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).

	Mg
3.0	RE
2.5	Zn
0.6	Zr

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.

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_9Ce (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: 14.7-14.8 x 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 ft^2/hr (Ref. 16).

2.2 Other Physical Properties

2.2.1 Density: 0.0665 lb/in^3, 1.84 gr/cm^3 (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 $5x10^7$ 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. $2.4x10^3$ ksi (Ref. 31).

3.6.4 Tangent Modulus.

3.6.5 Secant Modulus.

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 corrision 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.

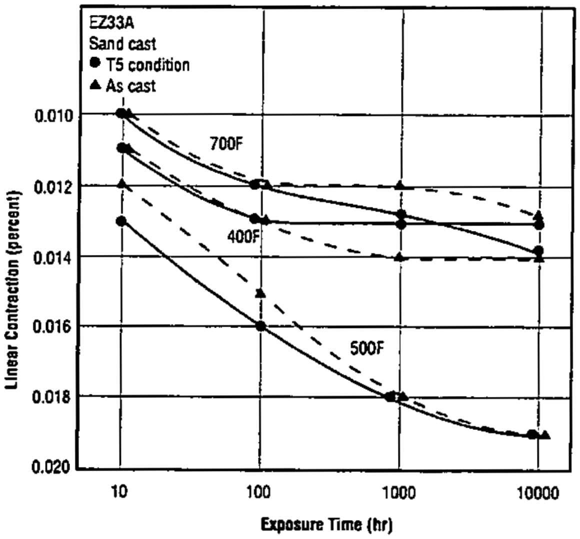

Fig. 1.9.4.1 Linear contraction in castings during long-time exposure to elevated temperatures (Refs. 28, 31)

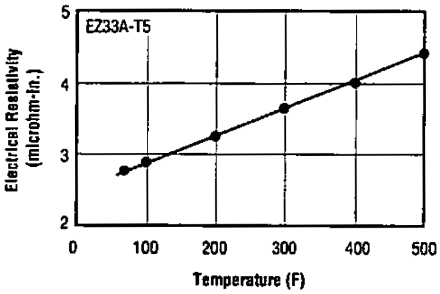

Fig. 2.2.2.1 Effect of temperatures up to 500F on electrical resistivity (Ref. 11)

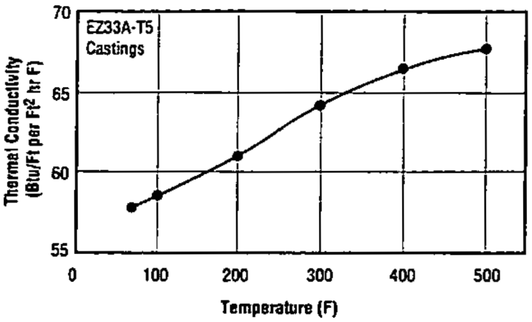

Fig. 2.1.3.1 Effect of temperatures up to 500F on thermal conductivity (Ref. 11)

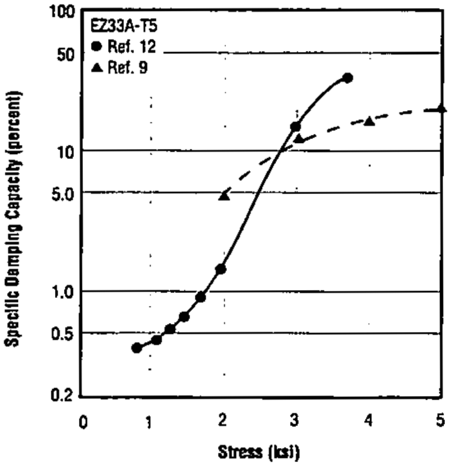

Fig. 2.2.5.1 Effect of stress on specific damping capacity (Refs. 9, 12)

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	—	—	—	—	—	—	—
		Brinell Hardness								
All sand castings		**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.

Table 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

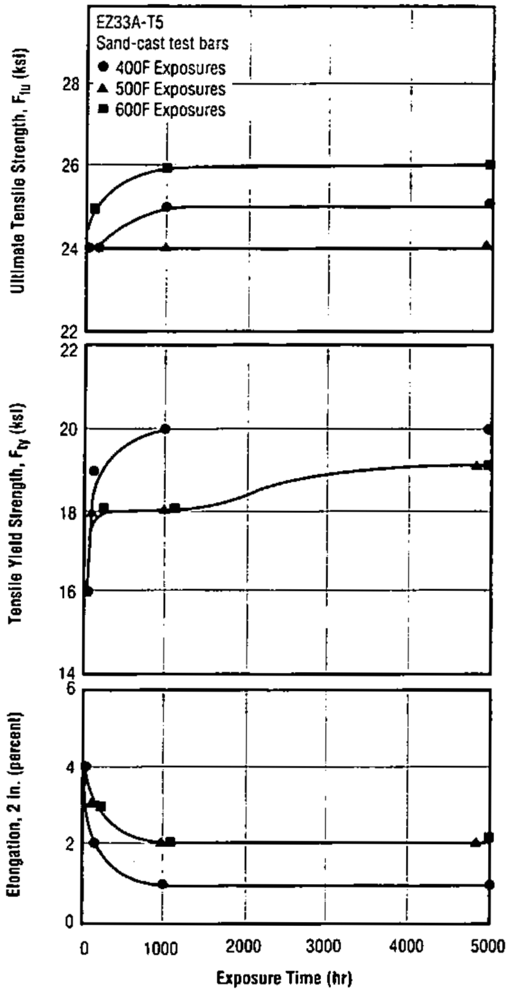

Fig. 3.2.1.4 Effects of exposure at elevated temperatures on tensile properties at room temperature (Ref. 31)

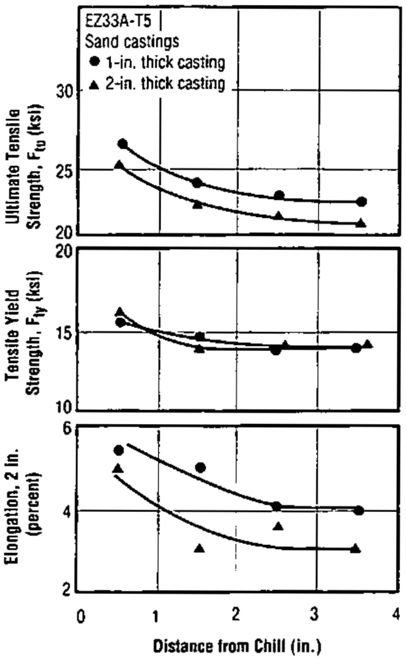

Fig. 3.2.1.5 Effects of end chill on tensile properties of sand-cast plates of two different thicknesses (Ref. 34)

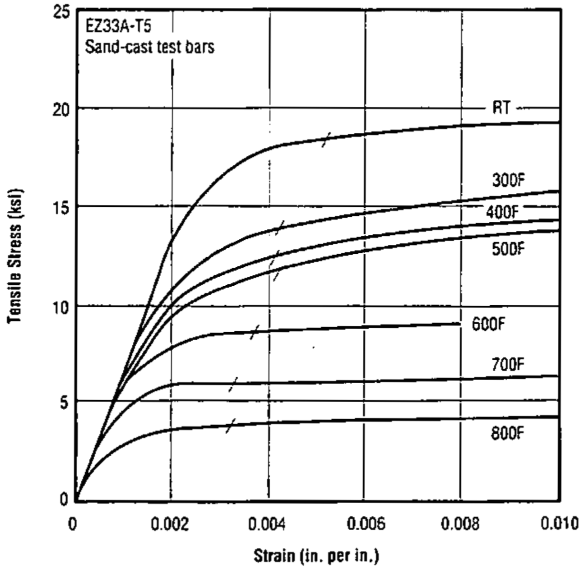

Fig. 3.3.1.1 Stress-strain curves at room and elevated temperatures (Ref. 28)

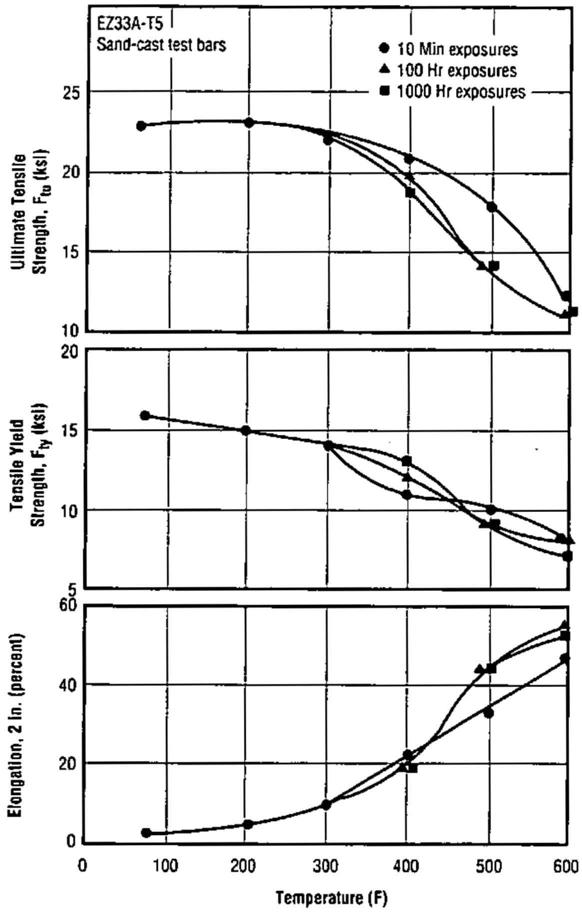

Fig. 3.3.1.2 Elevated-temperature tensile properties after various exposure times at test temperatures (Refs. 28, 31)

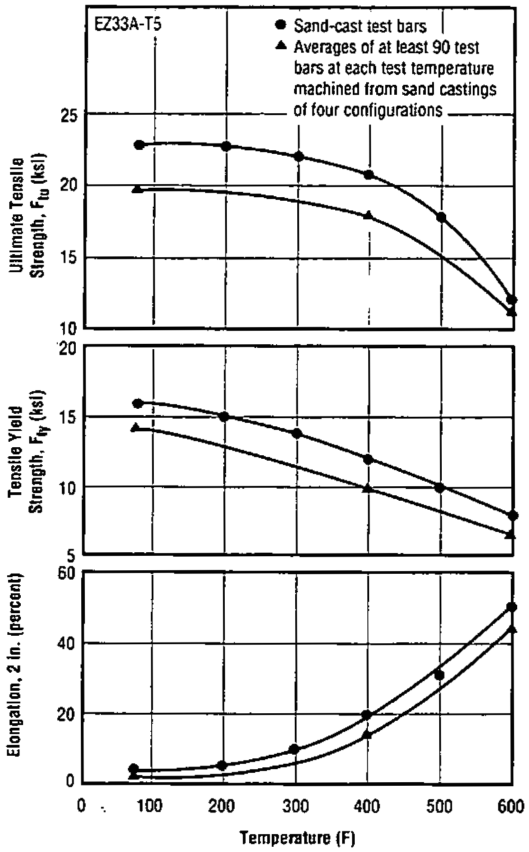

Fig. 3.3.1.3 Comparison of room- and elevated-temperature tensile properties of sand-cast test bars and production castings; holding time at elevated test temperatures was 10 minutes (Ref. 28)

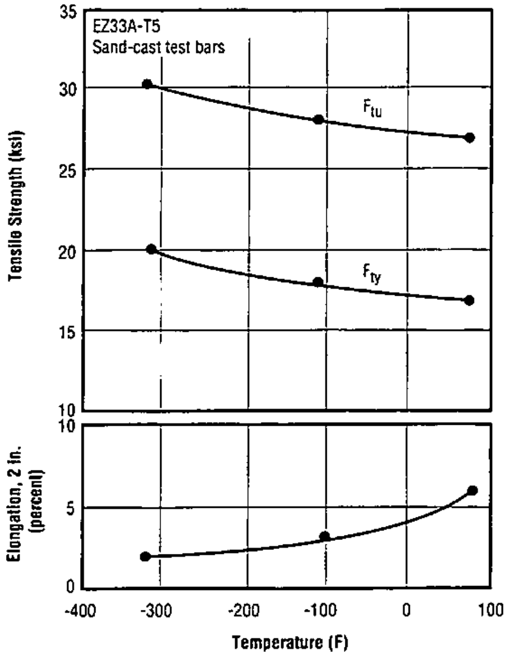

Fig. 3.3.1.4 Effect of low temperatures on tensile properties (Ref. 35)

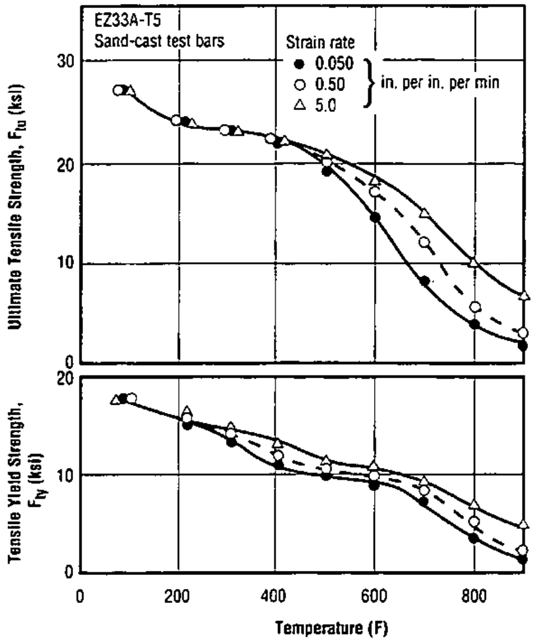

Fig. 3.3.1.5 Effect of temperature and strain rate on tensile properties (Ref. 36)

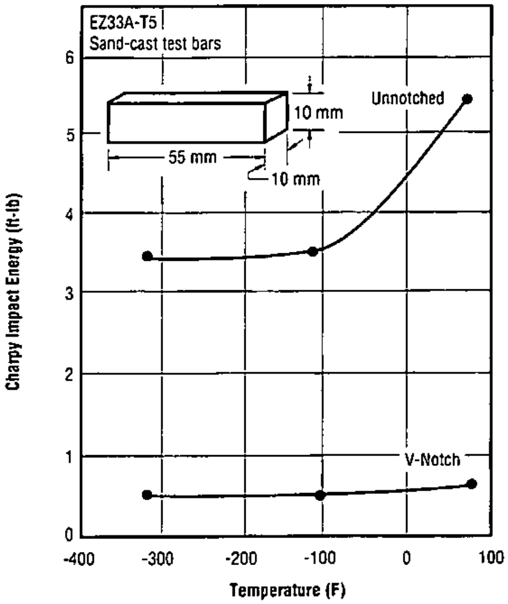

Fig. 3.3.3.1 Effect of low temperatures on Charpy impact resistance (Refs. 9, 35)

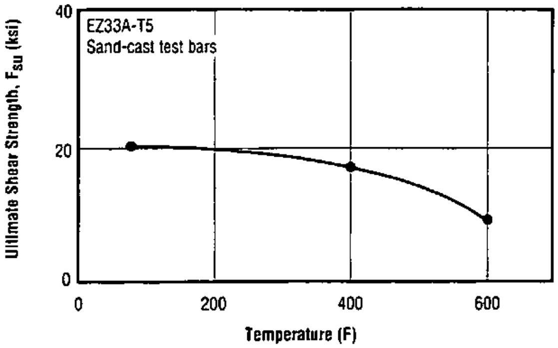

Fig. 3.3.5.1 Effect of temperature on shear strength (Ref. 37)

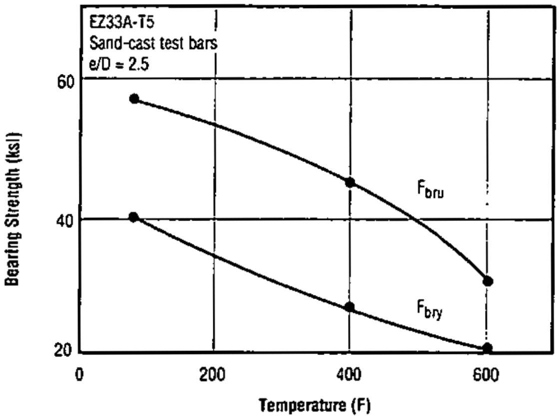

Fig. 3.3.6.1 Effect of temperature on bearing properties (Ref. 37)

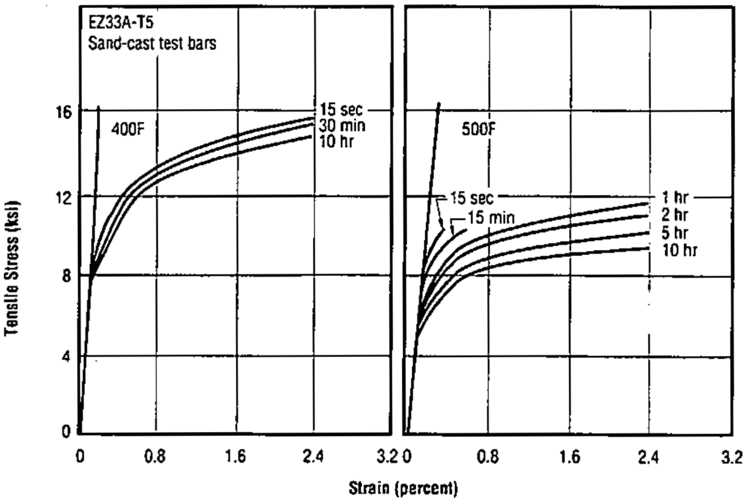

Fig. 3.4.1 Isochronous stress-strain curves at 400 and 500F (Refs. 9, 28)

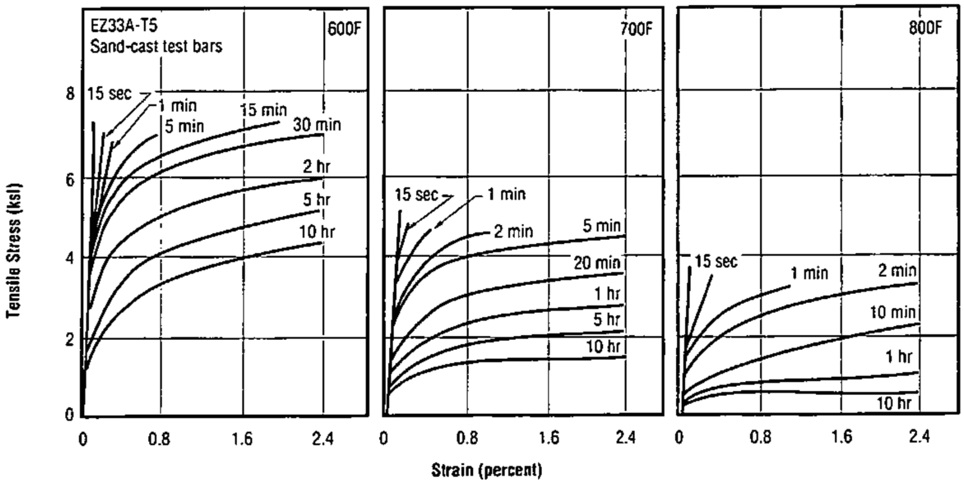

Fig. 3.4.2 Isochronous stress-strain curves at 600, 700 and 800F (Refs. 9, 28)

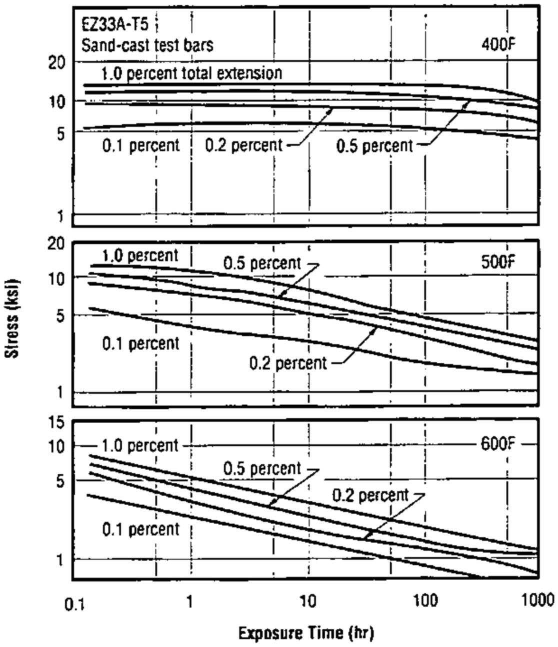

Fig. 3.4.3 Total creep strain curves (Ref. 28)

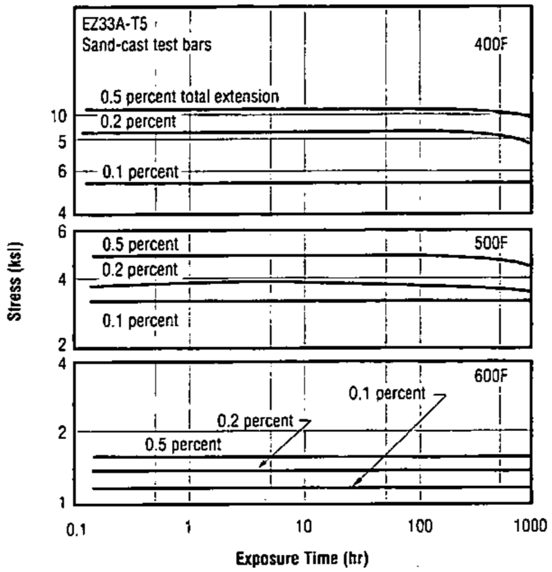

Fig. 3.4.4 Effects of exposure time at test temperature prior to loading on 100-hour creep strength (Ref. 28)

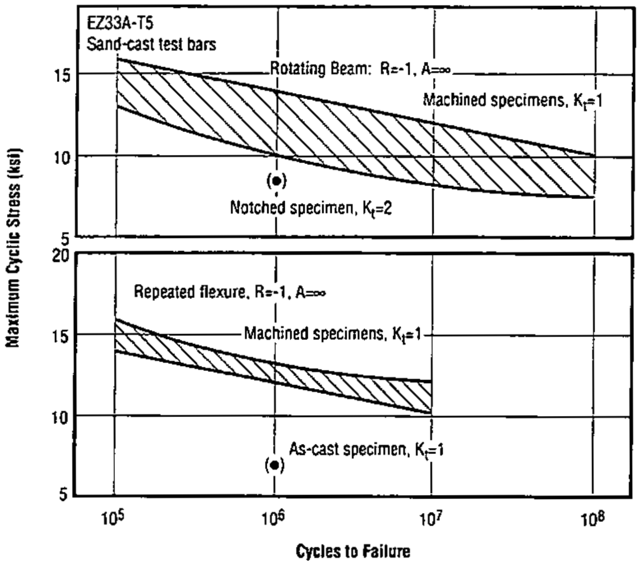

Fig. 3.5.1 Fatigue cycles to failure as a function of maximum cyclic stress for both rotating-beam and flexure specimens (Refs. 38, 39, 40)

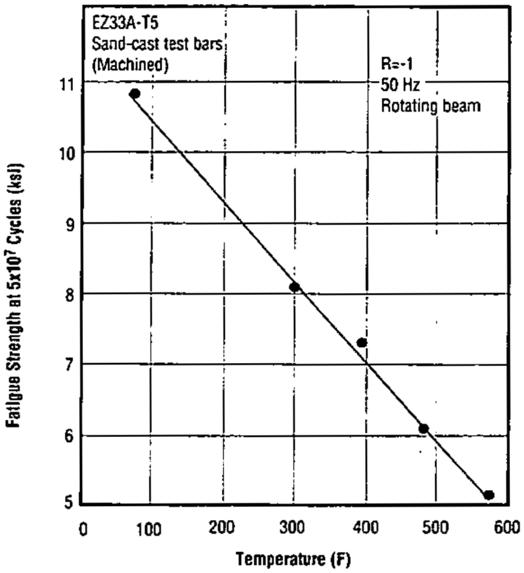

Fig. 3.5.2 Effect of elevated temperatures on fatigue strength (maximum cyclic stress) at $5x10^7$ cycles (Ref. 41)

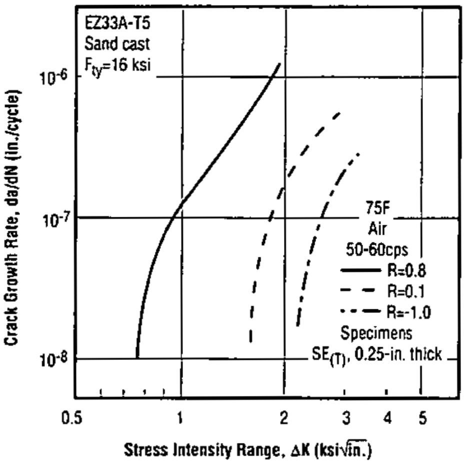

Fig. 3.5.3 Fatigue crack growth rates at three R levels (ratio of minimum to maximum cyclic stress) (Ref. 32)

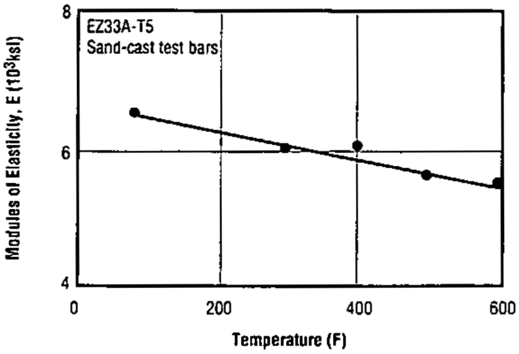

Fig. 3.6.2.1 Modulus of elasticity at room and elevated temperatures (Ref. 42)

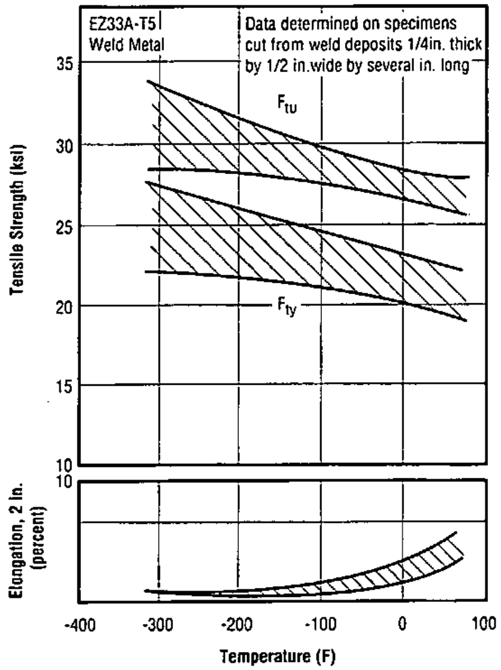

Fig. 4.3.1 Effect of low temperatures on tensile properties of weld metal deposited by GMAW process (Ref. 44)

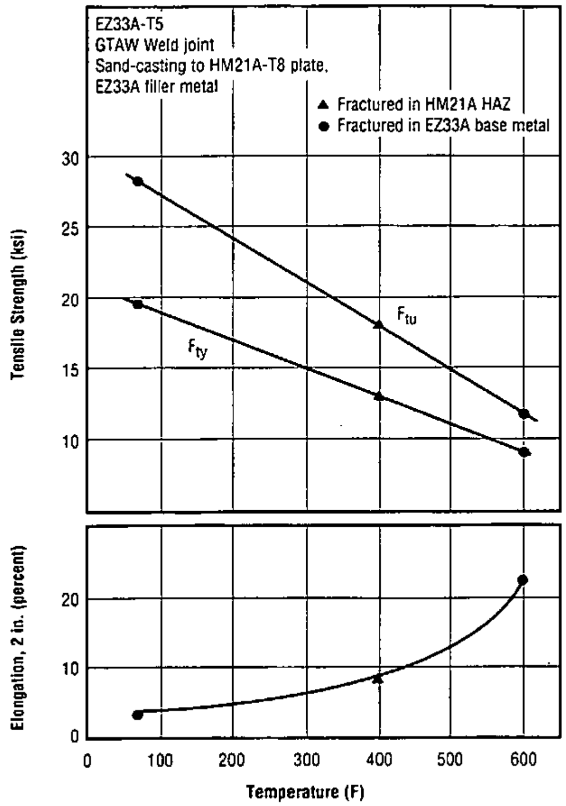

Fig. 4.3.2 Tensile properties at various temperatures of specimens containing GTAW butt weld between EZ33A-T5 sand casting and HM21A-T8 magnesium-alloy plate with EZ33A filler metal (Ref. 45)

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

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.

References

1. AMS 4442D, Society of Automotive Engineers (January 1985).
2. AMS 4396C, Society of Automotive Engineers (October 1986).
3. ASTM B 80-91, ASTM Annual Book of Standards (Vol. 2.02).
4. ASTM B 199-87, ASTM Annual Book of Standards (Vol. 2.02).
5. ASTM B 403-90, ASTM Annual Book of Standards (Vol. 2.02).
6. ASTM B 93-92, ASTM Annual Book of Standards (Vol. 2.02).
7. SAE J465, Society of Automotive Engineers.
8. ASTM B 661-91, ASTM Annual Book of Standards (Vol. 2.02).
9. ASM International Metals Handbook, Tenth Edition, Vol. 2 (1990).
10. Bethke, J. J., and Gallacio, A., "Effect of Corrosion Resistant Coatings on the Fatigue Strength of Cast Magnesium Alloys," Materials and Technology Division, Frankford Arsenal, Report No. MMT 1-77 (August 1977).
11. "Physical Properties of Magnesium and Magnesium Alloys," Dow Chemical Co., Metal Products Department, Code 2.51 (April 10, 1967).
12. "Magnesium Elektron Alloys Design," Magnesium Elektron Inc., 1270 Ave. of the Americas, NY, NY 10020.
13. "Heat Treating Sand and Permanent Mold Magnesium Castings," Dow Chemical Co., Metal Products Department, Form 141-35-68 (1968).
14. Holdeman, G. E., "Metallography in the Magnesium Foundry," *Transactions AFS* Vol. 64, pp. 698-708 (1956).
15. ASM Metals Handbook, Ninth Edition, Vol. 9, pp. 427-434 (1985).
16. "Shop Guide for Elevated-Temperature Magnesium Alloys," Dow Chemical Co., Magnesium Department, Bulletin No. 141-204 (March 1959).
17. "Heat Treatment of Sand and Permanent Mold Magnesium Casting," Dow Chemical Co. (February 1987).
18. "Arc Welding of Magnesium," Dow Chemical Co., Metal Products Dept., Form No. 141-300-67 (Revised) (1967).
19. ASM International, Metals Handbook, Tenth Edition, Vol. 4 (1991).
20. ASM Metals Handbook, Ninth Edition, Vol. 4 (1981).
21. ASM Metals Handbook, Eighth Edition, Vol. 2 (1964).
22. ASM International Metals Handbook, Ninth Edition, Vol. 13 (1987).
23. ASM Metals Handbook, Eighth Edition, Vol. 1 (1961).
24. Groshart, E., "Magnesium Part I-The Metal," *Metal Finishing* Vol. 83, pp. 17-20 (October 1985).
25. ASM Metals Handbook, Ninth Edition, Vol. 6 (1983).
26. *Recommended Practices for Sand Casting Aluminum and Magnesium Alloy*, American Foundrymen's Society, second edition, Chapter 10, pp. 63-68 (1965).
27. "Magnesium EZ33A," *Engineering Alloy Digest*, Filing Code Mg-65 (May 1968).
28. "Room- and Elevated-Temperature Properties of Magnesium Casting Alloys," Dow Chemical Co., Bulletin 141-176 (1959).
29. "Crucible Melting of Magnesium Alloys," Dow Chemical Co., Bulletin 181-27.
30. Conture, A., and Meier, J. W., "The Effects of Test Bar Variables on the Tensile Properties of Magnesium Casting Alloys," *Journal of Materials* Vol. 1 (December 1966).
31. "Magnesium Design," Dow Chemical Co., Form No. 141-91-457 (1957).
32. Liaw, P. K; Ho, T. L.; and Donald, J. K., "Near-Threshold Fatigue Crack Growth Behavior in a Magnesium Alloy," *Scripta Metallurgica* Vol. 18, pp. 821-824 (August 1984).
33. Pellegrim, C. J., "Investment-Cast Zirconium Bearing Magnesium-Base Alloys," *AFS Transactions* Vol. 70, pp. 1229-1234 (1962).
34. Lagowski, B., and Meier, J. W., "Premium Strength in Sand-Cast Magnesium Alloys," *AFS Transactions* Vol. 72, pp. 673-685 (1964).
35. Reed, R. P.; Mikesell, R. P.; and Greeson, R. L., "Some Mechanical Properties of Magnesium Alloys at Low Temperatures," ASTM STP No. 287, pp. 61-73 (1961).
36. "Effect of Testing Speed and Temperature on the Mechanical Properties of Some Magnesium Alloys," Dow Chemical Co., Metal Products Department, Code 2.52 (June 8, 1959).
37. "Shear, Bearing, and Hardness Data for Cast Alloys," Dow Chemical Co., Metal Products Department (May 20, 1958).
38. Buckelew, H. C., "Magnesium Alloy Use Cuts Aircraft Wheel Cost, Weight," *SAE Journal* Vol. 72, pp. 90-94 (April 1964).
39. "Data Sheet on Fatigue Properties," Dow Chemical Co., Metal Products Department (May 20, 1958).
40. "Alcoa Data Sheet on EZ33A-T5," Aluminum Company of America (August 29, 1957).

41. *Design*, Magnesium Elektron Ltd., 1270 Ave. of the Americas, NY, NY 10020.

42. Fenn, A. W., Jr., "Young's Modulus of Magnesium Alloys As a Function of Temperature and Metallurgical Variables," *ASTM Proceedings* Vol. 58, pp. 826-837 (1958).

43. "Machining Magnesium," booklet by Dow Chemical Co., Metal Products Department, Form No. 141-288-66 (1964).

44. Fenn, R. W., Jr., and Lockwood, L. F., "Low-Temperature Properties of Welded Magnesium Alloys," *Welding Journal* Vol. 39, pp. 352S-361S (1960).

45. "Shop Guide for Elevated-Temperature Magnesium Alloys," Dow Chemical Co., Magnesium Department, Bulletin No. 141-204 (March 1959).

46. "Brazing, Bonding, Soldering, and Special Welding of Magnesium," Dow Chemical Co., Metal Products Department, Form No. 141-313-66 (1966).