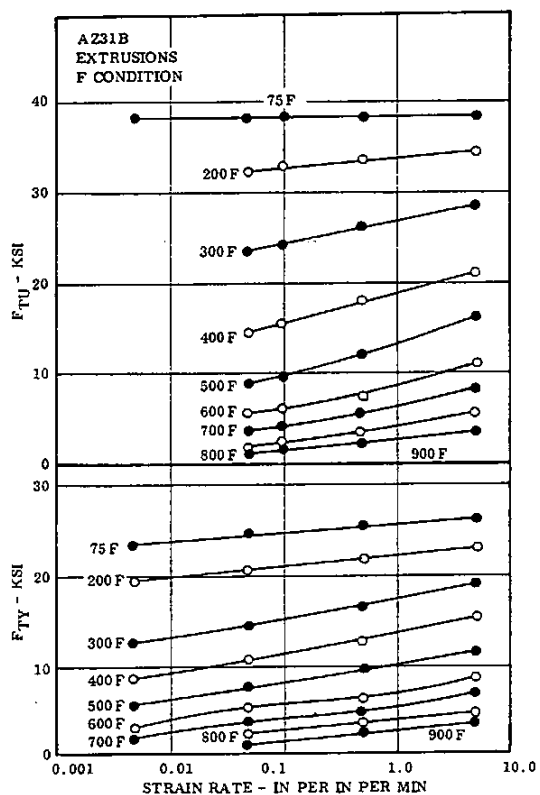


FIG. 3.0317 EFFECTS OF STRAIN RATE ON TENSILE PROPERTIES OF EXTRUSIONS IN F CONDITION AT VARIOUS TEMPERATURES. (9)

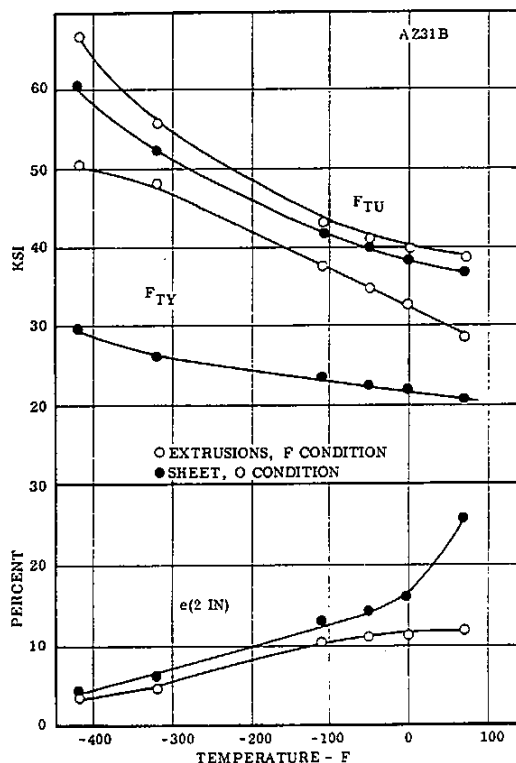


FIG. 3.0318 LOW TEMPERATURE TENSILE PROPERTIES OF EXTRUSIONS AND SHEET. (9)

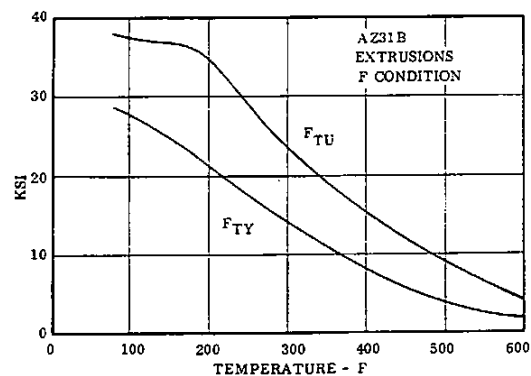


FIG. 3.0319 ELEVATED TEMPERATURE TENSILE STRENGTH OF EXTRUSIONS. (9)

Mg
3 Al
1 Zn

AZ 31B

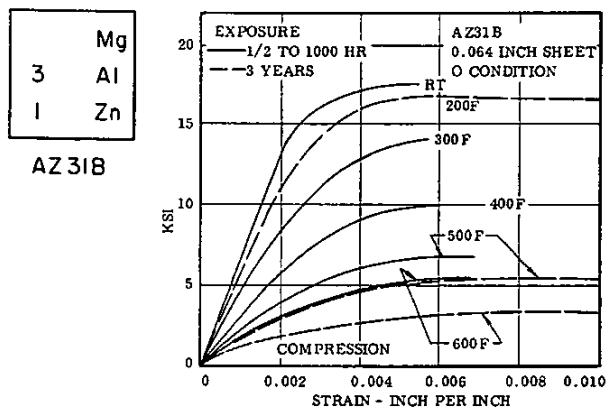


FIG. 3.03211 EFFECT OF ELEVATED TEMPERATURE EXPOSURE ON STRESS-STRAIN CURVES IN COMPRESSION FOR SHEET IN O CONDITION. (23)(24)

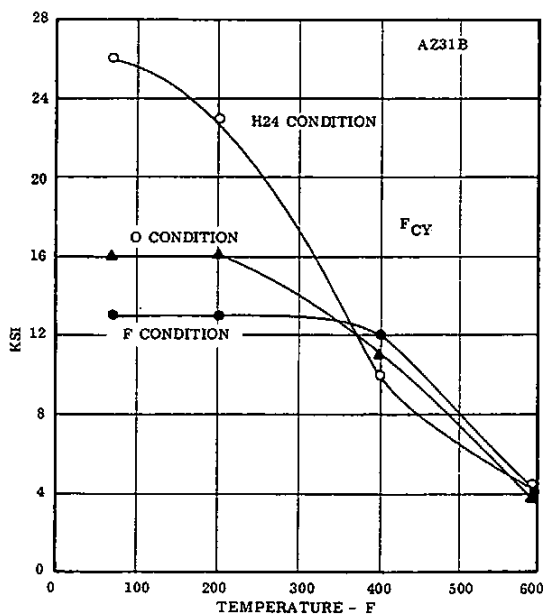


FIG. 3.0322 ELEVATED TEMPERATURE COMPRESSIVE YIELD STRENGTH. (29)

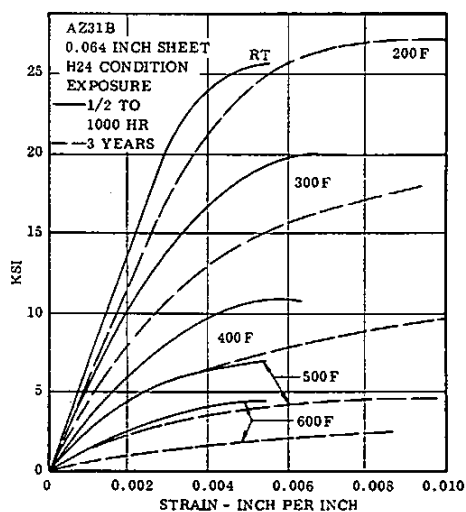


FIG. 3.03212 EFFECT OF ELEVATED TEMPERATURE EXPOSURE ON STRESS-STRAIN CURVES IN COMPRESSION FOR SHEET IN H24 CONDITION. (24)(25)

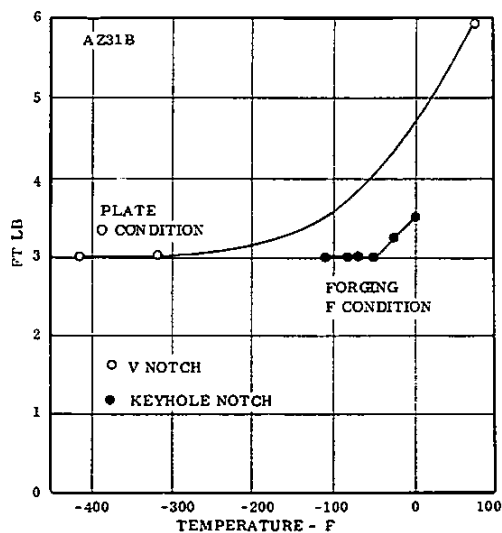


FIG. 3.0331 CHARPY IMPACT PROPERTIES AT LOW TEMPERATURES. (26)(29)

REVISED: JUNE 1971

NONFERROUS ALLOYS

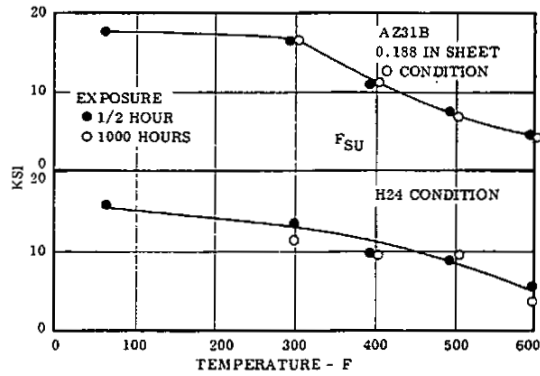


FIG. 3.0351 EFFECT OF TEMPERATURE AND EXPOSURE TIME ON SHEAR STRENGTH. (23)(30)

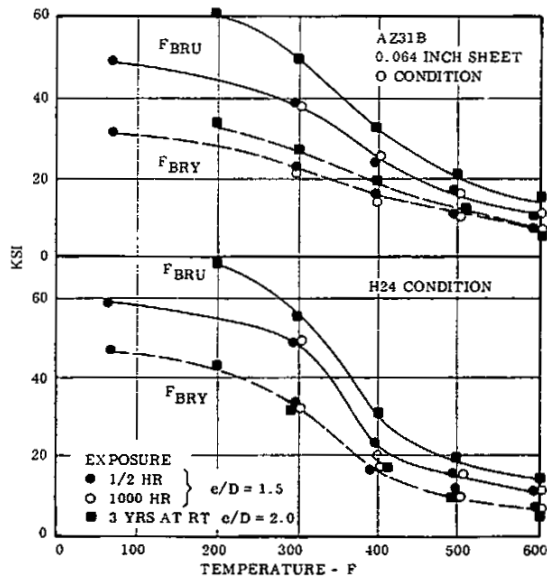


FIG. 3.0361 EFFECT OF TEST TEMPERATURES AND EXPOSURE TIME ON BEARING PROPERTIES. (23)(24)(30)

	Mg
3	Al
1	Zn

AZ31B

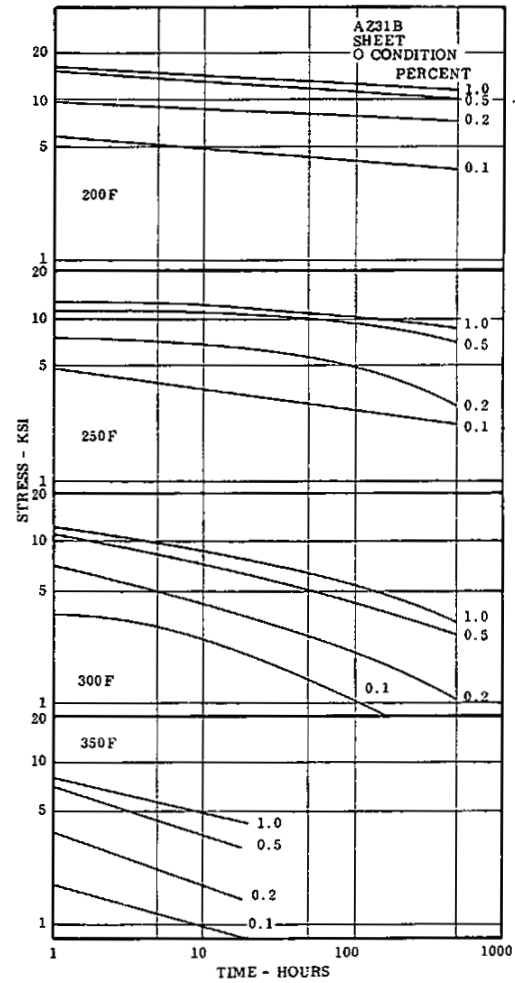


FIG. 3.041 TOTAL CREEP STRAIN CURVES FOR SHEET IN O CONDITION. (9)

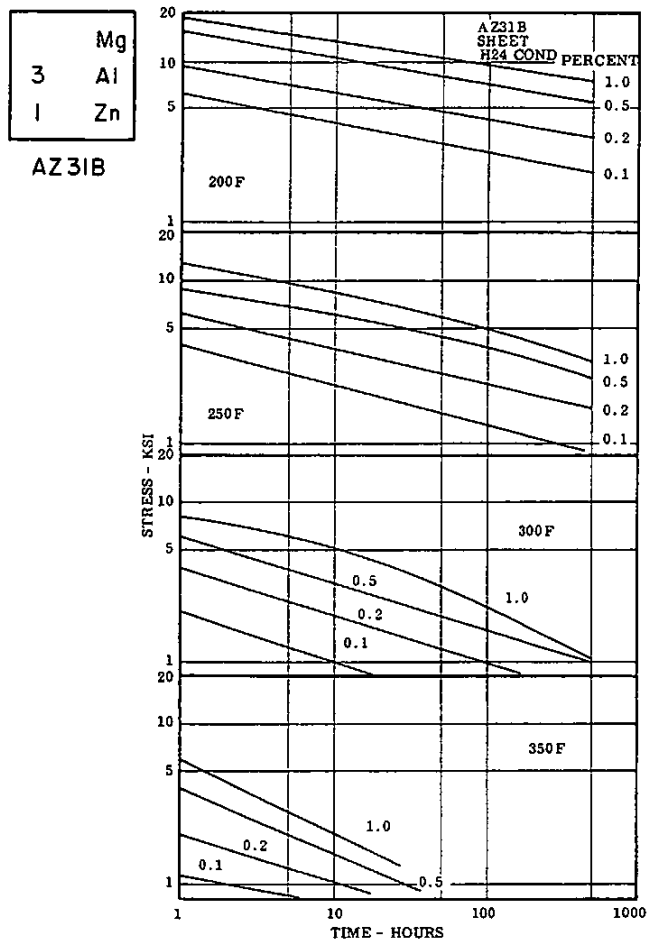


FIG. 3.042 TOTAL CREEP STRAIN CURVES FOR SHEET IN H24 CONDITION. (9)

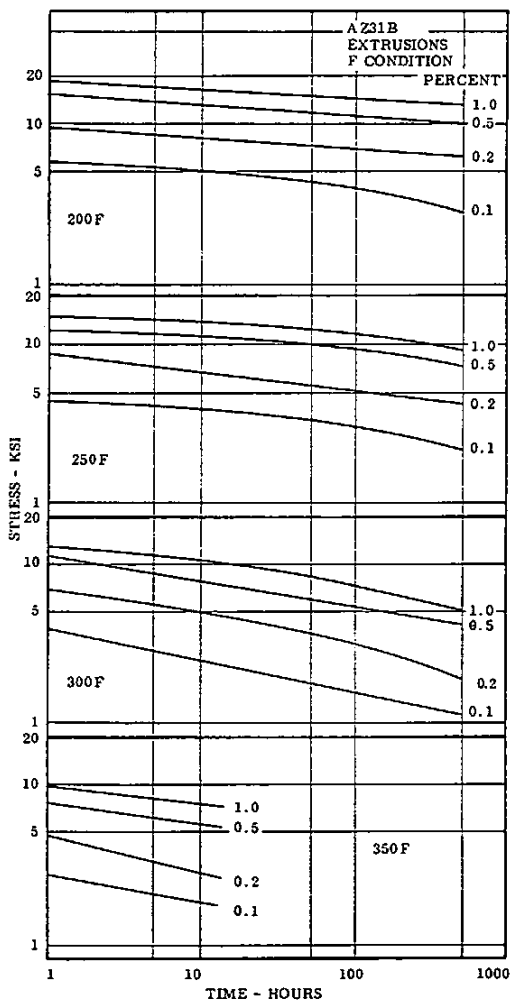


FIG. 3.043 TOTAL CREEP STRAIN CURVES FOR EXTRUSIONS IN F CONDITION. (9)

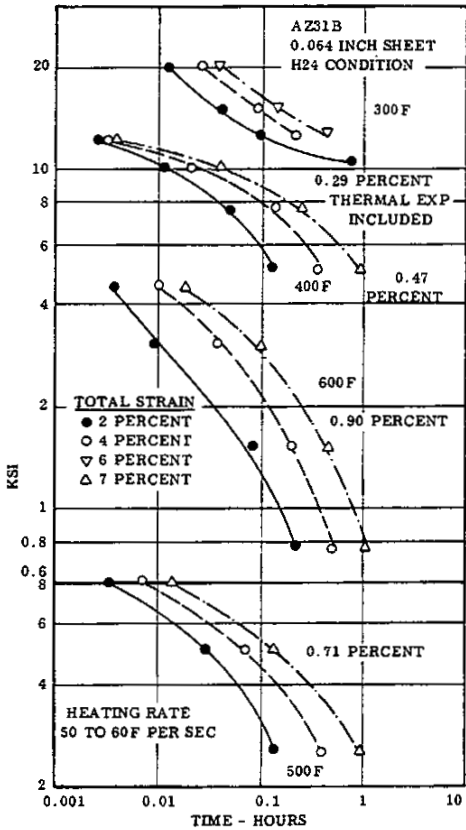


FIG. 3.044 SHORT TIME TOTAL STRAIN CURVES AT 300 TO 600 F FOR SHEET IN H24 CONDITION. (31)

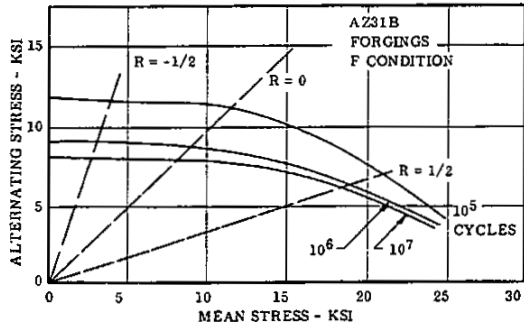


FIG. 3.053 STRESS RANGE DIAGRAM FOR FORGINGS AT 90 PERCENT SURVIVAL LEVEL. (33)

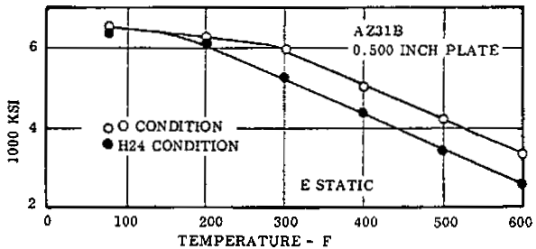


FIG. 3.062 MODULUS OF ELASTICITY. (35)

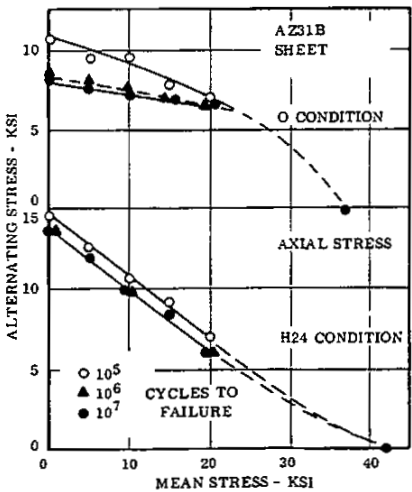


FIG. 3.052 STRESS RANGE DIAGRAMS FOR SHEET IN THE O AND H24 CONDITIONS. (34)

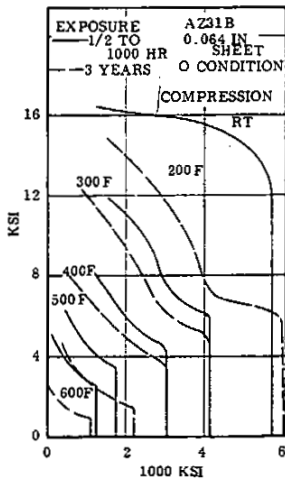


FIG. 3.064 TANGENT MODULUS CURVES IN COMPRESSION FOR SHEET IN O CONDITION. (23)(24)

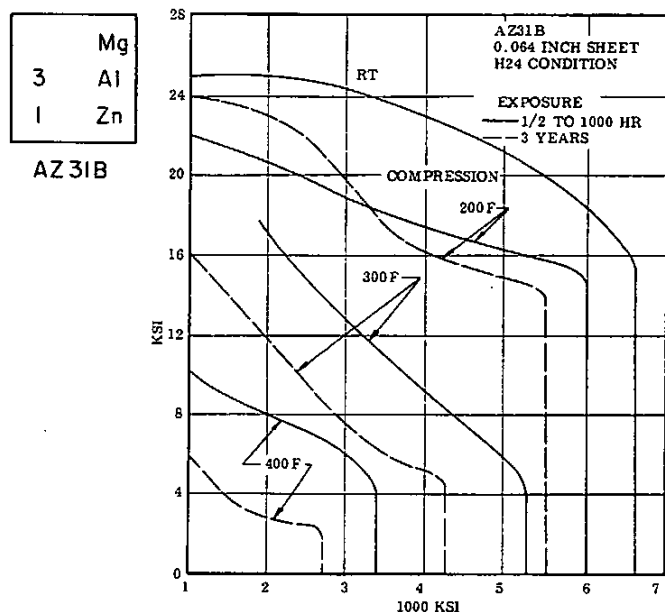


FIG. 3.065 TANGENT MODULUS CURVES IN COMPRESSION FOR SHEET IN H24 CONDITION. (24)(30)(36)

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36. AF TR 6517, Part 3 (June 1954).
37. Forming Magnesium, Part 1, Form 141-305-66, Dow Metal Products Department, Midland, Michigan (1966).
38. Forming Magnesium, Part 3, Form 141-307-66, Dow Metal Products Department, Midland, Michigan (1966).
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1. GENERAL
AZ61A is a non-heat treatable wrought alloy which is readily extruded and does not respond to age-hardening heat treatment. Its strength increases and its ductility decreases at low operation temperature. Toughness, cold formability, welding and machining characteristics are good, although the material has a tendency to harden when cold worked. The alloy should not be used above 400F. Corrosion resistance is good. AZ61 is primarily a general purpose extrusion and forging alloy with medium strength for use at room and slightly elevated temperatures, (3)(10).

- 1.01 Commercial Designation
AZ61A.

- 1.02 Alternate Designation
Dowmetal J1.

- 1.03 Specifications
Table 1.03.

TABLE 1.03

AMS	Form	ASTM	Federal	Foreign
4350F	Extrusions (SAE 520)	-	QQ-M-31	BS 1354*
4358A	Forgings (SAE 530)	B 91-63	QQ-M-40	BS 1351*
	Extruded bars, rods and shapes	B 91-63	-	-
	Extruded tubes	B107-63	QQ-M-31	-
		B217-63	WW-T-825	-
		-	-	AZM **

* British
** German

- 1.04 Composition
Table 1.04.

TABLE 1.04

Source	(1)(2)(3)		(3)(4)	
	Percent		Percent	
	Min	Max	Min	Max
Aluminum	5.8	7.2	5.8	7.2
Copper	-	0.05	-	0.05
Iron	-	0.005	-	0.005
Manganese	0.15	-	0.15	-
Nickel	-	0.005	-	0.005
Silicon	-	0.30	-	0.10
Zinc	0.40	1.5	0.40	1.5
Other impurities, total	-	0.30	-	0.30
Magnesium	Balance		Balance	

- 1.05 Heat Treatment
1.051 Anneal 650F, (10).
Stress relief anneal. 500F.
Full anneal. 650F.
1.0511 Sheet. 500F, 15 minutes.
1.0512 Hard rolled sheet. 400F, 1 hour.
1.0513 Extrusions and forgings. 500F, 15 minutes.
1.052 Condition F. 450 to 550F, 1 hour.
1.053 Shortness temperature. Above 780F.
1.054 Hot working temperature. 450 to 750F, (10).

- 1.055 Recrystallization temperatures. 550F, 1 hour, increase after 20 percent reduction, (10).

- 1.06 Hardness

- 1.07 Forms and Conditions Available

The alloy is available in extruded rods, bars and solid shapes as well as extruded hollow shapes and tubing, forgings and welding rod, (2)(3)(5).

- 1.08 Melting and Casting Practice

- 1.081 Casting temperature. 1200 to 1300F, (10).

- 1.09 Special Considerations

2. PHYSICAL AND CHEMICAL PROPERTIES

- 2.01 Thermal Properties

- 2.011 Melting range. 977 to 1145F, (5)(10).

785F is minimum "burning" (liquefaction) temperature, (10).

- 2.012 Phase changes

- 2.0121 Time-temperature-transformation diagrams

- 2.013 Thermal conductivity

At 212 to 570F, 46.0 Btu per ft (hr sq ft F), (10)(7).

At 212 to 570F, 48.4 Btu per ft (hr sq ft F), (3).

At RT, 33.9 Btu per ft (hr sq ft F), (9).

- 2.014 Thermal expansion

At RT to 212F, 14.0×10^{-6} in per in per F, (3)(7).

At RT to 212F, 14.5×10^{-6} in per in per F, (5).

At RT to 750F, 16.0×10^{-6} in per in per F, (3)(5).

- 2.015 Specific heat

At RT, 0.25 Btu per lb F, (3)(10)(13).

- 2.016 Thermal diffusivity

- 2.02 Other Physical Properties

- 2.021 Density

At RT, 0.065 lb per cu in, 1.8 gr per cu cm, (3)(9)(10)(13).

- 2.022 Electrical properties

At RT, 4.92 microhm-in, (3)(9)(10)(13).

- 2.023 Magnetic properties

The alloy is non-magnetic, (9).

- 2.024 Emissivity

- 2.025 Damping capacity

- 2.03 Chemical Properties

- 2.031 AZ61A is corrosion resistant to attack by most alkalis, numerous organic chemicals, concentrated hydrofluoric acid and solutions of the alkali metals arsenates, fluorides, chromates and dichromates. It is susceptible to stress corrosion. Moist air increases the amount of surface attack due to the presence of chlorides, especially in marine atmosphere noticeable by the formation of a thin gray oxide film. It does not corrode in dry air, (3). Resistance to corrosion decreases with increasing amounts of copper, nickel and iron, (10).

- 2.04 Nuclear Properties

3. MECHANICAL PROPERTIES

- 3.01 Specified Mechanical Properties

- 3.011 AMS-specified properties, Table 3.011.

TABLE 3.011

Source	(1)				(2)	
Alloy	Mg-6Al-1Zn				Forgings	
Form	Extrusion (Bars, rods and shapes)				Die	Hand
Condition	As extruded				As forged	
Thickness-in	0.250	0.250 to 2.500	2.500 to 4.499*	Hollow shapes all wall thicknesses		
F _{tu} min-ksi	38	40	38	36	38**	38**
F _{ty} min-ksi	20	24	22	16	22**	22**
e, (2in) min-percent	8	9	5	7	-	-
e, (4D) -percent	-	-	-	-	6	6

* Not over 25 square inch
** No minimum values

Mg
6 Al
1 Zn

AZ61A

Mg
6 Al
1 Zn

AZ 61 A

3.012 Design mechanical properties for alloy in Condition F, Table 3.012.

TABLE 3.012

Source	(7)				
Alloy	Mg-6Al-1Zn				
Form	Extruded bar, rod and solid shapes		Extruded Hollow shapes	Extruded tubes	Forging
Condition	F				
Thickness - in	≤ 0.249	0.250 to 2.499		0.028 to 0.750	
F _{tu}	-ksi L 38	39	36	36	38
	-ksi T -	-	-	-	-
F _{ty}	-ksi L 21	24	16	16	22
	-ksi T -	-	-	-	-
F _{cy}	-ksi L 14	14	11	11	14
	-ksi T -	-	-	-	-
F _{su}	-ksi 19	19	-	-	19
F _{bru}	-ksi (e/D=1.5) 45	45	-	-	50
	(e/D=2.0) 55	55	-	-	60
F _{bry}	-ksi (e/D=1.5) 28	28	-	-	28
	(e/D=2.0) 32	32	-	-	32
e, percent	8	9	7	7	6

3.02 Mechanical Properties at Room Temperature

3.021 Tension

3.0211 Stress-strain diagrams

3.02111 Stress-strain curve for forgings in tension, Fig. 3.02111.

3.02112 Stress-strain curve for extrusion in tension, Fig. 3.02112.

3.0212 Mechanical properties at room temperature for bars, rods and shapes, Table 3.0212.

TABLE 3.0212

Source	(9)			
Alloy	Mg-6Al-1Zn			
Form	Bars, rods and shapes			
Condition	F			
Thickness - in	≤ 0.250	0.250 to 1.499	1.500 to 2.499	2.500 to 5.000
F _{tu}	46	45	45	45
F _{ty}	33	33	33	31
F _{cy}	20	24	24	22
e(2ln)typ-percent	17	16	16	15
e(2ln)min-percent	8	10	10	7
F _{cy}	-	19	19	21
F _{bru}	65	68	58	68
F _{bry}	56	56	56	56
F _{ty}	38	41	41	-
F _{su}	30	32	32	-
F _{ty}	20	20	20	-
F _{ty}	18	18	18	-
Hardness, BHN	-	60	60	-

3.0213 Typical mechanical properties at room temperature for press forgings, extruded bars, rods and shapes, extruded tubing and hollow shapes, and sheet, Table 3.0213.

TABLE 3.0213

Source	(10)			
Alloy	Mg-6Al-1Zn			
Form	Press Forgings	Extruded bars, rods, shapes	Ext tubing, hollow shapes	Sheet
Condition	Not given			
Thickness - in				
F _{tu}	43	45	41	44
F _{ty}	26	33	24	32
e, typ-percent	12	16	14	8
Hardness, BHN *	55	60	50	-
RE	66	72	60	-
F _{su}	21	20	-	-
F _{cy}	18	19	16	22
F _{bru}	-	68	-	-
F _{bry}	-	41	-	-

* 500-kg load, 10 mm ball

** 3/16 in pin diameter

3.022 Compression
3.0221 Stress-strain diagrams.
3.02211 Stress-strain curve for forgings in compression, Fig. 3.02211.

3.02212 Stress-strain curve for extrusion in compression, Fig. 3.02212.

3.023 Impact

3.024 Bending

3.025 Torsion and shear

3.026 Bearing

3.027 Stress concentration

3.0271 Notch properties

3.0272 Fracture toughness

3.028 Combined properties

3.03 Mechanical Properties at Various Temperatures

3.031 Tension

3.0311 Stress-strain diagrams

3.0312 Effect of low temperature on tensile properties of extrusions, Fig. 3.0312.

3.0313 Effect of low and elevated temperature on tensile properties of extrusions, Fig. 3.0313.

3.0314 Effect of room and elevated temperature on tensile properties of extrusions, Fig. 3.0314.

3.0315 Effect of room and elevated temperature and exposure on tensile properties of extrusion, Fig. 3.0315.

3.0316 Effect of room and elevated temperature and strain rate on tensile properties of extrusion, Fig. 3.0316.

3.0317 Typical and minimum mechanical properties of alloy in Condition F, Table 3.0317.

TABLE 3.0317

Source	(3)	
Alloy	Mg-6Al-1Zn	
Form	Extruded rods, bars and solid shapes	Extruded hollow shapes and tubing
Condition	F	
Thickness - in	Not given	
F _{tu}	45	41
F _{ty}	40	36
F _{cy}	33	24
e, (2ln)typ-percent	24	16
e, (2ln)min-percent	16	14
F _{cy}	10	7
F _{bru}	19	16
F _{bry}	14	11
F _{ty}	68	-
F _{ty}	41	-
Hardness, BHN-typ	60	50
RE-typ	72	60

3.032 Compression

3.0321 Stress-strain diagrams

3.033 Impact

3.0331 Effect of low and room temperature on impact strength of extruded bar, Fig. 3.0331.

3.034 Bending

3.035 Torsion and shear

3.036 Bearing

3.037 Stress concentration

3.0371 Notch properties

3.0372 Fracture toughness

3.038 Combined properties

3.04 Creep and Creep Rupture Properties

3.041 Creep curves at 200F for extrusions, Fig. 3.041.

3.042 Creep curves at 250F for extrusions, Fig. 3.042.

3.043 Creep curves at 300F for extrusions, Fig. 3.043.

3.044 Creep curves at 350F for extrusions, Fig. 3.044.

3.05 Fatigue Properties

3.051 S-N curves for bar in Condition F, Fig. 3.051.

3.052 S-N curves for plate in Condition F, Fig. 3.052.

3.053 S-N curves for plate in Condition F, Fig. 3.053.

3.054 Stress range diagram for extrusions in Condition F, Fig. 3.054.

- 3.06 Elastic Properties
- 3.061 Poisson's ratio, 0.35, (5)(9).
- 3.062 Modulus of elasticity
- 3.0621 Modulus of elasticity, 6.5×10^3 ksi, (3)(5)(9).
 6.3×10^3 ksi, (7).
- 3.0622 Compression modulus of elasticity, 6.3×10^3 ksi, (7).
- 3.063 Modulus of rigidity, 2.4×10^3 ksi, (7)(9).
4. FABRICATION
- 4.01 Formability, see also 1.053 and 1.054.
- 4.011 Most forgings are made from extruded forging stock at a temperature of 500 to 900F and can be forged to any shape by pressing. However, they should not be hammer-forged, (3).
- 4.012 Cold working requires special care, since the material tends to harden, (3).
- 4.013 When sharp bends are required, heating of the work and tools is recommended, (3).
- 4.02 Machining and Grinding
- 4.021 This alloy has excellent machining characteristics. High cutting speeds, large top and side rake and chip clearance are recommended.
 HSS lathe tools for rough cutting require the following:
 8-10° front clearance
 8-10° side clearance
 10-15° top rake
 5-15° side rake
 15-25° cutting edge angle
 The same machining characteristics with a slightly reduced top rake apply approximately for forming tools. Although dry machining is normally used for mill and lathe operations, mineral oil is recommended for fine cuts or to avoid distortion by heating. Water soluble oil or water coolants should not be used. The life of high speed tools equals the life of carbide tipped tools when machining other metals. However, in larger production carbide tipped tools should be preferred. Since the material does not drag or tear an excellent surface finish can be achieved.
- 4.03 Welding
- 4.031 Helium or inert-gas arc welding. The alloy can be arc welded producing a high strength with a 89 percent joint efficiency by using either helium or inert gas. Spot welding characteristics are excellent. Residual stresses in welded parts should be stress relieved. Post stress relief, 500F, 15 minutes. Gas welding should be limited because of corrosion difficulties caused by entrapped flux. The flux must be removed by immersion in hot water followed by a chrome pickle and boiled 2 hours in 5 percent sodium dichromate solution. Inert-gas tungsten arc joint tensile strength = 40 ksi and elongation of 8 percent (2 in). Flash welding can be used in high production welding and yields a joint efficiency of 85 to 95 percent, a weld strength of about 36 to 42 ksi and an elongation of about 4 to 6 percent (2 in), (3)(11).
- 4.04 Heat Treatment
 Post stress relief, 500F, 15 minutes. See Section 4.03. Stress relief anneal, 500F. Residual stress is relieved by applying the above heat treatment. See section on welding, (3)(11). This heat treatment is necessary in order to avoid stress corrosion, (9).
- 4.05 Surface Treatment

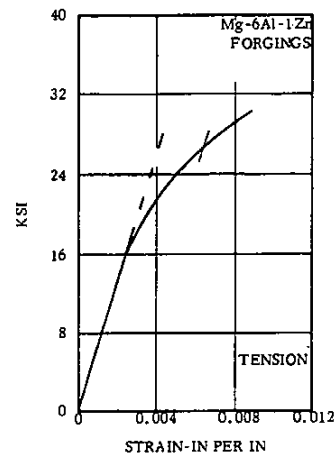


FIG. 3.02111 STRESS-STRAIN CURVE FOR FORGINGS IN TENSION (9, p. 55)

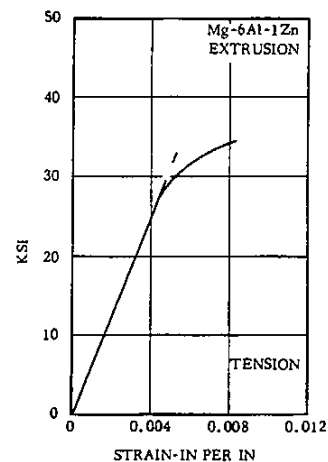


FIG. 3.02112 STRESS-STRAIN CURVE FOR EXTRUSION IN TENSION (9, p. 49)

Mg
6 Al
1 Zn

AZ 61 A

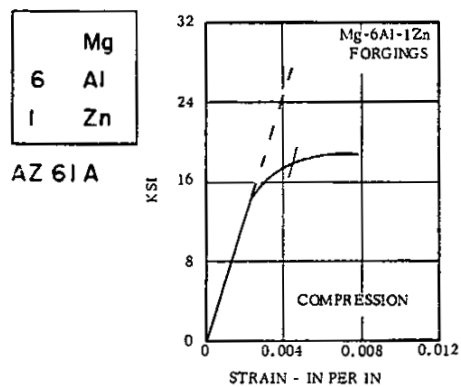


FIG. 3.02211 STRESS-STRAIN CURVE
FOR FORGINGS IN COM-
PRESSION (9, p. 55)

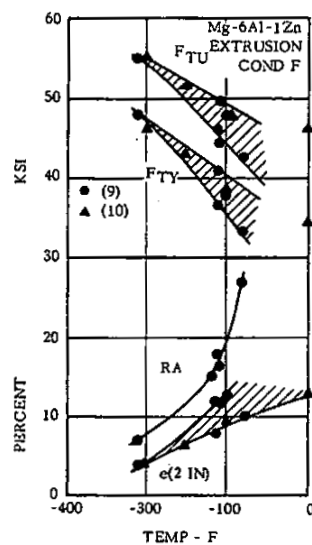


FIG. 3.0312 EFFECT OF LOW TEMPERA-
TURE ON TENSILE PROPERTIES
OF EXTRUSIONS
(9, p. 187) (10, p. 1108) (12)

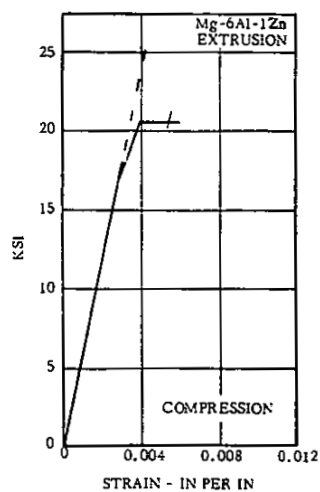


FIG. 3.02212 STRESS-STRAIN CURVE
FOR EXTRUSION IN COM-
PRESSION (9, p. 50)

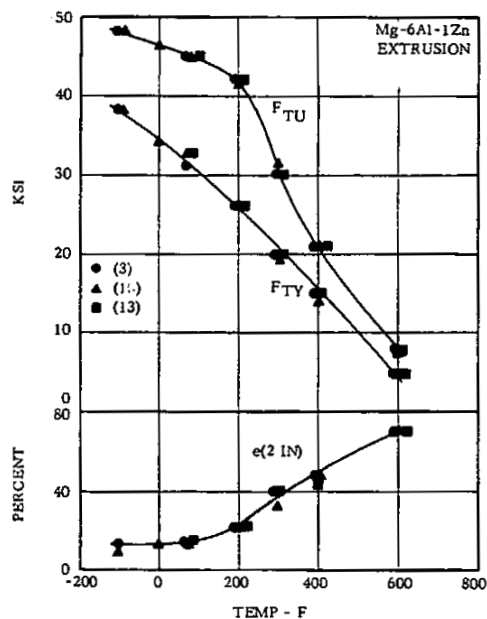


FIG. 3.0313 EFFECT OF LOW AND ELEVATED TEMPERA-
TURE ON TENSILE PROPERTIES OF EXTRUSIONS
(3, p. 1) (10, p. 1108) (13, p. 593)

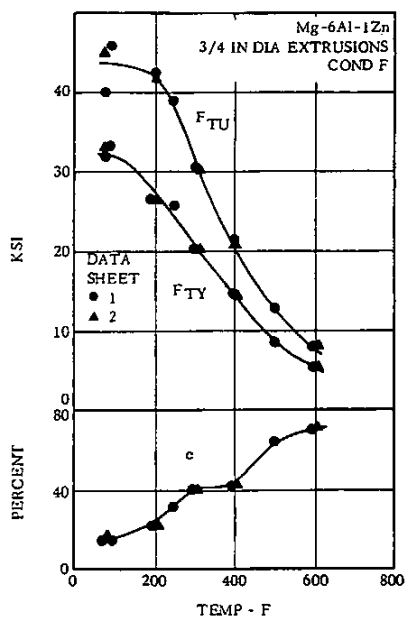


FIG. 3.0314 EFFECT OF ROOM AND ELEVATED TEMPERATURE ON TENSILE PROPERTIES OF EXTRUSIONS (4, p. 237)

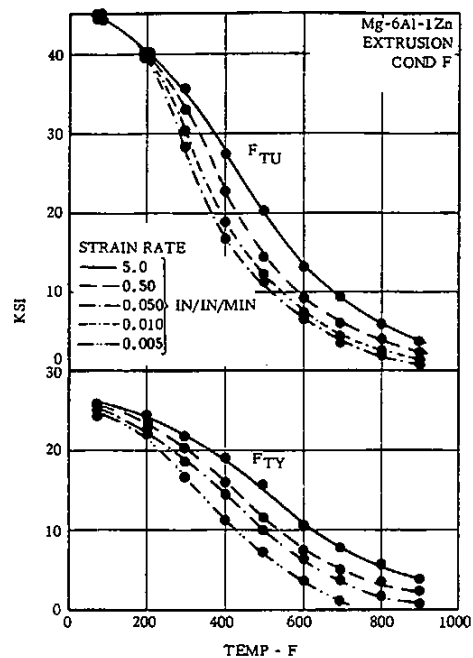


FIG. 3.0316 EFFECT OF ROOM AND ELEVATED TEMPERATURE AND STRAIN RATE ON TENSILE PROPERTIES OF EXTRUSIONS (8, Tbl. III)

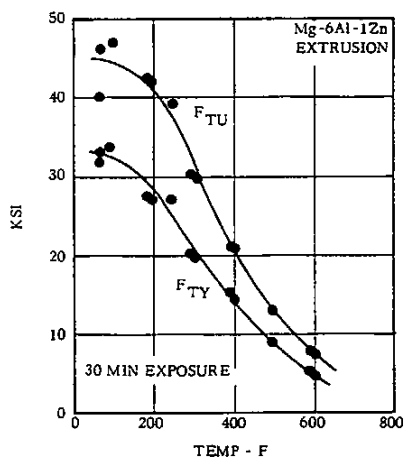


FIG. 3.0315 EFFECT OF ROOM AND ELEVATED TEMPERATURE AND EXPOSURE ON TENSILE PROPERTIES OF EXTRUSION (4, p. 236)

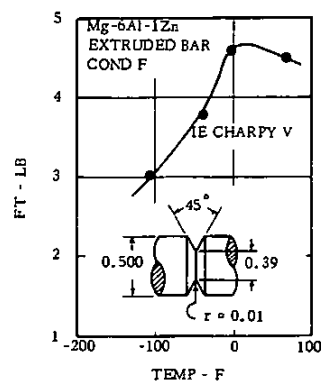


FIG. 3.0331 EFFECT OF LOW AND ROOM TEMPERATURE ON IMPACT STRENGTH OF EXTRUDED BAR (13, p. 594)

Mg
6 Al
1 Zn

AZ 61 A

	Mg
6	Al
1	Zn

AZ 61A

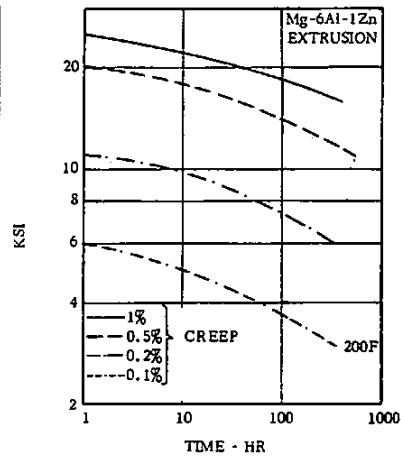


FIG. 3.041 CREEP CURVES AT 200F FOR EXTRUSIONS (4, p. 236) (13)

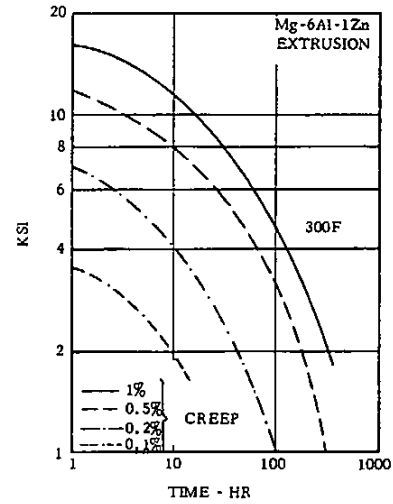


FIG. 3.043 CREEP CURVES AT 300F FOR EXTRUSIONS (4, p. 236)

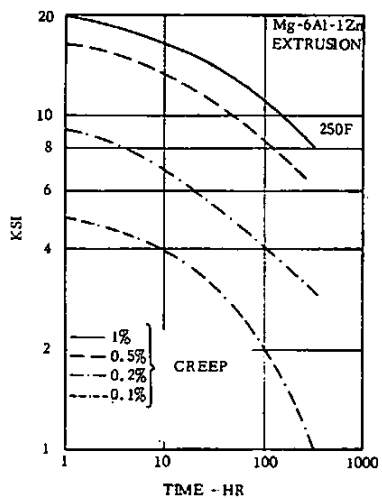


FIG. 3.042 CREEP CURVES AT 250F FOR EXTRUSIONS (4, p. 236)

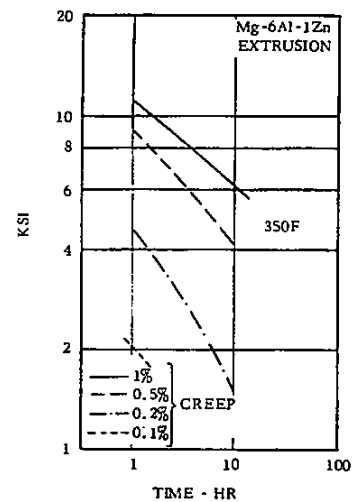


FIG. 3.044 CREEP CURVES AT 350F FOR EXTRUSIONS (4, p. 236) (13)

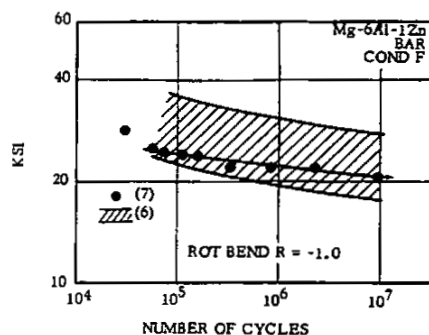


FIG. 3.051 S-N CURVES FOR BAR IN CONDITION F
(6, p. 19)

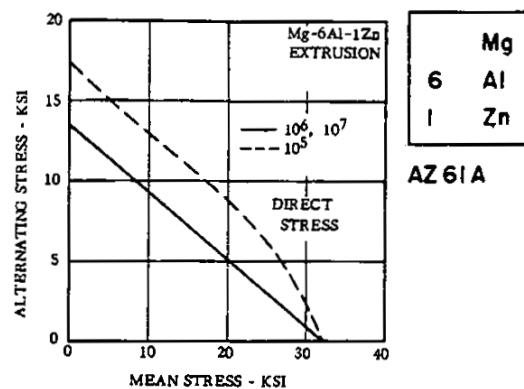


FIG. 3.054 STRESS RANGE DIAGRAM FOR
EXTRUSION IN CONDITION F (14)

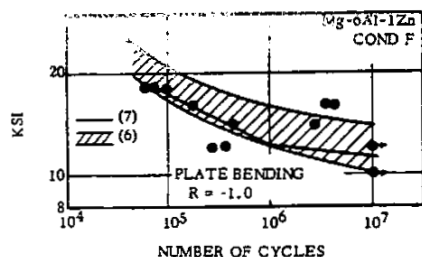


FIG. 3.052 S-N CURVES FOR PLATE IN CONDITION F
(6, p. 16)

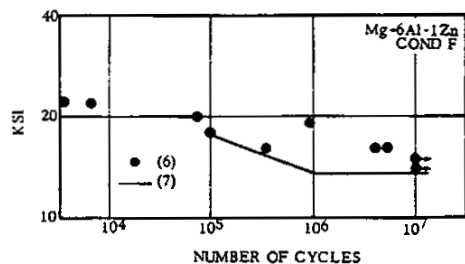


FIG. 3.053 S-N CURVE FOR PLATE IN CONDITION F
(6, p. 17) (7)

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CODE 3603

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Revised June 1997

REVISED: MARCH 1963

NONFERROUS ALLOYS

1. GENERAL

This alloy is a member of the aluminum and zinc containing family of heat treatable magnesium casting alloys. It has maximum ductility and an intermediate yield strength, and it is used up to about 300 F in various conditions of heat treatment. It is available in form of sand and permanent mold castings. This alloy is inferior to other casting alloys in regard to porosity and pressure tightness. The weldability of this alloy is inferior to that of most casting alloys.

1.01 Commercial Designation. AZ 63 A.1.02 Alternate Designations. Dow Metal H, Mazlo AM-265 (obsolete).1.03 Specifications. Table 1.03.

TABLE 1.03		
AMS	Form	Federal
4420 G	Sand castings (F Condition)	QQ-M-56a
4422 H	Sand castings (T4 Condition)	
4424 F	Sand castings (T6 Condition)	
-	Permanent mold castings	QQ-M-55a

1.04 Composition. Table 1.04.

TABLE 1.04			
Source	AMS (1) (2) (3)		
	Min	Percent	Max
Aluminum	5.3		6.70
Zinc	2.5		3.50
Manganese	0.15		-
Silicon	-		0.30
Copper	-		0.10
Nickel	-		0.010
Other impurities total	-		0.30
Magnesium	Balance		

1.05 Heat Treatment1.051 Stress relief after welding, 500 F, 1 hr.1.052 Solution treat F Condition to T4 Condition, 720 to 730 F, 12 hr, rapid air cool, (5, p. 8).1.053 Age

1.0531 F Condition to T5 Condition, 490 to 510 F, 4 hr, (5, p. 8).

1.0532 T4 Condition to T6 Condition, 415 to 435 F, 5 hr, (5, p. 8).

1.054 Heat and reheat treatments after welding F, T4 or T6 Conditions, see 4.03.1.06 Hardenability. Hardens fully in all section sizes on rapid air cooling and subsequent aging.1.07 Forms and Conditions Available

1.071 Alloy is available in the full commercial range of sizes for sand and permanent mold castings.

1.072 Castings are available in F, T4 and T6 Conditions. They can also be supplied in T5 Condition on special request.

1.08 Melting and Casting Practice. Standard magnesium alloy melting and casting practice, see 4.01.1.09 Special Considerations1.091 Stress relief is required after welding to prevent stress cracking.

1.092 For solution treating an atmosphere containing at least 0.5 percent sulfur dioxide is required.

2. PHYSICAL AND CHEMICAL PROPERTIES

2.01 Thermal Properties2.011 Melting range. 685 to 1135 F.2.012 Phase changes. Alloy is subject to precipitation.2.013 Thermal conductivity. Table 2.013.

TABLE 2.013

Source				
AZ 63 A				
Sand cast				
Condition	F	T4	T5	T6
Thermal cond Btu ft per (hr sq ft F)	34.1	30.2	37.7	35.3

2.014 Thermal expansion. See AZ 31 B.2.015 Specific heat. 0.25 Btu per (lb F).2.016 Emissivity. See AZ 31 B.2.017 Dimensional changes on exposure of castings to elevated temperatures, Fig. 2.017.2.02 Other Physical Properties2.021 Density. 0.0656 lb per cu in. 1.81 gr per cu cm, (8).2.022 Electrical resistivity. Table 2.022.

TABLE 2.022

Source				
AZ 63 A				
Sand and permanent mold castings				
Condition	F	T4	T5	T6
Temp - F	Electrical resistivity, microhm in			
RT	4.8	5.5	4.33	4.65
100	4.91	-	4.45	4.76
200	5.23	-	4.8	5.08

2.023 Magnetic properties. Alloy is nonmagnetic.2.03 Chemical Properties. See AZ 31 B also.2.031 Corrosion resistance of Mg-Al-Zn casting alloys is slightly inferior to that of zirconium containing casting alloys and also to that of all wrought alloys.2.032 Paint protection is advised where service in excess of a few years in industrial atmosphere is desired or generally for thin sections.2.033 Exposure to marine and seawater atmosphere requires a protective coating.2.034 Stress corrosion may occur after welding unless stress relieved.2.04 Nuclear Properties. See AZ 31 B.

3. MECHANICAL PROPERTIES

3.01 Specified Mechanical Properties3.011 AMS specified and producers' minimum mechanical properties. Table 3.011.3.02 Mechanical Properties at Room Temperature. See 3.03 also.3.021 Typical mechanical properties for alloy in various conditions, Table 3.021.

TABLE 3.021

Source				
Dow (5, p. 6)				
AZ 63 A				
Condition	F	T4	T5	T6
F_{tu} , ksi	29	40	29	40
F_{ty} , ksi	14	13	14	19
$e(2 \text{ in.})$, percent	6	12	4	5
F_{cy} , ksi	14	13	14	19
F_{bru} , ksi				
($e/D = 2.0$)	60	60	60	75
F_{bry} , ksi				
($e/D = 2.0$)	40	44	40	52
F_{su} , ksi	18	18	19	21
Hardness,				
BHN	50	55	55	73
RE	59	66	66	83

3.022 Effect of exposure to elevated temperatures on tensile properties of sand cast test bars in T6 Condition, Fig. 3.022.3.023 Yield strength in compression of cast magnesium alloys is essentially the same as that in tension.

Mg
6 Al
3 Zn

AZ 63 A

	Mg
6	Al
3	Zn

AZ 63 A

TABLE 3.011

Source	AMS (1)		AMS (2)				AMS (3)		
	Dow (6)		Dow (6)			Dow (6)	Dow (6)		
Alloy	AZ 63 A								
Form	Castings								
Condition	F		T4		T5		T6		
Specimen type	Cast test bars	From castings Avg (a)	Cast test bars	From Castings Avg (a)	Single specimen	Cast test bars	Cast test bars	From Castings Avg (a)	Single specimen
F _{tu} min - ksi	24	18	34	25.5	17	24	34	25.5	17
F _{ty} min - ksi	10	-	10	10	9	11	16	14.5	12
e(2 in), min - percent	4	1	7	1.75	-	2	3	0.75	-
F _{cy} min - ksi	10(b)	-	10(b)	-	-	11	16(b)	-	-
F _{bru} min									
(e/D = 1.5) - ksi	36(b)	-	36(b)	-	-	-	50(b)	-	-
(e/D = 2.0) - ksi	50(b)	-	50(b)	-	-	50	65(b)	-	-
F _{brv} min									
(e/D = 1.5) - ksi	28(b)	-	32(b)	-	-	-	36(b)	-	-
(e/D = 2.0) - ksi	30(b)	-	36(b)	-	-	30	45(b)	-	-
F _{su} min - ksi	16(b)	-	17(b)	-	-	17	19(b)	-	-
Hardness, BHN (500 kg, 10 mm)									
- min	-	48	-	48	-	-	-	65	-
- max	-	-	-	60	-	-	-	85	-

(a) Average values for at least 4, preferably 10, specimens

(b) Dow only

- 3.03 Mechanical Properties at Various Temperatures
- 3.031 Short time tension properties
- 3.0311 Stress strain curves for sand cast test bars in T4 Condition at room and elevated temperatures, Fig. 3.0311.
- 3.0312 Stress strain curves for sand cast test bars in T6 Condition at room and elevated temperatures, Fig. 3.0312.
- 3.0313 Effect of exposure and test temperature on tensile properties of sand cast test bars, Fig. 3.0313.
- 3.032 Short time properties other than tension
- 3.0321 Effect of test temperature on bearing properties of sand cast test bars, Fig. 3.0321.
- 3.0322 Effect of test temperature on shear strength of sand cast test bars, Fig. 3.0322.
- 3.0323 Effect of low test temperature on impact strength of sand cast test bars, Fig. 3.0323.
- 3.033 Static stress concentration effects
- 3.0331 Effect of stress concentration on notch strength ratio of sand cast test bars, Fig. 3.0331.
- 3.04 Creep and Creep Rupture Properties
- 3.041 Total strain curves for sand cast test bars in T6 Condition at 200 to 500 F, Fig. 3.041.
- 3.05 Fatigue Properties
- 3.051 Room temperature fatigue strength, Table 3.051.

TABLE 3.051

Source	(7)						
Form	Sand Cast Test Bars						
Cond	Method	Stress Ratio	Stress Concentration	Fatigue Strength - ksi at Cycles			
		A	R	10^5	10^6	10^7	10^8
F	Rot beam	-1	Smooth	15 to 18	12 to 15	10 to 13	9.5 to 12
T4			K = 1	18 to 23	16 to 21	14 to 19	13 to 17
T6				17 to 20	15 to 18	12 to 16	11 to 15
F	Direct stress	0.600.25	Smooth	22 to 25	20 to 23	18 to 21	-
T4			K = 1	23 to 27	21 to 24	18 to 21	-
T6				25 to 30	23 to 26	22 to 25	-

- 3.052 Average stress range diagrams for direct stress and reverse bending for sand cast test bars, Fig. 3.052.
- 3.06 Elastic Properties
- 3.061 Modulus of elasticity, 6,500 ksi, (12).
- 3.062 Modulus of rigidity, 2,400 ksi, (12).
- 3.063 Poisson's ratio, 0.35, (12).
- 3.064 Tangent modulus curves in tension and compression for sand castings, Fig. 3.064.

4. FABRICATION

- 4.01 Forming and Casting
- 4.011 The production of magnesium alloy castings necessitates a variety of special measures. Melting and alloying is performed in cast or welded low carbon steel pots. Nickel containing steel is not permissible because of pickup of nickel.
- 4.0112 The metal is melted and kept under a special flux cover. Moisture should be avoided. Flux, sulfur powder, sand or a special powder (GI) are used to prevent and extinguish fires.
- 4.0113 The molding sand contains sulfur as an ingredient.
- 4.0114 Design of magnesium castings should allow generous fillets and avoid abrupt section changes due to high sensitivity to notching.
- 4.012 Good castings should possess about 90 to 95 percent of the tensile and yield strength values of the separately cast test bars if the section thickness does not exceed 1 1/2 in. Specifications usually require that specimens cut from actual sections should average 75 percent minimum of the test bar values.
- 4.013 Casting temperatures for this alloy are as follows. Sand castings 1350 to 1550 F. Permanent mold castings, 1200 to 1500 F. Remelt ingots, 1200 to 1300 F.
- 4.014 The castability of this alloy is inferior to that of the other Mg-Al-Zn alloys since it has a greater tendency to form microshrinkage and pressure tightness is more difficult to obtain.
- 4.02 Machining properties of cast magnesium alloys are the same as those of wrought alloys, see AZ 31 B.
- 4.03 Welding. See AZ 31 B also.
- 4.031 General. Although castings in this alloy can be repaired by fusion welding, using AZ 63 A or AZ 92 A welding rod, it is considered difficult to weld. It is inferior in this respect to the other Mg-Al-Zn casting alloys and considerably inferior to alloys containing rare earths or thorium as major alloying elements. Castings may be repaired, preferably by arc welding methods, if they are subsequently inspected for soundness and cracks. Gas welding is only used for field repairs. Preheating should precede welding, and heat treatment should be preferably performed after welding. Stress relief is not required if the casting is welded in F Condition and subsequently solution treated.
- 4.032 Heat treating and reheat treating after welding, Table 4.032.

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NONFERROUS ALLOYS

TABLE 4.032					
Source (11.0.76)					
AZ 63 A					
Alloy	Condition before welding	Condition after welding	Welding rod	Preheat at 715 to 735F*	Heat treatment after welding* ST**and RAC Aging
F	T4		AZ 63 A	All Sections	725 to 730F 10 hr
F	T6		AZ 63 A	Thin and restrained sections only	725 to 735F 30 min
T4, T6	T4		AZ 63 A or AZ 92 A		425F, 5hr
T4, T6	T6				

* Heating from 500F up should be at 150F per hr maximum

** SO₂ atmosphere not required for 725 to 735F, 30 min

4.04 Heating and Heat Treating

- 4.041 Castings in this and other Mg-Al-Zn alloys are usually loaded into the furnace at 500 F and brought to the solution treating temperature within about 2 hr at a uniform rate. Heating at 750 F or higher should be performed in an air atmosphere containing 1/2 percent minimum sulfur dioxide. An exception see Table 4.032.
- 4.043 Support is required on solution treating thin sections.
- 4.044 Rapid air cooling after solution usually requires fans.
- 4.045 Overheating resulting in local melting and fires should be prevented. For extinguishing fires the furnace should be equipped with an inlet for borontrichloride or borontrifluoride.

4.05 Surface Treating

- 4.051 Castings can generally be surface treated in the same manner as wrought products.
- 4.052 Cleaning and pickling of sand castings consists commonly of blast cleaning, acid pickling and chrome pickling, to provide surface protection during shipment and storage. Chrome pickle is also used as a paint base, although other treatments may be specified.

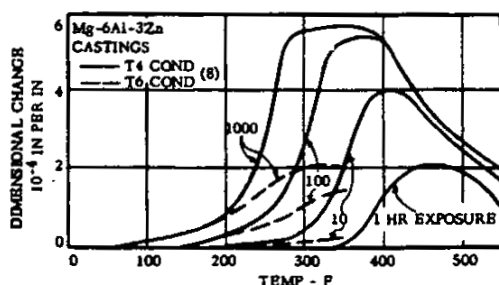


FIG. 2.017 DIMENSIONAL CHANGES ON EXPOSURE OF CASTINGS TO ELEVATED TEMPERATURES (8, FIG. 15, TBL. XV)

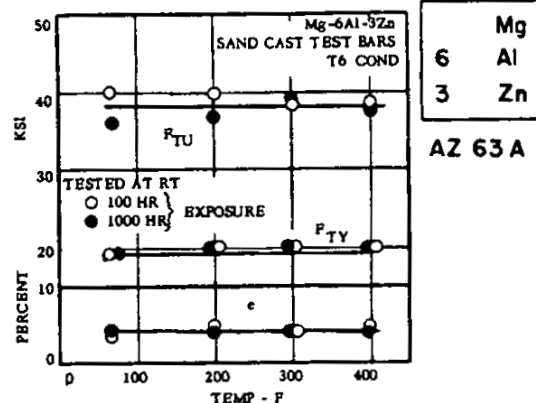


FIG. 3.022 EFFECT OF EXPOSURE TO ELEVATED TEMPERATURES ON TENSILE PROPERTIES OF SAND CAST TEST BARS IN T6 CONDITION (6)

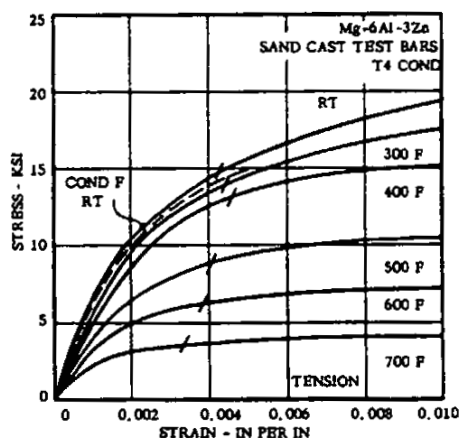


FIG. 3.0311 STRESS STRAIN CURVES FOR SAND CAST TEST BARS IN T4 CONDITION AT ROOM AND ELEVATED TEMPERATURES (8)

	Mg
6	Al
3	Zn

AZ 63 A

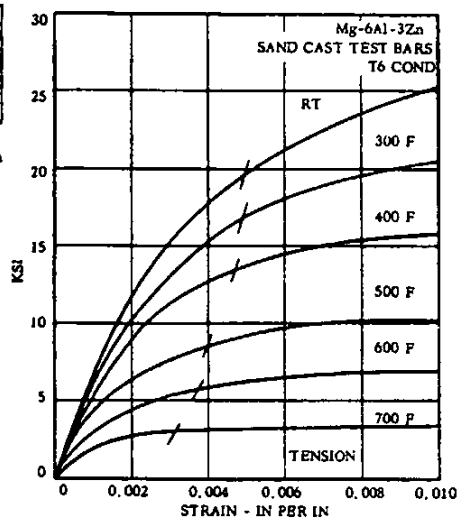


FIG. 3.0312 STRESS STRAIN CURVES FOR SAND CAST TEST BARS IN T6 CONDITION AT ROOM AND ELBATED TEMPERATURES

(8)

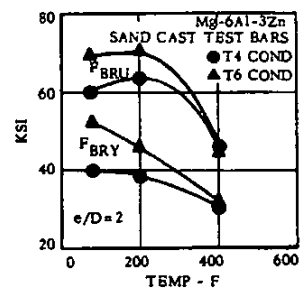


FIG. 3.0321 EFFECT OF TEST TEMPERA-TURE ON BEARING PROPERTIES OF SAND CAST TEST BARS

(9)

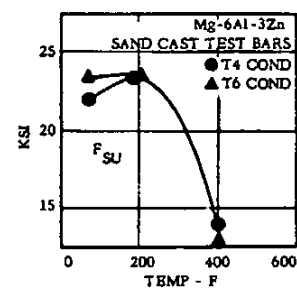


FIG. 3.0322 EFFECT OF TEST TEMPERA-TURE ON SHEAR STRENGTH OF SAND CAST TEST BARS

(9)

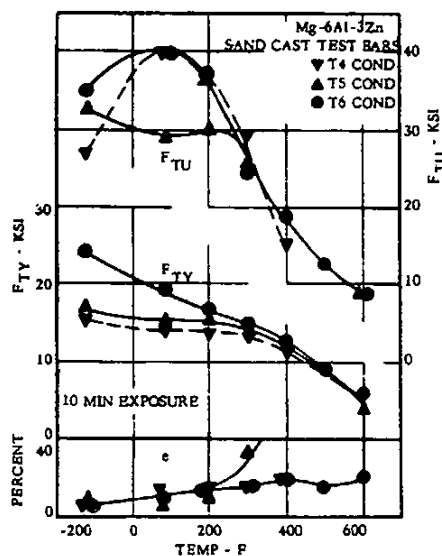


FIG. 3.0313 EFFECT OF EXPOSURE AND TEST TEM-PERATURE ON TENSILE PROPERTIES OF SAND CAST TEST BARS

(6)

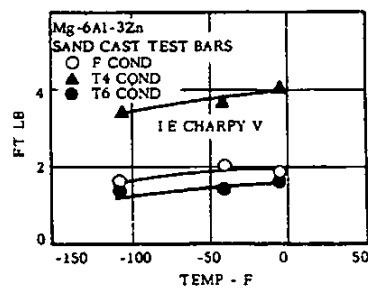


FIG. 3.0323 EFFECT OF LOW TEST TEMPERATURE ON IMPACT STRENGTH OF SAND CAST TEST BARS

(6)

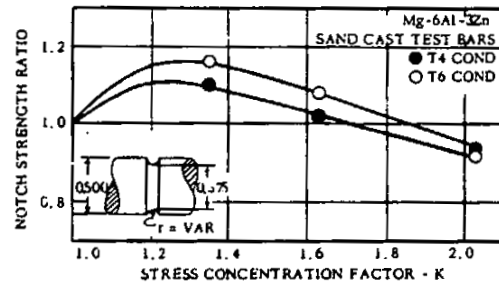


FIG. 3.0331 EFFECT OF STRESS CONCENTRATION ON NOTCH STRENGTH RATIO OF SAND CAST TEST BARS (6)

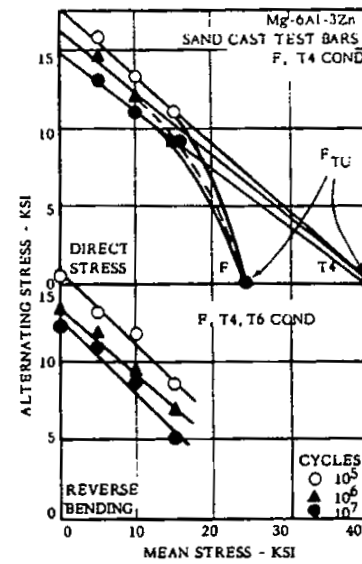


FIG. 3.052 AVERAGE STRESS RANGE DIAGRAMS FOR DIRECT STRESS AND REVERSE BENDING FOR SAND CAST TEST BARS (10)

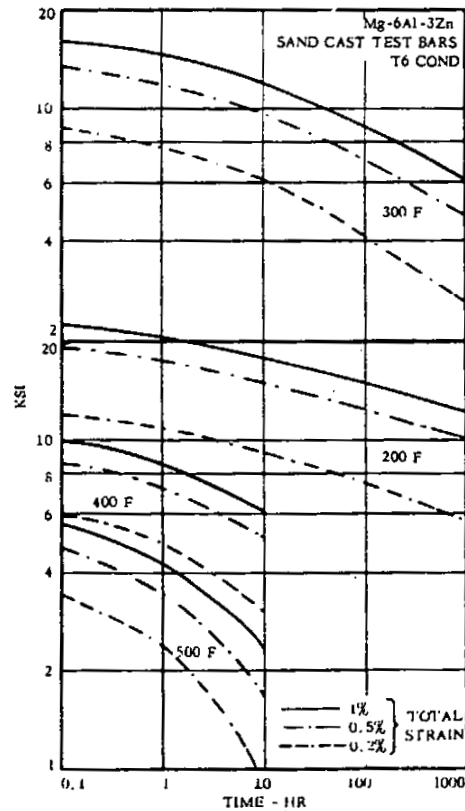


FIG. 3.041 TOTAL STRAIN CURVES FOR SAND CAST TEST BARS IN T6 CONDITION AT 200 TO 500 F (8, Tab. XIII)

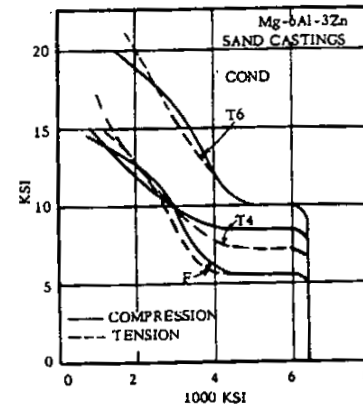


FIG. 3.064 TANGENT MODULUS CURVES IN TENSION AND COMPRESSION FOR SAND CASTINGS (13)

Mg
6 Al
3 Zn
AZ 63 A

	Mg
6	Al
3	Zn

AZ 63 A

REFERENCES

- 1 AMS 4420 G. (Aug. 15, 1958)
- 2 AMS 4422 H. (Aug. 15, 1958)
- 3 AMS 4424 F. (Aug. 15, 1958)
- 4 The Dow Chemical Co., "Electrical and Thermal Properties of Magnesium and Magnesium Alloys", (July 9, 1958)
- 5 The Dow Chemical Co., "Heat Treating of Magnesium Sand and Permanent Mold Castings", Bulletin No. 141-35, (1957)
- 6 The Dow Chemical Co., "Magnesium Design", (1957)
- 7 The Dow Chemical Co., "Dow Data Sheet on Fatigue Properties", (May 20, 1958)
- 8 The Dow Chemical Co., "Room and Elevated Temperature Properties of Magnesium Cast Alloys", Bulletin No. 141-176, (1958)
- 9 The Dow Chemical Co., "Shear, Bearing, and Hardness Data for Cast Alloys", (Feb. 11, 1957)
- 10 Ordnance Corps, "Magnesium and Magnesium Alloys", Ordnance Materials Handbook, ORDP 20-303, (Sept. 1956)
- 11 The Dow Chemical Co., "Joining Magnesium", (1956)
- 12 Alloy Digest, "Magnesium AZ63A", Filing Code Mg-32, (March, 1957)
- 13 Dow, (1959)

REVISED MARCH 1963

NONFERROUS ALLOYS

1. GENERAL

This heat treatable magnesium-aluminum-zinc alloy is one of the strongest alloys for forgings and solid extrusions for service up to 300 F. It is available in various conditions. It has limited ductility at room temperature. It is difficult to forge and its use, therefore, limited to press forging at a slow rate. Welds in this alloy require stress relief.

1.01 Commercial Designation. AZ 80 A.

1.02 Alternate Designations. AZ 80 X, Dowmetal 0-1, Mazlo AMC 58 S (all obsolete).

1.03 Specifications. Table 1.03.

TABLE 1.03		
AMS	Form	Federal
4360 C	Forgings (T5 Cond)	QQ - M - 40

1.04 Composition. Table 1.04.

TABLE 1.04		
Source	AMS (1)	
	Min	Max
Aluminum	7.8	9.2
Zinc	0.20	0.8
Manganese	0.12 (a)	-
Silicon	-	0.30 (b)
Copper	-	0.05
Nickel	-	0.005
Iron	-	0.005
Other impurities (total)	-	0.30
Magnesium	Balance	

(a) Dow gives 0.15

(b) Dow gives 0.05

(b) Dow gives 0.05													
TABLE 3.011													
(2)													
AZ 80 A													
AMS (1)													
AZ 80 A													
Form													
Extrusions													
Forgings													
Die Forgings													
Hand Forgings													
Condition													
F													
T5													
F													
T5													
T5													
T5													
Thickness - in													
Under 0.250													
0.250 to 1.499													
1.500 to 2.499													
2.500 to 5.000													
Under 0.250													
0.250 to 1.499													
1.500 to 2.499													
2.500 to 5.000													
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< 2													
≥ 2													
≥ 50lb													
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(a)													
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(a) Individual Specimen

(b) Average of 8 Specimen

(c) 1000 Kg 10mm.

1.05 Heat Treatment.

1.051 Stress relief after forming or welding.

1.0511 F Condition. 500 F, 15 min.

1.0512 T5 Condition. 400 F, 1 hr.

1.0513 T6 Condition. 600 F, 1/4 hr.

1.052 Solution treat forgings to T6 Condition. 750 F, 2 to 4 hr, air cool.

1.053 Age F Condition to T5 Condition. 350 F, 24 hr.

1.054 Age T4 Condition of forgings to T6 Condition. 350 F, 24 hr.

1.06 Hardenability. Alloy hardens fully in all section sizes on aging either hot worked or solution treated material.

1.07 Forms and Conditions Available

1.071 Solid extrusions and forgings are available in all commercial sizes for magnesium alloys.

1.072 Solid extrusions are available in the F and T5 Conditions.

1.073 Forgings are available in the F, T5 and T6 Conditions.

1.08 Melting and Casting Practice. See AZ 31 B.

1.09 Special Considerations. See AZ 31 B also.

1.091 Stress relief is required after forming and welding to prevent stress cracking.

1.092 Forging this alloy is difficult.

2. PHYSICAL AND CHEMICAL PROPERTIES

2.01 Thermal Properties

2.011 Melting range. 800 to 1115 F.

2.012 Phase changes. Alloy is subject to precipitation.

2.013 Thermal conductivity. 29.0 Btu ft per (hr sq ft F).

2.014 Thermal expansion. See AZ 31 B.

2.015 Specific heat. 0.25 Btu per (lb F).

2.016 Thermal diffusivity. 1.08 sq ft per hr.

2.02 Other Physical Properties

2.021 Density. 0.0649 lb per cu in. 1.80 gr per cu cm.

2.022 Electrical resistivity. 5.71 microhm in.

2.023 Magnetic properties. Alloy is nonmagnetic.

2.03 Chemical Properties. Same as AZ 31 B.

2.04 Nuclear Properties. See AZ 31 B.

3. MECHANICAL PROPERTIES

3.01 Specified Mechanical Properties

3.011 AMS and producers' specified mechanical properties, Table 3.011.

3.02 Mechanical Properties at Room Temperature. See 3.03 also.

3.021 Typical mechanical properties, Table 3.021.

Mg
8.5 Al
0.5 Zn

AZ 80 A

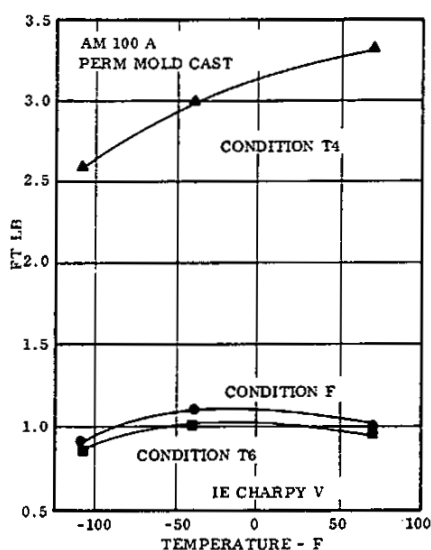


FIG. 3.0331 EFFECT OF LOW TEMPERATURES ON CHARPY V-NOTCH IMPACT ENERGY. (13)

	Mg
IO	Al
Q.I	Mn

AM 100 A

REFERENCES

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- "Properties of Magnesium Alloys," ASM Metals Handbook, 8th edition, Volume I (1961) pp. 1095-1112.
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- "Selection and Application of Magnesium and Magnesium Alloys," ASM Metals Handbook, Volume I (1961) pp. 1067-1086.
- "Arc Welding Magnesium," Form No. 141-300-67, The Dow Chemical Company, Metal Products Department (1965).
- "Resistance Welding Magnesium," Form No. 141-304-66, The Dow Chemical Company, Metal Products Department (1966).
- "Magnesium Finishing," Form No. 141-288-67, The Dow Chemical Company, Metal Products Department (1967).

Mg
8.5 Al
0.5 Zn

AZ 80 A

TABLE 3.021

Source		(2X3)							
Alloy		AZ 80 A							
Form		Extrusions				Forgings			
Condition		F				T5			
Thickness - in		< 1.500		1.500 to 5.000		< 1.500		1.500 to 5.000	
F_{tu} - ksi		49	48	46		55	53 to 50	50	50
F_{ty} - ksi		36	35	31		38 to 40	39 to 38	34	34
e , percent		11	9	8		7	6	6	5
F_{cy} - ksi		-	-	25		35	32 to 31	28	27
F_{su} - ksi		22		22		24		23	-
F_{tru} - ksi		-	-	-		-	-	-	-
($e/D = 2.0$)		.68		-		-	-	80	-
F_{br} - ksi		-	-	-		-	-	-	-
($e/D = 2.0$)		.68		-		-	-	-	-

- 3.022 Stress strain curves in tension and compression for forgings, Fig. 3.022.
- 3.023 Effect of exposure to elevated temperatures on tensile properties of extrusions, Fig. 3.023.
- 3.024 Effect of stress concentration on notch strength ratio of extrusions, Fig. 3.024.
- 3.03 Mechanical Properties at Various Temperatures
- 3.031 Short time tension properties
- 3.0311 Effect of exposure and test temperature on tensile properties of extrusions and forgings, Fig. 3.0311.
- 3.032 Short time properties other than tension
- 3.033 Static stress concentration effects
- 3.04 Creep and Creep Rupture Properties
- 3.041 Total strain curves for forgings at 200 and 300 F, Fig. 3.041.
- 3.05 Fatigue Properties
- 3.051 Fatigue properties of extrusions and forgings, Table 3.051.

TABLE 3.051

Source		(5, p. 4.115, 4.116)							
Form		(1) Extrusions				(2) Forgings			
Cond	Temp F	Method	Stress Ratio		Stress Concentration	Fatigue Strength - ksi at Cycles			
			A	R		10^5	10^6	10^7	10^8
(1) F	RT	Rot beam	∞	-1	Smooth	25 to 30	23 to 28	21 to 26	20 to 24
(2) F					(K = 1)	28 to 30	24 to 26	20 to 22	18 to 20
(2) T4						-	21 to 24	18 to 21	16 to 18
(2) T5						26 to 30	22 to 25	19 to 21	16 to 19
(2) T6						23 to 27	19 to 22	16 to 19	14 to 16
(1) F	RT	Rev bend	∞	-1	As extruded	19 to 21	13 to 16	12 to 14	-
(2) T6					As forged	16 to 20	13 to 16	12 to 15	-
(6)									
(1) T5	RT	Rev bend	∞	-1	Smooth	20	15	12.5	-
(2) T5		Rot beam	∞	-1	Smooth	25	-	20	18
					Notched	16.5	-	9.5	9.5
					K = 2	20.5	-	11	10.5
					Notched	10.5	-	6.5	5
					K = 2				

- 3.06 Elastic Properties
- 3.061 Modulus of elasticity, 6500 ksi.
- 3.062 Modulus of rigidity, 2400 ksi.
- 3.063 Tangent modulus curves in tension and compression for extrusions in T5 Condition, Fig. 3.063.

4. FABRICATION

- 4.01 Forming and Casting
- 4.011 Forming of extrusions in the F Condition can be best performed at 550 F, with the time at temperature limited to 1/2 hr.

- 4.012 Forming of extrusions in the T5 Condition can be best performed at 380 F, with the time at temperature limited to 1 hr.
- 4.013 Forging of this alloy is difficult and, therefore, limited to press forging simple designs. In addition, the rate of deformation should be low. Hammer forgings are not generally produced. Upset forging should be preceded by heating at 750 to 775 F, for 2 to 6 hr, to prevent hot shortness.
- 4.02 Machining. Same as AZ 31 B.
- 4.03 Welding. Extrusions and forgings can be welded in all conditions by the inert gas electric arc method. No flux is necessary. The preferred welding rod is AZ 92 A. Welded assemblies must be stress relieved to avoid cracking.
- 4.04 Heating and Heat Treating. See AZ 63 A.
- 4.05 Surface Treating. See AZ 63 A.

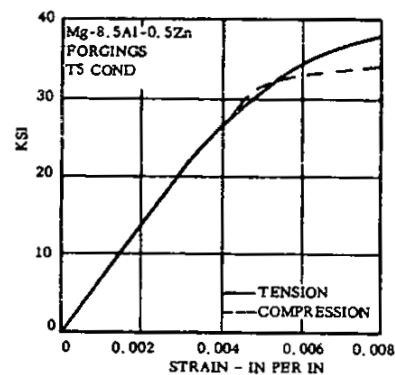


FIG. 3.022 STRESS STRAIN CURVES IN TENSION AND COMPRESSION FOR FORGINGS

(2)

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NONFERROUS ALLOYS

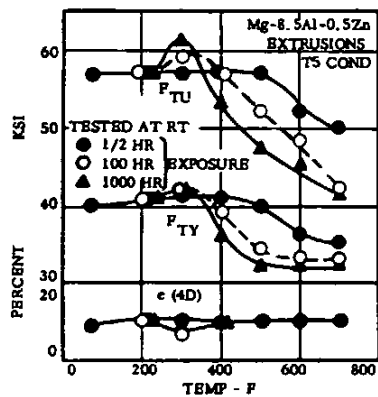


FIG. 3.023 EFFECT OF EXPOSURE TO ELEVATED TEMPERATURES ON TENSILE PROPERTIES OF EXTRUSIONS (4)

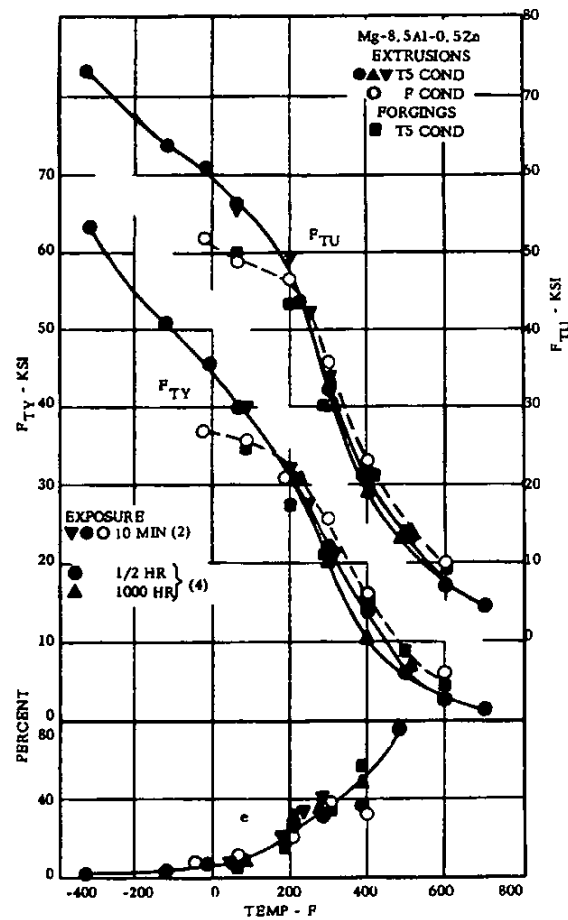


FIG. 3.031 EFFECT OF EXPOSURE AND TEST TEMPERATURE ON TENSILE PROPERTIES OF EXTRUSIONS AND FORGINGS (2)(4)

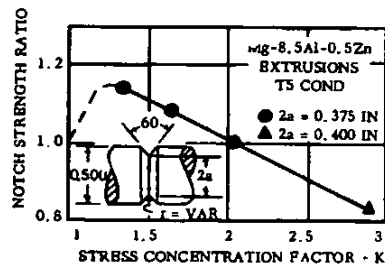


FIG. 3.024 EFFECT OF STRESS CONCENTRATION ON NOTCH STRENGTH RATIO OF EXTRUSIONS (2)

Mg
8.5 Al
0.5 Zn
AZ 80 A

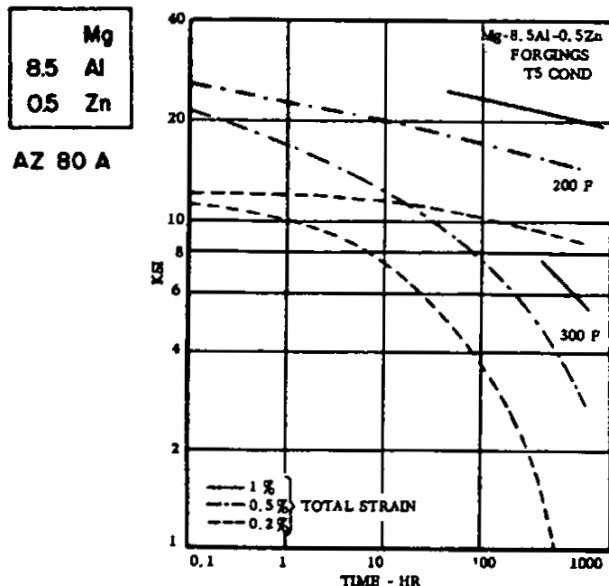


FIG. 3.041 TOTAL STRAIN CURVES FOR FORGINGS AT 200 AND 300 F (5)

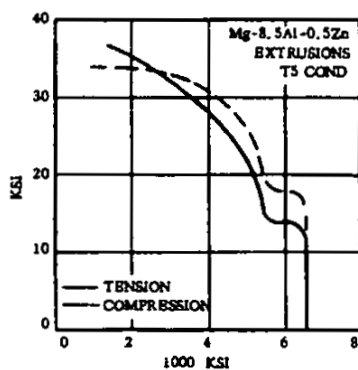


FIG. 3.063 TANGENT MODULUS CURVES IN TENSION AND COMPRESSION FOR EXTRUSIONS IN T3 CONDITION (5)

REFERENCES

- 1 AMS 4360 C, (June 15, 1952)
- 2 The Dow Chemical Co., "Magnesium Design," (1957)
- 3 The Dow Chemical Co., Magnesium Dept., "Magnesium Alloys and Products," (1958)
- 4 The Aluminum Co. of America, "Mechanical Properties at Various Temperatures for AZ 80 A," Alcon Research Laboratory Data Sheet, (Aug. 7, 1957)
- 5 ANC-S, "Strength of Metal Aircraft Elements," (March 1955)
- 6 Ordnance Corps Pamphlet, "Ordnance Materials Handbook, Magnesium and Magnesium Alloys," ORDP 20-303, (Sept. 1956)

1 General

AZ91 is a magnesium-aluminum-zinc casting alloy that provides an excellent combination of castability and mechanical and physical properties for use at temperatures up to about 300-350F. It is produced in three alloy variations, A, B, and D, for die castings and in two alloy variations, C and E, for sand, permanent-mold, and investment castings. The D and E variations specify lower impurity limits, particularly iron, nickel, and copper, which result in greatly improved corrosion resistance with little effect on mechanical properties. Consequently, the D and E variations are generally preferred for aerospace applications. The less pure variations, A, B, and C, which are less expensive, may be used in applications where corrosion resistance is not an important consideration. Die castings are usually used in the as-cast condition, whereas sand, permanent-mold, and investment castings are normally age-hardened. Primarily in its purer (more corrosion-resistant) variations, the alloy has present and potential aerospace applications in gearbox cases, transmission and engine compressor housings, under-carriage wheels, and cockpit canopy frames (Refs. 11, 19, 20, 21).

1.1 Commercial Designations

AZ91 (A, B, C, D, or E).

1.2 Alternate Designations

UNS Numbers: M11910 (AZ91A), M11912 (AZ91B), M11914 (AZ91C), M11916 (AZ91D), M11919 (AZ91E) (Ref. 11).

1.3 Specifications**1.3.1 [Table] Specifications.****1.4 Composition****1.4.1 [Table] Composition.****1.5 Heat Treatment (Refs. 10, 17, 23)**

The conditions of heat treatment for AZ91, as well as of other magnesium casting alloys, are designated as follows: F (as-cast), T5 (artificially aged), T4 (solution heat treated), and T6 (age hardened after solution treatment). The alloy designation AZ91D-F, for example, is indicative of die-cast D alloy variation in the F (as-cast) condition, which is normal for die castings; whereas the designation AZ91E-T6 indicates sand, permanent-mold, or investment casting E alloy variation in the T6 (age-hardened) condition.

1.5.1 Condition T5, artificial aging: age as-cast (F) material at 335F for 16 hours or, alternatively, at 420F for 4 hours, air cool.**1.5.2 Condition T4, solution heat treatment: soak at 775F for 18 hours, fast fan cool to room temperature; alternatively, to minimize grain growth, soak at 775F 6 hours plus 665F 2 hours plus 775F 10 hours, fast fan**

cool to room temperature. To prevent possible eutectic melting and its adverse effects on properties, it is suggested that the castings be loaded into the furnace at 500F and brought to the soaking temperature over about a 2-hour period at a uniform rate of heating.

	Mg
9	Al
0.7	Zn

1.5.3 Condition T6, age hardening after solution treatment: soak at 335F for 18 hours, or alternatively at 420F for 5-6 hours, air cool.

The suggested holding times at the various heat treating temperatures are adequate for section thicknesses up to at least 2 in. Longer times may be required for castings with thicker sections.

1.5.4 Furnaces used for heat treating magnesium alloys are usually the air-chamber type and may be electrically heated or oil- or gas-fired. Since magnesium castings are subject to excessive surface oxidation at temperatures of 750F and above, a protective atmosphere containing a minimum of 0.5 percent sulfur dioxide or 3 percent carbon dioxide is recommended for the solution treatment. Inert gases, which are more expensive, may also be used.

If the temperature during solution treatment accidentally exceeds the specified level by an appreciable amount, the castings may ignite and burn, although sulfur-dioxide or carbon-dioxide atmospheres have an inhibiting effect. Once magnesium alloys start to burn, however, the sulfur dioxide or carbon dioxide supplies oxygen to the fire. A magnesium fire in a gas-tight furnace can be extinguished by the introduction of boron trifluoride gas through a small opening.

1.6 Hardness**1.6.1 [Table] Hardness for various heat-treated conditions at room temperature.****1.7 Forms and Conditions Available**

Alloy variations A, B, and D are available in the form of die castings, which are used primarily in Condition F (as-cast). The other alloy variations, C and E, are available as sand, permanent-mold, and investment castings; they may be heat treated to Condition T4, T5, or T6, but probably are most often used in the T6 Condition (fully solution-treated and aged).

1.8 Melting and Casting Practice (see AM100A, Code 3410, Section 1.08; see also Section 1.9, first paragraph)**1.9 Special Considerations**

For optimum mechanical properties, fine grain size is necessary in AZ91 castings, as well as in other magnesium-alloy castings. During melting operations, grain refinement can be effected either by a controlled

superheat or by carbon inoculation. In superheating, the melt is heated to 1650-1700F, held for about 15 minutes, cooled to the pouring temperature fairly rapidly by removing the crucible from the furnace, and then poured. Carbon inoculation involves the plunging of organic compounds such as hexachloroethane or hexachlorobenzene into the melt, although other carbonaceous materials, such as lampblack, may also be used. Since the organic compounds release chlorine, they function as degasers as well as grain refiners (Refs. 13, 22).

The beneficial effects of grain refinement can be lost as a result of grain growth (also called germination) during solution heat treatment. Sensitivity to this phenomenon is accentuated by very fine, as-cast grain size; by internal stresses, which tend to occur in chilled areas and at saw cuts; and by excessive time at the solution-treating temperature. An effective preventative measure is the alternative (interrupted) solution treatment given in Section 1.5.2 (Refs. 13, 17, 23).

The ignition temperature of magnesium alloys is generally considered to be close to the melting point, but fine shavings, powders, and ribbons can ignite at somewhat lower air temperatures. Magnesium fires cannot be extinguished by water or fire extinguishers of the vaporizing liquid, foam, ordinary dry chemical, or carbon-dioxide types. Their use accelerates burning and may cause an explosion. Magnesium fires can be extinguished only by covering the burning area with a material that will exclude air and not react with burning magnesium. Graphite powder and magnesium melting fluxes are the most commonly used extinguishers (Refs. 13, 17, 24).

AZ91 grows slightly when exposed for long periods of time to temperatures above 200F.

1.9.1 [Table] Maximum linear growth of castings due to long-time exposure to 300F.

1.9.2 [Figure] Linear growth of castings due to long-time exposures at temperatures from 212 to 425F.

AMS specifications (Refs. 1, 3, 4) prohibit the suppliers of AZ91 castings from repairing defective castings by peening, plugging, welding, impregnation, or other methods unless they obtain written permission from the purchaser.

Although not yet commercially available, AZ91 alloy products made by means of rapid-solidification processing have been shown to have substantially improved mechanical properties with corrosion resistance at least as good as that of conventional AZ91 castings of the same composition. This process involves the production of fine particles or thin ribbons of the alloy rapidly solidified by one of several techniques, such as Free Jet Melt Spinning, Planar Flow Casting, and Atomization. The rapidly solidified material is cold

compacted into bulk material, about 60 percent of theoretical density, for further processing by extrusion, forging, or rolling into final shape and near theoretical density (Refs. 38, 39).

1.9.3 [Table] Comparison of the tensile properties and hardness of bars extruded from sand-cast billets with those of bars made by rapid-solidification processing including similar final extruding.

2 Physical Properties and Environmental Effects

2.1 Thermal Properties

2.1.1 Melting Range, 875-1105F (Refs. 5, 6, 7, 11).

2.1.2 Phase Changes. In the as-cast condition (F), the alloy consists mostly of magnesium-aluminum-zinc solid solution, with massive intergranular and interdendritic magnesium-aluminum compounds known as b-phase. In relatively large sections, because of slow cooling rates from the casting temperature, the b-phase also forms as a lamellar secondary phase along the grain boundaries. Also present in the as-cast alloy are some particles of magnesium-silicon and manganese-aluminum compounds, which are not affected by heat treatment. Solution treatment (T4) dissolves the magnesium-aluminum compounds (b-phase) into the solid solution; subsequent age hardening (T6) induces their precipitation in a discontinuous lamellar network along the grain boundaries (Refs. 15, 16).

2.1.2.1 Time-temperature transformation diagrams.

2.1.3 Thermal Conductivity.

2.1.3.1 [Figure] Effects of temperatures up to 500F on thermal conductivity.

2.1.4 Thermal Expansion. Mean coefficient of thermal expansion of AZ91A and AZ91C from 68 to 392F: $15.1-15.2 \times 10^{-6}$ in. per in. per F (Ref. 14).

2.1.5 Specific Heat.

2.1.5.1 [Figure] Effects of temperatures up to 1400F on specific heat.

2.1.6 Thermal Diffusivity.

2.1.6.1 [Table] Thermal diffusivity at 68F.

2.2 Other Physical Properties

2.2.1 Density: 0.0654 lb. per cu. in., 1.81 gr. per cu. cm. (Refs. 5, 6, 7, 8).

2.2.2 Electrical Properties.

2.2.2.1 [Figure] Effects of temperatures up to 500F on electrical resistivity.

2.2.3 Magnetic Properties. Alloy is nonmagnetic.

2.2.4 Emittance (see ZK60A, Code 3506, Figure 2.024).

2.2.5 Damping Capacity.

2.2.5.1 [Table] Damping capacity of die castings at various stress levels.

2.3 Chemical Environment

Use of magnesium alloys in aerospace applications has been limited by their susceptibility to corrosion in marine and other aggressive environments. This problem in AZ91 castings has been substantially alleviated by the relatively recent introduction of the high-purity D and E alloy variations with intrinsic corrosion resistance approaching that of aluminum alloys. The improved corrosion resistance of the D and E variations is a result of greatly reduced limits for the heavy-metal impurities—copper, nickel, and iron—plus control of the ratio of iron to manganese contents to a level of 0.032 or less (Ref. 13).

2.3.1 [Figure] Comparison of corrosion rates of AZ91C and E in the T6 Condition with that of A357 aluminum casting alloy both totally immersed in 3.5 percent sodium-chloride solution and in 5 percent salt fog.

2.3.2 [Figure] Comparison of corrosion-pitting depth in AZ91C and E in the T6 Condition with that in A357 aluminum casting alloy after total immersion for 14 days in 3.5 percent sodium-chloride solution.

The corrosion rates for AZ91D-F (die castings) in 5 percent salt fog (ASTM B 117) and totally immersed in 5 percent sodium-chloride solution are about 10 and 45 mil per year, respectively, which compare reasonably well with AZ91E-T6 (sand castings) corrosion rates as shown in Figure 2.3.1 (Ref. 31).

In the older alloy variations (A, B, and C), differences in iron content can have marked effects on corrosion rates in various types of environments (Ref. 31).

2.3.3 [Table] Effects of a variation in iron content on the corrosion rate of AZ91C-T6 sand castings in various types of environments.

Because of the high electrochemical activity of magnesium, galvanic corrosion tends to occur in AZ91, as well as in other magnesium alloys, in areas where they are in electrical contact with most other structural metals in the presence of an electrolyte. Such attack can occur, for example, in areas where magnesium-alloy surfaces are in contact with dissimilar-metal bolts. Use of a nonmetallic sealing compound between all such contact areas can be effective in preventing the attack (Ref. 21).

2.3.4 [Figure] Comparison of corrosion rates of AZ91C and E with that of A357 aluminum casting alloy when galvanically coupled to aluminum and to carbon steel and immersed in 3.5 percent sodium-chloride solution.

Use of ferrous abrasives for surface cleaning can leave iron contamination on casting surfaces, which is detri-

mental to corrosion resistance. Acid pickling can be used to remove such contamination, but use of high-purity alumina, silica, or glass beads is preferable to ferrous abrasives (Ref. 20).

2.3.5 [Table] Effects of heat-treat condition and surface condition on the corrosion rate of AZ91E as a result of 10-day salt-spray testing in accordance with ASTM B 117.

Recent studies have revealed that AZ91 is susceptible to stress corrosion cracking in aqueous environments (Ref. 41).

2.3.6 [Figure] Time to stress-corrosion failure as a function of tensile stress for die-cast specimens in two different environments; and, for comparison, the ultimate tensile strength (F_{tu}) of comparison specimens after similar exposures without stress.

2.4 Nuclear Environment**3 Mechanical Properties****3.1 Specified Mechanical Properties**

3.1.1 [Table] AMS specified mechanical properties.

3.1.2 [Table] ASTM specified mechanical properties.

3.2 Mechanical Properties at Room Temperature

3.2.1 Tension Stress-strain Diagrams and Tension Properties.

3.2.1.1 [Figure] Tensile stress-strain curve for die-cast test bar at room temperature.

3.2.1.2 For room-temperature stress-strain curves of sand-cast test bars, see Figure 3.3.1.1.

3.2.1.3 [Table] Typical tensile properties of separately cast test bars at room temperature.

3.2.1.4 [Figure] Effects of exposures up to 1000 hours at 300F on room-temperature tensile properties of sand castings in the T6 condition.

3.2.1.5 [Figure] Effects of long-time exposures at various elevated temperatures on room-temperature tensile yield strength and percent elongation of sand castings in the T4 Condition.

3.2.2 Compression Stress-strain Diagrams and Compression Properties.

3.2.2.1 [Figure] Compressive stress-strain curve for die-cast test bar at room temperature.

3.2.2.2 [Table] Compressive yield strength at room temperature for different alloy variations and heat treatments.

3.2.3 Impact.

3.2.3.1 [Table] Charpy V-notch impact strength at room temperature for die castings and sand castings in various heat-treated conditions.

- 3.2.4 Bending.
- 3.2.5 Torsion and Shear.
 - 3.2.5.1 [Table] Shear strength at room temperature for different alloy variations and heat treatments.
- 3.2.6 Bearing.
 - 3.2.6.1 [Table] Bearing properties at room temperature for different alloy variations and heat treatments.
- 3.2.7 Stress Concentration.
 - 3.2.7.1 Notch properties.
 - 3.2.7.2 Fracture toughness.
- 3.2.8 Combined Properties.
- 3.3 Mechanical Properties at Various Temperatures**
 - 3.3.1 Tension Stress-strain Diagrams and Tension Properties.
 - 3.3.1.1 [Figure] Stress-strain curves at room and elevated temperatures for sand-cast test bars.
 - 3.3.1.2 [Figure] Effect of test temperature on tensile properties of sand-cast test bars.
 - 3.3.1.3 [Figure] Effects of test temperature and strain rate on tensile properties of sand-cast test bars in the T6 condition.
 - 3.3.2 Compression Stress-strain Diagrams and Compression Properties.
 - 3.3.3 Impact.
 - 3.3.3.1 [Table] Charpy V-notch impact strength of sand castings at temperatures from 75 to -320F.
 - 3.3.4 Bending.
 - 3.3.5 Torsion and Shear.
 - 3.3.5.1 [Figure] Effect of test temperature on shear strength of sand-cast test bars.
 - 3.3.6 Bearing.
 - 3.3.6.1 [Figure] Effect of test temperature on bearing properties of sand-cast test bars.
 - 3.3.7 Stress Concentration.
 - 3.3.7.1 Notch properties.
 - 3.3.7.2 Fracture toughness.
 - 3.3.8 Combined Properties.
- 3.4 Creep and Creep-Rupture Properties**
 - 3.4.1 [Figure] Isochronous stress-strain curves at 300 and 400F for sand-cast test bars in the T6 condition.
 - 3.4.2 A recent investigation of AZ91A-F die castings has revealed that the alloy is susceptible to creep deformation at room temperatures and stresses below the yield strength (Ref. 40).

3.4.2.1 [Figure] Creep strain of die-cast test bars as a function of time at room temperature and a tensile stress of 19.5 ksi.

3.5 Fatigue Properties

- 3.5.1 [Table] Rotating-beam fatigue strength (R = -1) of different alloy variations at room temperature.
- 3.5.2 [Figure] Fatigue S-N range for sand castings in the T6 Condition.
- 3.5.3 [Figure] Fatigue-crack growth rates for two different sections of a sand casting.

3.6 Elastic Properties

- 3.6.1 Poisson's Ratio, 0.35 (Refs. 11, 25).
- 3.6.2 Modulus of Elasticity.
 - 3.6.2.1 [Figure] Modulus of elasticity at room and elevated temperatures.
- 3.6.3 Modulus of Rigidity, 2.4×10^6 psi (Refs. 11, 25).
- 3.6.4 Tangent Modulus.
- 3.6.5 Secant Modulus.

4 Fabrication

4.1 Forming

4.2 Machining and Grinding

AZ91, as well as other magnesium alloys, has excellent machinability, which enables it to be machined at high speeds and feeds. The low cutting pressures and rapid dissipation of generated heat combine to provide long tool life, dimensional stability, and good surface finish (Ref. 30).

4.3 Joining

Although welding is not recommended for die castings (AZ91A, B, and D), gas-tungsten-arc and gas-metal-arc welding are both applicable for repair and joining of sand, permanent-mold, and investment castings. AZ92A or AZ91C are the recommended filler alloys. Whereas preheat and interpass temperatures of 650-750F are recommended for thin and restrained sections, heavy and unrestrained sections may be welded with little or no preheat (Refs. 11, 32).

- 4.3.1 If the T4 Condition is desired after welding, the castings should be in that condition prior to welding and then postweld treated as follows: 1/2 hour at 775F in protective atmosphere (see Section 1.5.4), fast fan cool (Ref. 32).
- 4.3.2 If the T6 Condition is desired after welding, the castings should be in either the T4 or T6 condition prior to welding and then postweld treated as follows: 1/2 hour at 775F in protective atmosphere (see Section

1.5.4), fast fan cool, + 4 hours at 420F or 16 hours at 335F, AC (Ref. 32). The short times at 775F (1/2 hour) for the postweld T4 and T6 treatments are used to avoid germination (see Section 1.9, second paragraph) in the deposited weld metal (Ref. 32).

- 4.3.3 AZ91C and E castings can be welded to most wrought magnesium alloys by the same methods given in Section 4.3, first paragraph. For optimum properties, the castings to be welded should be in the heat-treated condition finally desired. Postweld treatments as given in Sections 4.3.1 and 4.3.2 provide optimum T4 or T6 properties in the casting segment, but may be detrimental to the wrought material depending on the specific alloy (Ref. 32).
- 4.3.4 If optimum mechanical properties are not required, welded castings or cast-wrought weldments should, nevertheless, be stress relieved one hour at 500F in order to prevent stress-corrosion cracking (Ref. 32).
- 4.3.4.1 [Table] Tensile properties of sand-cast plates, both base metal and sections with transverse GMA welds across the gage lengths of the test specimens.
- 4.3.4.2 [Figure] Fatigue S-N curves for sand-cast plates, both base metal and sections with transverse GMA welds across the test areas.
- 4.3.4.3 [Figure] Fatigue-crack growth rates in GMA repair weld deposits made with AZ92A magnesium-alloy electrodes in two different sections of a sand casting.

Gas welding, soldering, brazing, and spot welding are not normally recommended for AZ91 alloy, particularly for critically stressed applications or for service under conditions of vibration or fatigue (Refs. 29, 34).

4.4 Surface Treatment

For corrosion protection during shipping and handling, AZ91, as well as other magnesium-casting alloys, are normally chrome pickled (AMS 2475) or, alternatively, coated with a light corrosion-inhibiting oil by the producing foundries prior to shipment. (Refs. 1, 2, 3, 4). A wide range of chemical and electrochemical cleaning and surface treatments is available for paint adhesion and corrosion protection (Ref. 31, see also AM 100A, Code 3410, Sections 4.042, 4.043, and 4.044 for details).

A study of the effects of various surface treatments and finishes on the rotating-beam fatigue strength of AZ91C-T6 castings showed that acid pickling has detrimental effects on fatigue strength, whereas shot peening has beneficial effects which, in most instances, are sufficient to overcome any detrimental effects of acid pickling or coatings. For the most part, chromate coatings, anodic coatings, and paints have only minor but variable effects on fatigue strength (Ref. 27).

- 4.4.1 [Table] Effects of various surface treatments and finishes on the rotating-beam fatigue strength of sand castings at 10 million cycles.

Table 1.3.1 Specifications (Refs. 1-11)

Alloy: AZ91			
Specification	Alloy Variations	Conditions	Form
AMS 4437D	C	T6	Sand Castings
AMS 4446	E	T6	Sand Castings
AMS 4490G	A	F	Die Castings
AMS 4452A	C	T6	Investment Castings
ASTM B 80-90	C, E	F, T4, 5, 6	Sand Castings
ASTM B 94-88	A, B, D	F	Die Castings
ASTM B 199-87	C, E	F, T4, 5, 6	Permanent Mold Castings
ASTM B 403-87	C, E	F, T4, 5, 6	Investment Castings
ASTM B 93-90	A, B, C, D, E	F	Ingot
MIL-M-46062	C	-	Sand and Permanent Mold Castings
QQ-M-56	C	-	Sand Castings
QQ-M-38	A	F	Die Castings
QQ-M-55	C	-	Permanent Mold Castings

Note: In addition to these product specifications, ASTM B 661-90 and MIL-M-6857 cover heat treatment of magnesium alloys including AZ91.

Table 1.4.1 Composition (Refs. 1-9)

Alloy: AZ91										
Alloy Variations	A		B		D		C (a)		E (b)	
Form (c)	Die Cast						Sand, Investment, Permanent Mold Cast			
Specification	AMS (3), ASTM (6)		ASTM (6)		ASTM (6)		AMS (1)		AMS (2)	
Element	Percent		Percent		Percent		Percent		Percent	
	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max
Aluminum	8.3	9.7	8.3	9.7	8.3	9.7	8.1	9.3	8.1	9.3
Zinc	0.35	1.0	0.35	1.0	0.35	1.0	0.40	1.0	0.40	1.0
Manganese	0.13	-	0.13	-	-	0.15	0.13	0.30	0.17	0.35
Silicon	-	0.50	-	0.50	-	0.10	-	0.30	-	0.030
Copper	-	0.10	-	0.35	-	0.030	-	0.10	-	0.030
Nickel	-	0.03	-	0.03	-	0.002	-	0.01	-	0.0010
Iron	-	-	-	-	-	0.005	-	-	-	0.005
Others, each	-	-	-	-	-	0.02	-	0.10	-	0.01
Others, total	-	0.30	-	-	-	-	-	0.30	-	-
Magnesium	Remainder		Remainder		Remainder		Remainder		Remainder	

(a) The composition shown for AZ91C is taken from the AMS specification for sand castings (Ref. 1); the AMS specification for investment castings (Ref. 4) and the ASTM specifications for sand (Ref. 5), investment (Ref. 8), and permanent mold (Ref. 7) castings differ only slightly, primarily in the limits for manganese content.

(b) The composition shown for AZ91E is taken from the AMS specification for sand castings (Ref. 2); the ASTM specifications for sand (Ref. 5), investment (Ref. 8), and permanent mold (Ref. 7) castings differ only slightly, primarily in lower maximum limits for silicon and copper contents.

(c) The ASTM specified compositions for ingot in all five alloy variations (Ref. 9) are quite similar to those shown above, the most pronounced differences being somewhat more restricted ranges for the principal alloying elements and in some instances for the residual elements in the ingot specification.

Table 1.6.1 Hardness for various heat-treated conditions at room temperature (Refs. 5, 6, 7, 11, 13)

Alloy: AZ91				
Type Casting	Alloy Variation	Condition	Hardness	
			Brinell (a)	Rockwell E
Die	A, B, D	F	63	75
Sand, Permanent Mold, Investment	C, E	F	60	66
		T5	62	-
		T4	55	62
		T6	70	77

(a) 10 mm ball, 500 Kg

Table 1.9.1 Maximum linear growth of castings due to long-time exposure at 300F (Ref. 23)

Alloy: AZ91C	
Form	Castings
Condition	Maximum Linear Growth (in./in.)
F	0.00040
T4	0.00077
T6	0.00055

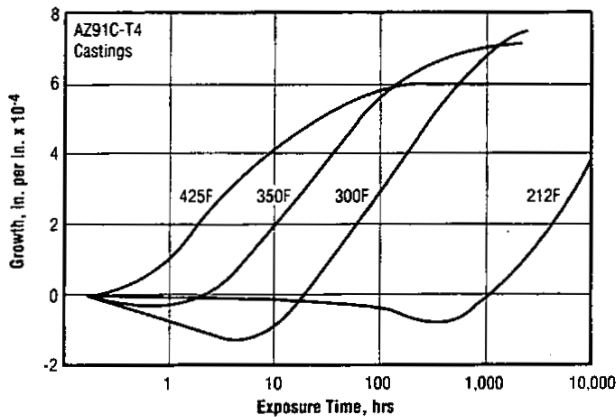


Fig. 1.9.2 Linear growth of castings due to long-time exposures at temperatures from 212 to 425F (Ref. 25)

Table 1.9.3 Comparison of the tensile properties and hardness of bars extruded from sand-cast billets with those of bars made by rapid-solidification processing including similar final extruding (Refs. 38, 39)

Alloy: AZ91E						
Initial Form	Further Processing (a)	Heat Treat	F_{ty} (ksi)	F_{tu} (ksi)	e (percent, 4D)	Hardness Rockwell E
Sand-cast bar	Extruded	None	32.8	45.4	15.6	81
Sand-cast bar	Extruded	T6 (b)	24.2	47.7	11.1	78.5
RS + C (c)	Extruded	None	56.7	66.3	12.1	97.5

(a) Extruded at 480F, extrusion ratio 20, ram speed 0.5 mm per sec

(b) Heat treated after extruding

(c) Rapidly solidified by Free Jet Melt Spinning and compacted

Note: For comparison of the sand-cast and extruded bars with conventional cast test bars see Table 3.2.1.3, in which Condition F and T6, respectively, correspond to heat treatments labeled "None" and "T6" in this table

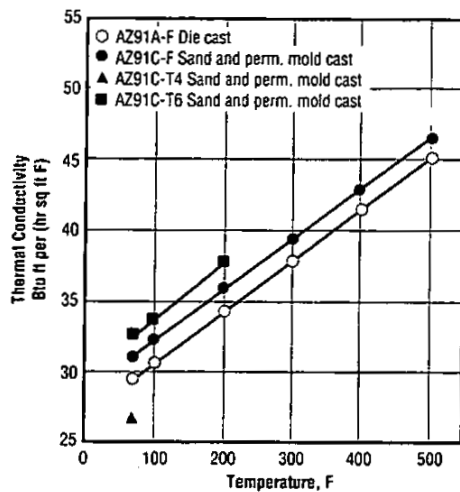


Fig. 2.1.3.1 Effects of temperatures up to 500F on thermal conductivity (Ref. 14)

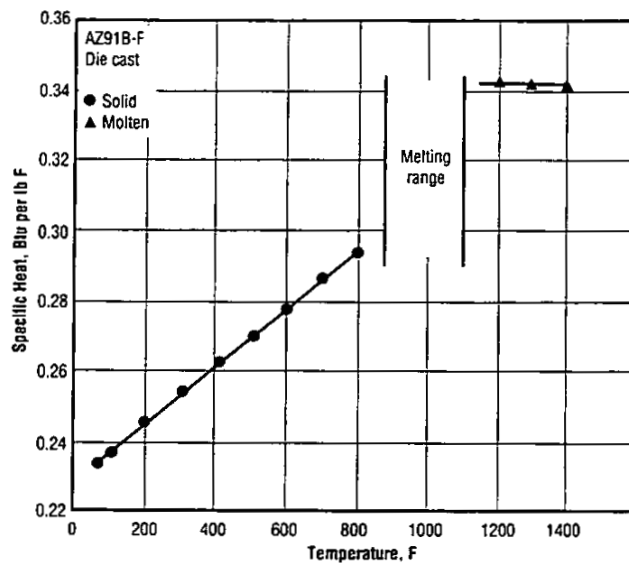


Fig. 2.1.5.1 Effects of temperatures up to 1400F on specific heat (Ref. 14)

Table 2.1.6.1 Thermal diffusivity at 68F (Ref. 14)

Alloy: AZ91			
Alloy Variation	Condition	Casting Type	Diffusivity (sq ft per hr)
A	F	Die	1.12
C	F	Sand & Permanent Mold	1.17
C	T4	Sand & Permanent Mold	1.00
C	T6	Sand & Permanent Mold	1.23

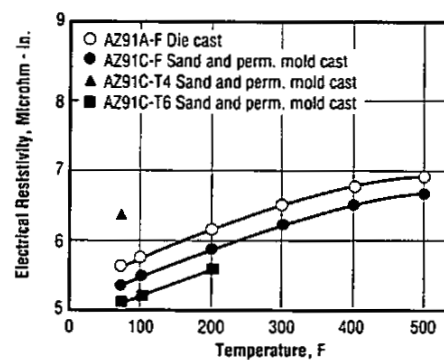


Fig. 2.2.2.1 Effects of temperatures up to 500F on electrical resistivity (Ref. 14)

Table 2.2.5.1 Damping capacity of die castings at various stress levels (Ref. 17)

Alloy: AZ91A, B, D	
Form	Die Castings
Condition	F
Stress (ksi)	Specific Damping Capacity (percent)
1.0	2.67
2.0	5.33
3.0	12.0
3.5	16.0
5.0	29.3

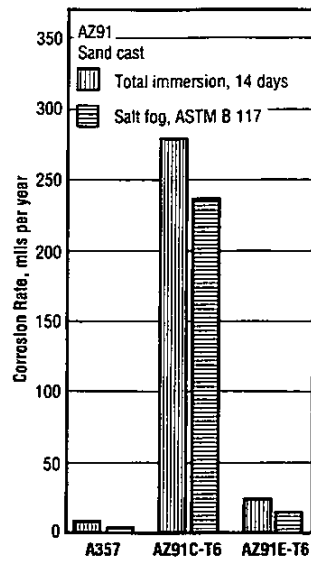


Fig. 2.3.1 Comparison of corrosion rates of AZ91C and E in the T6 condition with that of A357 aluminum casting alloy both totally immersed in 3.5-percent sodium-chloride solution and in 5 percent salt fog (Ref. 21)

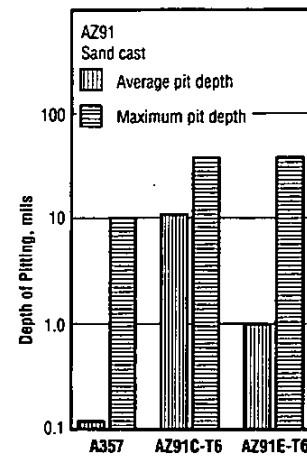


Fig. 2.3.2 Comparison of corrosion-pitting depth in AZ91C and E in the T6 condition with that in A357 aluminum casting alloy after total immersion for 14 days in 3.5-percent sodium-chloride solution (Ref. 21)

Table 2.3.3 Effects of a variation in iron content on the corrosion rate of AZ91C-T6 sand castings in various types of environments (Ref. 31)

Alloy: AZ91C		
Form	Sand Castings	
Condition	T6	
Iron Content (percent)	0.035	<0.005
Environment	Corrosion Rate (mils per year)	
Rural	0.17	0.11
Industrial	0.60	0.55
Marine	0.87	0.25
20% salt spray	3740	27.9

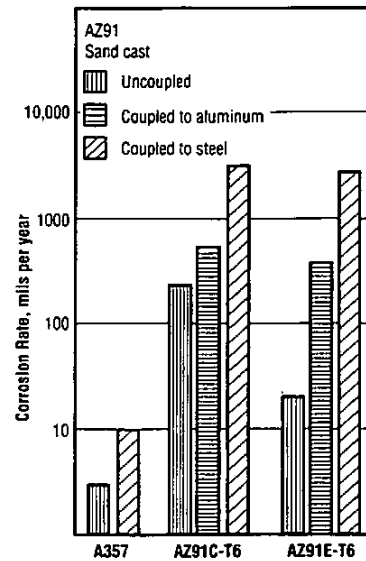


Fig. 2.3.4 Comparison of corrosion rates of AZ91C and E with that of A357 aluminum casting alloy when galvanically coupled to aluminum and to carbon steel and immersed in 3.5-percent sodium-chloride solution (Ref. 21)

Table 2.3.5 Effects of heat-treat condition and surface condition on the corrosion rate of AZ91E as a result of 10-day salt spray testing in accordance with ASTM B 117 (Ref. 20)

Alloy: AZ91E		
Form	Sand Cast	
Heat Treat Condition	Surface Condition	Corrosion Rate (mils per year)
F	(1)	260-277
F	(2)	<14-29
F	(3)	14-29
T4	(3)	5-7
T6	(3)	4-9

- (1) Steel-shot blasted
 (2) Sand blasted, acid etched, and chrome pickled
 (3) Wet-belt abraded with 80-mesh silicon carbide

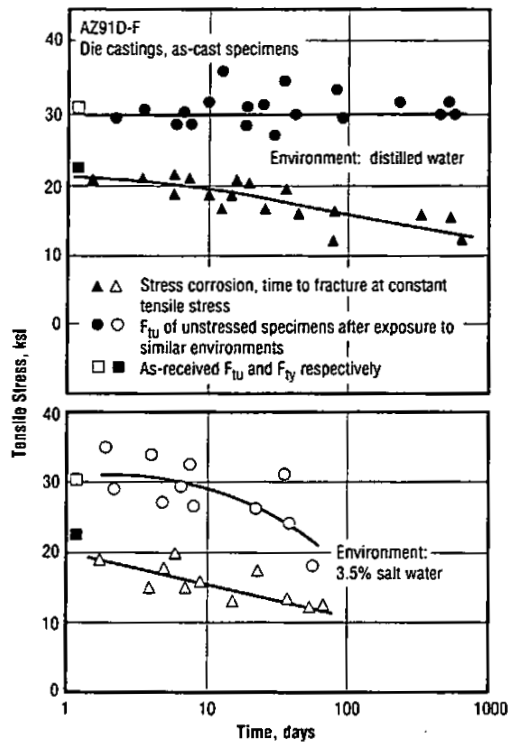


Fig. 2.3.6 Time to stress-corrosion failure as a function of tensile stress for die-cast specimens in two different environments; and, for comparison, the ultimate tensile strength (F_{tu}) of comparison specimens after similar exposures without stress (Ref. 41)

Note 1: The specimens were half submerged in the indicated environments; the stress-corrosion specimens fractured at the air-water interface, but the comparison specimens fractured at random locations in the gage length in subsequent tensile tests.

Note 2: The deterioration in strength of the companion unstressed specimens after about 10 days in salt water was a result of general corrosive attack.

Table 3.1.1 AMS specified mechanical properties (Refs. 1, 2, 4)

Alloy: AZ91						
Condition		T6				
Form (e)	Alloy Variation	Tensile Specimens	F_{ty} (ksi) min	F_{tu} (ksi) min	e (percent, 4D) min	BHN (d)
Sand Cast	C	(a)	16	34.0	3.0	65-85/75-95
		(b)	12	17.0	0.75	65-85/75-95
	E	(a)	16	34.0	3.0	65-85/75-95
		(b)	12	17.0	-	65-85/75-95
		(c)	14.5	25.5	0.75	65-85/75-95
Investment Cast	C	(a)	16	34.0	3.0	-
		(b)	12	17.0	-	-
		(c)	14.5	25.0	1.0	-

(a) Separately cast

(b) Cut from casting, single specimen

(c) Cut from casting, average of four or more specimens

(d) 10 mm ball 500 Kg load/10 mm ball 1000 Kg load; any area of casting except at gate and riser locations

(e) The AMS specification for AZ91A-F die castings (Ref. 3) includes no mechanical-property requirements

Table 3.1.2 ASTM specified mechanical properties (Refs. 5, 7, 8)

Alloy: AZ91					
Tensile Specimens		Separately Cast to Size			
Form (a)	Alloy Variation	Condition	F_{ty} (ksi) min	F_{tu} (ksi) min	e (percent, 2 in.) min
Sand Cast	C	F	11.0	23.0	-
		T4	11.0	34.0	7
		T5	12.0	23.0	2
		T6	16.0	34.0	3
	E	T6	16.0	34.0	3
Investment Cast	C	F	10.0	18.0	-
		T4	10.0	34.0	7
		T5	11.0	20.0	2
		T6	16.0	34.0	3
	E	T6	16.0	34.0	3
Permanent Mold Cast	C	F	11.0	23.0	-
		T4	11.0	34.0	7
		T5	12.0	23.0	2
		T6	16.0	34.0	3
	E	T6	16.0	34.0	3

(a) The ASTM specifications for AZ91A, B, and D-F die castings (Ref. 6) and for AZ91A, B, C, D, and E-F ingot (Ref. 9) include no mechanical-property requirements

AZ 91

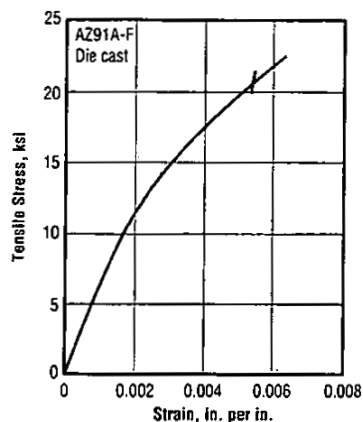


Fig. 3.2.1.1 Tensile stress-strain curve for die-cast test bar at room temperature (Ref. 25)

Table 3.2.1.3 Typical tensile properties of separately cast test bars at room temperature (Refs. 6, 11, 13)

Alloy: AZ91					
Form	Die Cast	Sand, Permanent Mold, Investment Cast			
Alloy Variations	A, B, D	C, E			
Condition	F	F	T4	T5	T6
F_{ty} (ksi)	22-23	14	13	17	21
F_{tu} (ksi)	33-34	24	40	26	40
e (percent, 4D)	3	2.5	15	3	6

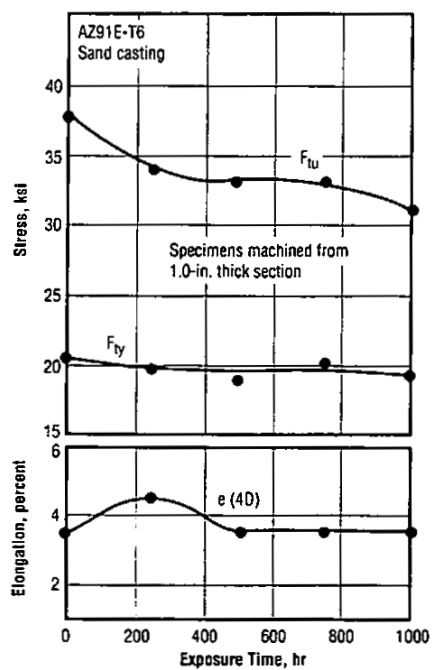


Fig. 3.2.1.4 Effects of exposures up to 1000 hours at 300F on room-temperature tensile properties of sand castings in the T6 condition (Ref. 21)

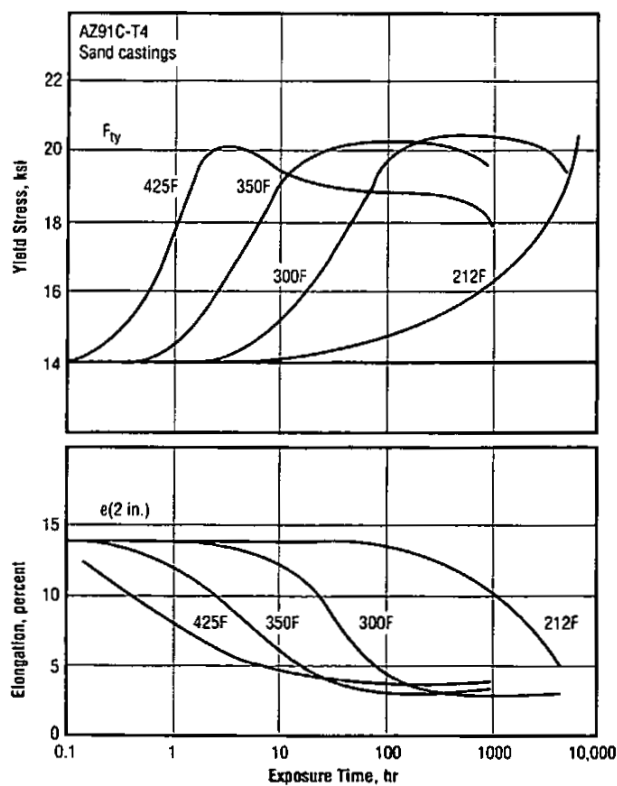


Fig. 3.2.1.5 Effects of long-time exposures at various elevated temperatures on room temperature tensile yield strength and percent elongation of sand castings in the T4 condition (Ref. 25)

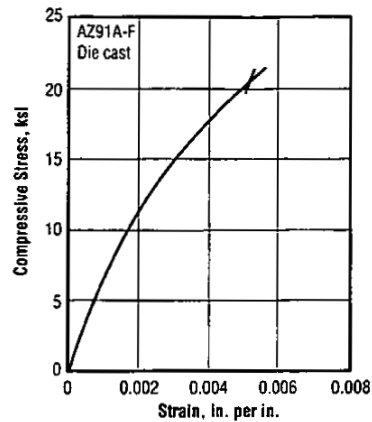


Fig. 3.2.2.1 Compressive stress-strain curve for die-cast test bar at room temperature (Ref. 25)

Table 3.2.2.2 Compressive yield strength at room temperature for different alloy variations and heat treatments (Ref. 11)

Alloy: AZ91			
Form	Alloy Variations	Condition	F _{cy} (ksi)
Die Cast	A, B, D	F	24
Sand, Permanent Mold	C, E	F	14
		T4	13
		T6	19

Table 3.2.3.1 Charpy V-notch impact strength at room temperature for die castings and sand castings in various heat-treated conditions (Ref. 11)

Alloy: AZ91			
Form	Alloy Variation	Condition	Charpy V IE (ft lb)
Die Cast	A, B, D	F	2.0
Sand Cast	C, E	F	0.58
		T4	3.0
		T6	1.0

Table 3.2.5.1 Shear strength at room temperature for different alloy variations and heat treatments (Refs. 11, 33)

Alloy: AZ91			
Form	Alloy Variation	Condition	F _{su} (ksi)
Die Cast	A, B, D	F	20
Sand, Permanent Mold	C, E	F	18
		T4	20
		T6	21

Table 3.2.6.1 Bearing properties at room temperature for different alloy variations and heat treatments (Refs. 11, 25)

Alloy: AZ91				
Form	Alloy Variations	Condition	F _{brv} (ksi)	F _{bru} (ksi)
Sand, Permanent Mold	C, E	F	40	60
		T4	44	60
		T6	52	75

Note: Ratio edge distance to hole diameter, (e/d) = 2.5

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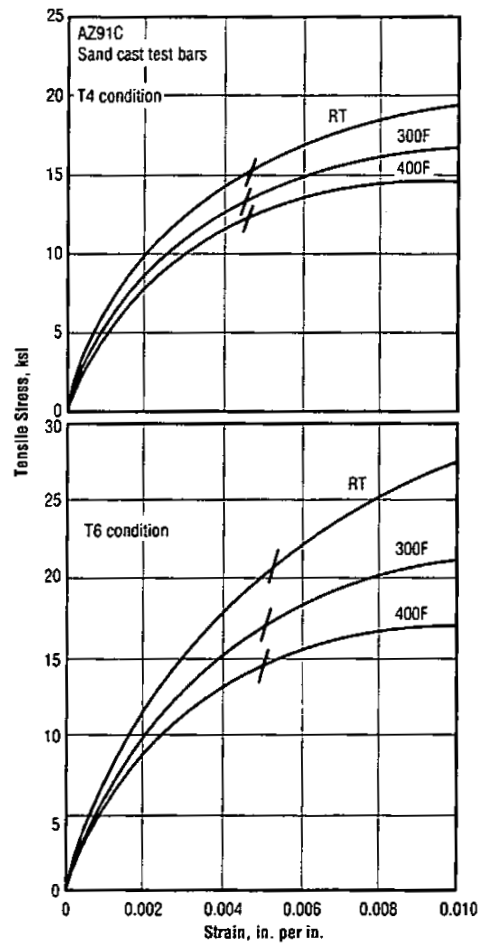


Fig. 3.3.1.1 Stress-strain curves at room and elevated temperatures for sand-cast test bars (Ref. 35)

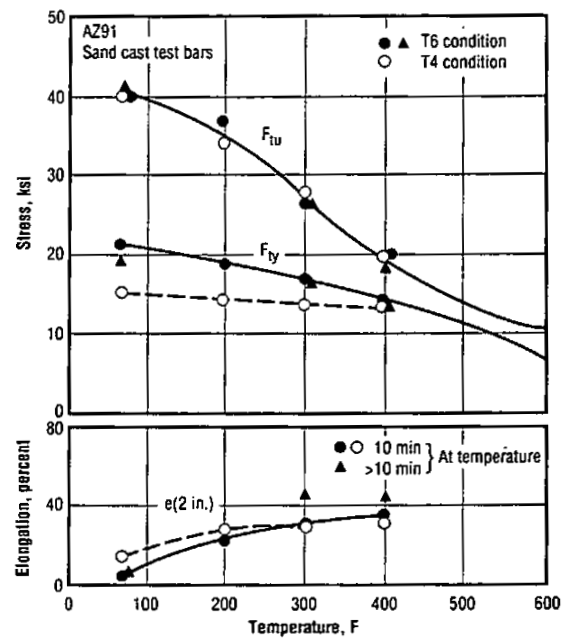


Fig. 3.3.1.2 Effect of test temperature on tensile properties of sand-cast test bars (Refs. 25, 35)

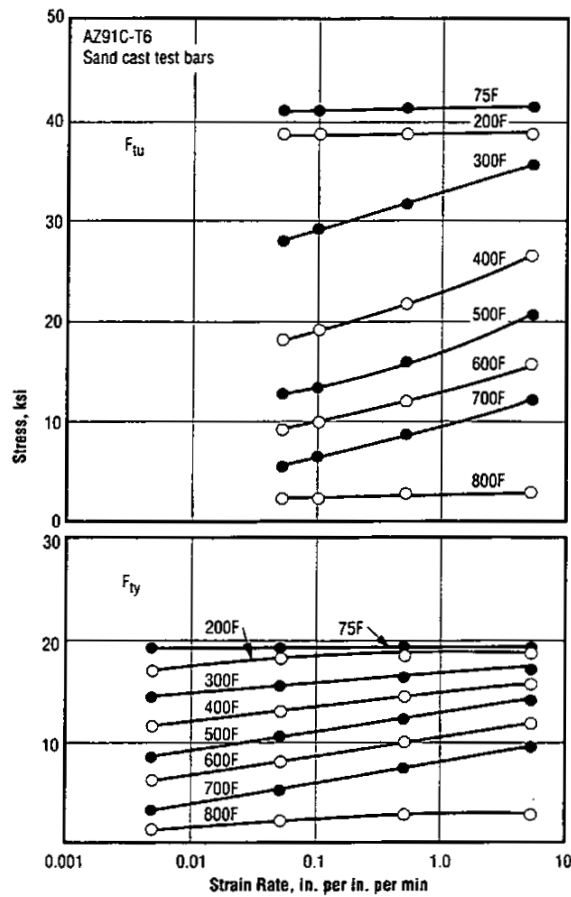


Fig. 3.3.1.3 Effects of test temperature and strain rate on tensile properties of sand-cast test bars in the T6 condition (Ref. 35)

Table 3.3.3.1 Charpy V-notch impact strength of sand castings at temperatures from 75 to -320F (Ref. 29)

Alloy: AZ91C	
Form	Sand Cast
Condition	T6
Temperature (F)	Charpy V IE (ft lb)
75	1
-110	1
-320	3/4

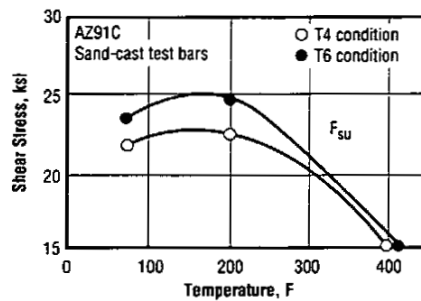


Fig. 3.3.5.1 Effect of test temperature on shear strength of sand-cast test bars (Ref. 36)

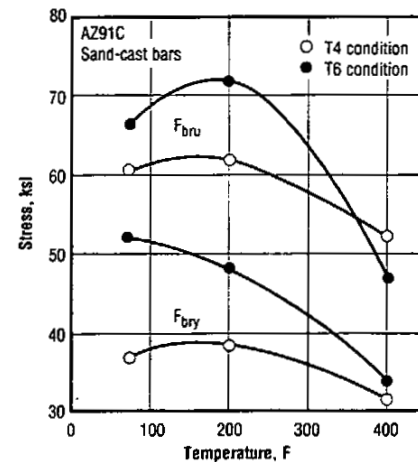


Fig. 3.3.6.1 Effect of test temperature on bearing properties of sand cast test bars (Ref. 36)

AZ 91

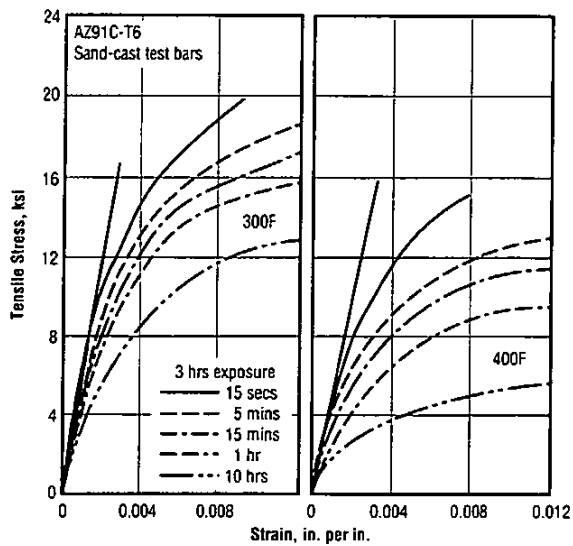


Fig. 3.4.1 Isochronous stress-strain curves at 300 and 400F for sand-cast test bars in T6 condition (Ref. 37)

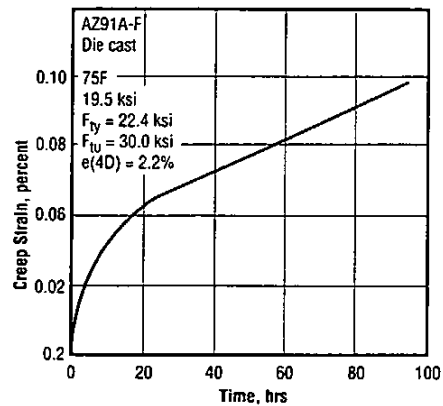


Fig. 3.4.2.1 Creep strain of die-cast test bars as a function of time at room temperature and a tensile stress of 19.5 ksi (Ref. 40)

Table 3.5.1 Rotating-beam fatigue strength ($R = -1$) of different alloy variations at room temperature (Ref. 11)

Alloy: AZ91				
Form	Alloy Variation	Condition	Cycles to Failure	Maximum Cyclic Stress (ksi)
Die Cast	A, B, D	F	5×10^8	14
Sand, Permanent Mold	C, E	T6	10^8	12-14

Note: Specimen surfaces machined and polished

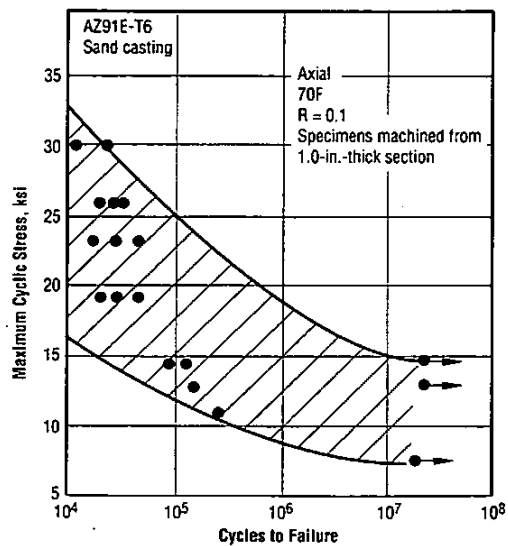


Fig. 3.5.2 Fatigue S-N range for sand castings in the T6 condition (Ref. 21)

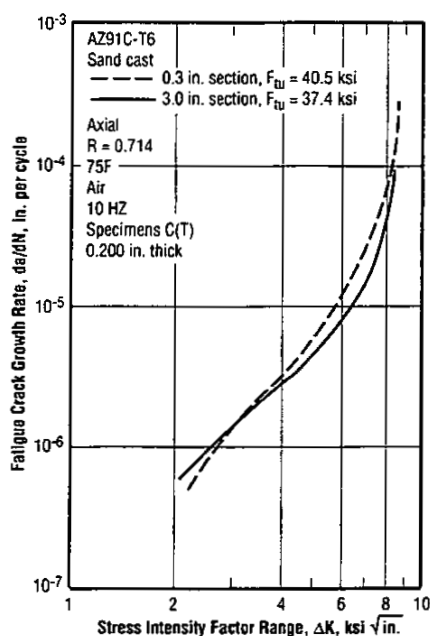


Fig. 3.5.3 Fatigue-crack growth rates for two different sections of a sand casting (Ref. 12)

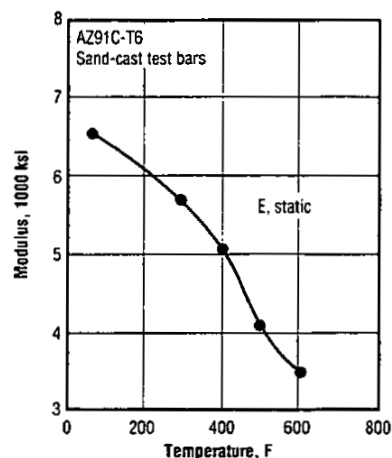


Fig. 3.6.2.1 Modulus of elasticity at room and elevated temperatures (Ref. 28)

Table 4.3.4.1 Tensile properties of sand-cast plates, both base metal and sections with transverse GMA welds across the gage lengths of the test specimens (Ref. 18)

Alloy: AZ91C							
Form	Sand-Cast Plates						
Test Section	Preweld Heat Treatment	Postweld Heat Treatment	Preheat (F)	Filler	F _{ty} (ksi)	F _{tu} (ksi)	e (percent, 2 in.)
Base Metal	T6	T6	400	-	17.9	35.3	3.7
Welded	T6	T6	400	AZ92A	22.1	39.7	4.3
Base Metal	T4	T6	-	-	20.5	41.9	6.5
Welded	T4	T6	-	AZ91C	20.6	34.2	3.3

Note: All tensile properties are the averages of three tests

AZ 91

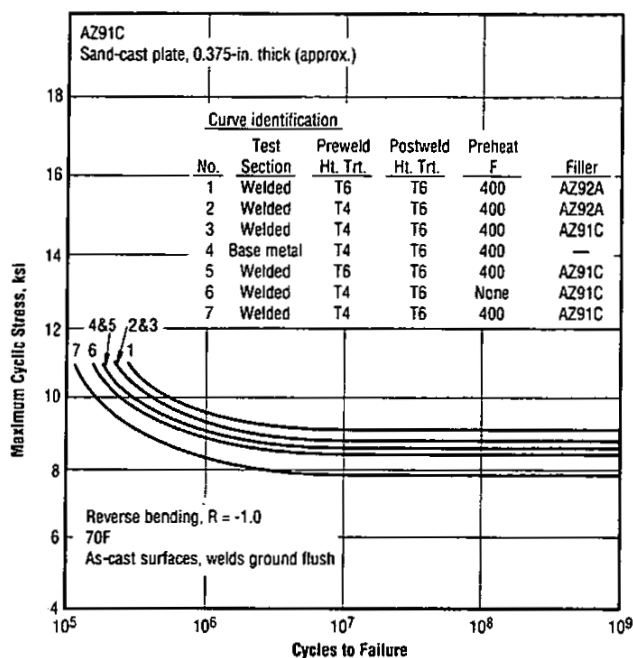


Fig. 4.3.4.2 Fatigue S-N curves for sand-cast plates, both base metal and sections with transverse GMA welds across the test areas (Ref. 18)

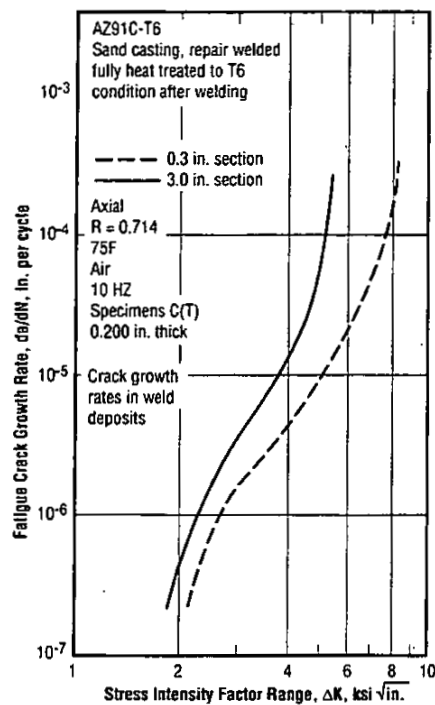


Fig. 4.3.4.3 Fatigue-crack growth rates in GMA repair weld deposits made with AZ92A magnesium alloy electrodes in two different sections of a sand casting (Ref. 12)

Table 4.4.1 Effects of various surface treatments and finishes on the rotating-beam fatigue strength of sand castings at 10 million cycles (Ref. 27)

Alloy: AZ91C		
Form	Sand Castings, 0.625-in. Plates	
Condition	T6 ($F_{tu} = 39.4$ ksi)	
Surface Condition	Fatigue Strength at 10^7 cycles (ksi)	Percent of Control
As polished (control samples)	12	100
Polished, peened	15	125
Polished, alkaline cleaned, pickled	9.5	79
plus, No. 20 chromate conversion coating	10	84
No. 7 chromate conversion coating	9.5	79
HAE light anodic coat	11	92
HAE heavy anodic coat	10	84
No. 17 light anodic coat	8	67
No. 17 heavy anodic coat	9	75
Polished, peened, alkaline cleaned, pickled	15.5	129
plus, No. 20 chromate conversion coating	14.5	121
No. 7 chromate conversion coating	13	108
HAE light anodic coat	14	117
HAE heavy anodic coat	11.5	96
No. 17 light anodic coat	14.5	121
No. 17 heavy anodic coat	11	92
Polished, peened, alkaline cleaned, pickled, HAE heavy anodic coat		
plus, Epoxy primer and lacquer (5 mils total)	12.5	104
Epoxy primer and Alkyd top coat (5.5 mils)	12	100
Epoxy primer and polyurethane (5.4 mils)	11	92
Chloro-rubber and polyurethane (5.3 mils)	12	100
Polished, alkaline cleaned		
plus, HAE light anodic coat	14	117
HAE heavy anodic coat	14	117

Note:

1. Fatigue test conditions: $R = -1$, 70F, 10,000 cpm
2. Polished: No. 400 polishing paper in longitudinal direction
3. Peened: 0.125-in.-dia steel shot to 5A Almen intensity
4. Pickled: Dilute nitric plus sulfuric acid for 10 sec
5. Alkaline cleaned: immersed in sodium orthosilicate solution

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AZ 91

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REVISED MARCH 1963

NONFERROUS ALLOYS

1. GENERAL

AZ 92 A is a heat treatable casting alloy which is a member of the aluminum and zinc containing family. Of this family it has the highest yield strength combined with moderate elongation and good pressure tightness. It is available in the form of sand, permanent mold, investment castings and welding rod. Castings of this alloy give stable properties up to 200 F and under low operating stresses give satisfactory service up to 350 F. It has good machinability and can be welded.

1.01 Commercial Designation. AZ 92 A.1.02 Alternate Designation1.03 Specifications, Table 1.03.

TABLE 1.03			
AMS	Form	Military	ASTM
4434 F	Castings, sand (T6 Cond)	QQ-M-56(F, T7)	B 80-56T (F, T6)
4453	Castings, investment (T6 Cond)	-	-
4484 E	Castings, permanent mold (T6 Cond)	QQ-M-55 (F, T6)	B 199-56T
-	Ingot	-	B 93-56T

1.04 Composition, Table 1.04.

TABLE 1.04		
Source	AMS (1) (2) (3)	
	Min	Max
Aluminum	8.3	9.7
Zinc	1.6	2.4
Manganese	0.10	-
Silicon	-	0.30
Copper	-	0.10
Nickel	-	0.01
Other impurities total	-	0.30
Magnesium	Balance	

1.05 Heat Treatment

1.051 Solution treat. As cast P Condition to T4 Condition.

1.0511 Load into preheated furnace (approximately 500 F), raise to 760 to 770 F in about 2 hr, hold at temperature for 18 hr, air cool. Use 0.5% SO₂ (min) in furnace atmosphere during heat and soak periods, (4, p. 3).1.0512 Load into preheated furnace (approximately 500 F), raise to 760 to 770 F in about 2 hr, hold at temperature for 6 hr, furnace cool to 660 to 670 F, hold for 2 hr, raise to 760 to 770 F, hold for 10 hr, air cool. Use 0.5% SO₂ (min) in furnace atmosphere during heat and soak cycles. This treatment prevents germination, (4, p. 3).

1.052 Age

1.0521 As cast to T5 Condition, age at 490 to 510 F for 4 hr, air cool, (4, p. 2-3).

1.0522 T4 to T6 Condition, after solution heat treat, age at 490 to 510 F for 4 hr, air cool, (4, p. 4).

1.06 Hardenability1.07 Forms and Conditions Available

1.071 Alloy is available in the full commercial range of sizes for sand, permanent mold and investment castings.

1.072 Castings are available in F, T4, T5 and T6 Conditions although use is almost exclusively in the T6 Condition.

1.08 Melting and Casting Practice

1.081 Standard magnesium alloy melting and casting practice.

1.09 Special Considerations

1.091 Heat treat temperature must not exceed 772 F to prevent burning, (6).

2. PHYSICAL AND CHEMICAL PROPERTIES

2.01 Thermal Properties

2.011 Melting range. 830 to 1100 F minimum. Liquation (burning) temperature 770 F, (6).

2.012 Transformation temperature. None.

2.013 Thermal conductivity, Table 2.013.

TABLE 2.013 *

Source	(7, Tbl. V)			
	F	T4	T5	T6
Temp - F	Bru ft per (hr sq ft F)			
68	30.2	25.6	33.6	33.6
100	-	-	35.1	35.1
200	-	-	38.7	38.7
300	-	-	-	41.8
400	-	-	-	44.8
500	-	-	-	47.6

* Calculated from electrical resistivity data

2.014 Thermal expansion at low and elevated temperatures, Fig. 2.014.

2.0141 Dimensional growth due to exposure at various temperatures, Fig. 2.0141.

2.015 Specific heat. 0.245 Bru per (lb F).

2.016 Emissivity. Variations in alloy composition do not significantly effect emissivity values.

2.0161 Effect of test temperature on emissivity of alloy, Fig. 2.0161.

2.017 Diffusivity. Thermal, 0.135 sq in per sec, (9, p. 19).

2.02 Other Physical Properties

2.021 Density. 0.066 lb per cu in, 1.828 gr per cu cm.

2.022 Electrical resistivity, Table 2.022.

TABLE 2.022

Source	(7, Tbl. IV)			
	F	T4	T5	T6
Temp - F	Microhm - in			
68	5.51	6.61	4.88	4.88
100	-	-	5.00	5.00
200	-	-	5.35	5.35
300	-	-	-	5.75
400	-	-	-	6.10
500	-	-	-	6.46

2.023 Magnetic properties. Nonmagnetic.

2.03 Chemical Properties2.031 Corrosion resistance

2.0311 Alloy is resistant to most alkalis, some hydrocarbons, aldehydes, ethyl alcohol, phenols, amines, esters and most oils as well as pure chromic and hydrofluoric acids. Stress corrosion may occur after welding unless stress relieved.

2.0313 Susceptible to galvanic corrosion in presence of more noble metal unless protected.

2.032 Oxidation resistance. In moist air, alloy forms oxide film which retards but does not stop further oxidation. Needs full protection in marine atmospheres.

3. MECHANICAL PROPERTIES

3.01 Specified Mechanical Properties

3.011 AMS specified and producer's minimum mechanical properties, Table 3.011.

	Mg
9	Al
2	Zn

AZ 92 A

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PAGE 1

Mg
9 Al
2 Zn

AZ 92 A

TABLE 3.011

TABLE 3.011						
Source	AMS (1) (3)	AMS (2)	Dow (9, p. 23)			
Alloy	Mg-9Al-2Zn					
Form	Sand and permanent mold castings	Investment castings	Sand and permanent mold castings			
Condition	T6	T6	F	T4	T5	T6
F _{tu} min - ksi	34 (a), 25.5 (b), 17 (c)	37 (a), 27.5 (b), 19 (c)	20	34	20	34
F _{ty} min - ksi	18 (a), 16 (b), 13.5 (c)	20 (a), 17.5 (b), 15 (c)	10 (f)	10 (f)	11 (f)	18 (f)
e, min - percent	1 (a) (d), 0.75 (i)	1 (a) (e), 0.7 (b) (g)	1 (d)	6 (d)		1 (d)
Hardness,						
BHN - min	70 (h)	63 (f)				
MAX	95 (h)	93 (f)				

(a) For cast tensile specimens

(b) Average for tensile specimens

cut from castings (not less than 4, preferably 10 specimens)

(c) For individual tensile specimen cut from castings

(d) In 2 in gage length

(e) In 1 in gage length

(f) Converted from Rockwell E 75-95

(g) In 4 D

(h) 500 kg - 10 mm ball

(i) AMS 4434 F specifies 2 in gage length

AMS 4484 E specifies 4 D gage length

3.02 Mechanical Properties at Room Temperature

3.021 Typical mechanical properties, Table 3.021.

3.05 Fatigue Properties

3.051 S-N curves for fatigue properties of alloy, Fig. 3.051.

3.052 Shot peening or surface rolling of castings induce residual compressive stresses favorable to increased fatigue life, (8, p. 36).

TABLE 3.021

Source	(9, p. 23)			
Alloy	Mg-9Al-2Zn			
Form	Sand and permanent mold castings (separately cast test bars)			
Condition	F	T4	T5	T6
F _{tu} typ - ksi	24	40	24	40
F _{ty} typ - ksi	14	14	14	21
e (2 in) typ - percent	2	10	2	2
F _{cy} typ - ksi	14	14	-	21
F _{su} typ - ksi	19	19	20	22
F _{bu} typ - ksi	50	68	50	80
F _{bu} typ - ksi	46	46	46	65
Hardness, BHN - typ	65	63	-	84

3.06 Elastic Properties

3.061 Modulus of elasticity at room and elevated temperatures, Fig. 3.061.

3.062 Modulus of rigidity, 2,400 ksi.

3.063 Poisson's ratio, 0.35.

4. FABRICATION

4.01 Forming and Casting

4.011 General. Standard flux melting procedure is used for magnesium alloys. Molten metal must be kept covered with flux. Crucibles having clay as a bond are attacked by molten magnesium while steel crucibles are not attacked. Welded low carbon or cast steel crucibles are almost always used. Impurities may be picked up from nickel steel crucibles. Moisture must be avoided.

4.012 Casting temperature. Sand, 1350 to 1550 F. Permanent mold, 1200 to 1500 F. Ingots, 1200 to 1300 F, (6).

4.02 Machining

This alloy possesses excellent machinability.

4.03 Welding

Alloy has fair weldability.

4.031 Alloy is welded by the inert shielded tungsten arc method, using an AZ 92 A welding rod, (6).

4.032 Gas welding is used mostly for emergency repairs. When gas welding, all flux must be completely removed by immersion and scrubbing in hot water. Part should be given chrome pickle treatment and then boiled for 2 hr in 5 percent sodium dichromate solution.

4.033 This alloy can be satisfactorily resistance welded, (6).

4.034 Stress relieve after welding, see 4.0423.

4.04 Heating and Heat Treating

4.041 Solution treatments require an atmosphere of at least 0.5 percent sulfur dioxide.

4.042 Heat treatment after welding with AZ 92 A welding rod.

4.0421 From T4 or T6 Condition before welding to T4 Condition after welding, heat 30 min at 760 to 770 F, (5).

4.0422 From T4 or T6 Condition before welding to T6 Condition after welding, heat 30 min at 760 to 770 F, age 4 hr at 500 F, (5).

4.0423 Stress relief after welding, 500 F, 30 min, (5).

3.022 Effect of exposure to elevated temperature on room temperature tensile properties of alloy in T6 Condition, Fig. 3.022.

3.023 The compressive yield strength of this alloy is essentially the same as the tensile yield strength, (8, p. 25).

3.024 Stress strain curves in tension at room temperature for alloy in F, T4 and T6 Condition, Fig. 3.024.

3.025 Stress strain curves in compression at room temperature for alloy in F, T4 and T6 Condition, Fig. 3.025.

3.026 Tangent modulus curves in tension at room temperature for alloy in F, T4 and T6 Condition, Fig. 3.026.

3.027 Tangent modulus curves in compression at room temperature for alloy in F, T4 and T6 Condition, Fig. 3.027.

3.028 Effect of stress concentration factor on room temperature notch tensile strength ratio of alloy in T4 and T6 Condition, Fig. 3.028.

3.03 Mechanical Properties at Various Temperatures

3.031 Short time tensile properties

3.0311 Stress strain curves at room and elevated temperature of alloy in T6 Condition, Fig. 3.0311.

3.0312 Effect of test temperature on tensile properties of alloy in T5 and T6 Condition, Fig. 3.0312.

3.0313 Effect of exposure and test temperature on tensile properties of alloy in T6 Condition, Fig. 3.0313.

3.0314 Effect of test temperature and strain rate on tensile properties of alloy in T6 Condition, Fig. 3.0314.

3.032 Short time properties other than tension

3.0321 Effect of test temperature on shear strength of alloy in T6 Condition, Fig. 3.0321.

3.0322 Effect of test temperature on bearing properties of alloy in T6 Condition, Fig. 3.0322.

3.04 Creep and Creep Rupture Properties

3.041 Creep curves of alloy in T6 Condition, Fig. 3.041.

3.042 Isochronous stress strain curves for alloy in T6 Condition at 300 and 400 F, Fig. 3.042.

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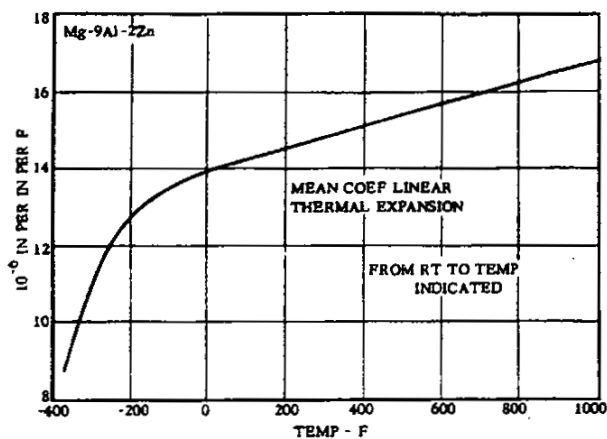


FIG. 2.014 THERMAL EXPANSION AT LOW AND ELEVATED TEMPERATURES (7, Tab. I)

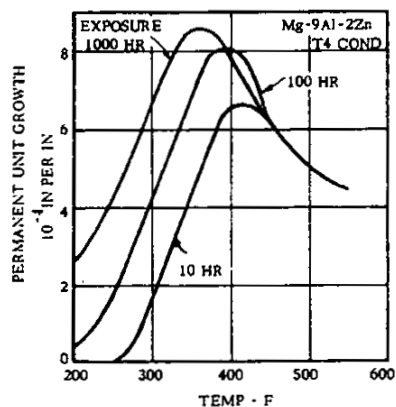


FIG. 2.014: DIMENSIONAL GROWTH DUE TO EXPOSURE AT VARIOUS TEMPERATURES (8, p. 16-17)

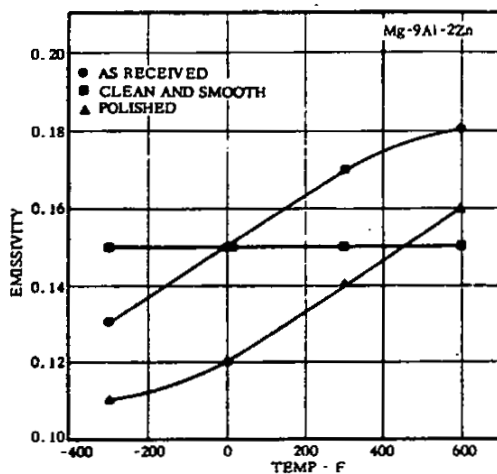


FIG. 2.016: EFFECT OF TEST TEMPERATURE ON EMISSIVITY OF ALLOY (14)

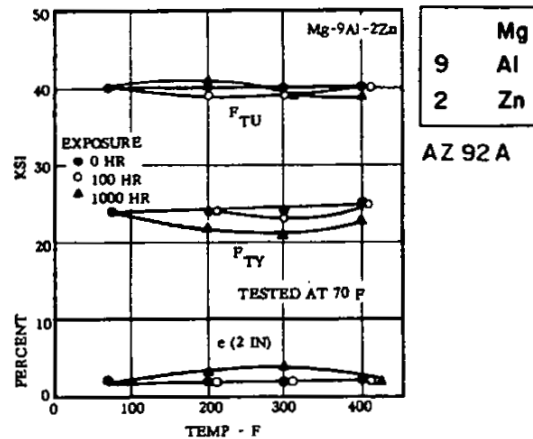


FIG. 3.022 EFFECT OF EXPOSURE TO ELEVATED TEMPERATURE ON ROOM TEMPERATURE TENSILE PROPERTIES OF ALLOY IN T6 CONDITION (8, p. 179)

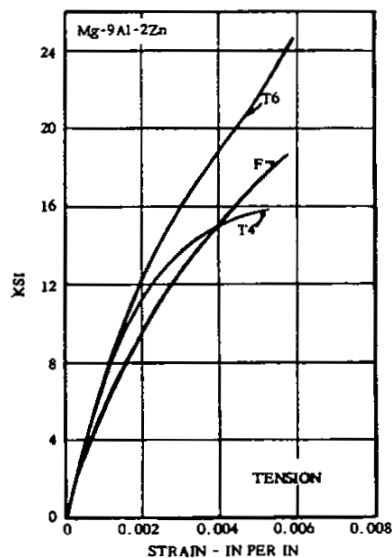


FIG. 3.024 STRESS STRAIN CURVES IN TENSION AT ROOM TEMPERATURE FOR ALLOY IN F, T4 AND T6 CONDITION (11, p. 4.62-4.69)

Mg	9
Al	2
Zn	2

AZ 92A

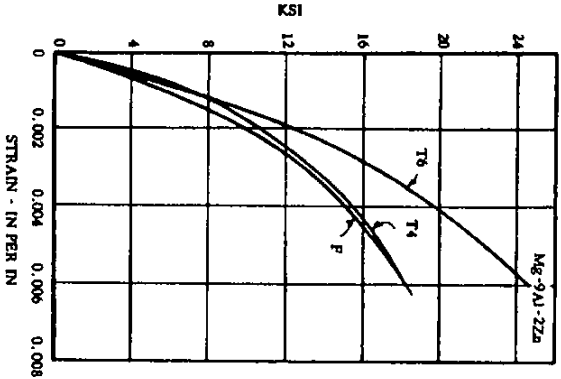


FIG. 3.025 STRESS STRAIN CURVES IN COMPRESSION AT ROOM TEMPERATURE FOR ALLOY IN F, T4 AND T6 CONDITION (11, p. 4.62-4.69)

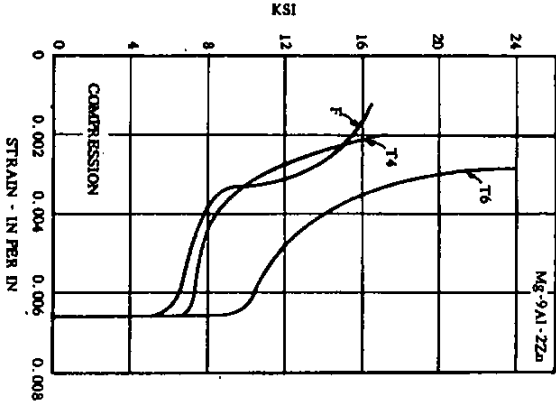


FIG. 3.027 TANGENT MODULUS CURVES IN COMPRESSION AT ROOM TEMPERATURE FOR ALLOY IN F, T4 AND T6 CONDITION (11, p. 4.62-4.69)

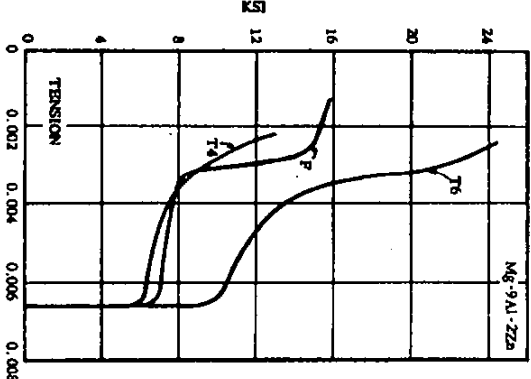


FIG. 3.026 TANGENT MODULUS CURVES IN TENSION AT ROOM TEMPERATURE FOR ALLOY IN F, T4 AND T6 CONDITION (11, p. 4.62-4.69)

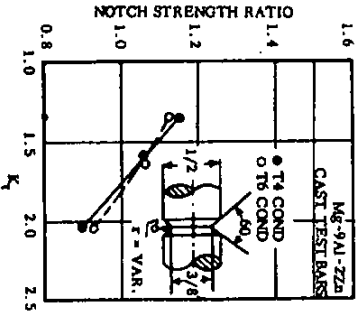


FIG. 3.028 EFFECT OF STRESS CONCENTRATION FACTOR ON ROOM TEMPERATURE NOTCH TENSILE STRENGTH RATIO OF ALLOY IN T4 AND T6 CONDITION (8, p. 185)

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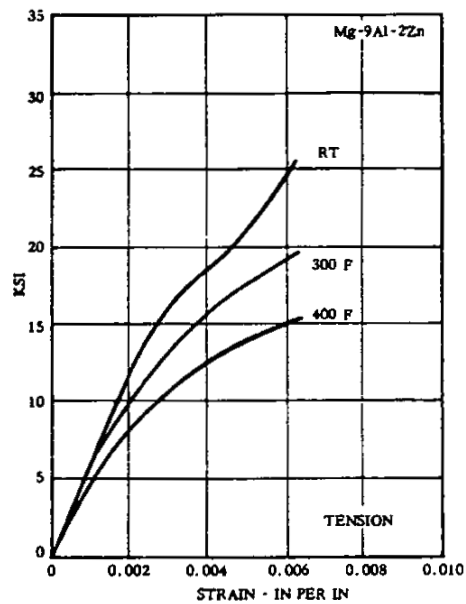


FIG. 3.0311 STRESS STRAIN CURVES AT ROOM AND ELEVATED TEMPERATURE OF ALLOY IN T6 CONDITION (11, p. 4.69-4.70)

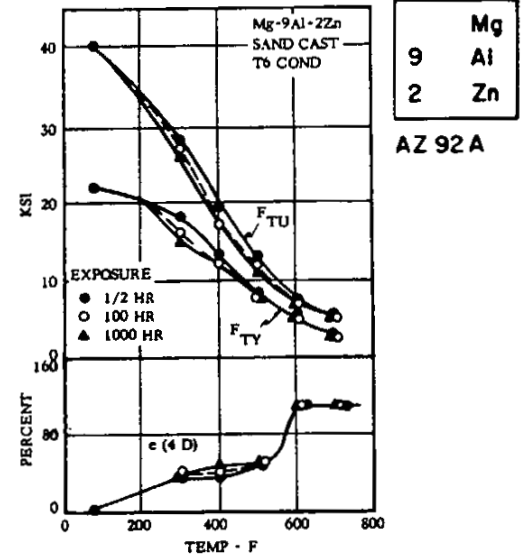


FIG. 3.0313 EFFECT OF EXPOSURE AND TEST TEMPERATURE ON TENSILE PROPERTIES OF ALLOY IN T6 CONDITION (10)

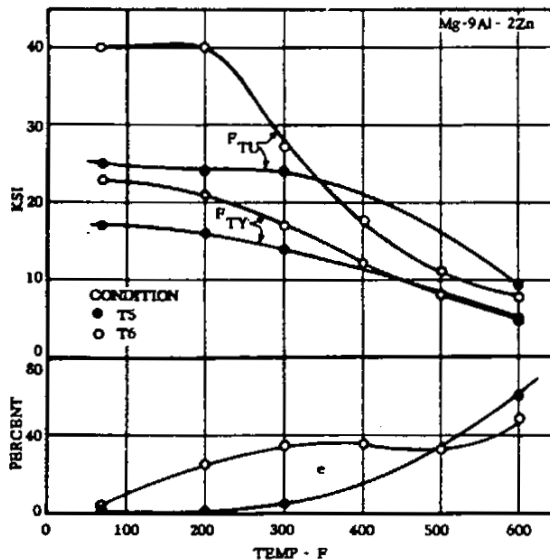


FIG. 3.0312 EFFECT OF TEST TEMPERATURE ON TENSILE PROPERTIES OF ALLOY IN T5 AND T6 CONDITION (8, p. 175)

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Mg
9 Al
2 Zn

AZ 92 A

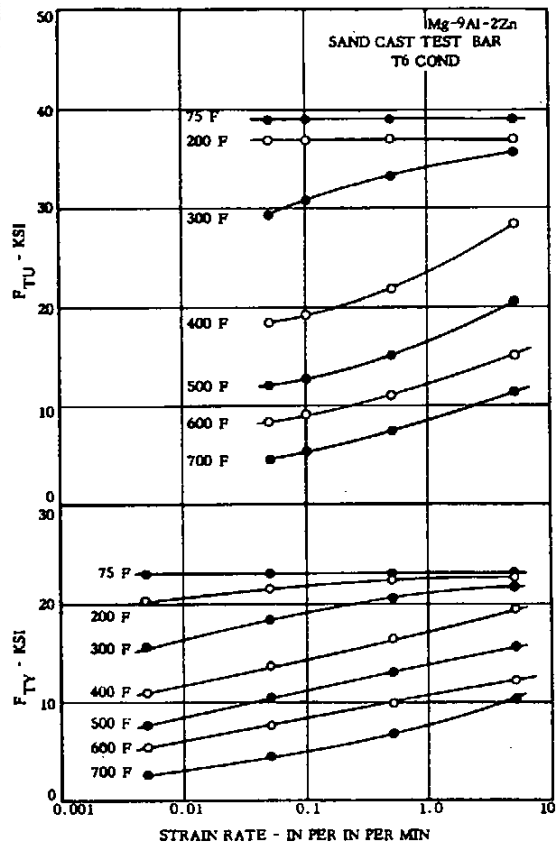


FIG. 3.0314 EFFECT OF TEST TEMPERATURE AND STRAIN RATE ON TENSILE PROPERTIES OF ALLOY IN T6 CONDITION (12, Tbl. IV)

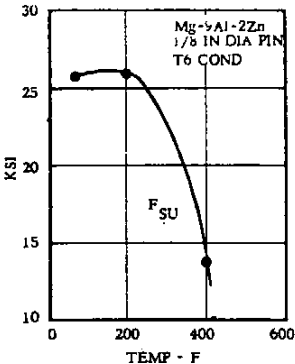


FIG. 3.0321 EFFECT OF TEST TEMPERATURE ON SHEAR STRENGTH OF ALLOY IN T6 CONDITION (13)

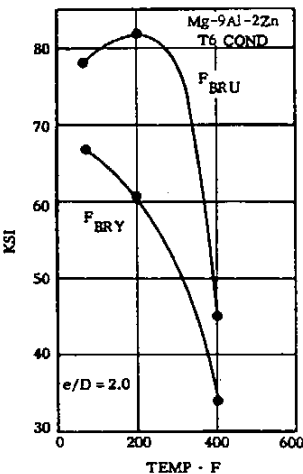


FIG. 3.0322 EFFECT OF TEST TEMPERATURE ON BEARING PROPERTIES OF ALLOY IN T6 CONDITION (13)

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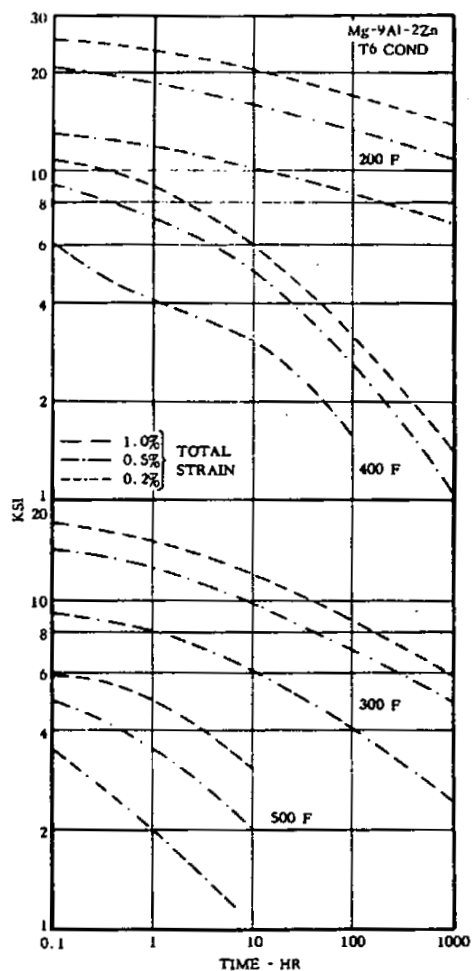


FIG. 3.041 CREEP CURVES OF ALLOY IN T6 CONDITION (8, p.183)

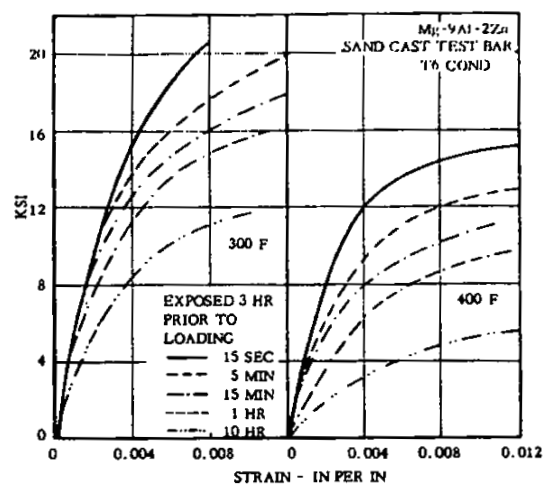


FIG. 3.042 ISOCHRONOUS STRESS STRAIN CURVES FOR ALLOY IN T6 CONDITION AT 300 AND 400 F (15)

Mg
9 Al
2 Zn

AZ 92 A

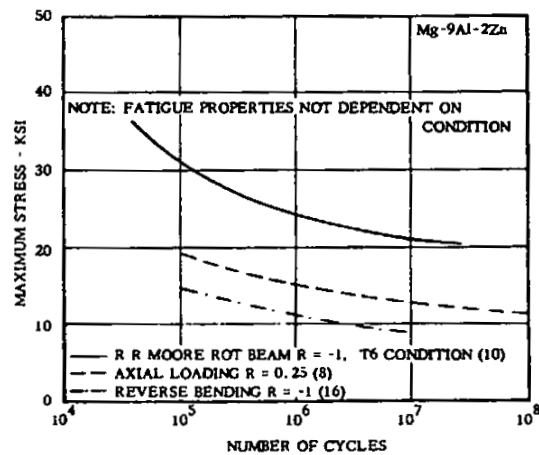


FIG. 3.051 S-N CURVES FOR FATIGUE PROPERTIES OF ALLOY (8, p.38) (10) (16)

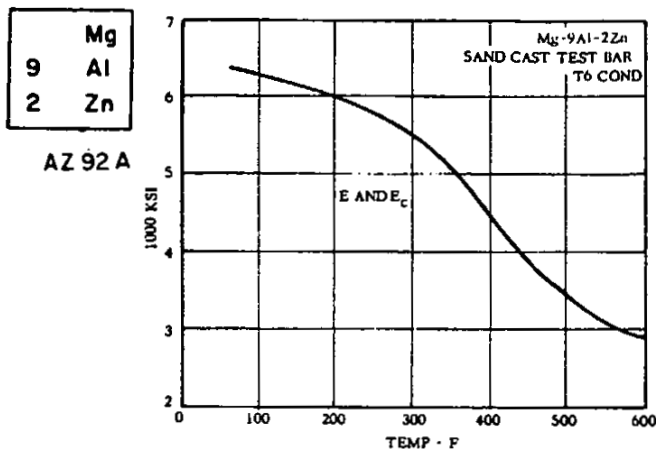


FIG. 3.061 MODULUS OF ELASTICITY AT ROOM AND ELEVATED TEMPERATURES
(11, p. 4.68)

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- 1 AMS 4434 F, (Aug. 15, 1958)
- 2 AMS 4453, (Jan. 15, 1960)
- 3 AMS 4484 E, (Jan. 15, 1959)
- 4 The Dow Chemical Co., Magnesium Department, "Heat Treating of Magnesium Sand and Permanent Mold Castings", Bulletin No. 141-35-957 (1957)
- 5 Brooks, M. E., The Dow Chemical Co., Personal Communication, (July 18, 1961)
- 6 ASM Metals Handbook, "Properties and Selection of Metals", Vol. 1, 8th Edition (1961)
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- 8 The Dow Chemical Co., Magnesium Department, "Magnesium Design", Bulletin Form No. 141-91-57, (1957)
- 9 The Dow Chemical Co., Magnesium Department, "Magnesium Alloys and Products", Bulletin Form No. 141-96-58, (1958)
- 10 Alcoa Research Laboratories, "Mechanical Properties at Various Temperatures of AZ 92 A-T6 Sand Castings", Data Sheet, (Aug. 29, 1957)
- 11 "Strength of Metal Aircraft Elements", Supply and Logistics Handbook, BNL, MIL-HDBK-5, (Dec. 30, 1958)
- 12 The Dow Chemical Co., Magnesium Technical Service and Development, "Effect of Testing Speed and Temperature on the Mechanical Properties of Some Magnesium Alloys", Letter Enclosure, Code 2.52, (June 8, 1959)
- 13 The Dow Chemical Co., Magnesium Technical Service and Development, "Shear, Bearing and Hardness Data for Cast Alloys", Letter Enclosure, Code 2.32 WB, (Feb. 11, 1957)
- 14 The Dow Chemical Co., Magnesium Technical Service and Development, "Heat Transfer Characteristics of Magnesium Alloys", Letter Enclosure, Code 2.46 HB, (Feb. 24, 1959)
- 15 The Dow Chemical Co., Magnesium Technical Service and Development, "Isochronous Stress-Strain Curves of Magnesium Casting Alloys", Letter Enclosure, Code 1.8 HB, (Oct. 31, 1958)
- 16 The Dow Chemical Co., Unpublished Data Sheet RDB/was, (May 20, 1958)

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1. **GENERAL**
EK31XA is a heat treatable magnesium alloy containing the rare earths neodymium and praseodymium (didymium) and also zirconium as hardeners. The alloy is available in the form of forgings in the T6 condition for long time service up to 450F, or for shorter periods of service at temperatures up to 550F. Up to 500F, EK31XA forgings are superior to HM21A and HK31A forgings in the T5 condition.

- 1.01 Commercial Designation
EK31XA.

- 1.02 Alternate Designation
None.

- 1.03 Specifications
None.

- 1.04 Composition
Table 1.04.

TABLE 1.04

Source	(4)		(3)
	Min	Max	Nominal
Didymium*	3.5	4.0	3.2
Zirconium	0.4	1.0	0.6
Magnesium	Balance		Balance

* Didymium, a mixture of rare earth metals, is essentially 55 percent neodymium and 15 percent praseodymium.

- 1.05 Heat Treatment
1.051 Solution treatment: 1020 to 1030F, 1 hour, hot water quench at 130 to 170F, (Ref 1).
1.052 Age solution treated material to T6 condition. Heat to 390 to 410F, hold 16 hours, (Ref 1).
1.053 Solution treat rolled rings: 1020 to 1030F, 1 to 4 hours, hot water quench at 140 to 180F, (Ref 3).
1.054 Age rolled rings to T6 condition: Heat to 390 to 410F, hold 16 to 24 hours, (Ref 3).
1.055 Protective atmospheres of SO₂ or BF₃ must be used at the solution treat temperature of 1025F, (Ref 1).

- 1.06 Hardness
1.061 At 70F: 75-81 RE
67-71 Brinell, (Ref 1).

- 1.062 This alloy has a relatively low hardenability and requires hot water quenching to develop full properties after solution treating and aging.

- 1.07 Forms and Conditions Available
1.071 Forgings are available in the full commercial range of sizes in the T6 condition.

- 1.08 Melting and Casting Practice

- 1.081 Standard melting procedures normally used for magnesium alloys are employed for EK31XA.
1.082 The alloy is not recommended for use in the form of castings.

- 1.09 Special Considerations
1.091 This alloy develops inferior properties if quenching rate (after solution treatment) is too slow.
1.092 Forgings with thin and extended sections should be avoided due to possible warping during quenching, (Ref 1).
1.093 Etchants suitable for micro-examination of forged material include Glycol, Acetic Glycol, Acetic Picral, and Phospho Picral. 20 to 30 percent acetic acid is used for macroetching.

2. **PHYSICAL AND CHEMICAL PROPERTIES**

- 2.01 Thermal Properties
2.011 Melting range.
2.012 Phase changes. Alloy is subject to precipitation.
2.013 Thermal conductivity.
At 68F: 36 Btu ft per (Hr sq ft F).
At 600F: 43 Btu ft per (Hr sq ft F), (Ref 9).
2.014 Thermal expansion.

- 2.0141 Thermal coefficient of expansion.
At 68F: 14.5×10^{-6} in per in per F, (Ref 9).

- 2.015 Specific heat.
0.25 Btu per (lb F).

- 2.02 Other Physical Properties
2.021 Density.

- 0.0646 lb per cu in
1.79 gr per cu cm.
2.022 Electrical resistivity.
At 68F: 2.83 Microhm, in
At 600F: 4.72 Microhm, in, (Ref 9).

- 2.023 Magnetic properties. Alloy is nonmagnetic.
2.024 Emissivity.
2.025 Damping capacity.

- 2.03 Chemical Properties
(See also AZ31B)

- 2.031 Corrosion resistance. This alloy is relatively free from stress corrosion cracking.
2.032 The corrosion rate of this alloy is low in the 3 percent NaCl alternate immersion test.
2.033 Reference (7) is an excellent reference on corrosion protection of magnesium alloys.

- 2.04 Nuclear Properties

- 2.041 The large nuclear cross section of rare earth elements makes this alloy unsuitable for auxiliary reactor equipment where cross section is of significance.

3. **MECHANICAL PROPERTIES**

- 3.01 Specified Mechanical Properties

- 3.02 Mechanical Properties at Room Temperature
(See also 3.03)

- 3.021 Tension.
3.0211 Typical tensile properties of forgings. Table 3.0211.

TABLE 3.0211

Source	(4)	(1)	
Alloy	EK31XA		
Form	Forgings	Forgings (a)	
Condition	T6	A	B
F _{tu} , ksi	32	45	42
F _{ty} , ksi	26	26	25
F _{cy} , ksi	-	24	22
e, percent	9	6	4

(a) Laboratory forgings, 1 inch thick disks upset from 3 inch diameter by 8 inch long extruded billet, 90 percent reduction.
A Forging temperature, 600F.
B Forging temperature, 1000F.

Mg
3 Di
0.5 Zr
EK 31 XA

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Mg

3 Di

0.5 Zr

EK 31 XA

- 3.0212 Tensile and compressive properties of die forgings and rolled rings, Table 3.0212.

TABLE 3.0212

Source	(3)					
Alloy	EK31XA					
Form	Die(b) Forgings	Rolled Rings from 12 in Ingot (a)				
Condition	T6	T6				
Direction	(b) (not given)	Tang		Axial		Radial
		A	B	A	B	A B
F _{tu} , ksi	45	46	47	47	36	43 38
F _{ty} , ksi	26	31	37	36	18	18 17
F _{cy} , ksi	24	20	22	19	20	23 21
e, percent	6	7	6	5	8	14 12

(a) Ring dimension—45 in OD by 4 in square cross section.
 (b) Die forging data is based on limited number of tests.
 A Specimens from ID, OD and surface.
 B Specimens from mid radius and center.

- 3.022 Compression, (See Tables 3.0211 and 3.0212).
 3.023 Impact.
 3.0231 Charpy V notch data for specimens from forged wheels in T6 condition, Axial = 3.0 ft lbs Tangential = 1.5 ft lbs. (Ref 1).
 3.024 Bending.
 3.025 Torsion and shear.
 3.026 Bearing.
 3.027 Stress concentration.
 3.0271 Notch properties.
 3.0272 Fracture toughness.
 3.028 Combined properties.

- 3.03 Mechanical Properties at Various Temperatures
 3.031 Tension.
 3.0311 Effect of test temperature and test direction on tensile properties of forgings, Figure 3.0311.
 3.0312 Effect of temperature on tensile properties of forgings in the T6 condition, Figure 3.0312.
 3.0313 Effect of test temperature and forging temperature on tensile properties of disk forgings, Figure 3.0313.
 3.0314 Effect of test temperature on tensile properties of die forgings, Figure 3.0314.
 3.0315 Effect of test temperature and test direction on tensile properties of rolled rings, Figure 3.0315.

- 3.032 Compression.

- 3.033 Impact.
 3.034 Bending.
 3.035 Torsion and shear.
 3.0351 Effect of test temperature and test direction on shear strength of forged wheels, Figure 3.0351.
 3.036 Bearing.
 3.0361 Effect of test temperature and test direction on bearing properties of forged wheels, Figure 3.0361.
 3.037 Stress concentration.
 3.0371 Notch properties.
 3.0372 Fracture toughness.
 3.038 Combined properties.

- 3.04 Creep and Creep Rupture Properties
 3.041 Creep and total strain data for 100 hours time at 300 to 500F for forgings, Table 3.041.

TABLE 3.041

Source	(1)									
Form	1 In Thick Disks				33 In Dia Wheel			Impeller		
Condition	T6									
Forging Temp	600F		1000F							
Test Direction					Axial (rim)		Tang (rim)		Radial (fin)	
Time, Hour	100 Hr									
Temp-F	400	500	400	500	300	400	300	400	300	400
Stress for:										
0.1 percent creep, ksi	12.2	3.7	13.0	3.5	22	12	25	13	21	13
0.2 percent total strain, ksi	10.2	3.5	9.4	3.9	12	10	12	9.4	13	8.7
0.5 percent total strain, ksi	13.5	5.9	15.0	5.6	20	14	24	15	20	15

- 3.042 Isochronous stress strain curves at 300 to 600F for forgings, Figure 3.042.

- 3.05 Fatigue Properties
 3.051 Fatigue properties of forgings, Table 3.051.

TABLE 3.051

Source	(1)									
Form	33 In Dia Wheel Forgings									
Condition	Temp F	Method	Stress Ratio		Stress Concentration	Fatigue Strength ksi at Cycles				
			A	B		10 ⁵	10 ⁶	10 ⁷	10 ⁸	
T6	RT	Rotating Beam	∞	-1	Smooth K _t = 1	17 to 21	13 to 16	11 to 13	10 to 12.5	
						27 to 33	22 to 26	20 to 23	-	
	400F	Direct Stress	0.60	0.25		23 to 28	18 to 21	16 to 19	-	

- 3.052 S-N curves for smooth bar at room and elevated temperatures, Figure 3.052.
 3.053 S-N fatigue curves for forgings at room temperatures, Figure 3.053.
 3.054 S-N fatigue curves for notched specimens from forgings tested at room temperature, Figure 3.054.
 3.055 S-N fatigue curves for forgings at room temperature and at 400F, Figure 3.055.

- 3.06 Elastic Properties
 3.061 Poisson's Ratio, 0.30, (Ref 9).
 3.062 Modulus of elasticity at room and elevated temperatures, figure 3.061.
 3.063 Modulus of rigidity, 2500 ksi. (Ref 9).

4. FABRICATION

See also AZ33A

- 4.01 Formability
 4.011 Forging. This alloy is readily forgeable in closed dies. The properties of this alloy are not particularly sensitive to forging conditions since optimum properties are obtained by solution heat treating and aging. Warping due to thermal treatment and quenching may be a problem in forgings with thin extended web sections. The alloy has also been used in the production of seamless rings for space vehicle and missile programs as stiffeners for thin walled cylinders or conical shapes. The seamless rings are made by upsetting cast stock, punching and drilling a hole for the mandrel and expanding the ring by roll forging or press forging. Rings have also been made by rolling directly from cast blanks with no upsetting. (Ref 3).
 4.012

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- 4.02 Machining and Grinding
See HK31A
- 4.03 Welding. This alloy exhibits good weldability and no postweld stress relief is required to prevent cracking.
- 4.04 Heat Treatment
Distortion on quenching should be avoided by careful design.
- 4.05 Surface Treatment
Corrosion protection by surface treatments commonly used for magnesium alloys are applicable to EK31XA except dichromate (Dow No. 7), which is not recommended. More detailed information on corrosion protection by surface treatment is given in reference (7).

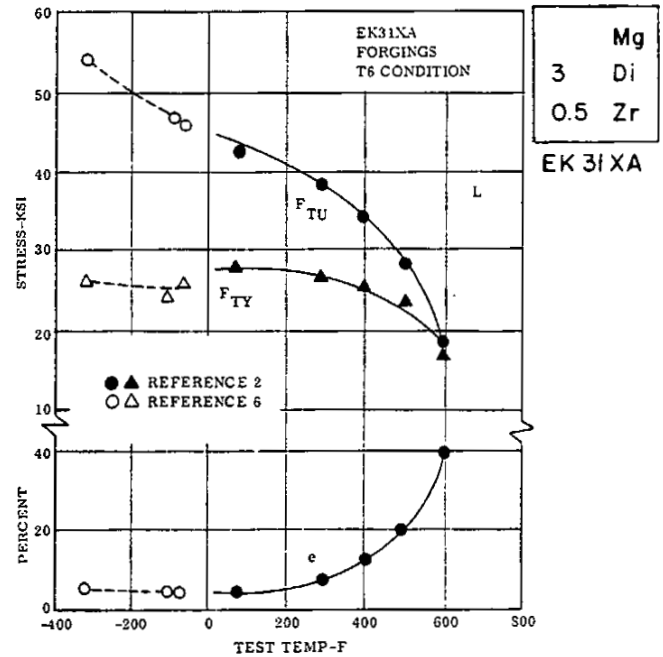


FIG. 3.0312 EFFECT OF TEMPERATURE ON TENSILE PROPERTIES OF FORGINGS IN THE T6 CONDITION.
(2)(6)

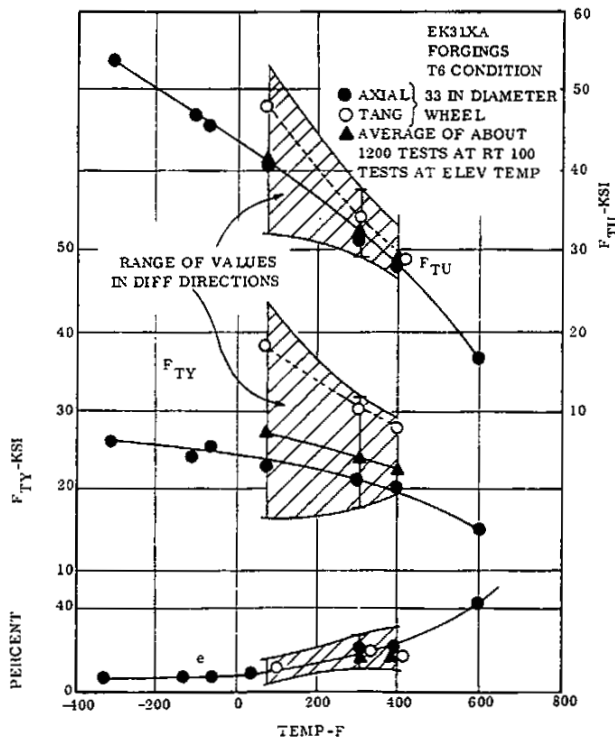


FIG. 3.0311 EFFECT OF TEST TEMPERATURE AND TEST DIRECTION ON TENSILE PROPERTIES OF FORGINGS.
(1)

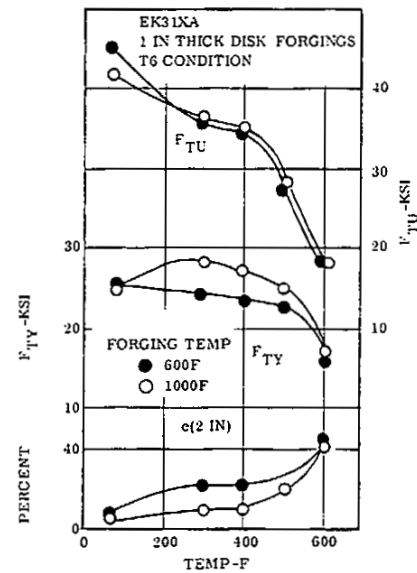


FIG. 3.0313 EFFECT OF TEST TEMPERATURE AND FORGING TEMPERATURE ON TENSILE PROPERTIES OF DISK FORGINGS.
(1)

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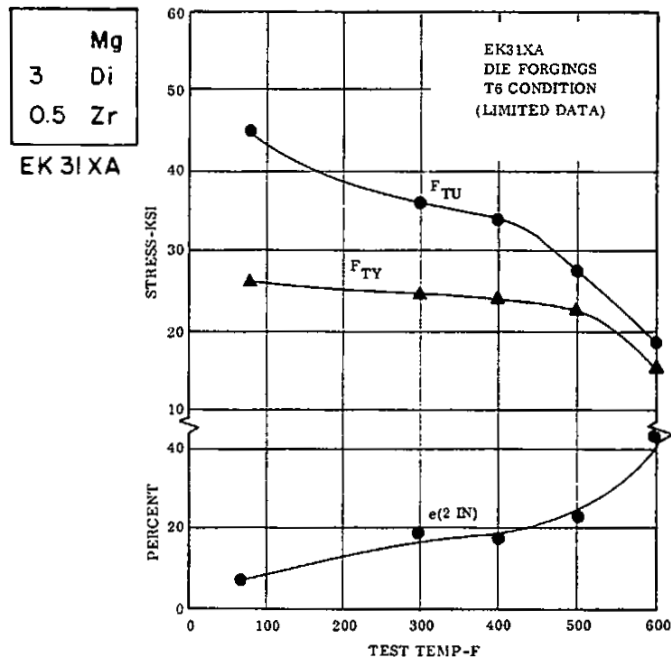


FIG. 3.0314 EFFECT OF TEST TEMPERATURE ON TENSILE PROPERTIES OF DIE FORGINGS.
(3)

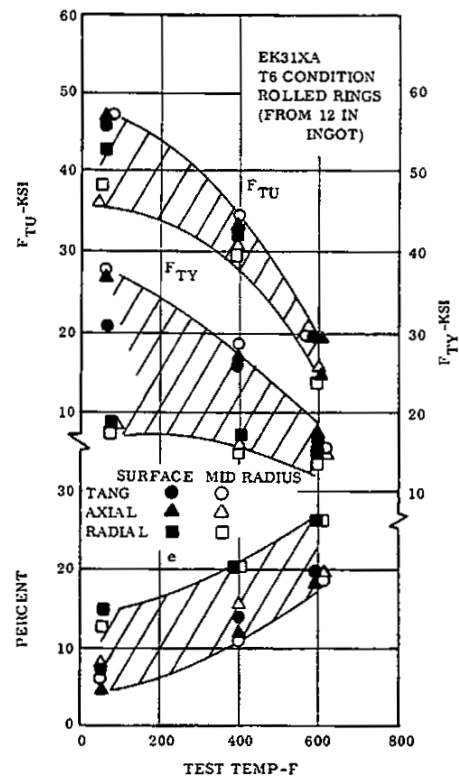


FIG. 3.0315 EFFECTS OF TEMPERATURE AND TEST DIRECTION ON TENSILE PROPERTIES OF ROLLED RINGS.
(3)

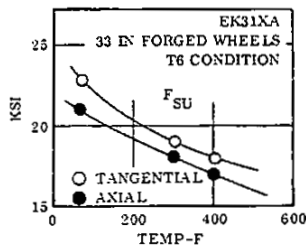


FIG. 3.0351 EFFECTS OF TEST TEMPERATURE AND TEST DIRECTION ON SHEAR STRENGTH OF FORGED WHEELS.

(1)

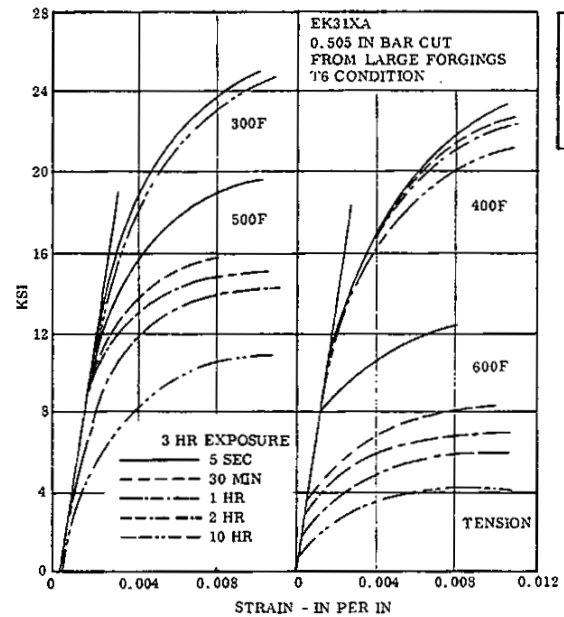


FIG. 3.042 ISOCHRONOUS STRESS STRAIN CURVES AT 300 TO 600F FOR FORGINGS.

(1)

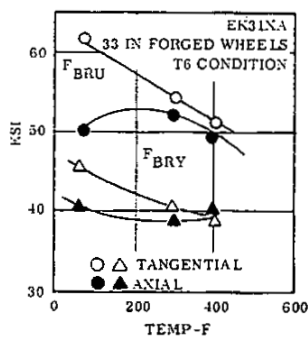


FIG. 3.0361 EFFECT OF TEST TEMPERATURE AND TEST DIRECTION ON BEARING PROPERTIES OF FORGED WHEELS.

(1)

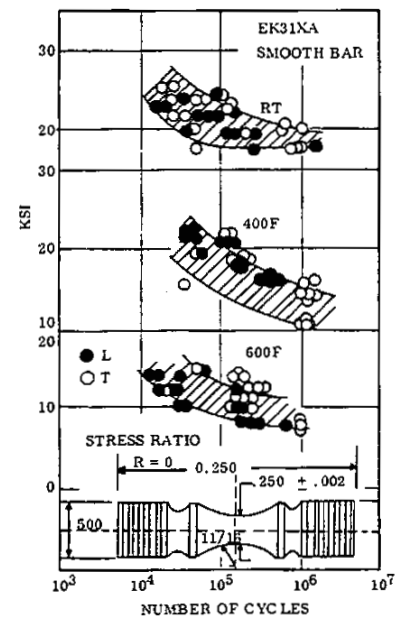


FIG. 3.052 S-N CURVES FOR SMOOTH BAR AT ROOM AND ELEVATED TEMPERATURE.

(2)

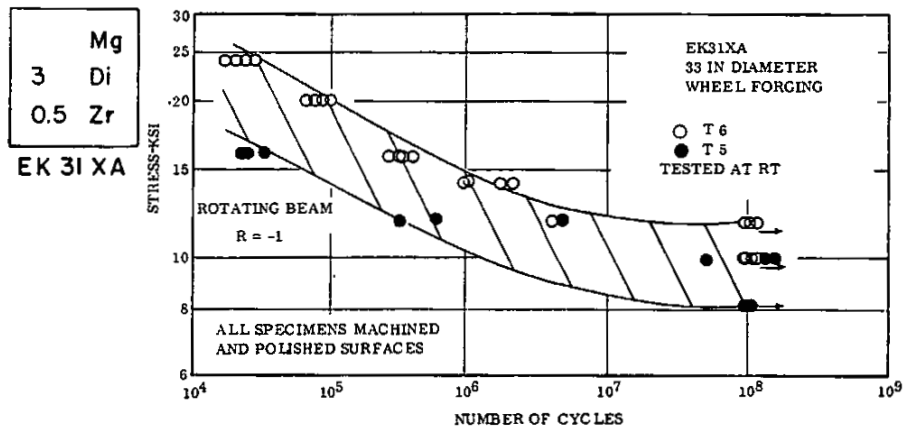


FIG. 3.053 S-N FATIGUE CURVES FOR FORGINGS AT ROOM TEMPERATURE.

(1)

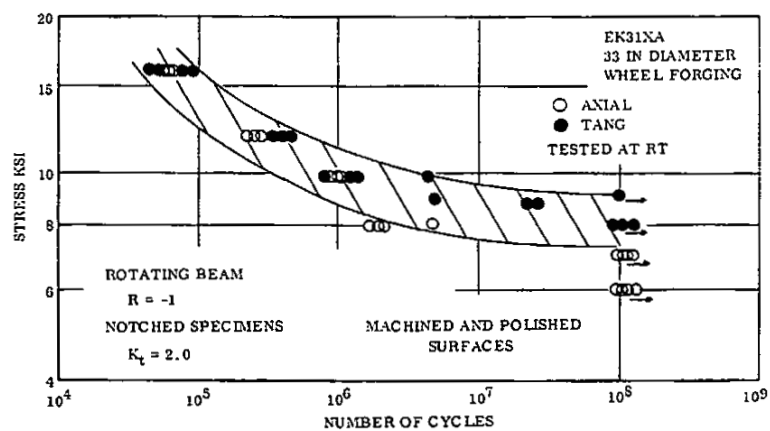


FIG. 3.054 S-N FATIGUE CURVES FOR NOTCHED SPECIMENS FROM FORGINGS TESTED AT ROOM TEMPERATURE.

(1)

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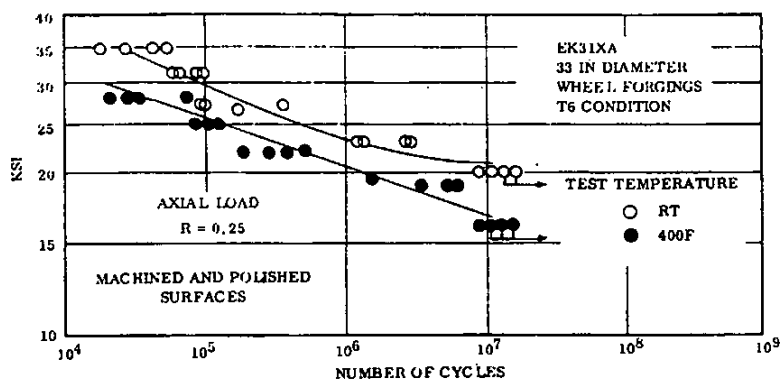


FIG. 3.055 S-N FATIGUE CURVE FOR FORGINGS AT ROOM TEMPERATURE AND 400F.

(1)

	Mg
3	Di
0.5	Zr
EK 31 X A	

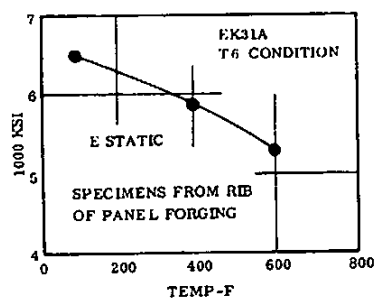


FIG. 3.061 MODULUS OF ELASTICITY AT ROOM AND ELEVATED TEMPERATURES.

(1)

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REVISED: MARCH 1968

NONFERROUS ALLOYS

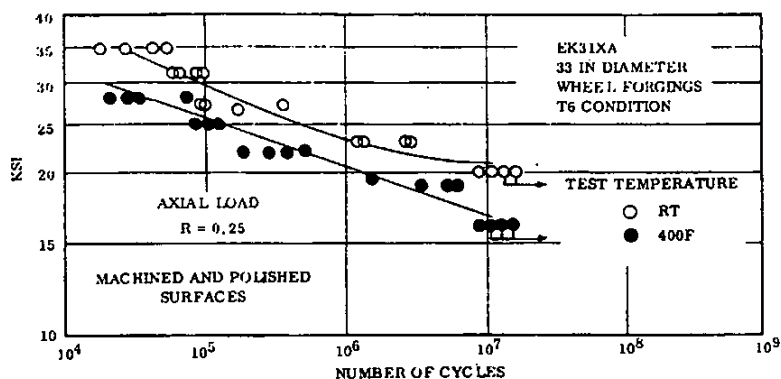


FIG. 3.055 S-N FATIGUE CURVE FOR FORGINGS AT ROOM TEMPERATURE AND 400F.

(1)

	Mg
3	Di
0.5	Zr
EK 31 X A	

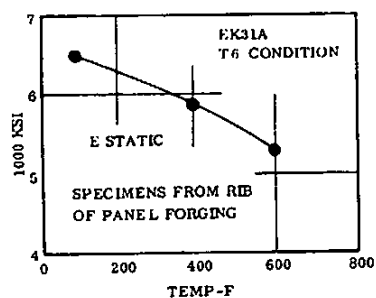


FIG. 3.061 MODULUS OF ELASTICITY AT ROOM AND ELEVATED TEMPERATURES.

(1)

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