

1. General

Aluminums 356.0 and A356.0 are heat-treatable, aluminum-silicon-magnesium casting alloys whose distinctive properties are primarily determined by their high silicon content in combination with magnesium. 356.0 is the conventional cast alloy, while castings of A356.0 are classified as "premium quality," guaranteed to meet specified high levels of mechanical properties. Premium quality results from advanced foundry practices and low impurity content, particularly iron. A356.0 exhibits higher tensile strength and ductility than does the 356.0 alloy.

Both 356.0 and A356.0 possess excellent castability, pressure tightness, and resistance to hot cracking. Fluidity is moderately high and the tendency toward shrinkage is low. Resistance to corrosion by salt spray is high. Weldability is acceptable by fusion techniques if proper procedures are employed.

356.0 and A356.0 have much in common with the aluminum casting alloy A357.0. The reader is therefore referred to the detailed discussions in the A357.0 chapter in this volume (Code 3109) for helpful information on most of the subjects covered in this chapter.

1.1 Commercial Designation

356.0 (UNS A03560); A356.0 (UNS A13560);
Aluminum Alloy, Welding Wire (UNS A94008)

1.2 Alternate Designations

ASTM SG70A (356 alloy); ASTM SG70B
(A356 alloy) (Ref. 27)

1.3 Specifications

1.3.1 [Table] AMS Specifications for 356.0 and A356.0 castings and applicable welding wire.

1.4 Composition

1.4.1 General Both 356.0 and A356.0 contain 6.5% to 7.5% Si and a maximum of 0.45% Mg.

The composition of A356.0 differs from that of 356.0 in that smaller amounts of other elements (particularly Fe) are allowed, and the minimum amount of Mg is 0.25% rather than 0.20%.

1.4.2 [Table] Composition specifications for 356.0 and A356.0.

1.4.3 Effect of element contents on tensile properties.

1.4.3.1 [Table] Composition, foundry practice, heat treatment, and properties of investment-cast test plates.

1.4.3.2 [Table] Composition, foundry practice, heat treatment, and properties of sand-cast test plates.

1.4.3.3 [Figure] Effect of magnesium content on the tensile properties of shell-investment castings.

Strength increases with increasing Mg content, while elongation decreases significantly.

1.4.3.4 [Figure] Effect of magnesium content on the tensile properties of sand-composite castings.

Strength increases with increasing Mg content, with a smaller relative decrease in elongation than occurs in shell-investment castings.

1.4.3.5 [Figure] Effect of iron content on the tensile properties of shell investment castings.

Strength is optimum with an Fe content of approximately 0.15 percent. Higher Fe content is detrimental to both strength and elongation.

1.4.3.6 [Figure] Effect of iron content on the tensile properties of sand composite castings.

Strength is optimum with an Fe content of approximately 0.15 percent. Higher Fe content is detrimental to both strength and elongation.

1.4.3.7 [Table] Composition and foundry practice of as-cast plates.

1.4.3.8 [Figure] Effect of titanium content on the grain sizes and quality indices of castings in three types of molds.

Titanium is added to these alloys as a grain refiner. The *Quality index, Q* is an empirical parameter which combines the benefits of higher ultimate tensile strength, F_{tu} , and higher elongation, e , as follows (Ref. 16):

$$Q = F_{tu} + 21.8 \log(e) \quad (\text{ksi}; e \text{ in percent})$$

Ti contents from 0.15 to 0.30 percent maximize the benefits of grain refinement for all three mold types.

1.4.3.9 [Table] Composition, foundry practice, and heat treatment of low-pressure-cast test components.

1.4.3.10 [Figure] Effect of strontium content on the tensile properties of low-pressure permanent mold castings.

Sr is added to these alloys to modify the structure of the strengthening silicon particles into a more-spherical shape (Ref. 65). At least 0.020 percent Sr is needed for any noticeable effect on tensile properties.

1.4.3.11 [Figure] Effect of strontium content on impact energy absorbed by unnotched bars from low-pressure permanent mold castings.

Improvement is seen for Sr contents above 0.010 percent.

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1.4.3.12 [Figure] Effect of strontium content on the quality indices of alloy as-cast in metal and sand molds.

For metal molds, Sr contents as high as 0.040 percent produce improvements in alloy quality, with and without Ti grain refinement. For sand molds, Sr contents above 0.020 percent do not produce additional improvement.

1.5 Heat Treatment

1.5.1 Basic temper designations

1.5.2 [Table] Typical Heat Treatment

Basic temper designations, applied to cast alloys	
F	As-cast
O	Annealed to improve ductility and dimensional stability
T	Heat-treated; applied to an alloy whose strength is stable within a few weeks of heat treatment; always followed by one or more digits to indicate quenching, and aging temperatures and times; standard heat-treat designations are
T4	Solutionized and quenched
T5	Artificially aged only
T6	Solutionized, quenched, and artificially aged
T7	Solutionized, quenched, and artificially overaged
<small>Variations in thermal treatment practice are shown as the second and third digits in the standard designations (e.g. T61). There is no consistent convention for the assignment of temper designation variations except that the general practice for solution heat-treated alloys has been to assign tempers T6, T61, and T62 to an ascending order in strength (Ref. 67).</small>	

1.5.3.1 [Table] Composition, foundry practice, and heat treatment.

Modifications to these typical heat treatments may be specified by users to produce properties required for specific applications.

1.5.3.2 [Figure] Effect of solution-treatment temperature on relative tensile properties of sand and permanent mold castings.

Full solutionizing occurs at a temperature of approximately 1020 F. Solutionizing at temperatures much above 1020 F results in a rapid loss of strength and elongation.

1.5.3.3 [Figure] Effect of solution-treatment temperature on variability of tensile properties of sand and permanent mold castings.

Solution-treatment temperatures above 1030 F significantly increase variability in tensile properties.

1.5.3.4 [Figure] Effect of solution-treatment time on tensile properties of shell investment castings.

Longer solution-treatment times produce an increase in elongation without decreasing strength.

1.5.3.5 [Figure] Effect of solution-treatment time on tensile properties of sand castings.

As with shell-investment castings, longer solu-

tion-treatment times produce an optimum combination of strength and ductility. Some yield strength loss is seen for treatment times of approximately 12 hours.

1.5.3.6 [Table] Composition, foundry practice, and heat treatment of sand and permanent-mold cast test bars.

1.5.3.7 [Figure] Effect of solution-treatment time on notched tensile strength of sand and permanent mold castings.

NTS increases with increasing solution-treatment time, up to 100 to 200 hours at a temperature of 340 F.

1.5.4 Quenching.

1.5.4.1 [Figure] Effect of quench water temperature on tensile properties of shell-investment castings.

A temperature of approximately 160 F is optimum for strength. Quench water temperature has little effect on the elongation of shell-investment castings.

1.5.4.2 [Figure] Effect of quench water temperature on tensile properties of sand castings.

Quenching in RT water produces the highest strength and elongation in sand castings. Significant loss in elongation occurs with boiling water.

1.5.4.3 [Figure] Effect of quench time on notched tensile strength of sand and permanent mold castings.

Quench time is the time required to cool the casting from its solutionizing temperature to approximately the quench temperature. Quench times longer than 100 seconds result in a rapid loss of NTS.

1.5.5 Delay time at room temperature.

1.5.5.1 [Figure] Effect of delay time between quench and the start of artificial aging on tensile properties of shell investment castings.

A 1-2 day delay time improves strength without significantly degrading elongation.

1.5.5.2 [Figure] Effect of delay time between quench and the start of artificial aging on tensile properties of sand castings.

A delay of 1/2 day causes a temporary drop in yield strength and a temporary increase in elongation. Little change in tensile properties is seen for delay times longer than one day.

1.5.6 Artificial aging.

1.5.6.1 [Figure] Effect of artificial aging time at 310 F on tensile properties of shell-investment castings.

Strength increases and elongation decreases with increasing aging time. The quality index calculated from these data (see 1.4.3.8 above for formula) of shell-investment castings is a maximum for aging times between 8 and 12 hours at this temperature.

1.5.6.2 [Figure] Effect of artificial aging time at 310 F on tensile properties of sand castings.

Aging times from approximately 4 to 6 hours produce the maximum quality index for sand castings, as calculated from these data.

1.5.6.3 [Figure] Effect of longer artificial aging times at 311 F and 340 F on tensile properties of sand and permanent mold castings.

After about 15 hours of aging, strength decreases rapidly and elongation remains low. After 30 hours elongation rises while strength remains at a very low level.

1.5.6.4 [Table] Composition, foundry practice, and heat treatment.

1.5.6.5 [Figure] Configurations of tensile and Charpy impact specimens.

1.5.6.6 [Figure] Effect of longer artificial aging times at 310 F on tensile properties of permanent mold castings. In these tests, strength peaked with aging times of 30 to 100 hours.

1.5.6.7 [Figure] Effect of longer artificial aging times at 310 F on Charpy impact energy absorbed and the ultimate-to-yield tensile strength ratio of permanent- mold castings.

The drop-off in these two measures indicates a loss of elongation with aging times longer than about 2 hours, reaching a minimum after 24 hours. This is consistent with the data in Figure 1.5.6.3.

1.5.6.8 [Table] Composition, foundry practice, and heat treatment of sand-cast test bars.

1.5.6.9 [Figure] Effect of aging temperature on tensile properties of sand and permanent-mold castings.

For 4 hours of aging, a temperature of approximately 375 F produces a desirable combination of strength and elongation.

1.5.6.10 [Figure] Effect of natural aging time on notched tensile strength of sand castings.

NTS stabilizes after approximately 24 hours at RT.

1.6 Hardness

1.6.1 Quenching in boiling water followed by aging develops full hardening in all commercial sizes of castings.

1.6.2 [Table] Desirable hardness ranges.

1.6.3 Effects of aging

1.6.3.1 [Figure] Effect of artificial aging temperature on hardness of sand and permanent mold castings.

For 4 hours of aging, maximum hardness is achieved with temperatures between 350 and 400 F. No significant difference was observed between the aging behaviors of permanent mold and sand cast alloys.

1.6.3.2 [Figure] Effect of natural aging time on hardness of sand and permanent mold castings.

Hardness stabilizes after approximately 24 hours at RT, with a 40-percent increase in the T4 condition and a 4-percent decrease in the T6 condition.

1.7 Forms and Conditions Available

1.7.1 356.0 is available in sand, permanent-mold, and centrifugal castings, usually with few restrictions as to shape, size, or section thickness.

1.7.2 A356.0 is available primarily in the form of permanent-mold premium-strength structural castings. A356.0 sand castings, however, are also produced as premium-grade castings.

1.7.3 Available heat treatment conditions (Ref. 14):

Available heat treatment conditions (Ref. 14):	
Sand-cast 356.0:	F, O, T4, T51, T6, T61, T7, T71
Permanent-mold cast 356.0:	F, O, T4, T51, T6, T61, T7, T71
Sand-cast A356.0:	F, O, T4, T6, T61
Permanent-mold cast A356.0:	F, O, T4, T6, T61

1.8 Melting and Casting Practice

1.8.1 General

1.8.1.1 356.0 and A356.0 have excellent castability characteristics, such as high fluidity, low tendency to shrink during solidification, high resistance to hot cracking, and good pressure tightness. These alloys are suitable for intricate castings containing thin sections and variable thicknesses (Ref. 29). For thin sections of castings, it may be necessary to use a mold coating to increase fluidity (Ref. 28).

1.8.1.2 The 356.0 alloy can be melted and cast using conventional aluminum-alloy practices, without any special considerations.

1.8.1.3 Premium-quality castings of the A356.0 alloy are guaranteed to meet a specified high level of mechanical properties, as measured using test bars cut from specified locations within the heat-treated casting (Ref. 18). Improved casting tech-

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niques need to be employed in order to obtain these superior properties, including the following:

1. High-purity ingot, with low iron content.
2. Adequate de-gassing and proper melting.
3. Streamlined gating to avoid turbulence and aspiration of mold gases.
4. Sufficient number of risers to adequately feed the casting.
5. Liberal use of chills to control solidification rate and provide directional solidification.

Melting of premium quality ingots is normally performed in silicon-carbide crucibles (rather than in iron pots) to minimize the possibility of iron pickup. Iron skimming tools used for removing dross should be coated with a suitable refractory wash of clay or lime, or with a similar refractory sodium-silicate binder (Ref. 23).

For A356.0 castings, specific aluminum processing technologies are recommended to ensure that high-quality metal is fed to low-pressure casting stations (Ref. 55). Proper molten metal processing in the furnace and casting station produces clean, degassed, and highly-filtered metal. Once charged in the furnace, the molten metal should never cascade during the entire handling process. Metal should never be transferred out of the furnace by ladles or by normal pouring. Instead, the mold cavity should be counter-gravity poured.

1.8.1.4 [Figure] Effect of pouring temperature on grain size of 356 castings.

Pouring temperatures above 1200 F result in a rapid increase in grain size, an expected degradation in tensile strength, and an expected increase in elongation.

1.8.1.5 Fluxing procedures for premium quality castings are essentially the same as those used in normal aluminum melting practice (Ref. 26).

1.8.2 Filtering of molten metal.

1.8.2.1 [Figure] Schematic elevation view showing a typical installation of a ceramic filter in a mold.

Filtering of the melt to remove impurities is one of the special foundry practices necessary for the production of premium-quality castings.

1.8.2.2 [Figure] Effect of filtering on tensile properties of sand and metal mold castings.

Some benefits were found in all cases, with the most significant being an increase in elongation when the ingot contained foundry returns, with a higher probability of impurities.

1.8.2.3 [Table] Composition, foundry practice, and heat treatment of sand-cast test bars.

1.8.2.4 [Figure] Effect of filtering on variability of

tensile properties of sand mold castings.

Filtering significantly reduces the variability in strength within a large population of tests, down to coefficients of variation from 2.3 to 3.6 percent. (COV = standard deviation / mean). Standard deviations in elongation were reduced approximately 0.5 percent in absolute value by filtering.

1.8.3 Strip casting.

1.8.3.1 [Figure] Schematic configuration of horizontal twin-roll strip caster.

Strip casting can produce a refinement in the structure of an alloy by increasing the cooling rate, with potential benefits to both strength and ductility (Ref. 43).

1.8.3.2 [Table] Composition, foundry practice, and heat treatment of strip-cast sheet.

1.8.3.3 [Figure] Effect of roll speed and contact angle on tensile properties of strip castings.

Strength and elongation were relatively constant for roll speeds below 5 rpm and dropped significantly at higher roll speeds. (No roll diameter given in Ref. 43). After 4 hours of aging, tensile properties of strip castings were approximately equal to those of conventional sand castings (Fig. 1.5.6.2).

1.9 Special Considerations

A detailed discussion of special melting and casting procedures required for producing premium quality parts is given in Ref. 66.

2 Physical Properties and Environmental Effects

2.1 Thermal Properties

2.1.1 Melting ranges

356.0 Alloy	1035 F to 1135 F
A356.0 Alloy	1035 F to 1130 F

2.1.2 Phase changes: 356.0 and A356.0 alloys are subject to precipitation.

2.1.3 [Table] Thermal conductivity

2.1.4 [Figure] Mean coefficient of thermal expansion of 356 castings.

2.1.5 Specific heat: 0.23 Btu/lb/F at 212 F (Ref. 15)

2.1.6 Thermal diffusivity.

2.2 Other Physical Properties

2.2.1 Density: 0.097 lb/in.³ (2.68 g/cm³).

2.2.2 Electrical properties.

2.2.2.1 [Table] Electrical resistivity and conductivity.

- 2.2.2.2 Electrical conductivity: See Table 2.2.2.1.
- 2.2.3 Magnetic properties: Alloys are non-magnetic.
- 2.2.4 Emittance: 0.035 to 0.070 at 77 F in air (Ref. 15).
- 2.2.5 Damping capacity.
- 2.3 Chemical Environments**
- 2.3.1 General corrosion. The general corrosion and atmospheric weathering resistances of 356.0 and A356.0 are very good, being comparable to the resistances of pure aluminum. These alloys may be used in industrial and seacoast environments without protection (Ref. 20). They also exhibit excellent resistance to stress-corrosion cracking.
- 2.3.2 Electrolytic solution potential of 356.0-T6 (solution: 53 g NaCl + 3 g H₂O₂) versus N/10 Calomel Electrode: 0.82 v (Ref. 14).
- 2.3.3 These alloys are subject to corrosion when exposed to hydrazine or UDMH (unsymmetrical dimethyl hydrazine) in the presence of moisture. Initial corrosive attack is very severe, after which the rate of attack is reduced because of a gradual build-up of a passive film. Passivation in a 30-percent solution of UDMH for 2 hours at 170-180 F renders the surfaces resistant to attack by diluted UDMH at room temperature. Resistance is also obtained by sulfuric acid anodizing and, to a lesser extent, by chromic acid anodizing (Ref. 22).
- 2.3.4 Effect of sea water on fatigue resistance: See Figure 3.5.15.
- 2.4 Nuclear Environments**
- 2.4.1 [Table] Effect of neutron radiation on tensile properties of cast test bars.
- 2.4.2 [Table] Effect of nuclear radiation at -420 F on tensile properties at -420 F.
- 2.4.3 [Figure] Typical effect of nuclear radiation at -420 F on room-temperature stress-strain curves of cast plates.
- 2.4.4 [Table] Effect of neutron radiation on tensile properties of A356.0 castings.

3 Mechanical Properties

3.1 Specified Mechanical Properties

- 3.1.1 [Table] AMS specifications for mechanical properties.
- 3.1.2 [Table] MIL-A-2118B specified tensile properties for specimens cut from castings of A356.0.

3.2 Mechanical Properties at Room Temperature

- 3.2.1 Tension-stress-strain diagrams-tension properties.
- 3.2.1.1 [Table] Composition, foundry practice, and heat treatment of investment-cast test bars.

3.2.1.2 [Table] Composition, foundry practice, and heat treatment of sand-cast test bars.

3.2.1.3 [Figure] Monotonic and cyclic tensile stress-strain curves for shell investment and sand castings.

A356.0 is a cyclic strain-hardening alloy. Stresses are the maximum measured during axial fatigue testing with an R-ratio of -1 (fully reversed) at approximately half-life. Sand castings, starting from a lower monotonic strength, hardened to the same strength as the shell-investment castings.

3.2.1.4 [Figure] Effect of dendrite arm spacing on tensile properties of shell investment and sand castings.

Dendrite arm spacings less than 0.0020 inch characterize an alloy with both higher strength and higher elongation.

3.2.1.5 [Table] Composition, foundry practice, and heat treatment of sand-cast test plates.

3.2.1.6 [Figure] Configuration of the Aluminum Association sand-cast test plates.

3.2.1.7 [Figure] Effect of dendrite arm spacing on tensile properties of sand cast test plates from at least six commercial foundries.

These round-robin tests by the Aluminum Association define the expected range of properties of sand casting components produced by a variety of commercial foundries in various thicknesses and distances from chills.

3.2.1.8 [Figure] Effect of dendrite arm spacing on tensile properties of sand-cast components from a commercial foundry following normal and modified melt processes.

These data illustrate the improvements in the properties of sand-cast components that can be achieved by a foundry through the development of special melting practices and the addition of custom-designed chills. Comparison is made with the Aluminum Association average properties shown in Figure 3.2.1.7.

3.2.1.9 [Table] Composition, foundry practice, and heat treatment of sand-cast automotive engine components.

3.2.1.10 [Figure] Effect of dendrite arm spacing on tensile properties of automotive engine component sand castings from a commercial foundry following conventional and improved low-pressure processes.

This improved low-pressure process described in Reference 55 uses heat-absorbing chill plates engineered and strategically located in the mold to promote rapid freezing and directional solidi-

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fication. Casting soundness and microstructure are thereby improved. See also 1.8.1.3 for recommended casting processes. Significant improvements are demonstrated in the tensile properties of sand-cast components, compared with the Aluminum Association average properties shown in Figure 3.2.1.7.

3.2.1.11 [Table] Composition, foundry practice, and heat treatment of permanent-mold cast test plates.

3.2.1.12 [Figure] Configuration of the Aluminum Association permanent-mold cast test plates.

3.2.1.13 [Figure] Effect of dendrite arm spacing on tensile properties of permanent-mold cast test plates of 356.0 alloy from seven commercial foundries.

These round-robin tests by the Aluminum Association define the expected range of properties of components cast in permanent molds produced by a variety of commercial foundries in various thicknesses and distances from chills.

3.2.1.14 [Figure] Effect of exposure to elevated temperature on room temperature tensile properties of sand-cast test bars in T51 condition.

Exposure to temperatures above 300 F can cause a significant loss of strength and a gain in elongation, depending on the exposure time.

3.2.1.15 [Figure] Effect of exposure to elevated temperature on room temperature tensile properties of sand-cast test bars in T7 condition.

Exposure to temperatures above 250 F can cause a significant loss of strength and a gain in elongation, depending on the exposure time.

3.2.1.16 [Table] Composition, foundry practice, and heat treatment of directionally-solidified ingots.

3.2.1.17 [Figure] Effect of cooling rate and heat treatment on tensile properties of specimens cut from directionally-solidified water-chilled ingots. As expected, properties near the chill, where dendrite cell sizes are smallest, are superior to those farther from the chill.

3.2.2 Compression - stress-strain diagrams - compression properties.

3.2.2.1 [Table] Compression, shear, and bearing properties of 356.0 and A356.0.

3.2.3 Impact: See Figures 1.4.3.11 and 1.5.6.7.

3.2.4 Bending.

3.2.5 Torsion and shear: See Table 3.2.2.1 and Figure 1.5.6.10.

3.2.6 Bearing: See Table 3.2.2.1.

Stress concentrations.

3.2.7.1 Notch properties: See Table 2.4.2.

3.2.7.2 Fracture toughness

3.2.7.2.1 [Figure] Configurations of compact tensile (CT) specimens for fracture toughness and crack propagation tests.

3.2.7.2.2 [Figure] Effect of thickness on fracture toughness of compact tensile (CT) specimens from unchilled shell-investment and water-chilled sand castings.

Projection to a thickness of 1.3 inch is required for the tougher water-chilled sand-cast material, following the trend of the shell-investment material.

3.2.7.2.3 [Figure] Effect of dendrite arm spacing on plane-strain fracture toughness projected from K_{IC} test data for unchilled shell-investment and water-chilled sand castings.

Reducing dendrite arm spacing 0.0020 inch by rapid solidification increases fracture toughness by approximately 20 percent.

3.2.7.2.4 [Figure] Configurations of compact tensile (CT) and short rod (SR) specimens cut from directionally-solidified ingots for fracture toughness tests.

3.2.7.2.5 [Figure] Effect of cooling rate on fracture toughness of specimens cut from directionally-solidified water-chilled ingots.

Again, reducing dendrite cell size by rapid solidification increases fracture toughness.

3.2.8 Combined properties.

3.3 Mechanical Properties at Various Temperatures

3.3.1 Tension - stress-strain diagrams - tension properties

3.3.1.1 [Figure] Monotonic stress-strain curves for permanent-mold cast test bars at various temperatures after an exposure time of one hour.

3.3.1.2 [Figure] Effect of elevated temperature exposure on the tensile properties of sand and permanent-mold cast test bars.

In addition to these data, it was found that after exposure to temperatures above 400 F the properties of as-cast and heat-treated materials were similar.

3.3.1.3 [Figure] Classification of fracture appearance of tensile test specimens from sand and permanent-mold cast test bars after exposure and testing at elevated temperature.

3.3.1.4 [Figure] Effect of exposure and testing at elevated temperature on tensile properties of sand cast test bars in T51 condition.

3.3.1.5 [Figure] Effect of exposure and testing at elevated temperature on tensile properties of sand cast test bars in T6 condition.

3.3.1.6 [Figure] Effect of exposure and testing at elevated temperature on tensile properties of sand cast test bars in T7 condition.

3.3.1.7 [Figure] Effect of exposure and testing at elevated temperature on tensile properties of sand cast test bars in T61 condition.

3.3.1.8 [Figure] Effect of exposure and testing at elevated temperature on tensile properties of sand cast test bars in T6 and T7 conditions.

3.3.1.9 [Figure] Effect of low test temperature on tensile properties of permanent-mold cast test bars in T6 condition.

3.3.2 Compression

3.3.3 Impact.

3.3.4 Bending.

3.3.5 Torsion and shear.

3.3.6 Bearing.

3.3.7 Stress concentration.

3.3.8 Combined properties.

3.4 Creep and Creep-Rupture Properties

3.4.1 [Figure] Creep and creep-rupture curves from room temperature to 400 F for sand castings in T7 condition.

3.4.2 [Figure] Creep and creep-rupture curves at 300 F for permanent-mold castings in T61 condition.

3.5 Fatigue Properties

3.5.1 Conventional high-cycle fatigue.

3.5.1.1 [Table] Composition, foundry practice, and heat treatment of sand- and permanent-mold fatigue test bars.

3.5.1.2 [Figure] Configuration of CO₂ sand mold for casting cantilever specimens tested in rotating bending fatigue in Ono- and Krause-type machines.

3.5.1.3 [Figure] Effect of dendrite arm spacing on high-cycle fatigue strength at 10⁷ cycles to failure.

Decreasing dendrite arm spacing by rapid cooling of the casting significantly increases long-life fatigue strength.

3.5.1.4 [Table] Composition, heat treatment, and tensile properties of sand cast plates for fatigue test specimens.

3.5.1.5 [Figure] Effect of exposure to ASTM artificial sea water on S-N curves for smooth specimens from sand cast plates.

Exposure times longer than 10 hours can significantly degrade long-life fatigue strength, by more than 50 percent for very long exposures and very

long lives.

3.5.1.6 [Table] Characteristics of fatigue test materials.

3.5.1.7 [Figure] Effect of casting method on stress-fatigue life curves for smooth specimens from die-cast wheels and from direct-chill cast billets, with and without extrusion.

The larger elongation and smaller porosity produced by direct-chill casting and extended further by extrusion result in a significant increase in fatigue strength at all lives.

3.5.2 Low-cycle fatigue.

3.5.2.1 [Figure] Configurations of specimens for tensile and axial-fatigue tests of shell-investment and of water-chilled sand castings.

3.5.2.2 [Figure] Strain-fatigue life curves for smooth axial fatigue specimens from three shell-investment castings poured at different mold temperatures.

The test data shown in Figure 3.2.1.3 and Figures 3.5.2.2 to 3.5.3.2 were produced during a comprehensive round-robin research program conducted by the Society of Automotive Engineers Fatigue Design and Evaluation (SAEFDE) committee, with participation by six companies and the University of Iowa.

3.5.2.3 [Figure] Composite of strain-fatigue life curves for smooth axial fatigue specimens from three castings cooled at different rates, showing mean fatigue strength and mean-minus-2 standard deviations fatigue strength.

The latter is approximately 20 percent lower than the mean strength expressed in terms of maximum strain.

3.5.2.4 [Figure] Comparison of strain-fatigue life curves for smooth axial fatigue specimens from unchilled shell-investment castings and water-chilled sand castings.

Strain-cycling fatigue strength is also significantly increased by rapid solidification which reduces dendrite arm spacing and increases elongation.

3.5.2.5 [Figure] Effect of dendrite arm spacing on axial strain-cycling fatigue strength at 10⁷ cycles to failure of smooth specimens from unchilled shell-investment castings and water-chilled sand castings.

Reducing dendrite arm spacing significantly increases long-life strength in strain-cycling fatigue, as was shown earlier for stress-cycling fatigue (see Fig. 3.5.1.3).

3.5.2.6 [Figure] Effect of tensile elongation on axial strain-cycling fatigue strength at 10⁷ cycles to fail-

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ure of smooth specimens from unchilled shell-investment castings and water-chilled sand castings.

Low-cycle fatigue strength increases rapidly with increasing tensile elongation.

3.5.2.7 [Figure] Effect of mean strain on axial strain-fatigue life behavior of smooth specimens from shell-investment castings.

Compared to strain-cycling fatigue life with zero mean strain (R-ratio = -1) tensile mean strains reduce fatigue life while compressive mean strains increase it, with relatively larger effects at longer lives.

3.5.3 Fatigue-crack propagation.

3.5.3.1 [Figure] Scatter bands of fatigue-crack growth rates at two R-ratios for CT specimens from three shell-investment castings and one water-chilled sand casting, containing data from several laboratories.

No consistent differences were found between the crack growth rates for the two types of castings.

3.5.3.2 [Figure] Effect of dendrite arm spacing on crack-propagation threshold stress intensity at two R-ratios and on projected plane-strain fracture toughness of shell-investment and water-chilled sand castings. Differences in threshold stress intensity are consistent with differences in fracture toughness, when analyzed on the basis of dendrite arm spacing.

3.6 Elastic Properties

3.6.1 Poisson's ratio: 0.33 (Ref. 15).

3.6.2 [Figure] Modulus of elasticity at various temperatures.

3.6.3 [Figure] Modulus of rigidity at various temperatures.

3.6.4 Tangent modulus.

3.6.5 Secant modulus.

4 Fabrication

4.1 Forming

4.1.1 Hot Isostatic Pressing (HIP)

4.1.1.1 [Table] Composition, heat treatment, and HIP treatment.

Hot isostatic pressing (HIP) can be used to form or bond materials at high temperatures with pressures acting on all surfaces simultaneously. The most widely-used pressurized gas is argon. Originally developed for the gas-pressure bonding of materials and powder compaction applications, HIP has been proven capable of healing micro-porosity in castings and thereby

upgrading mechanical properties. HIP also makes possible the salvaging of castings that have been scrapped because of internal porosity (Refs. 58 and 67).

4.1.1.2 [Figure] Configurations of permanent steel molds and fracture toughness specimens used for testing the effects of hot isostatic pressing (HIP).

4.1.1.3 [Figure] Effect of hot isostatic pressing (HIP) on void fraction and tensile properties of test specimens as-cast in permanent steel molds.

Void fraction is dramatically reduced by HIP, both in mean value and standard deviation from the mean. This leads to increases in all mean tensile properties measured in the as-cast condition. Most significant are the increases in mean ultimate tensile strength and elongation. Both increases and decreases are found in the standard deviations of tensile properties.

4.1.1.4 [Figure] Effect of HIP on tensile properties of heat-treated test specimens.

4.1.2 Laser Shock Processing (LSP)

4.1.2.1 [Table] Composition, heat treatment, and laser shock treatment.

Laser shock processing (LSP) is an experimental technique in which laser-induced shock waves are used to alter the surface structure of a material, in a manner analogous to shot-peening. The first atomic layers of the material are vaporized. Sub-surface plastic deformation occurs which results in beneficial compressive residual stresses (Ref. 59). During fatigue cycling, these act as compressive mean stresses (or strains) which have the potential of increasing fatigue life (see Fig. 3.5.2.7).

4.1.2.2 [Figure] Configuration of notched fatigue test specimens loaded in three-point bending to test the effects of laser shock processing (LSP) on sand castings, showing overlapping impact areas at root of notch.

4.1.2.3 [Figure] Effect of laser shock processing (LSP) on stress-fatigue life curves for notched bar specimens from chilled sand castings.

Treatment by LSP increased mean fatigue strength by 30 to 50 percent, although the data exhibit large scatter.

4.1.3 Thixoforging

4.1.3.1 [Table] Preliminary comparison of tensile properties of thixoforged and conventionally-cast 356 alloys.

Thixoforging is a combination of forging and casting technologies which uses the physical state between solidus and liquidus temperatures to drastically reduce the material's flow stress and

thereby the required forming loads. Like a casting, near-perfect reproduction of complex die geometries is possible with thixoforging (Ref. 63).

4.2 Machining and Grinding

- 4.2.1 General. The machinability of these alloys is fair. Tool wear is greater for 356.0 and A356.0 than for 355 alloy because of their higher silicon content. Carbide cutting tools and lubricants such as lard oil and kerosene are recommended for general machining. For tapping of threads, pure lard oil is preferred.

4.3 Welding

- 4.3.1 General. A detailed discussion of the welding of aluminum castings is given in Reference 30. 356.0 and A356.0 alloys are readily weldable by GTA techniques. Gas welding, metal arc, carbon arc, and atomic hydrogen techniques have also been used, usually with a furnace for preheating. Foundry welding of small defects, etc., is usually performed with a filler metal of the same composition as the parent cast metal. For repair or assembly welding, 4043 filler metal is recommended in order to keep cracking sensitivity at a minimum (Ref. 30).
- 4.3.2 Temperatures exceeding 400 F during preheating or welding will affect the mechanical properties of heat-treated castings. After welding, however, the castings can be heat treated again to restore their properties. A general rule during welding is to keep the heat of welding concentrated in a narrow region.
- 4.3.3 Brazing of 356.0 and A356.0 is normally not recommended. It is possible, however, to braze these alloys by using special techniques (Ref. 31).

4.4 Heat Treatment

4.5 Surface Treatment

- 4.5.1 General. Because the resistance of these alloys to normal atmospheric weathering is good, protective coatings are not usually required. These alloys can be anodized to provide increased resistance to corrosion and abrasion. Other surface finishes such as electroplating, porcelain enameling, and painting can be applied for special purposes (Ref. 29).

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Table 1.3.1 AMS Specifications for 356.0 and A356.0 castings and applicable welding wire.

AMS No.	Alloy	Form	Quality/Condition	UNS No.	Similar Specification	References
4181B	4008	Welding wire	Annealed	A94008	AWS A5.10, Class R-A356.0	61
4260E	356.0-T6	Castings, Investment	Radiographic	A03560		2
4261D	356.0-T51	Castings, Investment	Radiographic Precipitation Heat Treated	A03560		69
4286D	356.0-T51	Castings, Permanent Mold	Radiographic Precipitation Heat Treated	A03560	FED-QQ-A-596 Alloy 356, Temper T51	5
4285B	356.0-T6	Castings, Centrifugal	Radiographic Solution and Precipitation Heat Treated	A03560		4
4284F	356.0-T6	Castings, Permanent Mold	Radiographic Solution and Precipitation Heat Treated	A03560	FED-QQ-A-596 Alloy 356	3
4217G	356.0-T6	Castings, Sand	Solution and Precipitation Heat Treated	A03560		1
4218G	A356.0-T61P	Castings, Sand or Composite Permanent Mold and Investment	Solution and Precipitation Heat Treated	A13560	MIL-A-21180, Alloy A356.0, Class 12	16

Table 1.4.2 Composition specifications for 356.0 and A356.0

Alloy	356.0				A356.0	
	Specifications		References		Designation	
	AMS 4217G AMS 4260E AMS 4261D AMS 4286D AMS 4181B	AMS 4284F AMS 4285B			AMS 4218G	
References	1, 2, 5, 61, 69		3, 4		6,16	
Designation	356.0-T6, -T51 4008		356.0-T6		356.0-T6P	
UNS	A03560 A94008		A03560		A13560	
Composition	Minimum	Maximum	Minimum	Maximum	Minimum	Maximum
Si	6.5	7.5	6.5	7.5	6.5	7.5
Mg	0.20	0.45	0.20	0.40	0.25	0.45
Ti	-	0.25	-	0.25	-	0.20
Fe	-	0.60	-	0.60	-	0.20
Cu	-	0.25	-	0.25	-	0.20
Zn	-	0.35	-	0.35	-	0.10
Mn	-	0.35	-	0.35	-	0.10
Be	-	0.0008 ^a				
Other, each	-	0.05	-	0.05	-	0.05
Other, total	-	0.15	-	0.15	-	0.15
Al	Remainder		Remainder		Remainder	

^a AMS 4181B only

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Table 1.4.3.1 Composition, foundry practice, heat-treatment, and properties of investment-cast test plates (Ref. 32)

Alloy	A356.0-T6			
Form	3-inch x 10-inch x 1/10-inch Thick Shell Investment Casting			
Foundry Practice	100 percent Ingot, Melt at 1350 F + (95%N + 5 % Freon) Degas + 1320 F Pour Into 1000 F Mold			
Composition	Base: 0.36 Mg, 0.04 Fe			
Heat Treat	1000 F 18 hr + WQ + 12-24 hr at RT + 310 F 5 hr			
Tensile Properties	F_{tu} (ksi)	F_{ty} (ksi)	e (percent)	Hardness (RE)
n = 10: Mean Standard Dev.	41.7 0.7	32.3 1.1	7.2 0.7	87 1.7
Plate Surface DAS Range	1.8 - 2.5 mils			

Table 1.4.3.2 Composition, foundry practice, heat-treatment, and properties of sand-cast test plates (Ref. 32)

Alloy	A356.0-T6			
Form	3-inch x 10-inch x 3/4-inch Thick Sand Composite Casting			
Foundry Practice	AFS 60 Bank Sand With 0.8 Percent Binder, Chills in Both Cope and Drag, Two Risers, Steel Wool and Screens in Well of Sprue, 60 percent Ingot, 40 percent returns, 3000-lb Melt + (90%N + 10% Chlorine) Degas + 1375 F Pour Into RT Mold			
Composition	Base: 0.38 Mg, 0.10 - 0.12 Fe			
Heat Treat	1000 F 18 hr + 40 F WQ + 12-24 hr at RT + 310 F 8 hr			
Tensile Properties	F_{tu} (ksi)	F_{ty} (ksi)	e (percent)	Hardness (RE)
n = 10: Mean Standard Dev.	41.9 1.7	32.4 0.3	6.4 1.2	88 1.7
Plate Surface DAS Range	0.9 - 1.1 mils			

Table 1.4.3.7 Composition, foundry practice of as-cast test plates (Ref. 33)

Alloy	A356.0
Form	2-inch D x 8.3-inch Long Cylinders In Cast Iron Mold 0.83-inch D x 7.9-inch Long Cylinders In Green or Furan Sand Molds
Foundry Practice	26-lb and 400-lb Melts + N ₂ Degas 15-20 Min at 1310 F Series B: 100 percent Virgin Ingot Series D: 100 percent Virgin Ingot or 100 percent Returns + 0.02 Sr With and Without Ceramic Foam Filters
Composition	Series B: 7.1 Si, 0.27 Mg, 0.02-0.31 Ti, 0.005 Mn, 0.12 Fe, 0.02 Zn Series D: 6.6 Si, 0.22 Mg, 0.17 Ti, 0.014 Mn, 0.08 Fe, 0.02 Zn
Heat Treat	None

Table 1.4.3.9 Composition, foundry practice, and heat-treatment of low-pressure-cast test components (Ref. 34)

Alloy	A356.0 and A356.0-T6
Form	12-inch x 7-inch x 4-inch Thick U-Shaped Components
Foundry	Pre-Heated Low-Pressure Molds 400-lb Melt Without Degas 4 Series of 15 to 30 Castings Each; Specimens Cut from Randomly Selected Castings
Composition	7.4 Si, 0.09 Fe, 0.006 Cu, 0.005 Mn, 0.42 Mg, 0.016 Zn, 0.07 Ti, 0-0.024 Sr
Heat Treat	One Lot As-Cast; One Lot 1000 F 13 hr + 77 F WQ + 310 F 8 hr

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Table 1.5.2 Typical heat Treatments

Alloy and condition	Method of casting ^a	Solution heat treatment			Artificial aging		Ref.
		Temp (F)	Time (hr)	Quench	Temp (F)	Time (hr)	
356.0-F	S or PM	None	None	None	None	None	
356.0-O	S or PM	650	2	None	None	None	14
356.0-T4	S or PM	980 - 1025	6 - 24	Water	None	None	67
356.0-T51	S or PM	None	None	None	430 - 450	6 - 12	67
356.0-T51	S or PM	None	None	None	440	7 - 9	68
356.0-T6	S	1000	12	Water	310	3 - 5	68
356.0-T6	PM	1000	4 - 12	Water	310	2 - 5	68
356.0-T6	S or PM	980 - 1025	6 - 24	Water	300 - 320	1 - 6	67
356.0-T61	S or PM	980 - 1025	6 - 24	Water	300 - 320	6 - 10	67
356.0-T7	S	1000	12	Water	400	3 - 5	68
356.0-T7	PM	1000	4 - 12	Water	440	7 - 9	68
356.0-T71	S	1000	10 - 12	Water	475	3	68
356.0-T71	PM	1000	4 - 12	Water	475	3 - 6	68
A356.0-F	S or PM	None	None	None	None	None	
A356.0-O	S or PM	650	2	None	None	None	14
A356.0-T4	S or PM	980 - 1025	6 - 24	Water	None	None	67
A356.0-T6	S	1000	12	Water	310	3 - 5	68
A356.0-T6	S or PM	980 - 1025	6 - 24	Water	300 - 320	1 - 6	67
A356.0-T61	PM	1000	6 - 12	Water	RT 310	8 (min) 6 - 12	68
A356.0-T61	S or PM	980 - 1025	6 - 24	Water	300 - 320	6 - 10	67

^a S = sand casting; PM = permanent-mold casting

Table 1.5.3.1 Composition, foundry practice, and heat treatment (Refs. 35 and 36)

Alloy	A356.2			
Form	Sand and Permanent-Mold Cast Test Bars			
Composition	Sand Castings		Permanent Mold Castings	
Element	Unmodified	Sr-Modified	Unmodified	Sr-Modified
Si	7.19	7.10	6.90	6.83
Mg	0.40	0.39	0.41	0.42
Fe	0.09	0.10	0.11	0.09
Ti	0.16	0.17	0.15	0.17
Sr	0.002	0.022	0.003	0.023
P	—	—	0.0013	0.0014
Sb	—	—	0.0059	0.0034
Cr	0.0012	0.0017	0.0022	0.0013
Mn	0.0028	0.0048	0.0053	0.0050
Cu	0.001	0.001	0.022	0.014
Foundry Practice	100 percent Virgin Melt at 1360 +/- 20 F (Sand Mold) or 1400 +/- 20 F (Permanent Mold) + Grain Refinement + N ₂ Degas + Ceramic Foam Filter			
Heat Treatment	<p>T6: Sand Mold: 1022 F, 100 min; WQ, 140 F; RT, 0 to 72 hr; 293 F to 394 F, 0 to 100 hr</p> <p>Permanent Mold: 1022 F, 50 min; WQ, 140 F; RT, 0 to 72 hr; 293 F to 394 F, 0 to 100 hr</p> <p>T4: Same solution treatment and quench as T6; no artificial aging</p>			

Notes: Radiograph all specimens: reject for visible defects

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Table 1.5.3.6. Composition, foundry practice, and heat treatment (Refs. 37 and 40)

Alloy	A356.2 As-Cast and -T6		
Form	Sand and Permanent-Mold Cast Test Bars		
Composition	Sand Castings		Permanent Mold Casting
Element	Unmodified	Sr-Modified	Sr-Modified
Si	6.65	6.67	7.20
Mg	0.37	0.39	0.41
Fe	0.07	0.08	0.09
Ti	0.12	0.11	0.13
Sr	0.001	0.020	0.025
P	0.01	0.01	0.02
Mn	0.03	0.02	0.02
Microstructure	Sand Castings		Permanent Mold Casting
Parameter	Unmodified	Sr-Modified	Sr-Modified
DAS (10 ⁻⁴ in.)	15 - 19	16 - 19	9 - 12
Grain Size (in.)	0.035	0.034	0.009
Porosity (percent)	0.13	0.85	0.02
Relative Pore Area			
Average	1.0	3.2	0.05
Max	5.5	21.7	0.28
Pore Aspect Ratio	3.1	3.4	3.9
Foundry Practice	100 percent Virgin Melt at 1370 +/- 20 F (Sand Mold) or 1400 +/- 20 F (Permanent Mold) + Ti Grain Refinement + N ₂ De-Gas + Ceramic Foam Filter		
Heat Treatment	Sand Mold: 1020 F, 2 to 200 hr; WQ, 140-160 F; RT, 24 hr; 310 F, 4 hr Permanent Mold: 1020 F, 2 to 200 hr; WQ, 140-160 F; RT, 24 hr; 340 F, 4 hr		
As-Cast Tensile Properties at RT			
F _{tu} (ksi)	23.9	24.4	28.7
F _{ty} (ksi)	14.6	14.5	14.6
e (percent)	4.7	6.1	7.4
Heat-Treated T6 Tensile Properties at RT			
F _{tu} (ksi)	39.6	43.5	45.4
F _{ty} (ksi)	32.5	30.8	35.5
e (percent)	2.8	9.3	7.6

Notes: Radiograph all specimens; reject for visible defects; ASTM B-108 test bars

Table 1.5.6.4. Composition, foundry practice, and heat treatment (Ref. 38)

Alloy	A356.0
Form	Metal Mold Cast Ingot
Composition	7.09 Si, 0.30 Mg, 0.08 Fe, 0.01 Ni, --- Zn, 0.09 Ti, 76 ppm Sr
Foundry Practice	Melt at 1292 F + Metal Mold at 302 F + Cooling at 7 to 30 F/s
Heat Treatment	1057 F, 0+ min; WQ; (311F, 0 to 200 hr

Table 1.5.6.8. Composition, foundry practice, and heat treatment (Ref. 39)

Alloy	A356.0
Form	Sand Cast Test Bars
Composition	7.04 Si, 0.39 Mg, 0.031 Cu, 0.32 Fe, 0.23 Mn, 0.00 Ni, 0.025 Zn, 0.001 Pb, 0.027 Ti
Foundry Practice	Melt at 1200 F 30 min to De-Gas + 1400 F 1 min + 1200 F Pour AFS 60 Silica Sand + Pepset 5000 Binder + Ceramic Foam Filter + Aluminum Block Chills
Heat Treatment	1000 F, 8 hr; WQ; 350 F and 420 F, 4 hr

Table 1.6.2 Desirable Hardness Ranges ^a

AMS	Alloy	Form	Hardness Range	Ref.
4181B	4008	Welding wire	—	61
4217G	356.0-T6	Castings	65 to 95 HB/10/500 or 70 to 100 HB/10/1000	1
4260E	356-T6	Castings, investment		2
4261D	356-T51	Castings, investment		69
4284F	356.0-T6	Castings, permanent mold	65 to 95 HB/10/500 or 70 to 100 HB/10/1000	3
4285B	356.0-T6	Castings, centrifugal		4
4286D	356.0-T51	Castings, permanent mold	50 HB/10/500, min or 55 HB/10/1000, min	5
4281G	A356.0-T6P	Castings	70 to 105 HB/10/500 or 75 to 110 HB/10/1000	16

^a Castings not to be rejected for out-of-range hardness if tensile property requirements are met

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Table 1.8.2.3. Composition, foundry practice, and heat treatment of sand-cast test bars (Refs. 41 and 42)

Alloy	A356.2-T6
Form	Sand Cast Test Bars
Composition	7.12 Si, 0.36 Mg, 0.11 Fe, 0.01 Zn, 0.11 Ti
Foundry Practice	100 percent Virgin Melt at 1300 F + Grain Refiner + Modifier, 30-50 min, N ₂ De-Gas + 1360 F Sample + 1300 F Sample + 1250 F Sample + Pour Sand Molds With and Without 2x2x3/4 inch Reticulated Ceramic Foam Filter
Heat Treatment	1000 F, 12 hr; WQ; 320 F, 4 hr; AC

Table 1.8.3.2. Composition, foundry practice, and heat treatment of strip-cast sheet (Ref. 43)

Alloy	A356.0 As-Cast and T6 Heat-Treated
Form	Strip-Cast Sheet
Composition	7.39 Si, 0.48 Mg, 0.33 Fe, 0.24 Zn, 0.14 Mn, 0.19 Cu
Foundry Practice	See Figure 1.8.3.1
Heat Treatment	1000 F, 12 hr; WQ; RT, 48 hr; 310 F, 4 hr Cast strip 0.12 to 0.20-in. thick x 3.9-in wide

Table 2.1.3. Thermal conductivity at RT of 356.0 and A356.0 (Refs. 14 and 20)

Alloy and Condition	Btu-ft/ (hr-sq. ft.-F)
356.0 -T51	97
356.0 - T6	87
356.0 -T6 ^a	92
356.0 -T7	90
A356.0 -T6	87

^a Chill-cast samples; all other samples cast in green-sand molds

Table 2.2.2.1. Electrical resistivity at RT and conductivity (Refs. 14 and 15)

Alloy and Condition	Resistivity (Ref. 15) (micro-ohm-inch)	Conductivity (Ref. 14) (percent IACS)
356.0-T51	1.60	43
356.0-T6	1.74	39
356.0-T7	1.70	40
A356.0-T6	—	40

Table 2.4.1. Effect of neutron radiation on tensile properties of 356.0 cast test bars (Refs. 19 and 24)

Irradiation Temperature (F)	Integrated Neutron Flux (a) (n cm ⁻²)	F _{tu} (ksi)		F _{ty} (ksi)		e (2 inches) (percent)	
		A	B	A	B	A	B
—	2.4 x 10 ²⁰	32.4	44.3	24.1	42.4	2.7	0.4
—	7.2 x 10 ²⁰	32.4	54.0	24.1	51.0	2.7	0.9
—	2.6 x 10 ²¹	32.4	45.0	24.1	36.0	2.7	1.5
120	2.04 x 10 ¹⁹	33.1	36.7	26.0	29.1	4.0	6.0
120	1.22 x 10 ²⁰	33.1	42.0	26.0	33.5	4.0	6.0
120	5.59 x 10 ²⁰	33.1	45.1	26.0	42.5	4.0	6.0
120	9.84 x 10 ²⁰	33.1	54.4	26.0	52.1	4.0	3.0

(a) Fast neutrons.

A - Not irradiated

B - Irradiated

Table 2.4.2. Effect of nuclear radiation at -420 F on tensile properties of A356.0-T6 cast plate at -420 F (Ref. 21)

Test	Pre and Post Irradiation Data at -420				
	Property	Specimen Type (b)	Control (average)	Irradiated (average) (a)	Change
F_{tu} (ksi)	L	44.7	52.8	+ 8.1	+ 18 (c)
F_{ty} percent	L	31.0	42.8	+ 11.8	+ 38 (c)
- 0.1 percent	L	1.5	1.4	- 0.1	- 7
RA (ksi)	L	2.8	0.8	- 2.0	- 72 (c)
F_{su} (ksi)	L	50.4	45.6	- 4.8	- 10 (c)
Notch Strength (ksi) ($K_t = 6.3$)	L	39.7	43.2	+ 3.5	+ 9
Notch/Unnotch Strength Ratio (d)	L	0.89	0.82	-	-

(a) Irradiated at 5×10^{18} nvt ($E > 1.0$ MeV) in liquid hydrogen.

(b) L = longitudinal specimen

(c) Statistically significant change; probability > 0.90.

(d) Notch specimen geometry:

- Width = 1.0 inch
- Notched Radius = 0.005 inch
- Notched Depth = 30 percent
- Notched Angle = 60 degrees
- Thickness = 0.063 inch

Table 2.4.4. Effect of neutron radiation on tensile properties of A356.0 (Ref. 25)

Irradiation Temperature (F)	Test Temp (F)	Fast Neutron Flux (a) ($n\text{ cm}^{-2}$)	F_{tu} (ksi)		F_{ty} (ksi)		e (2 inches) (percent)	
			A	B	A	B	A	B
120	RT	2.0×10^{19}	33.1	36.7	26	29.1	4	6
120	RT	1.2×10^{20}	33.1	42.0	26	33.5	4	6
120	RT	5.6×10^{20}	33.1	45.9	26	42.4	4	6
120	RT	9.8×10^{20}	33.1	54.4	26	52.1	4	3

(a) Energy greater than 1.0 MeV

A not irradiated

B Irradiated

Table 3.1.1. AMS specifications for mechanical properties (a)

AMS	Alloy	Form	F _{TU} (ksi)	F _{TY} (ksi)	e (percent)	Ref.
4181B	4008	Welding wire	-	-	-	61
4217G	356.0-T6	Castings Separately cast specimens: min.:	30.0	20.0	3.0	1
		Specimens integrally cast or cut from castings, min. average of at least 4; preferably 10:	22.5	15.0	0.7	
4260E	356-T6	Castings, investment Separately cast specimens: min.:	33.0	22.0	3.0	2
		Specimens integrally cast or cut from castings, min. average of at least 4; preferably 10:	25.0	16.5	1.0	
4284F	356.0-T6	Castings, permanent mold Separately cast specimens: min.:	33.0	22.0	3.0	3
		Specimens cut from castings, min.:	24.75	16.5	0.7	
4285B	356.0-T6	Castings, centrifugal Separately cast specimens: min.:	33.0	22.0	3.0	4
		Specimens cut from castings, min.:	24.8	16.5	1.0	
4286D	356.0-T51	Castings, permanent mold Separately cast specimens: min.:	25.0	-	-	5
		Specimens integrally cast or cut from castings, min. average of at least 4; preferably 10:	18.8	-	-	
4218G	A356.0-T6P	Castings	33.0	27.0	3.0	16
		Separately cast specimens: min.:	32.0	22.0	2.0	
		Specimens integrally cast, min.:	32.0	22.0	2.0	

(a) Specimens conforming to ASTM B557 or ASTM B557M

Table 3.1.2. MIL-A-21180B specified tensile properties for specimens cut from castings of A356.0 (Ref. 6)

Form	Special Mold, Permanent Mold, or Sand Mold with Chills					
Condition	T61					
Location of Castings	Designated Area			Any Area		
Class	1	2 (a)	3 (a)	10	11	12
F _{TU min} (ksi)	38.0	40.0	45.0	38.0	33.0	32.0
F _{TY min} (ksi)	28.0	30.0	34.0	28.0	27.0	22.0
e _{min} (percent)	5.0	3.0	3.0	5.0	3.0	2.0

(a) Obtainable only in favorable casting configurations and must be negotiated with the foundry.

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Table 3.2.1.1. Composition, foundry practice, and heat treatment (Ref. 44)

Alloy		A356.0-T6		
Form		Investment-Mold Cast Test Bars: Near-Net-Shape		
Composition		7.15 Si, 0.36 Mg, 0.009 Cu, 0.031 Fe, 0.008 Mn, 0.009 Zn, 0.05 Ti		
Foundry Practice		Melt at 1300 F + Pour + Investment Mold Temperatures: Casting X, RT; Casting Y, 1000 F; Casting Z, 1800 F		
Heat Treatment		MIL-A-21180,T6		
Casting	X	Y	Z	
DAS (10 ⁻⁴ in.)	13	24	26	
Tensile Properties				
E (10 ³ ksi)	10.1	10.1	10.3	
F _{TU} (ksi)	41.1	38.6	36.6	
F _{TY} (ksi)	33.3	32.5	31.5	
e (percent)	3.5	1.8	1.7	
RA (percent)	5.7	3.0	2.9	

Notes: Tensile specimens machined from cast bars

Table 3.2.1.2. Composition, foundry practice, and heat treatment (Ref. 44)

Alloy	A356.0-T6
Form	Sand-Mold Cast Test Bars: Near-Net-Shape
Composition	7.0 Si, 0.36 Mg, 0.04 Cu, 0.11 Fe, <0.01 Mn, 0.01 Zn, 0.15 Ti, <0.01 Cr, <0.01 Ni, < 0.01 Sn
Foundry Practice	Melt at 1310 F + Pour + Sand-Mold Casting W + Internal Cold-Water Chill Tube
Heat Treatment	MIL-A-21180,T6; 990 F, 12 hr
Casting	W
DAS (10^{-4} in.)	12
Tensile Properties	
E (10^3 ksi)	9.9
F _{tu} (ksi)	38.9
F _{ty} (ksi)	21.2
e (percent)	9.2
RA (percent)	8.5

Notes: Tensile specimens machined from cast bars

Table 3.2.1.5. Composition, foundry practice, and heat treatment (Ref. 52)

Alloy	A356.0-T6
Form	Sand-Mold Cast Test Plates
Composition	6.7-7.15 Si, 0.23-0.35 Mg, 0.01-0.19 Cu, 0.10-0.17 Fe, 0.01-0.07 Zn, 0.10-0.16 Ti
Foundry Practice	1350 F-1380 F Pour
Heat Treatment	T6

Note: Radiographic Quality Level AA-CS-M5-71: AA all plate sections

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Table 3.2.1.9. Composition, foundry practice, and heat treatment (Ref. 55)

Alloy	A356.0-T6
Form	Sand-Cast Automotive Engine Components: Blocks and Heads
Composition	
Unmodified:	7.01 Si, 0.36 Mg, <0.01 Cu, 0.11 Fe, 0.01 Zn, 0.07 Ti, 0.01 Mn, <0.01 Cr, <0.01 Ni, <0.01 Sn, <0.01 Pb, 0.003 P, <0.01 Sb, 0.001 Na, <0.001 Sr
Sr-Modified:	6.25 Si, 0.38 Mg, <0.01 Cu, 0.07 Fe, 0.01 Zn, 0.08 Ti, 0.04 Mn, <0.01 Cr, <0.01 Ni, <0.01 Sn, <0.01 Pb, 0.002 P, <0.01 Sb, 0.004 Na, 0.010 Sr
Foundry Practice	De-Gassed + Highly Filtered + Counter-Gravity Poured; Conventional low-pressure casting, and improved low-pressure process (ILP): Chill plate insert in mold engineered to produce rapid, controlled directional solidification
Heat Treatment	T6

Note: Brinell hardness: 81.8 to 98.1 HB500

Table 3.2.1.11 Composition, foundry practice, and heat treatment (Ref. 53)

Alloy	356.0-T6
Form	Permanent-Mold Cast Test Plates
Composition	6.84-7.48 Si, 0.28-0.44 Mg, 0.00-0.15 Cu, 0.34-0.53 Fe, 0.00-0.14 Zn, 0.08-0.15 Ti, 0.00-0.20 Mn
Foundry Practice	1360 F-1540 F Pour
Heat Treatment	T6

Note: Radiographic Quality Level AA-CS-M5-71: AA all plate sections

Table 3.2.1.16. Composition, foundry practice, and heat treatment (Ref. 64)

Alloy	A356.0-T5, - T6, and T7
Form	Directionally-solidified Ingots, 3-inch x 3-inch x 9-inch High
Composition	7.15 Si, 0.38 Mg, 0.08 Fe, 0.138 Ti, 0.0013 B
Foundry Practice	Melt in 50-lb Capacity Clay-graphite Crucible 1320 F + De-Gas Ar-10 percent Cl ₂ + Plaster Mold at 1420 F + Water-Chilled Copper Base + Top Insulation
Heat Treatment	
T5	Age 8 hr at 440 F
T6	Solutionize 12 hr at 1000 F; RT Age 8 hr; age 3 hr at 310 F
T7	Solutionize 12 hr at 1000 F; Age 8 hr at 440 F

Note: Specimen blanks sliced parallel to bottom chill for properties at different cooling rates

Table 3.2.2.1. Compression, shear, and bearing properties of 356.0 and A356.0 cast test bars (Refs. 7, 8, and 69)

Alloy	356.0						A356.0
	Sand				Permanent		Permanent
Condition	T51	T6	T7	T71	T6	T7	T61
$F_{cy, min}$ (ksi)	17	20	27	19	22	21	27
$F_{cy, typ}$ (ksi)	21	25	31	22	27	24	32
$F_{su, min}$ (ksi)	17	25	21	17	25	22	23
$F_{su, typ}$ (ksi)	20	26	24	20	30	25	28
$F_{bru, min}$ (ksi) ($e/D = 2.0$)	48	63	65	52	59	52	-
$F_{bru, min}$ (ksi) ($e/D = 2.0$)	32	40	52	36	40	38	-

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Table 3.5.1.1. Composition, foundry practice, and heat treatment (Ref. 56)

Alloy	A356.0-T6		
Form	Sand-Cast and Permanent-Mold Rotating Bending Fatigue Test Bars		
Composition	7 Si, 0.3 Mg, Ti		
Foundry Practice	(1310 F) Melt		
Mold Type	Permanent	Permanent	CO ₂ Sand
Mold Preheat (F)	300 F	660 F	–
Cooling Rate (F/s)	4.7	2.6	0.3
DAS (10 ⁻⁴ in.)	20	32	66
Heat Treatment	970 F, 8 hr; 320 F, 6 hr		

Table 3.5.1.4. Composition, heat treatment, and tensile properties (Ref. 57)

Alloy	A356.0-T6
Form	Wedge-Shaped Sand Castings 2.5-in. x 14-in. x 14-in.
Composition	7.3 Si, 0.12 Fe, 0.41 Mg, 0.02 Zn, 0.04 Ti, nil Mn
Heat Treatment	T6; Average Rockwell B Hardness 21
Tensile Properties	F _{TU} 32.9 ksi; F _{Ty} 21.2 ksi; e 2.5 percent; RA 2 percent

Notes: Laboratory air fatigue specimens: 0.250-inch D test section
Sea water fatigue specimens: 0.500-inch D test section

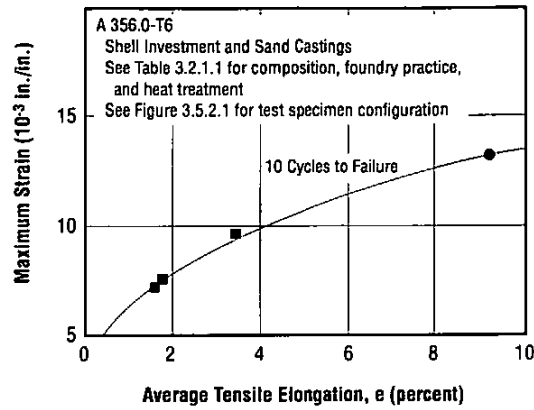


Figure 3.5.2.6 Effect of tensile elongation on axial strain-cycling fatigue strength at 10 cycles to failure of smooth specimens from unchilled shell investment castings and water-chilled sand castings (Refs. 44-47)

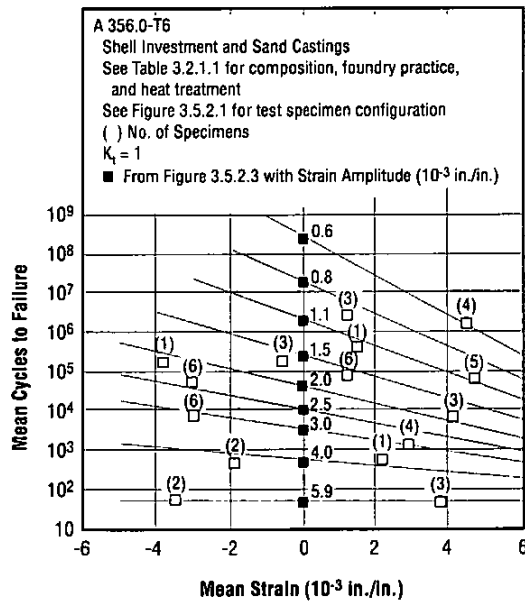


Figure 3.5.2.7 Effect of mean strain on axial strain-fatigue life behavior of smooth specimens from shell-investment castings (calculated from data in Ref. 51)

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Table 3.5.1.6. Characteristic of fatigue test materials (Ref.62)

Alloy		A357.0-T6 Sand-Cast	
Form:	Die-cast wheels (low pressure)	Direct-chill cast billets without extrusion	Direct-chill cast billets with extrusion before HT
Grain Size: (10 ⁻⁴ in.)	98	138	Longitudinal: 1575 Transverse 394
DAS (10 ⁻⁴ in.)	9	8	---
Porosity (percent)	1.0	0.0	0.0
F _{TU} (ksi):	41.8	45.7	43.5
F _Y (ksi):	32.2	33.4	31.9
e (percent):	6	16	20

Note: Direct-chill casting is a semi-continuous process

Table 4.1.1.1. Composition, heat treatment, and HIP treatment (Ref. 58)

Alloy	A356.0
Form.	Steel Permanent Mold Castings 1.5-in. D x 8-in
Composition	6.6 Si, 0.15 Fe, 0.38 Mg, 0.02 Zn, 0.17 Ti, 0.00 Mn, 0.04 Sb, 0.01 Cu, 0.01 Cr
Heat Treatment	None
HIP Treatment	970 F + 15 ksi, 2 hr

Table 4.1.2.1. Composition, heat treatment, and laser shock treatment (Ref. 59)

Alloy	A356.0
Form	Steel Permanent Mold Castings 1.5-in. D x 8-in.
Composition	7.05 Si, 0.2 Fe, 0.33 Mg, 0.03 Zn, 0.15 Ti, 0.03 Mn, 0.05 Cu
Heat Treatment	900 F, 6 hr; WQ 70 F; 320 F, 6 hr
Laser Shock Treatment	14.8 GW/in ² ; 5 impacts 0.0024-in. square, or 3 elliptical impacts; 50 percent overlap; 1 repetition

Table 4.1.3.1. Preliminary comparison of tensile properties of thixoforged and conventionally-cast 356 alloys (Ref. 63)

Property	Conventional Casting (typical)	Thixoforged Complex Part (a)	Change (percent)
Ultimate Tensile Strength, Ft _u (ksi)	49.3	43.5	-12
Tensile Yield Strength, Ft _y (ksi)	40.6	37.1	-9
Elongation, e (percent)	9.0	11.4	+27

(a) Ribbed plate 6.9 x 10.4 in.; thicknesses from 0.4 to 1.0 in.

A356

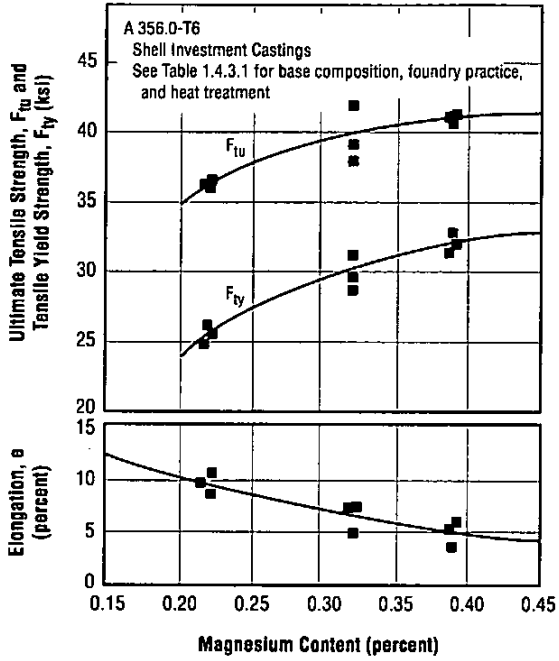


Figure 1.4.3.3 Effect of magnesium content on the tensile properties of shell investment castings (Ref. 32)

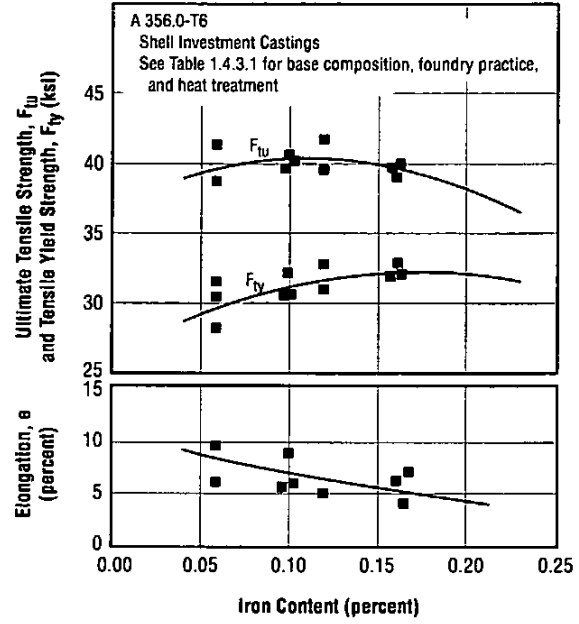


Figure 1.4.3.5 Effect of iron content on the tensile properties of shell investment castings (Ref. 32)

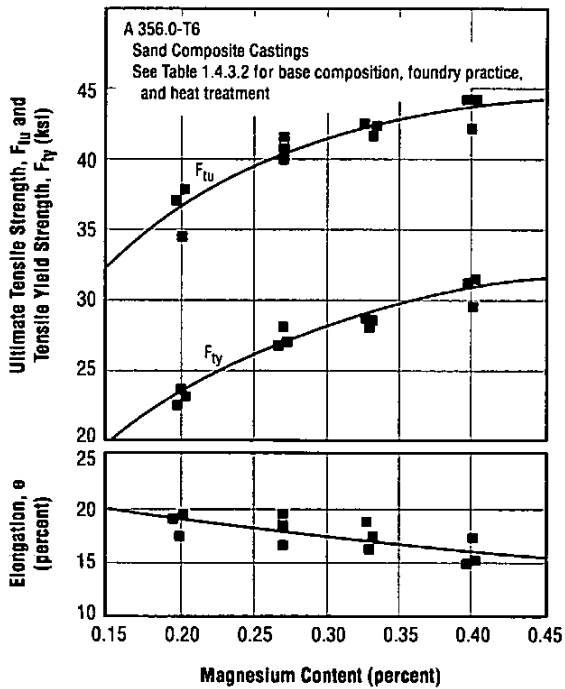


Figure 1.4.3.4 Effect of magnesium content on the tensile properties of sand composite castings (Ref. 32)

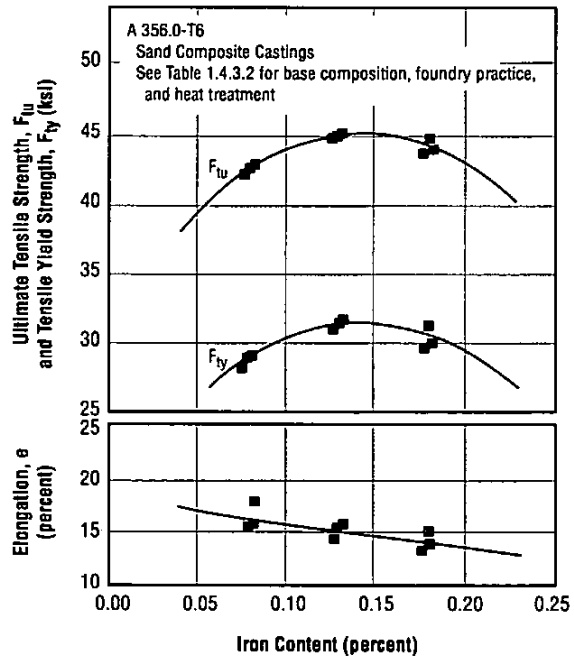


Figure 1.4.3.6 Effect of iron content on the tensile properties of sand composite castings (Ref. 32)

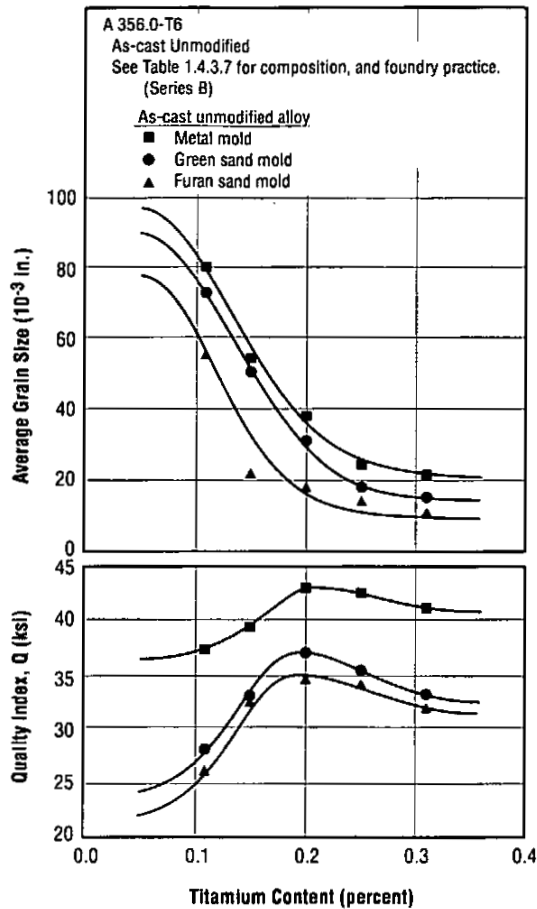


Figure 1.4.3.8 Effect of titanium content on the grain sizes and quality indices of castings in three types of molds (Ref. 33)

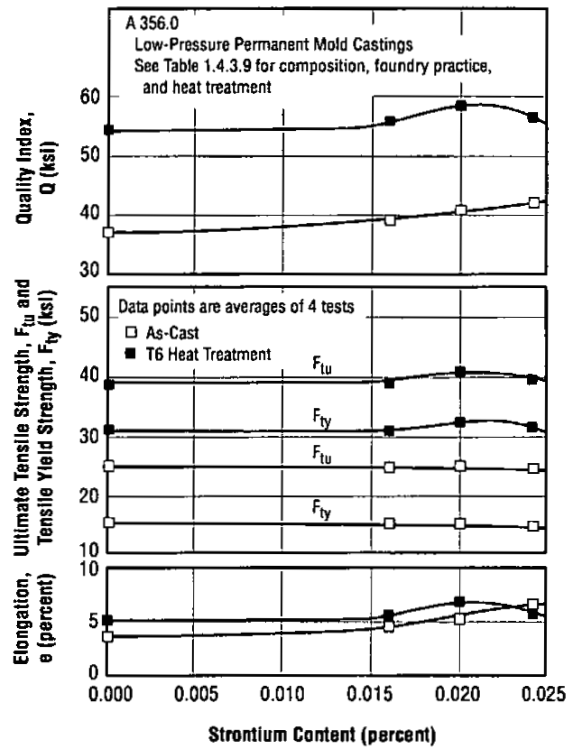


Figure 1.4.3.10 Effect of strontium content on the tensile properties of low-pressure permanent mold castings (Ref. 34)

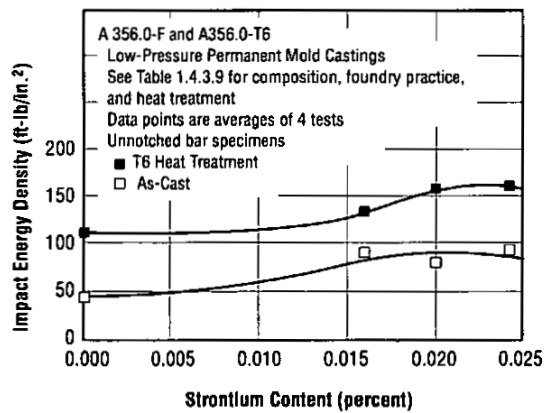


Figure 1.4.3.11 Effect of strontium content on impact energy absorbed by unnotched bars from low-pressure permanent mold castings (Ref. 34)

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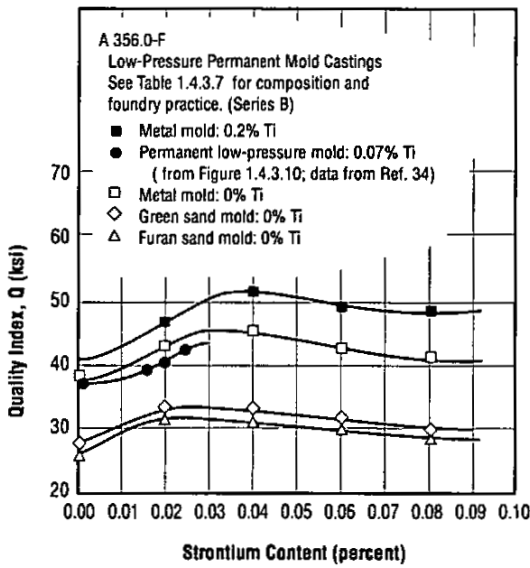


Figure 1.4.3.12 Effect of strontium content on the quality indices of alloy as-cast in metal and sand molds (Ref. 33)

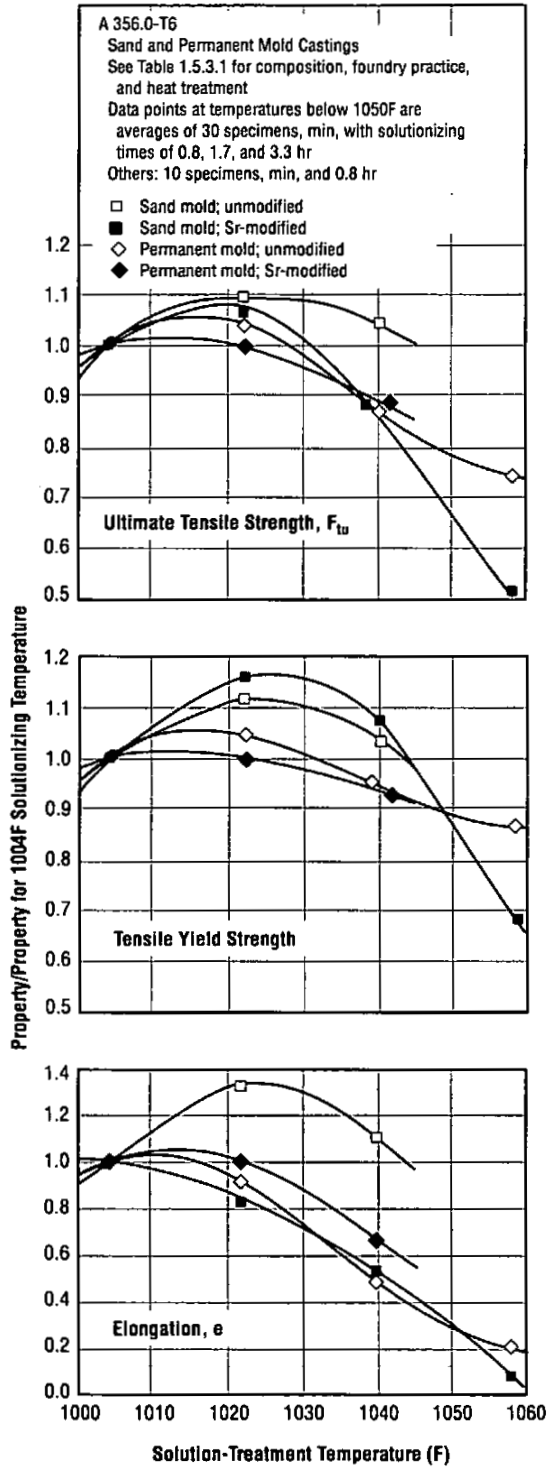


Figure 1.5.3.2 Effect of solution-treatment temperature on relative tensile properties of sand and permanent mold castings (Ref. 36)

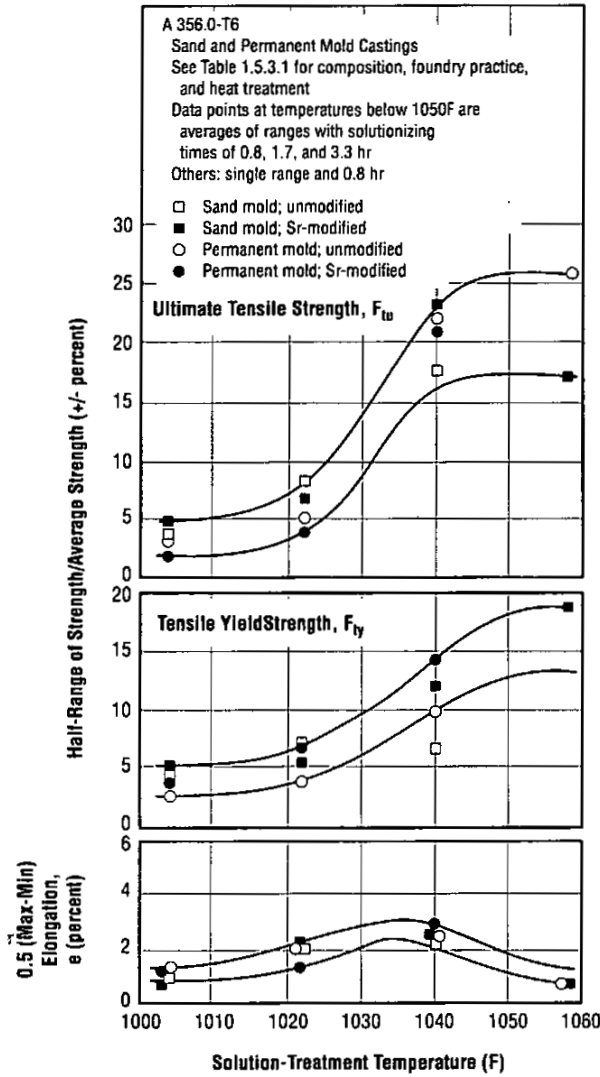


Figure 1.5.3.3 Effect of solution-treatment temperature on variability of tensile properties of sand and permanent mold castings (Ref. 36)

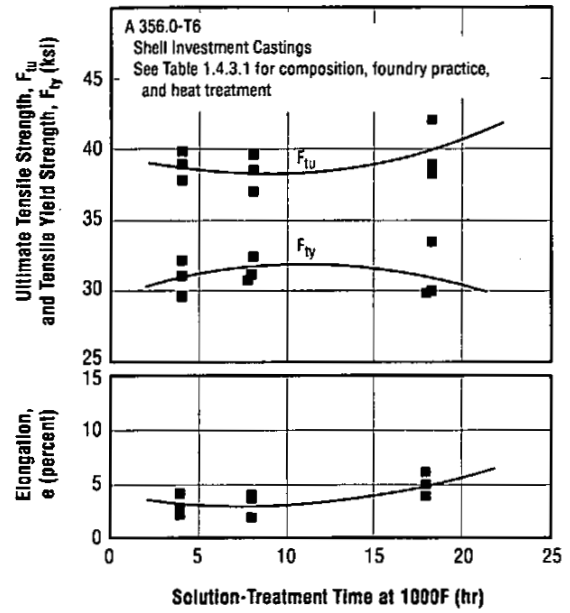


Figure 1.5.3.4 Effect of solution-treatment time on tensile properties of shell investment castings (Ref. 32)

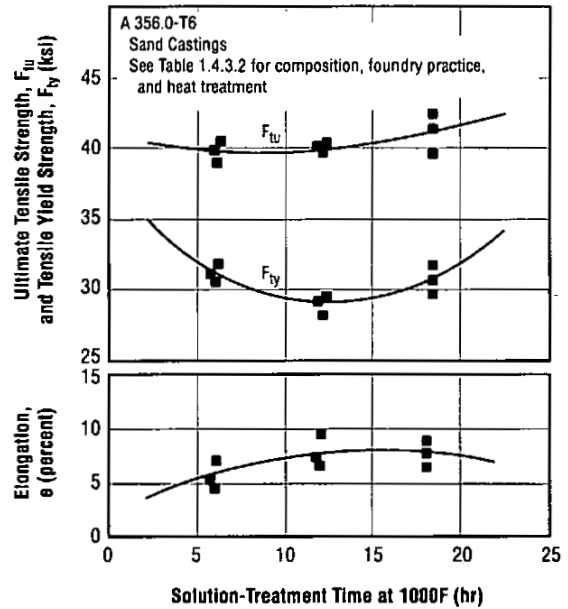


Figure 1.5.3.5 Effect of solution-treatment time on tensile properties of sand castings (Ref. 32)

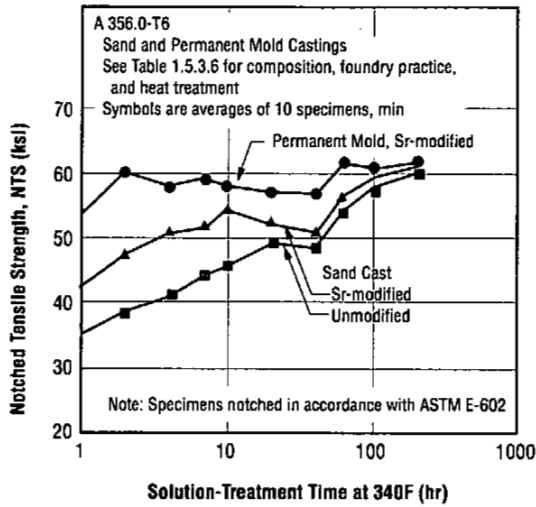


Figure 1.5.3.7 Effect of solution-treatment time on notched tensile strength of sand and permanent mold castings (Ref. 37)

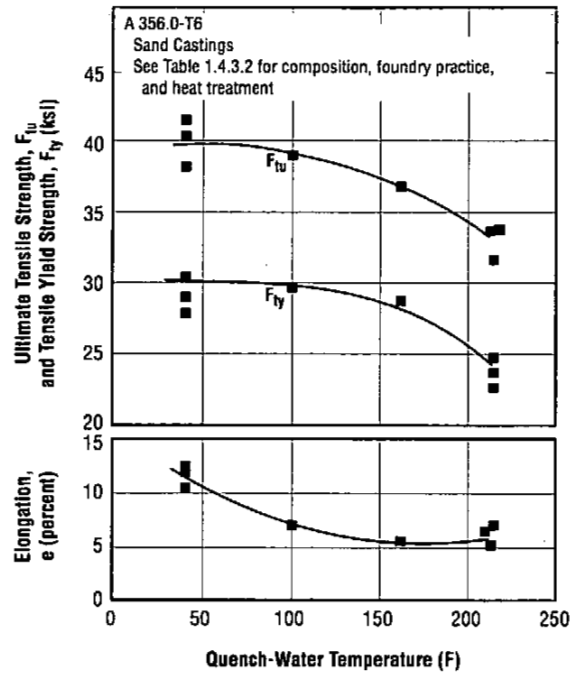


Figure 1.5.4.2 Effect of quench-water temperature on tensile properties of sand castings (Ref. 32)

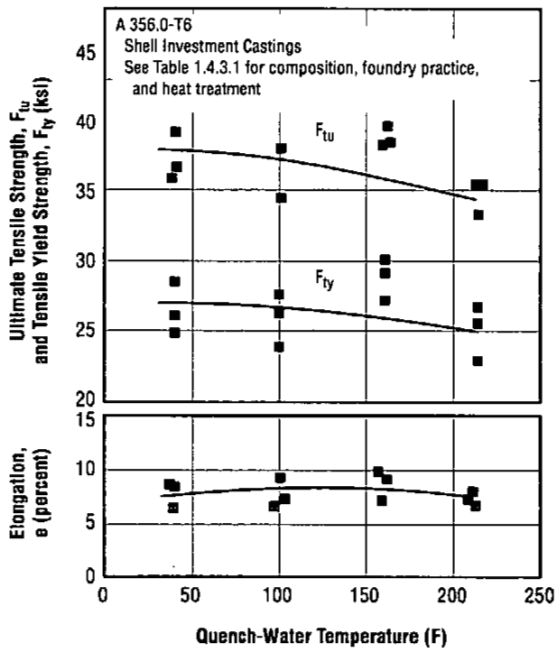


Figure 1.5.4.1 Effect of quench-water temperature on tensile properties of shell investment castings (Ref. 32)

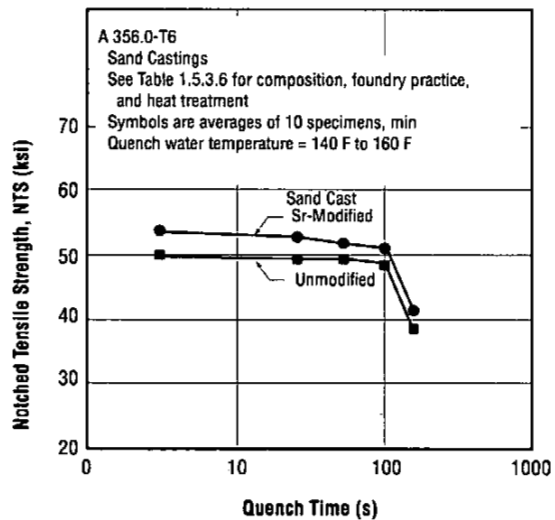


Figure 1.5.4.3 Effect of quench time on notched tensile strength of sand castings (Ref. 37)

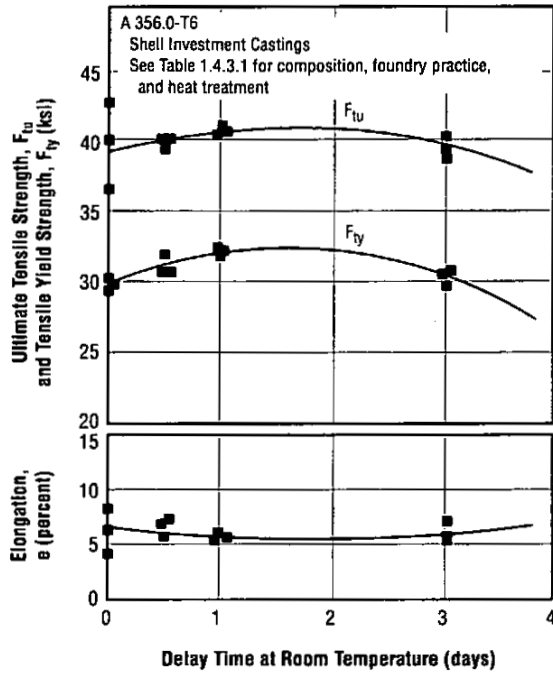


Figure 1.5.5.1 Effect of delay time between quench and the start of artificial aging on tensile properties of shell investment castings (Ref. 32)

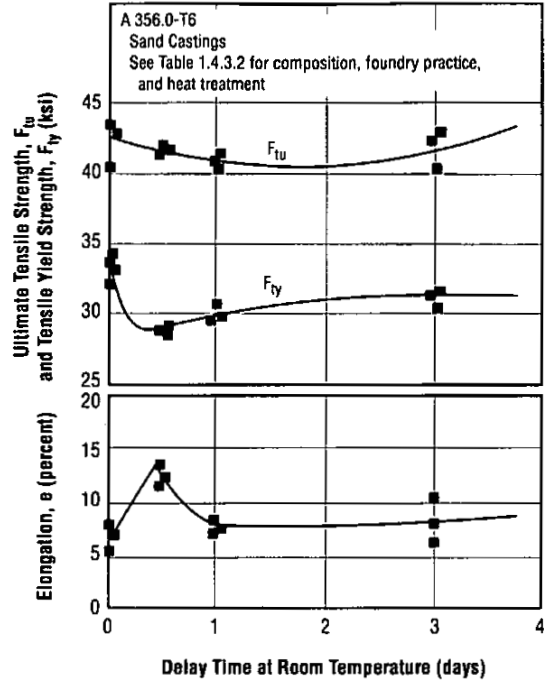


Figure 1.5.5.2 Effect of delay time between quench and the start of artificial aging on tensile properties of sand castings (Ref. 32)

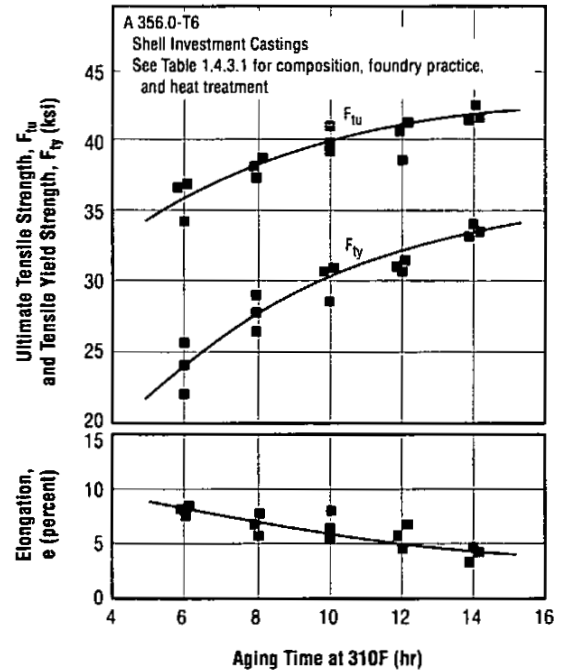


Figure 1.5.6.1 Effect of artificial aging time at 310 F on tensile properties of shell investment castings (Ref. 32)

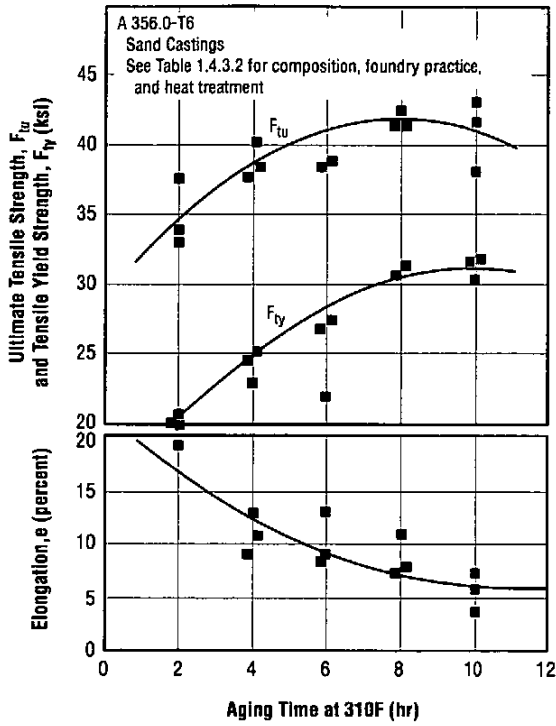


Figure 1.5.6.2 Effect of artificial aging time at 310 F on tensile properties of sand castings (Ref. 32)

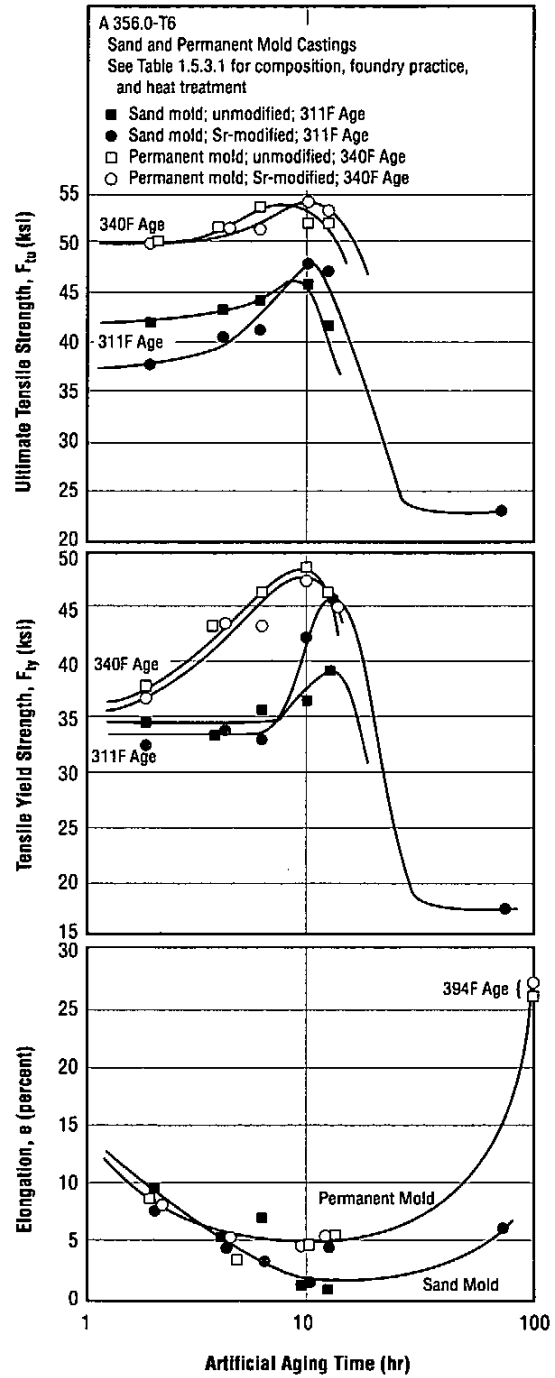


Figure 1.5.6.3 Effect of longer artificial aging times at 311 F and 340 F on tensile properties of sand and permanent mold castings (Ref. 35)

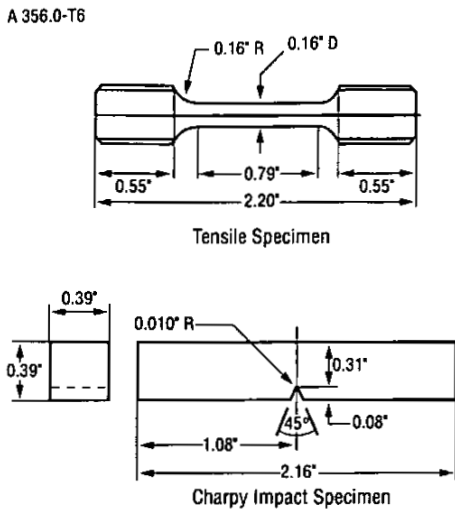


Figure 1.5.6.5 Configurations of tensile and Charpy impact specimens (Ref. 38)

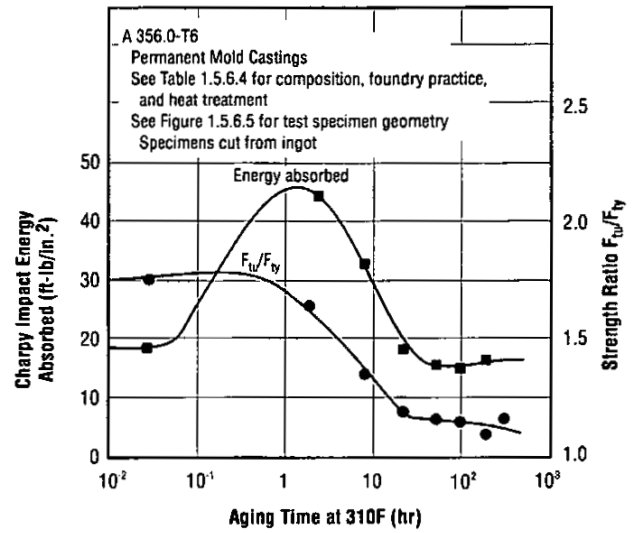


Figure 1.5.6.7 Effect of longer aging times at 310 F on Charpy impact energy absorbed and the ultimate-to-yield tensile strength ratio of permanent-mold castings (Ref. 38)

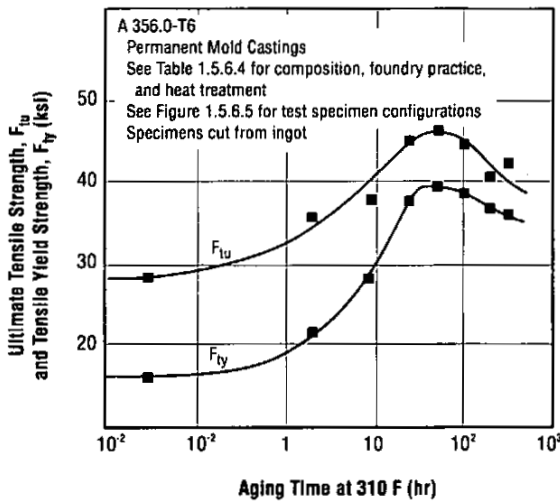


Figure 1.5.6.6 Effect of longer aging times at 310 F on tensile properties of permanent mold castings (Ref. 38)

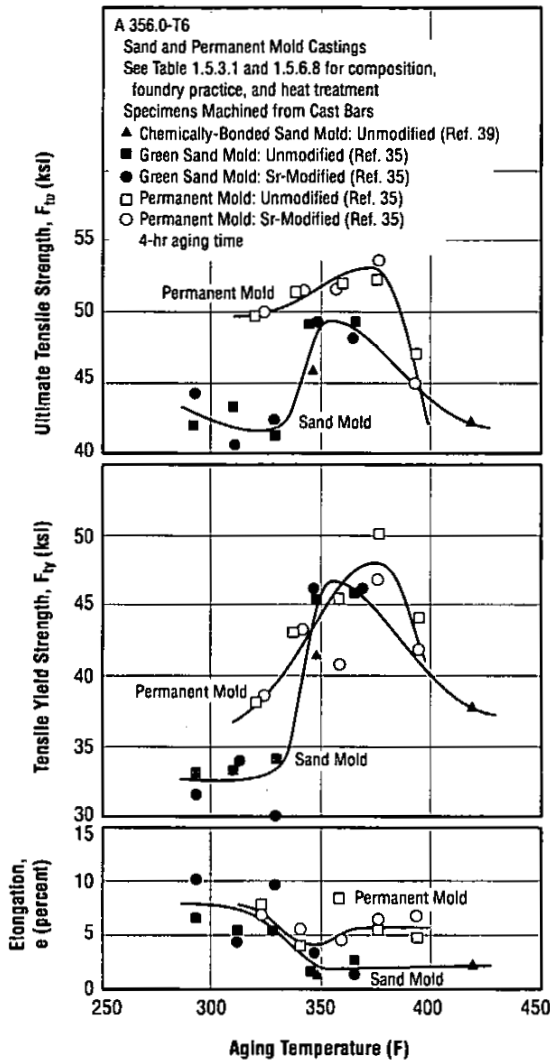


Figure 1.5.6.9 Effect of aging temperature on tensile properties of sand and permanent-mold castings (Refs. 35, 39)

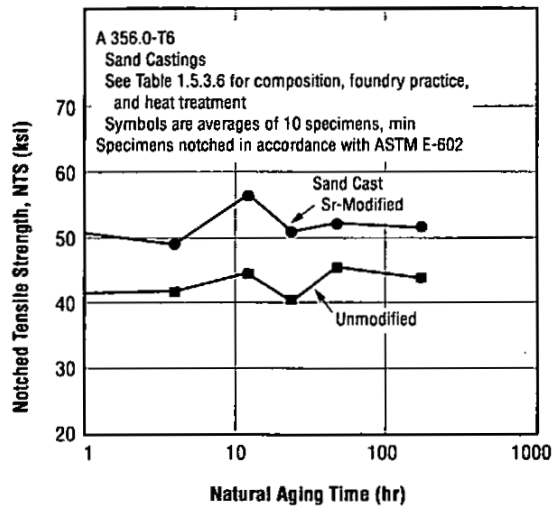


Figure 1.5.6.10 Effect of natural aging time on notched tensile strength of sand castings (Ref. 37)

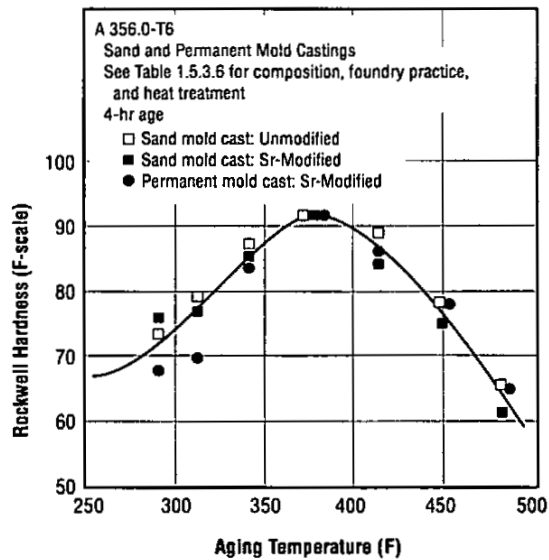


Figure 1.6.3.1 Effect of artificial aging temperature on hardness of sand and permanent mold castings (Ref. 40)

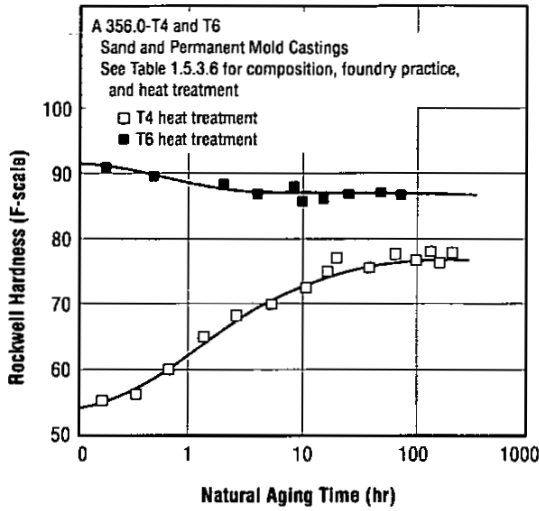


Figure 1.6.3.2 Effect of natural aging time on hardness of sand and permanent mold castings (Ref. 35)

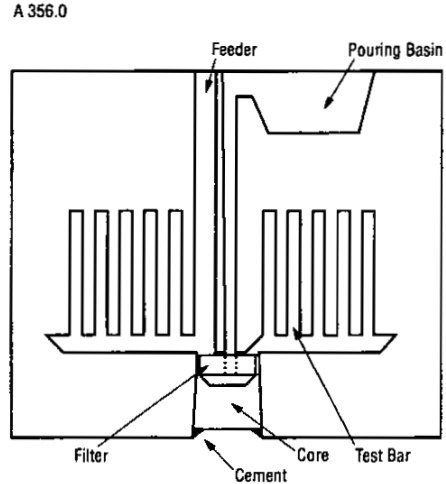


Figure 1.8.2.1 Schematic elevation view showing a typical installation of a ceramic filter in a mold (Ref. 39)

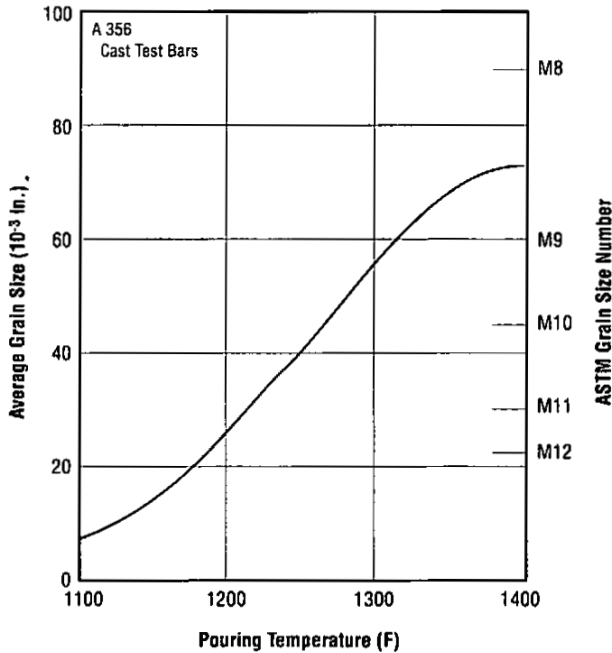


Figure 1.8.1.4 Effect of pouring temperature on grain size of 356 castings (Ref. 18)

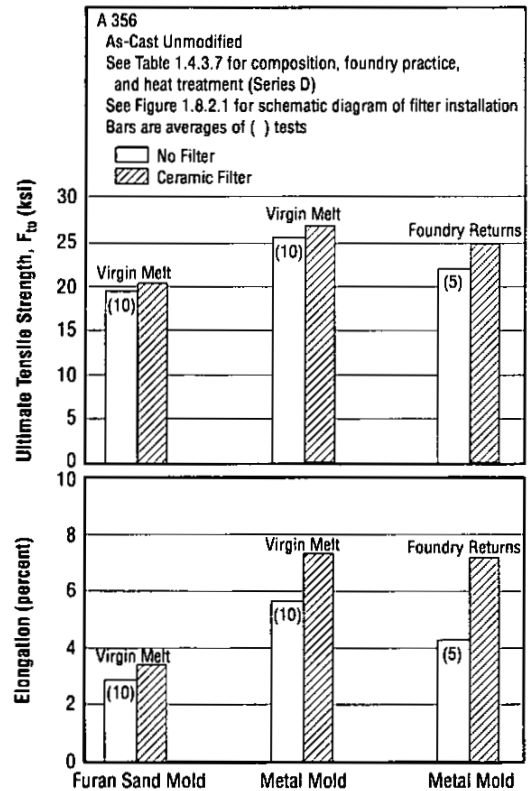


Figure 1.8.2.2 Effect of filtering on tensile properties of sand and metal mold castings (Ref. 33)

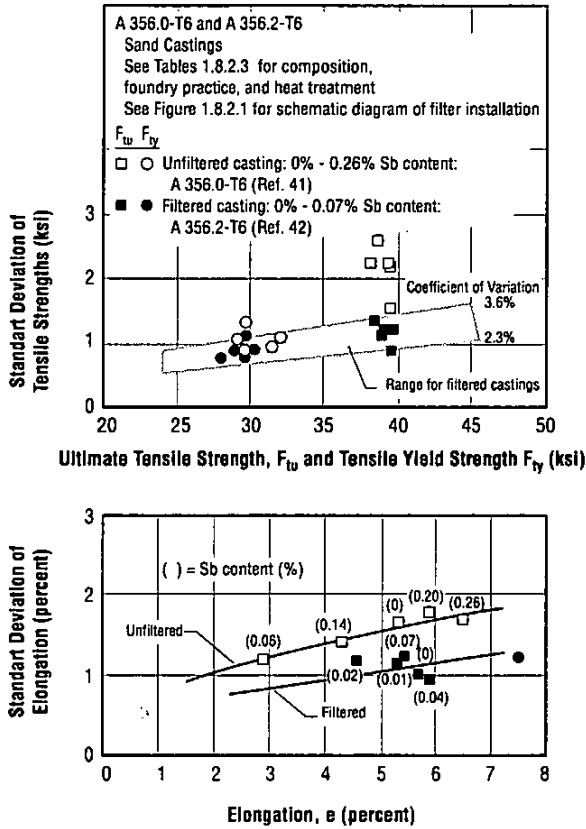


Figure 1.8.2.4 Effect of variability of tensile properties of sand mold castings (Refs. 41, 42)
 Note: Tensile testing conducted in accordance with ASTM B-557-84 procedures.

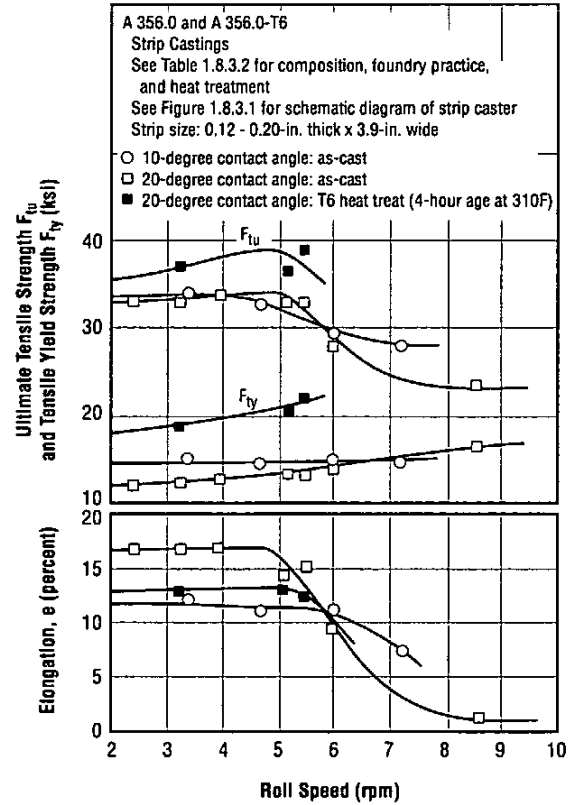


Figure 1.8.3.3 Effect of roll speed and contact angle on tensile properties of strip castings (Ref. 43)

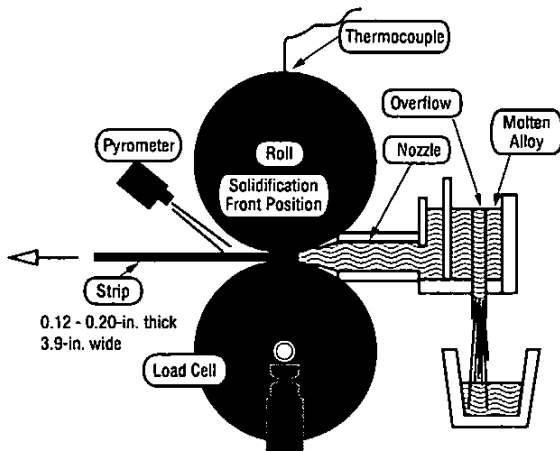


Figure 1.8.3.1 Schematic configuration of horizontal twin-roll strip caster (Ref. 43)

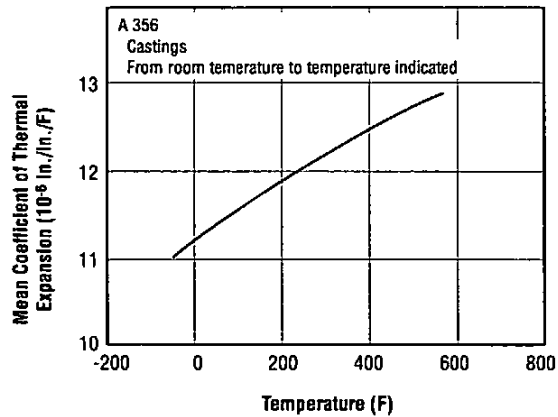


Figure 2.1.4 Mean coefficient of thermal expansion of 356 castings (Ref. 8)

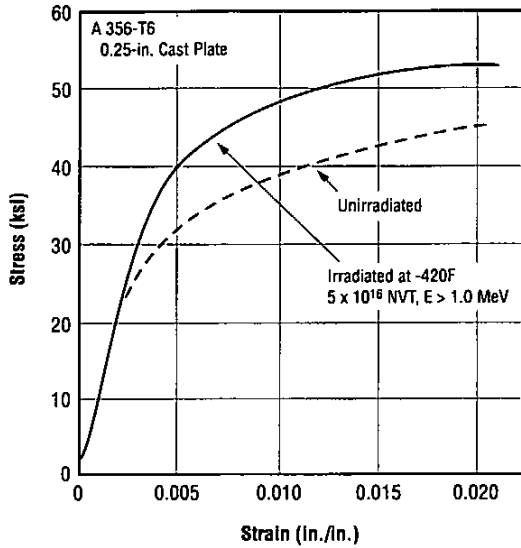


Figure 2.4.3 Typical effect of nuclear radiation at -420F on room-temperature stress-strain curves of cast plates (Ref. 21)

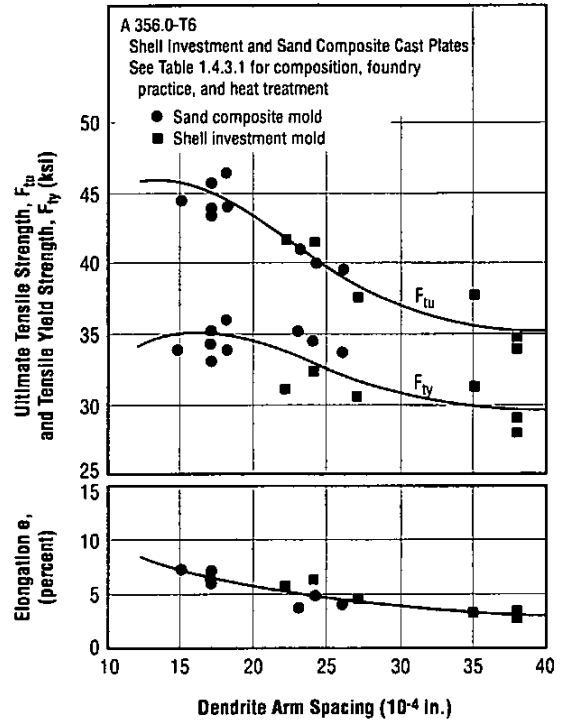


Figure 3.2.1.4 Effect of dendrite arm spacing on tensile properties of shell investment and sand castings (Ref. 32)

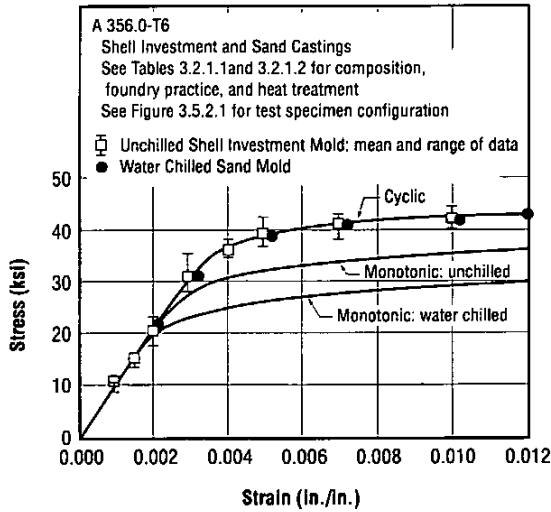
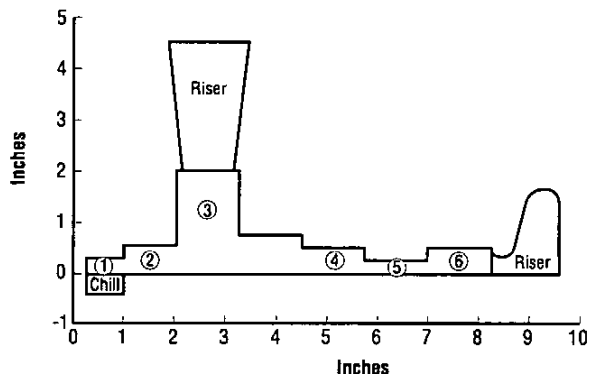


Figure 3.2.1.3 Monotonic and cyclic tensile stress-strain curves for shell investment and sand castings (Refs. 44, 45)

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A 356.0-T6
8-in. x 5-in. - 3.0 lbs



Location	Section Thickness (in.)	Description
1	1/4	Chilled Area
2	1/2	Adjacent to Chilled Area
3	2	Gate and Riser Area
4	1/2	Typical Section
5	1/4	Typical Section
6	1/2	Gate and Riser Area
—	0.505	Separately Cast Bar

Figure 3.2.1.6 Configuration of the Aluminum Association sand-test cast plates (Ref. 52)

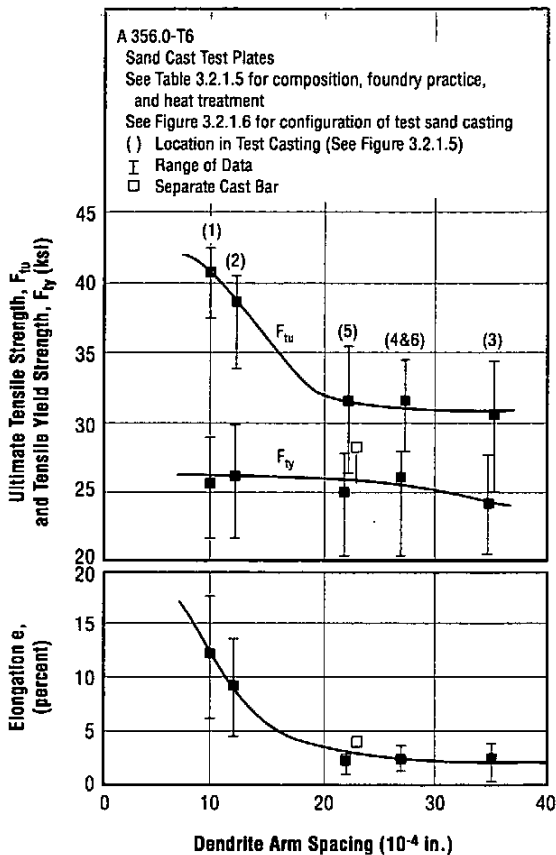


Figure 3.2.1.7 Effect of dendrite arm spacing on tensile properties of sand cast test plates from at least six commercial foundries (Ref. 52)

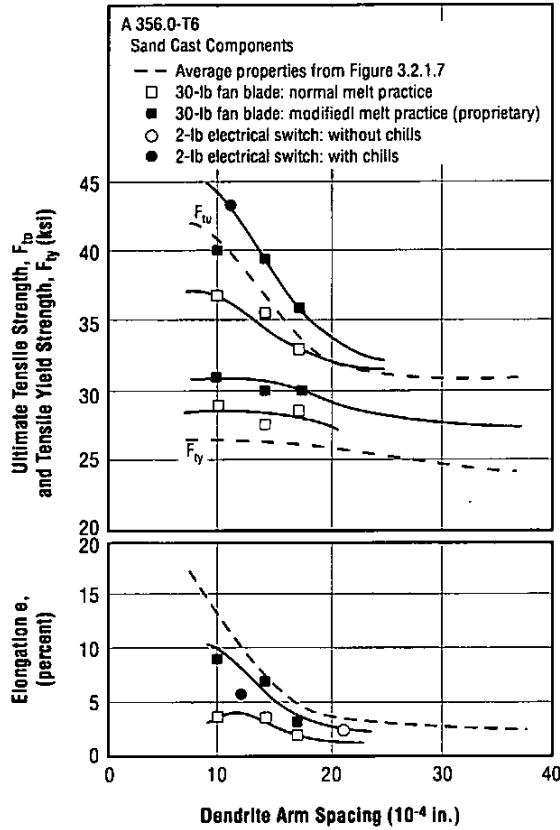


Figure 3.2.1.8 Effect of dendrite arm spacing on tensile properties of sand cast components from a commercial foundry following normal and modified melt processes (Ref. 54)

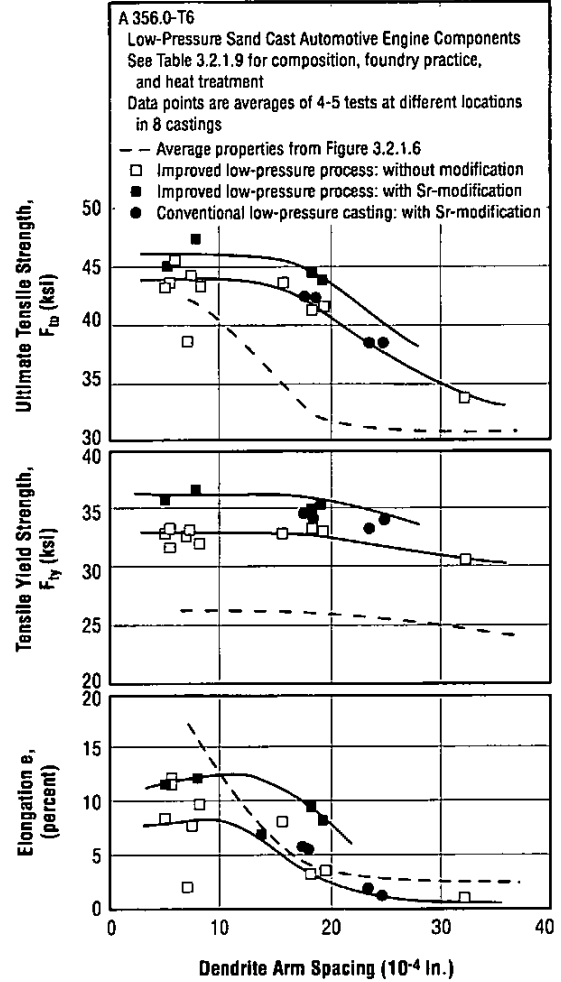


Figure 3.2.1.10 Effect of dendrite arm spacing on tensile properties of automotive engine component sand castings from a commercial foundry following conventional and improved low-pressure processes (Ref. 55)

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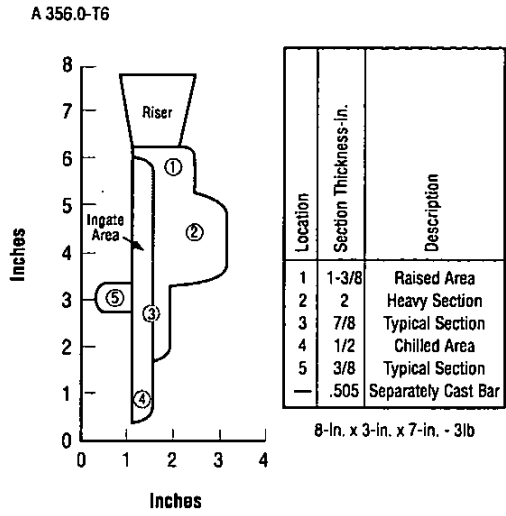


Figure 3.2.1.12 Configuration of the Aluminum Association permanent-mold cast plates (Ref. 53)

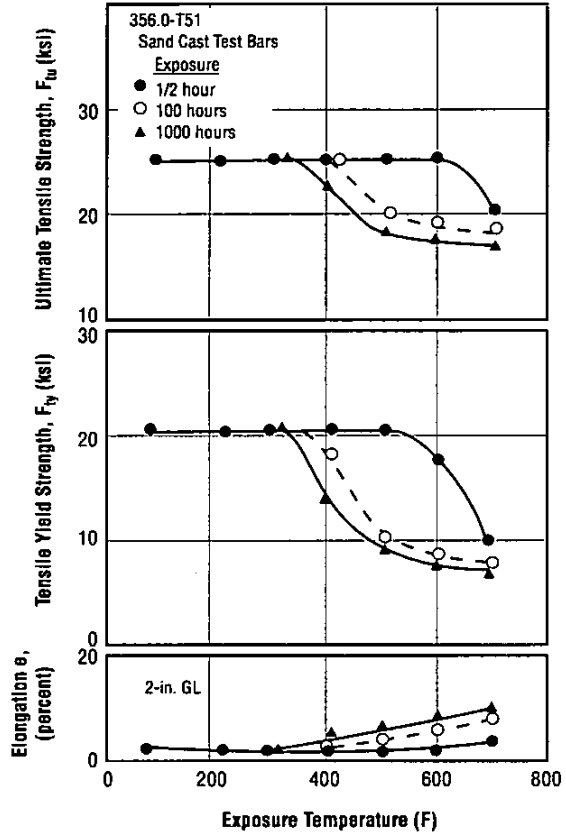


Figure 3.2.1.14 Effect of exposure to elevated temperature on room temperature tensile properties of sand-cast test bars in T51 condition (Ref. 10)

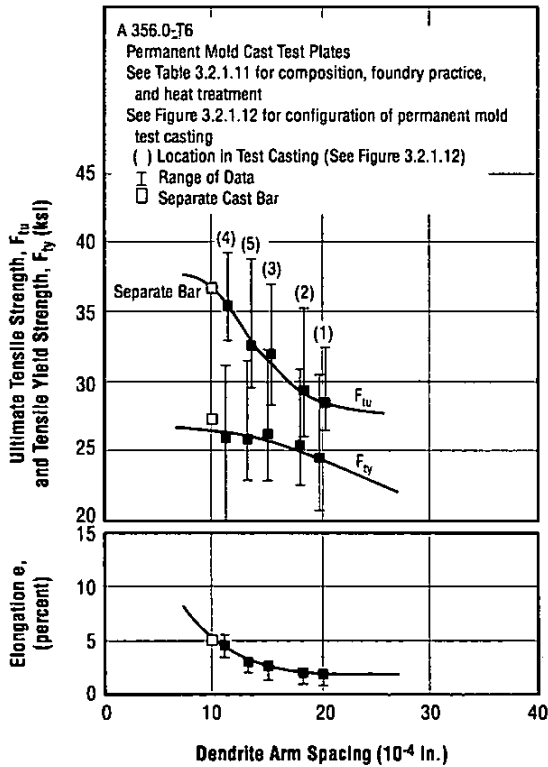


Figure 3.2.1.13 Effect of dendrite arm spacing on tensile properties of permanent-mold cast test plates from seven commercial foundries (Ref. 53)

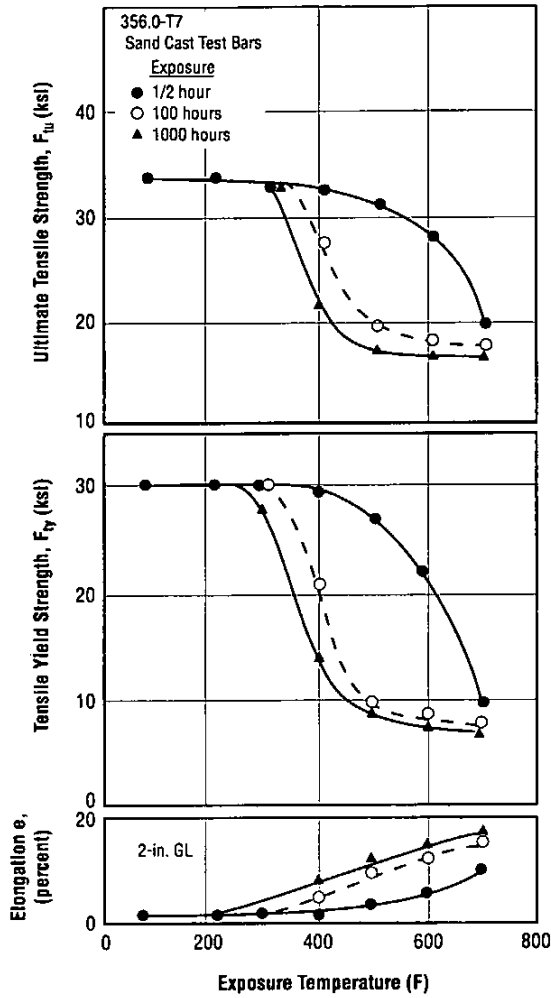


Figure 3.2.1.15 Effect of exposure to elevated temperature on room temperature tensile properties of sand cast test bars in T7 condition (Ref. 9)

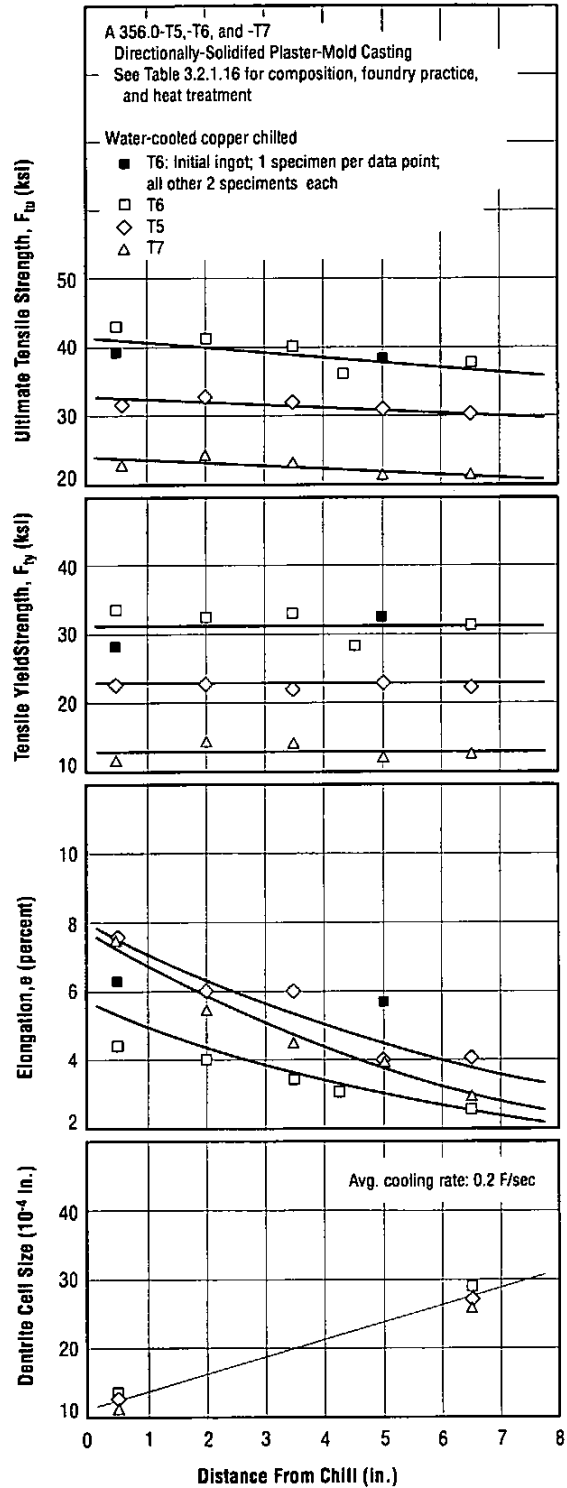
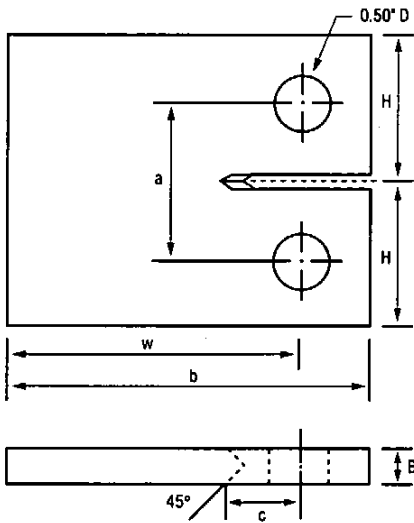


Figure 3.2.1.17 Effect of cooling rate and heat treatment on tensile properties of specimens cut from directionally-solidified water-chilled ingots (Ref 64).

A 356.0-T6



Specimen Type	Casting	B	H	W	a	b	c
Fracture toughness	W	0.36	1.68	2.80	-	3.50	0.78
		0.75	1.68	2.80	-	3.50	0.78
	X, Y, Z	0.36	1.37	2.29	-	2.94	0.75
		0.80	1.32	2.20	-	2.76	0.99
Crack propagation	W	0.36	1.68	2.80	-	3.50	0.78
	X, Y, Z	0.36	1.37	2.80	1.54	3.50	0.78

Figure 3.2.7.2.1 Configurations of compact tensile (CT) specimens for fracture toughness and crack propagation tests (Refs. 45, 50)

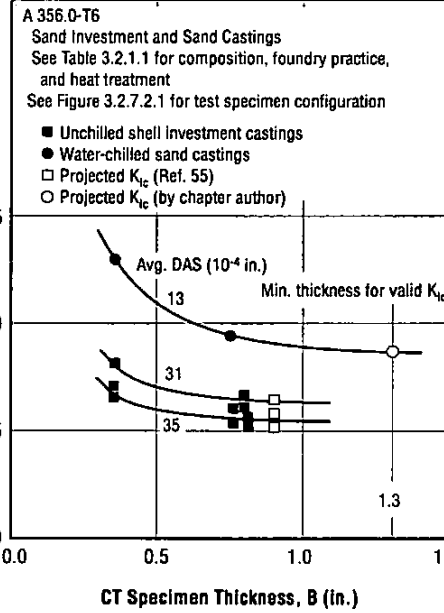


Figure 3.2.7.2.2 Effect of thickness on fracture toughness of compact tensile (CT) specimens from unchilled shell investment and water-chilled sand castings (Refs. 45, 50)

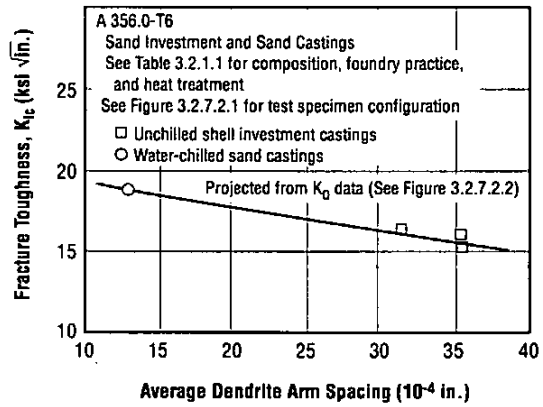


Figure 3.2.7.2.3 Effect of dendrite arm spacing on plane-strain fracture toughness projected from K_Q test data for unchilled shell investment and water-chilled sand castings

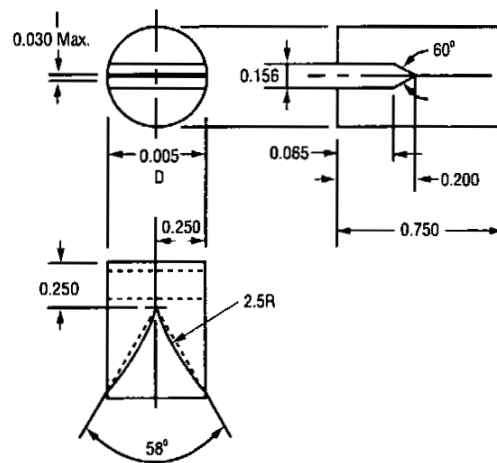
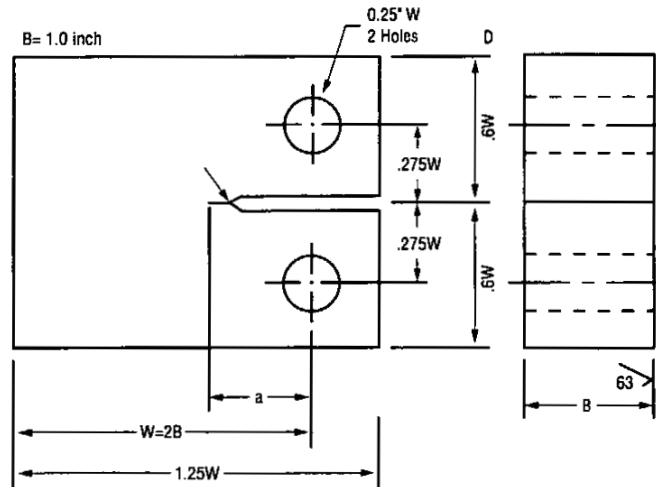


Figure 3.2.7.2.4 Configurations of compact tensile (CT) and short rod (SR) specimens for fracture toughness tests (Refs. 64)

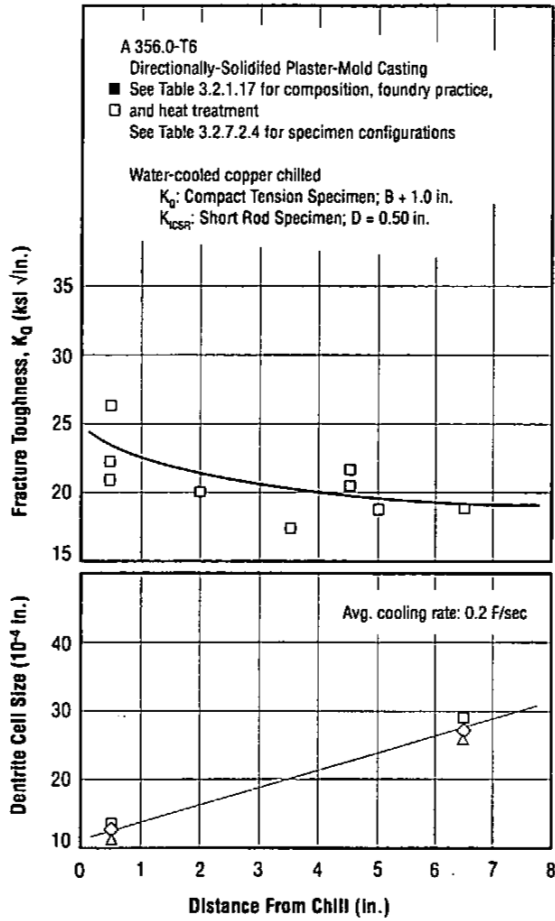


Figure 3.2.7.2.5 Effect of cooling rate on fracture toughness of specimens cut from directionally-solidified water-chilled ingots (Ref 64).

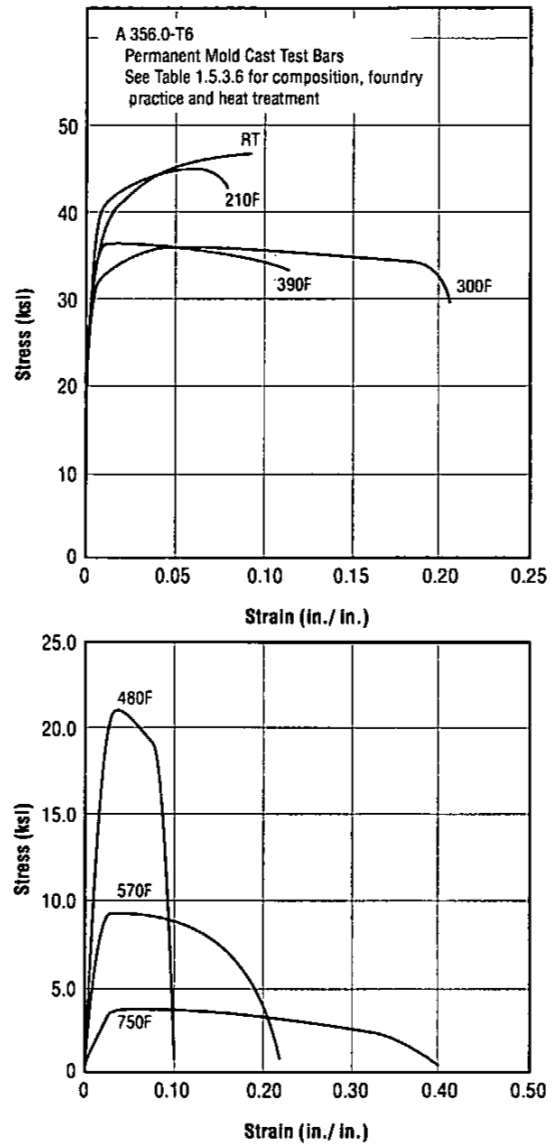


Figure 3.3.1.1 Monotonic stress-strain curves for permanent-mold cast test bars at various temperatures after an exposure time of one hour (Ref. 40)

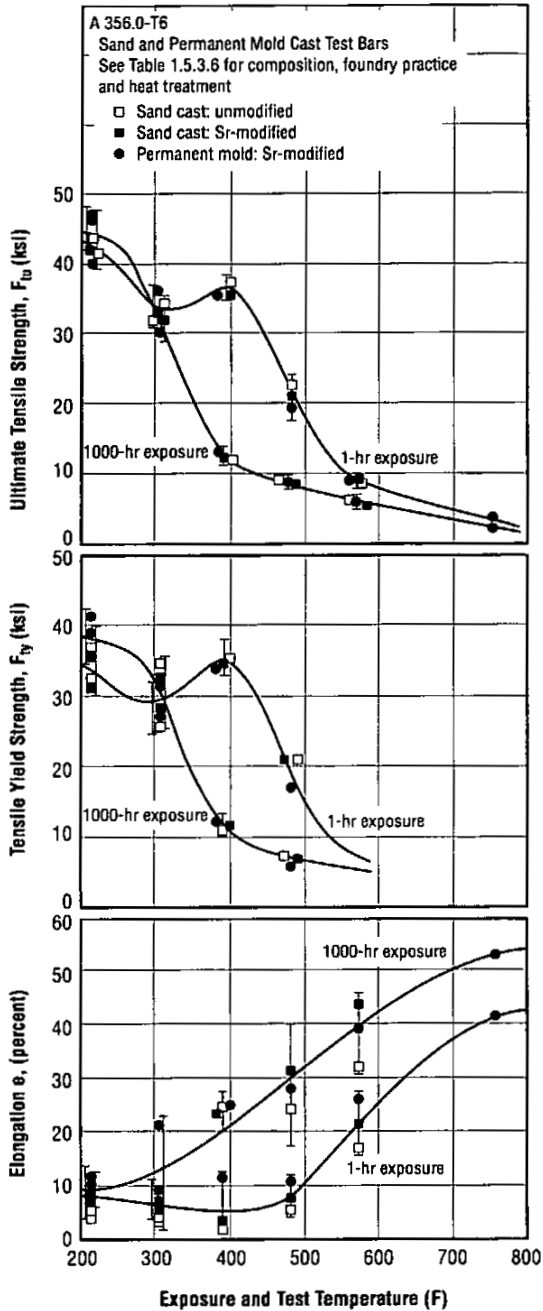
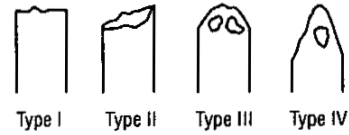


Figure 3.3.1.2 Effect of elevated temperature exposure on the tensile properties of sand and permanent-mold cast test bars (Ref. 40)

A 356.0-T6 Sand and Permanent Mold Cast Test Bars See Table 1.5.3.6 for composition, foundry practice and heat treatment



Temperature (F)	1 hr. Exposure			1000 hr. Exposure		
	SCU	SCM	PM	SCU	SCM	PM
210	I	I	I	I	I	I
300	I	I	I	I	I	II
390	I	I	II	II	II	II
480	II	II	III	II	II	III
570	II	II	IV	III	III	IV
750			IV			IV

SCU= sand cast, unmodified; SCM= sand cast, modified; PM= permanent mold.

Figure 3.3.1.3 Classification of fracture appearance of tensile test specimens from sand and permanent-mold cast test bars after exposure and testing at elevated temperature (Ref. 40)

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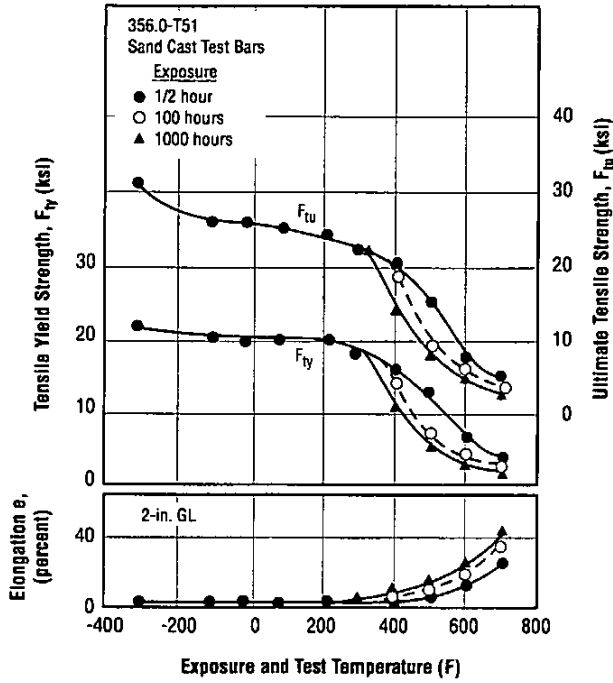


Figure 3.3.1.4 Effect of exposure and testing at elevated temperature on tensile properties of sand cast test bars in T51 condition (Ref. 10)

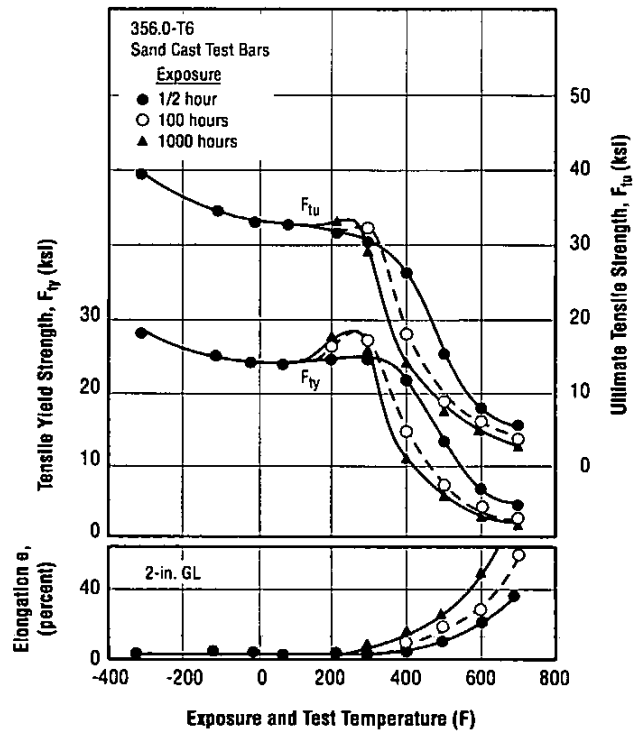


Figure 3.3.1.5 Effect of exposure and testing at elevated temperature on tensile properties of sand cast test bars in T6 condition (Ref. 13)

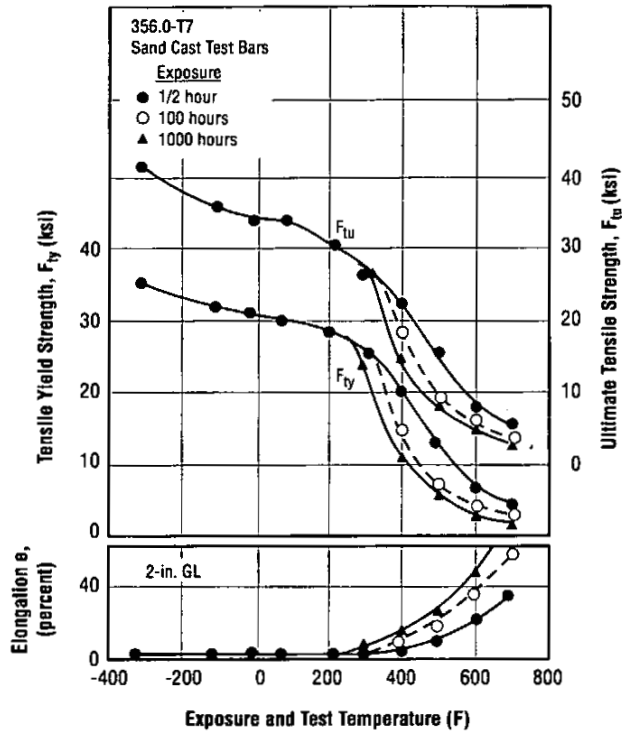


Figure 3.3.1.6 Effect of exposure and testing at elevated temperature on tensile properties of sand cast test bars in T7 condition (Ref. 9)

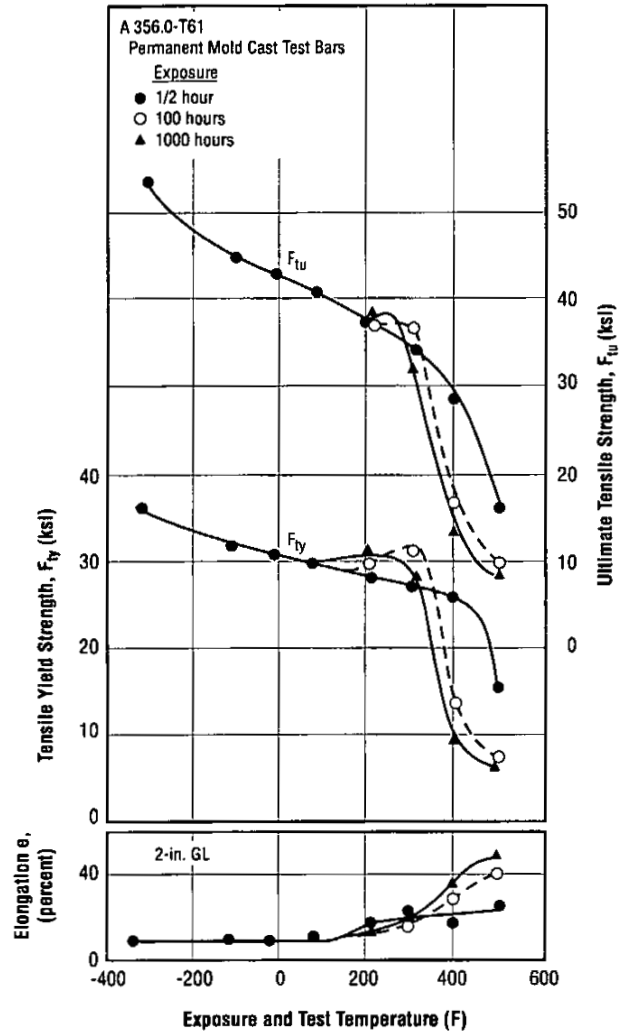


Figure 3.3.1.7 Effect of exposure and testing at elevated temperature on tensile properties of permanent-mold cast test bars in T61 condition (Ref. 12)

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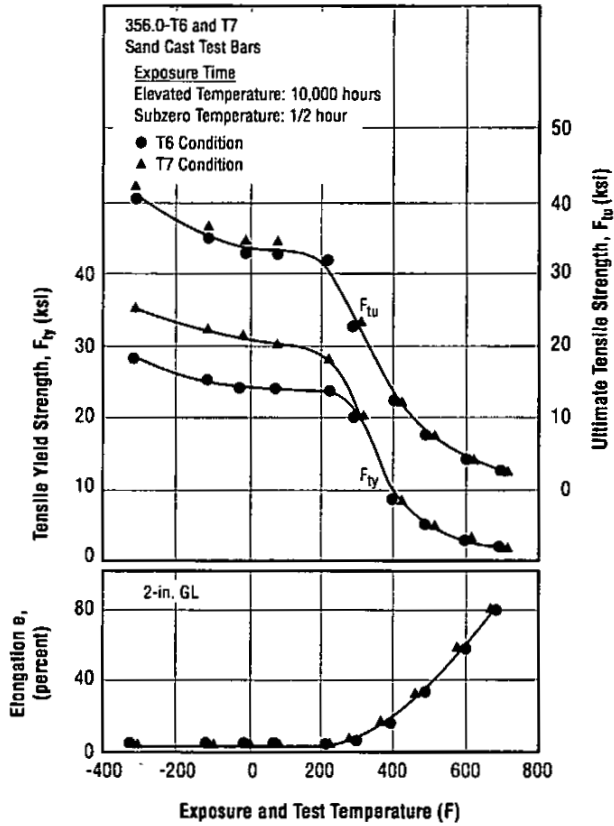


Figure 3.3.1.8 Effect of exposure and test temperature on tensile properties of sand cast test bars in T6 and T7 condition (Ref. 20)

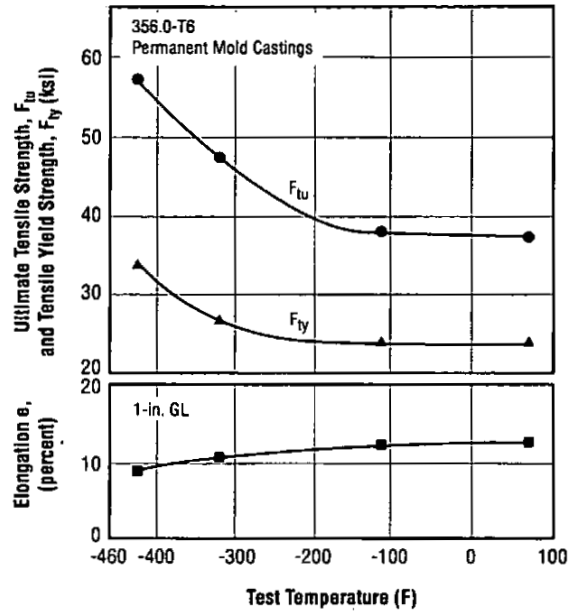


Figure 3.3.1.9 Effect of low test temperature on tensile properties of permanent mold castings in T6 condition (Ref. 17)

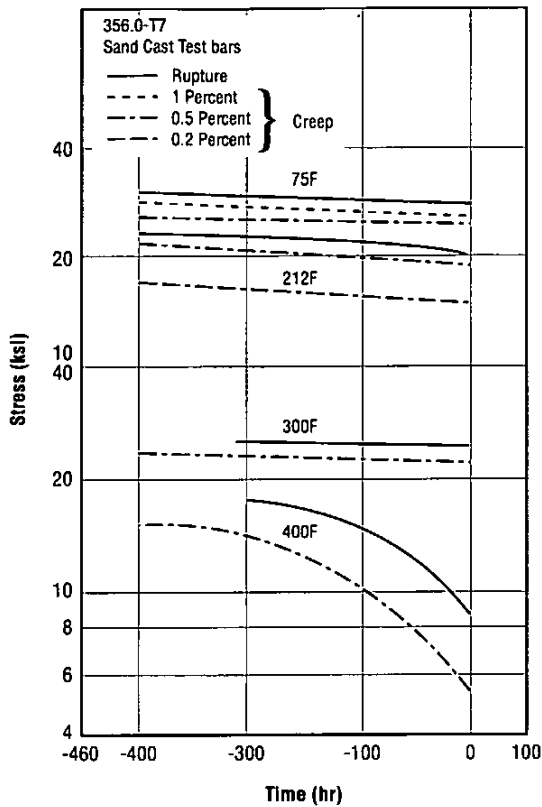


Figure 3.4.1 Creep and creep-rupture curves from room temperature to 400F for sand cast test bars in T7 condition (Ref. 9)

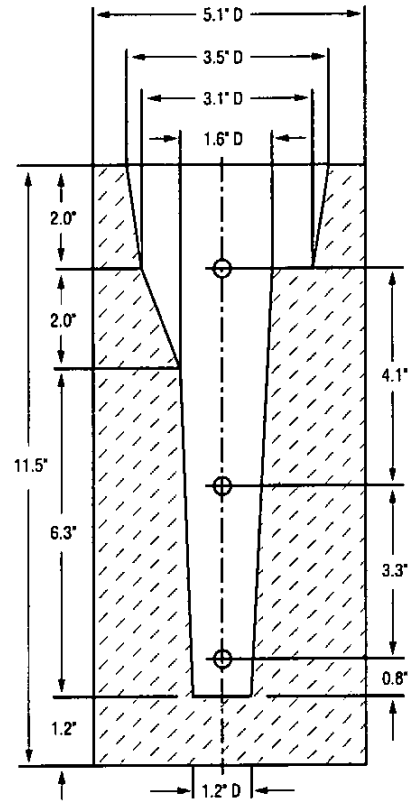


Figure 3.5.1.2 Configuration of CO₂ sand mold for casting cantilever specimens tested in rotating bending fatigue in Ono- and Krause-type machines (Ref. 56)

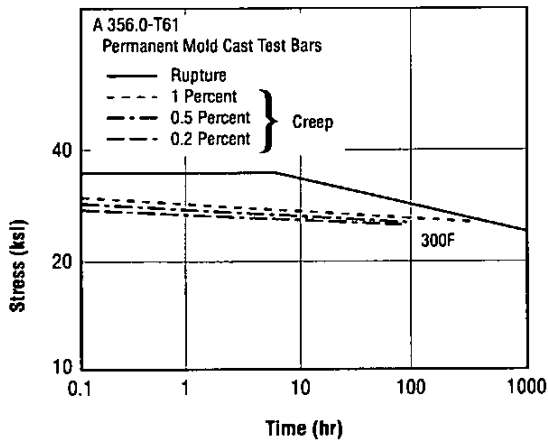


Figure 3.4.2 Creep and creep-rupture curves at 300F for permanent mold cast test bars in T61 condition (Ref. 12)

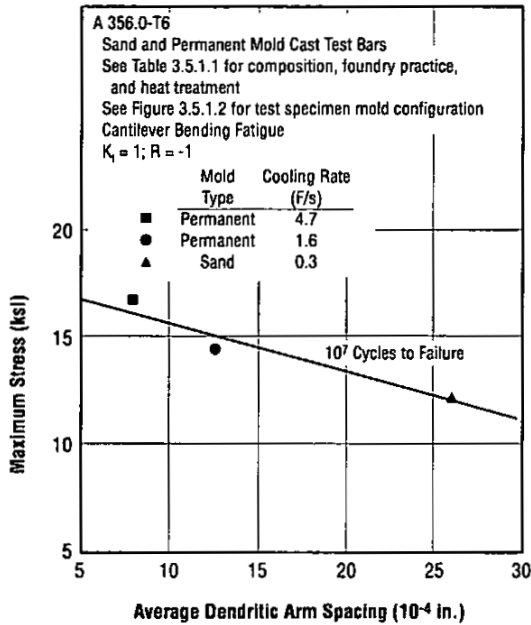


Figure 3.5.1.3 Effect of dendrite arm spacing on high-cycle fatigue strength at 10⁷ cycles to failure (Ref. 56)

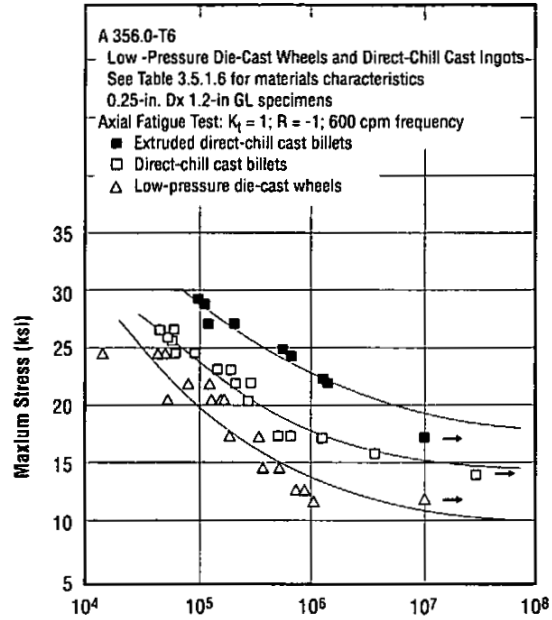


Figure 3.5.1.7 Effect of casting method on stress-fatigue life curves for smooth specimens from die-cast wheels and from direct-chill cast billets, with and without extrusions (Ref. 62)

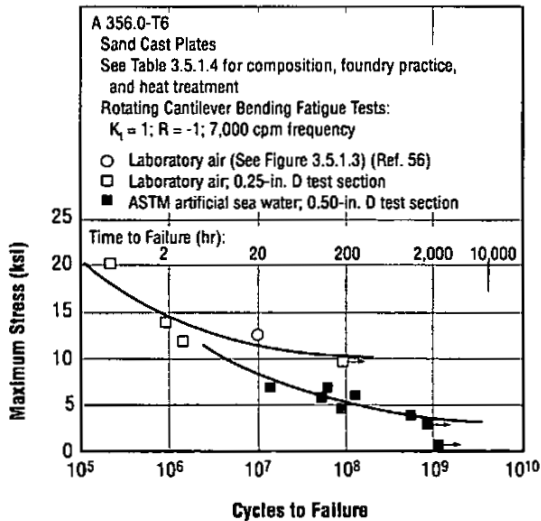


Figure 3.5.1.5 Effect of exposure to ASTM artificial sea water on S-N curves for smooth specimens from sand cast plates (Ref. 57)

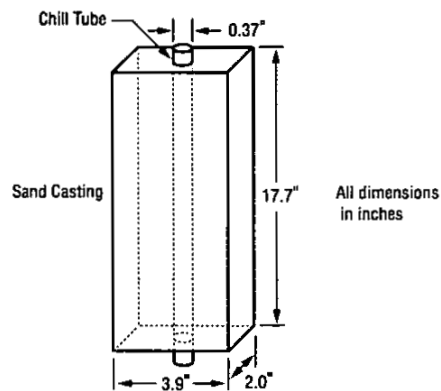
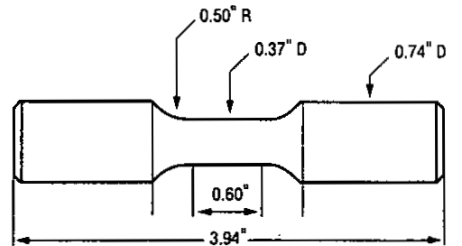


Figure 3.5.2.1 Configurations of specimens for tensile and axial-fatigue tests and configuration of water-chilled sand castings (Refs. 44, 45)

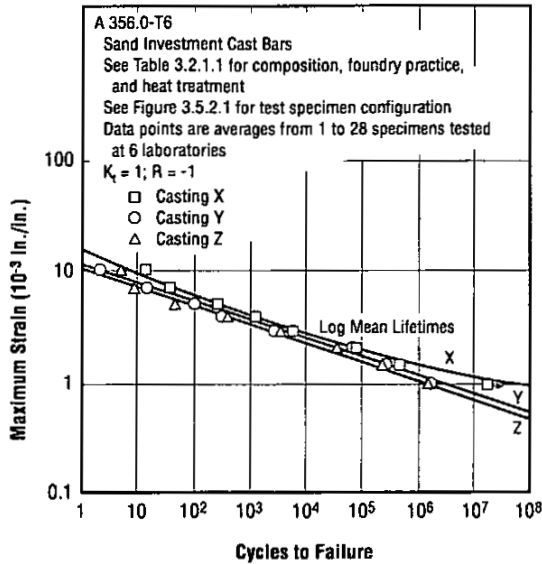


Figure 3.5.2.2 Strain-fatigue life curves for smooth axial fatigue specimens from three castings poured at different mold temperatures (Refs. 44, 46, 47)

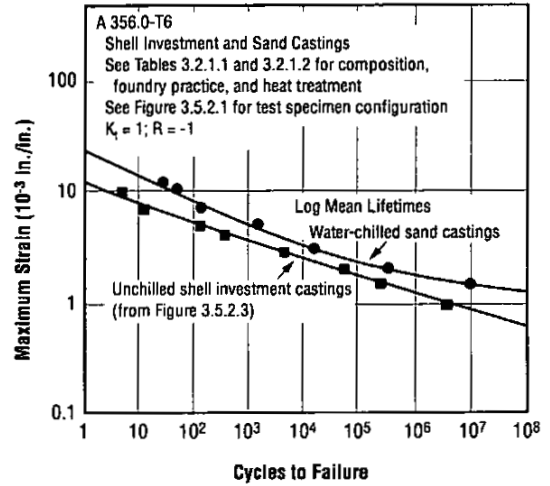


Figure 3.5.2.4 Comparison of strain-fatigue life curves for smooth axial fatigue specimens from unchilled shell-investment castings and water-chilled sand castings (Ref. 45)

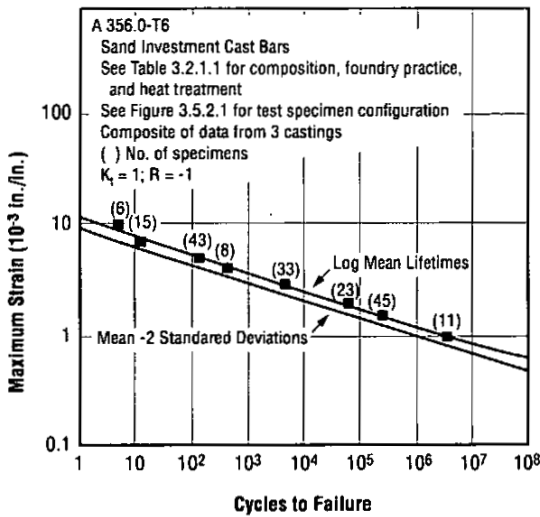


Figure 3.5.2.3 Composite of strain-fatigue life curves for smooth axial fatigue specimens from three shell investment castings poured at different mold temperatures, showing mean fatigue strength and mean-minus-2 standard deviations fatigue strength (Refs. 44, 46, 47)

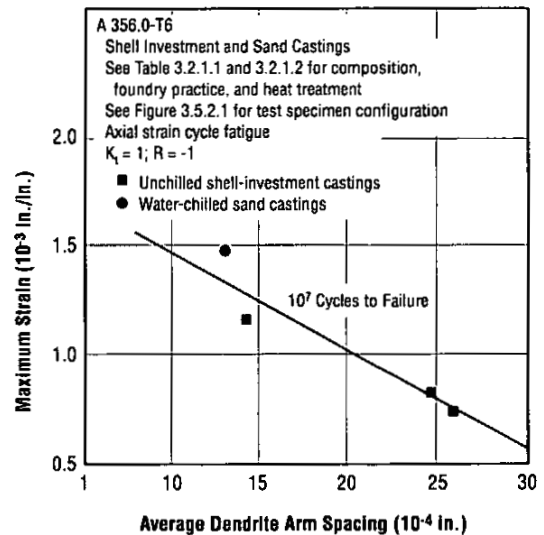


Figure 3.5.2.5 Effect of dendrite arm spacing on axial strain-cycling fatigue strength at 10^7 cycles to failure of smooth specimens from unchilled shell-investment castings and water-chilled sand castings (Refs. 44-47)

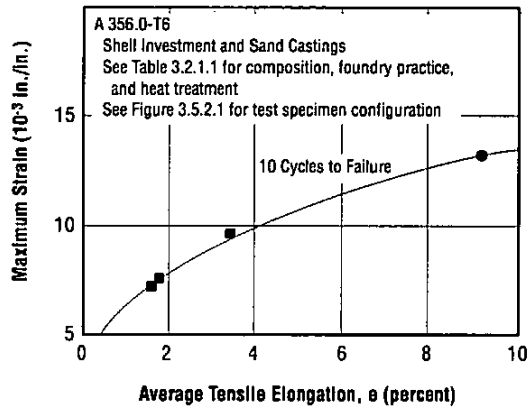


Figure 3.5.2.6 Effect of tensile elongation on axial strain-cycling fatigue strength at 10 cycles to failure of smooth specimens from unchilled shell investment castings and water-chilled sand castings (Refs. 44-47)

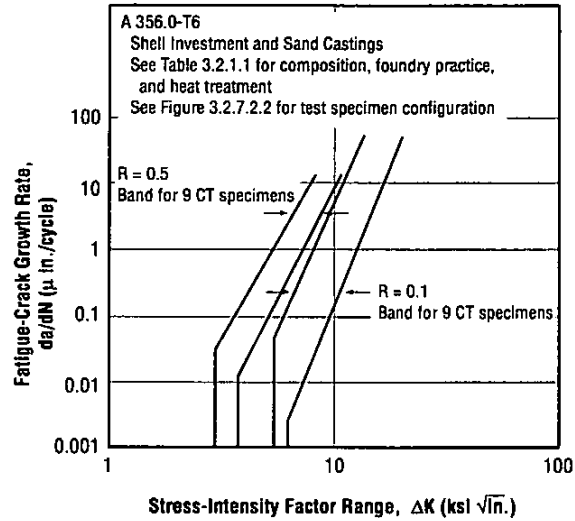


Figure 3.5.3.1 Scatter bands of fatigue-crack growth rates at two R-ratios for CT specimens from three shell-investment castings and one water-chilled sand casting, containing data from several laboratories (Refs. 45-49)

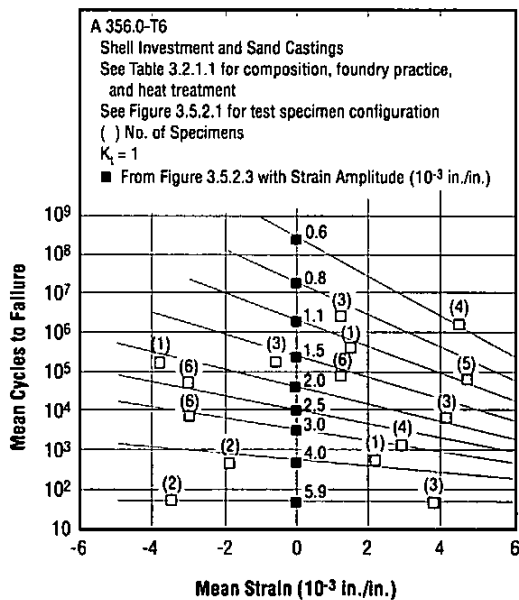


Figure 3.5.2.7 Effect of mean strain on axial strain-fatigue life behavior of smooth specimens from shell-investment castings (calculated from data in Ref. 51)

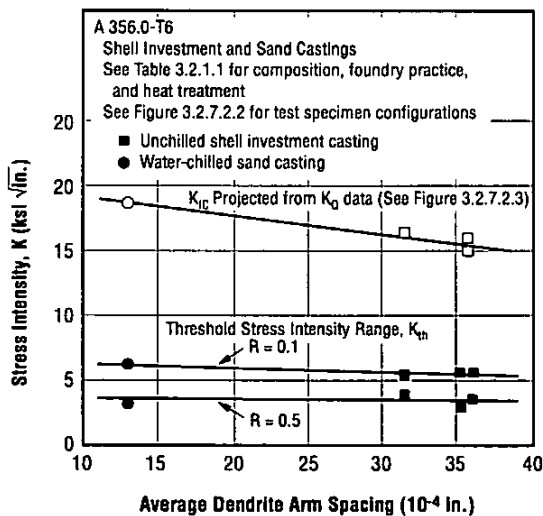


Figure 3.5.3.2 Effect of dendrite arm spacing on crack-propagation threshold stress intensity at two R-ratios and on projected plane-strain fracture toughness of shell-investment and water-chilled sand castings (Refs. 45-49)

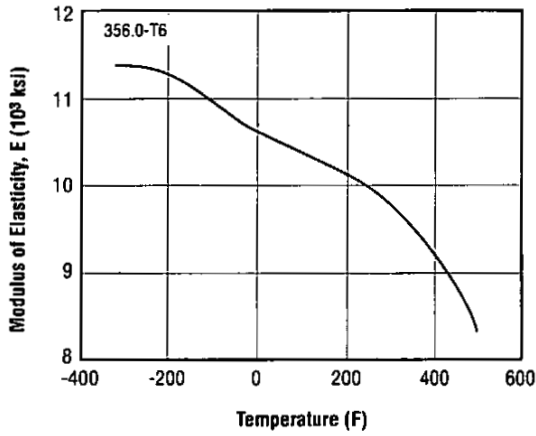


Figure 3.6.2 Modulus of elasticity at various temperatures (Ref. 11)

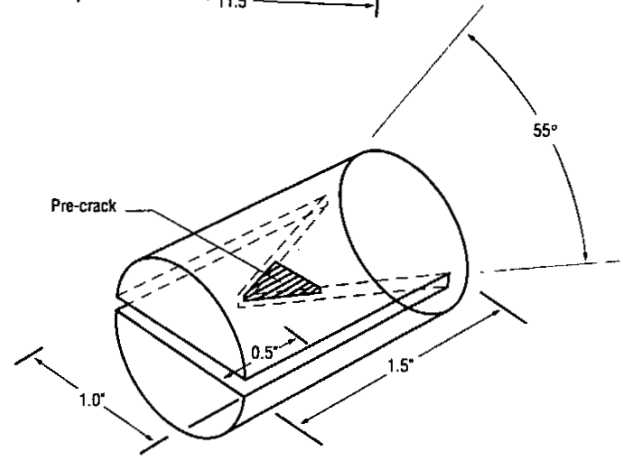
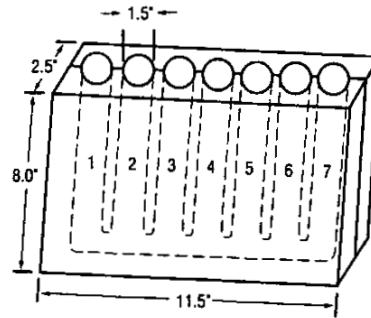


Figure 4.1.1.2 Configurations of permanent steel molds and fracture toughness specimens used for testing the effects of hot isostatic pressing (HIP) (Ref. 58)

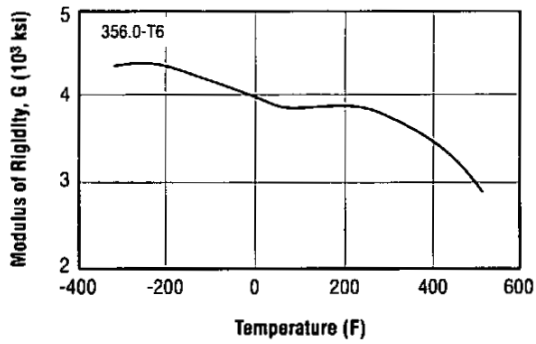


Figure 3.6.3 Modulus of rigidity at various temperatures (Ref. 11)

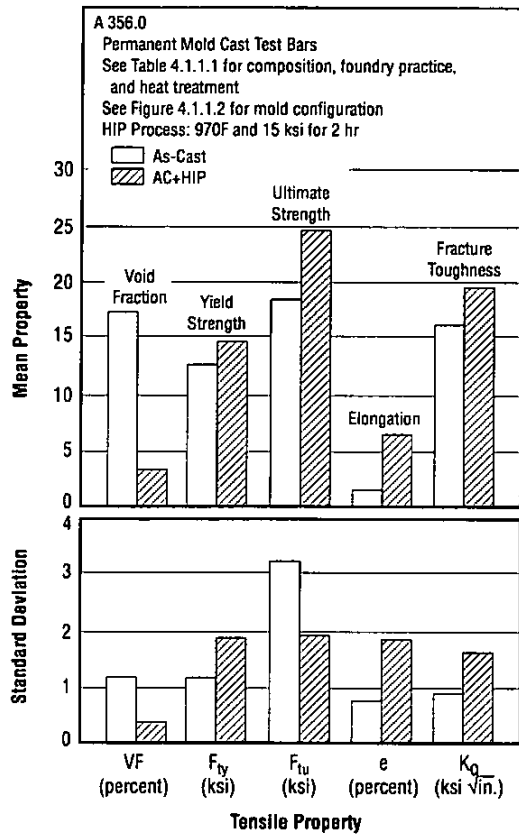


Figure 4.1.1.3 Effect of hot isostatic pressing (HIP) on void fraction and tensile properties of test specimens as-cast in permanent steel molds (Ref. 58)

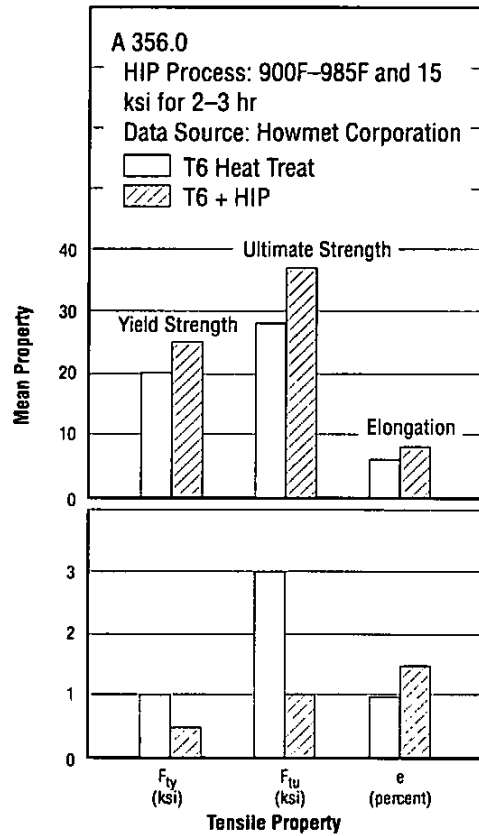


Figure 4.1.1.4 Effect of hot isostatic pressing (HIP) on tensile properties of test specimens heat-treated to the T6 condition (Ref. 68)

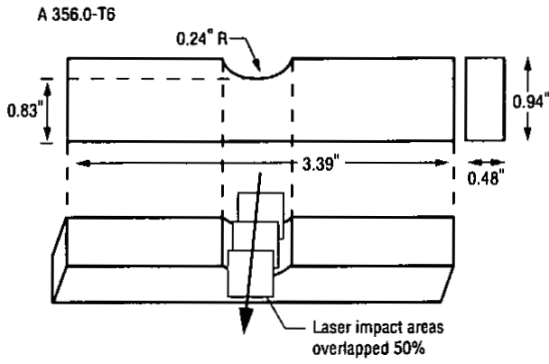


Figure 4.1.2.2 Configuration of notched fatigue test specimens loaded in three-point bending to test the effects of laser shock processing (LSP) on sand castings, showing overlapping impact areas at root of notch (Ref. 59)

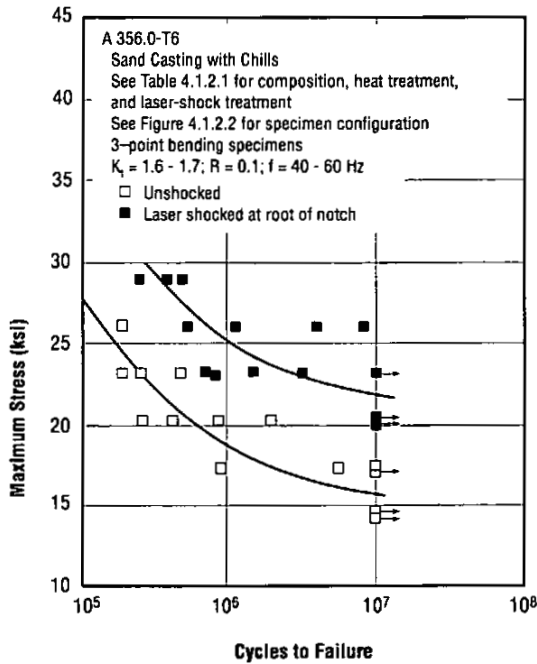


Figure 4.1.2.3 Effect of laser shock processing (LSP) on stress-fatigue life curves for notched bar specimens from chilled sand castings (Ref. 59)

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1. GENERAL

Aluminums 356 and A356 are heat treatable aluminum-silicon-magnesium casting alloys whose properties are primarily determined by a high silicon content in combination with magnesium. 356 is the conventional cast alloy, while castings of A356 are classified as premium quality castings, which are guaranteed to meet a specified high level of mechanical properties. Premium quality results from low impurity content (lower amount of iron) and advanced foundry practices.

Both 356 and A356 possess excellent castability, pressure tightness, and resistance to hot cracking. Fluidity is good and the tendency toward shrinkage is low. Resistance to corrosion by salt spray is high. Weldability is good by fusion techniques if proper procedures are employed. A356 exhibits higher tensile strength and ductility than does the 356 alloy.

356 is available in the form of sand and permanent mold castings, while A356 is primarily a permanent mold casting alloy. Data in the following sections apply to 356 unless specifically noted A356.

1.01 Commercial Designation
 356
 A356

1.02 Alternate Designation
 ASTM SG70A (356 alloy).
 ASTM SG70B (A356 alloy) (37).

1.03 Specifications
 Table 1.03.

TABLE 1.03

AMS	Alloy	Form	Similar Specification*
4217D	356-T6	Castings, sand	QQ-A-601, Class 3M
4260B	356-T6	Castings, investment	
4261	356-T51	Castings, investment	
4284D	356-T6	Castings, permanent mold	QQ-A-596, Class B
4295	356-T6	Castings, centrifugal	
4286A	356-T51	Castings, permanent mold	
4218B	A356	Castings, premium grade	MIL-A-21150B

* Military or Federal specification.

1.04 Composition
 Table 1.04.

TABLE 1.04

Source	AMS (1)(2)(3)(4)(5)		MIL (6), AMS (19)	
	356		A356	
	Percent		Percent	
Alloy	Minimum	Maximum	Minimum	Maximum
Copper	-	0.20	-	0.20
Magnesium	0.20	0.40	0.20	0.40
Manganese	-	0.30	-	0.10
Iron	-	0.60	-	0.20
Silicon	6.5	7.5	6.5	7.5
Zinc	-	0.30	-	0.10
Titanium	-	0.20	-	0.20
Other impurities				
each	-	0.05	-	0.05
total	-	0.15	-	0.15
Aluminum	Balance		Balance	

1.05 Heat Treatment
 1.051 Anneal (stress relieve) for dimensional stability. 650F, 2 hours, air cool (17).
 1.052 Solution treatment and artificial aging, Table 1.052.

TABLE 1.052

Source	(17)						
	Data	Typical Heat Treatment				Artificial Aging	
		Method of Casting	Solution Heat Treatment			Temp F (a)	Time Hours (d)
Temp F (a)	Time Hours (b)		Quench (c)				
356-T6	Sand	1000	12	Water	310	3-5	
356-T7	Sand	1000	12	Water	400	3-5	
356-T51	Sand	-	-	-	440	7-9	
356-T71	Sand	1000	12	Water	475	2-4	
356-T6	Permanent Mold	1000	8	Water	310	3-5	
356-T7	Permanent Mold	1000	8	Water	440	7-9	
A356-T6	Sand	1000	12	Water	310	2-5	
A356-T6	Permanent Mold	1000	8	Water	310	3-5	
A356-T61	Permanent Mold	1000	8-10	Water	320	8-10	

(a) Variation of temperature in furnace should not exceed plus or minus 10F.
 (b) Soaking time required for average casting. Time can be decreased or may have to be increased as demonstrated by experience.
 (c) Water temperature from 150 to 212F. 212F is preferred to minimize distortion.
 (d) Exact time is best established by experience to obtain typical properties.

Al
 7 Si
 0.3 Mg

356, A356

1.06 Hardness
 (see Tables 3.011 and 3.0212)
 1.061 Quenching in boiling water followed by aging develops full hardening in all commercial sizes of castings.
 1.062 Hardness of sand and permanent mold castings, Table 1.062.

TABLE 1.062

Source	Form	Hardness, BHN** (500 kg, 10mm ball)		
		(27)	(31)	(8)
356-T51	Sand Cast	60	60	60
356-T71	Sand Cast	-	-	60
356-T6	Sand Cast	70	70	70
356-T7	Sand Cast	75	-	75
356-T6	PM Cast*	80	-	80
356-T7	PM Cast	70	-	70
A356-T61	PM Cast	90	80	90

* PM - Permanent mold
 ** Hardness values determined from standard 1/2 inch diameter test specimens, individually cast in green sand or permanent molds.

1.07 Forms and Conditions Available
 1.071 356 is available in sand, permanent mold, and centrifugal castings, usually without any restrictions as to shape, size, or section thickness.
 1.072 A356 is available primarily in the form of permanent mold "premium strength structural castings" with properties to be negotiated with producer. Sand castings, however, are also produced as premium grade castings.
 1.073 Conditions available, Table 1.073.

TABLE 1.073

Source	(17)	
	Form	Conditions Available
356	Sand Cast	F, T51, T6, T7, T71
	Permanent Mold	F, T51, T6, T7
A356	Sand Cast	T6
	Permanent Mold	T6, T61

1.08 Melting and Casting Practice
 1.081 The 356 alloy can be melted and cast using conventional aluminum alloy practices without any special considerations.
 1.082 Premium quality castings of the A356 alloy are guaranteed to meet a specified high level of mechanical properties as measured by using test bars cut from specified locations within the heat treated casting (24). To obtain these superior properties, improved casting techniques

Al
7 Si
0.3 Mg

356, A356

- need to be employed, which include:
- 1) The use of high purity ingot (low iron content).
 - 2) Adequate degassing and proper melting.
 - 3) Streamlined gating design to avoid turbulence and aspiration of mold gases.
 - 4) The use of a sufficient number of risers to adequately feed the casting.
 - 5) Liberal use of chills to control solidification rate and provide directional solidification.
 - 6) The use of proper heat treatment to develop maximum properties.
- 1.083 Melting of premium quality ingots is normally performed in silicon carbide crucibles (rather than in iron pots) to minimize the possibility of iron pickup. Iron skimming tools used for dross removal should be coated with a suitable refractory wash of clay, lime or with a similar refractory sodium-silicate binder (33).
- 1.084 Effect of pouring temperature on grain size, Figure 1.084.
- 1.085 Fluxing procedures for premium quality castings are essentially the same as those used in normal aluminum melting practice (36).
- 1.086 A more detailed discussion of melting and casting procedures for premium quality parts is given in Reference 24.
- 1.09 Special Considerations
- 1.091 (See 1.082 for special considerations concerning premium quality castings of A356 alloy.)

2. PHYSICAL AND CHEMICAL PROPERTIES

- 2.01 Thermal Properties
- 2.011 Melting range.
356 alloy 1035 to 1135F
A356 alloy 1035 to 1130F (17).
- 2.012 Phase changes. Alloys are subject to precipitation.
- 2.0121 Time-temperature-transformation diagrams.
- 2.013 Thermal conductivity, Table 2.013.

TABLE 2.013

Source	(17) (27)	
Alloy	Condition	Thermal Conductivity at Room Temperature; Btu ft per (hr sq ft F)
356	T51	97
	T6	87
	T6*	92
	T7	90
A356	T6	87

* Chill cast samples - all other samples cast in green sand molds.

- 2.014 Thermal expansion, Figure 2.014.
- 2.015 Specific heat, 0.23 Btu per (lb F) at 212F (18).
- 2.016 Thermal diffusivity.
- 2.02 Other Physical Properties
- 2.021 Density, 0.097 lb per cu in; 2.68 gr per cu cm (17).
- 2.022 Electrical properties.
- 2.0221 Electrical resistivity, Table 2.0221.

TABLE 2.0221

Source	(18, p. 957)	
Condition	Electrical Resistivity at Room Temperature; Microhm Inch	
T51	1.60	
T6	1.74	
T7	1.70	

- 2.0222 Electrical conductivity (percent of IACS)
- | | |
|---------|----------|
| 356-T51 | 43 |
| 356-T6 | 39 |
| 356-T7 | 40 |
| A356-T6 | 40 (17). |
- 2.023 Magnetic properties. Alloys are nonmagnetic.
- 2.024 Emissance, 0.035 to 0.07 at 77F in air (18).
- 2.025 Damping capacity.

- 2.03 Chemical Properties
- 2.031 General. The general corrosion and atmospheric weathering resistance of 356 and A356 is very good, comparable to pure aluminum in this respect. The alloys may be used in industrial and seacoast atmospheres without protection (27). They also exhibit excellent resistance to stress-corrosion cracking. There are no known instances of failure by stress corrosion in service applications or in laboratory tests employing 3.5 percent NaCl alternate immersion. Electrolytic solution potential versus N/10 Calomel Electrode (solution: 53 gr NaCl + 3 gr H₂O₂). 356-T6 (sand-cast) 0.82 volt (17).
- 2.032 These alloys are subject to corrosion when exposed to hydrazine or UDMH (unsymmetrical dimethyl hydrazine) in the presence of moisture. Initially corrosive attack is very severe with a gradual build up of a passive film, after which the rate of attack is reduced. Passivation in a 30 percent solution of UDMH for 2 hours at 170-180F renders the surfaces resistant to attack by diluted UDMH at room temperature. Resistance is also obtained by sulfuric acid anodizing and, to a lesser extent, by chromic acid anodizing (32).
- 2.04 Nuclear Properties
- 2.041 Effect of neutron radiation on tensile properties of cast test bars, Table 2.041.

TABLE 2.041

Source	(25) (34)						
	356						
	Irradiation Temperature F	Integrated Neutron Flux n cm ⁻² *	F _{tu} ksi		F _{ty} ksi		e(2 inches) percent
A			B	A	B	A	B
-	2.4 x 10 ²⁰	32.4	44.3	24.1	42.4	2.7	0.4
-	7.2 x 10 ²⁰	32.4	54.0	24.1	51.0	2.7	0.9
-	2.6 x 10 ²¹	32.4	45.0	24.1	36.0	2.7	1.5
120	2.04 x 10 ¹⁹	33.1	36.7	26.0	29.1	4.0	6.0
120	1.22 x 10 ²⁰	33.1	42.0	26.0	33.5	4.0	6.0
120	5.59 x 10 ²⁰	33.1	45.1	26.0	42.5	4.0	6.0
120	9.84 x 10 ²⁰	33.1	54.4	26.0	52.1	4.0	3.0

* Fast neutrons.
A - Not irradiated
B - Irradiated

- 2.042 Comparison of mechanical properties before and after nuclear radiation at -420F, Table 2.042.

TABLE 2.042

Source	(30)				
Alloy	A356-T6 Cast Plate				
Test	Pre and Post Irradiation Data at -420F				
	Specimen Type (b)	Control (average)	Irradiate (average) (a)	Change	Percent Change
F _{tu} -ksi	L	44.7	52.8	+ 8.1	+18 (c)
F _{ty} -ksi	L	31.0	42.8	+11.8	+38 (c)
e -percent	L	1.5	1.4	- 0.1	- 7
RA -percent	L	2.8	0.8	- 2.0	-72 (c)
F _{su} -ksi	L	50.4	45.6	- 4.8	-10 (c)
Notch Strength - ksi (K _t = 6.3)	L	39.7	43.2	+ 3.5	+ 9
Notch/Unnotch Strength ratio (d)	L	0.89	0.82	-	-

(a) Irradiated at 5 x 10¹⁶ nvt (E>1.0 Mev) in liquid hydrogen.
(b) L = longitudinal specimen
(c) Statistically significant change; probability=0.90.
(d) Notch specimen geometry:
Width = 1.0
Notch Radius = 0.005
Notch Depth = 30 percent
Notch Angle = 60 degrees
Thickness = 0.063

- 2.043 Effect of nuclear radiation at -420F on stress-strain curves of plate (typical), Figure 2.043.
- 2.044 Effect of neutron radiation on tensile properties of A356 castings, Table 2.044.

TABLE 2.044

Source	(35)							
Alloy	A356							
Irradiation Temperature F	Test Temp F	Fast Neutron Flux (n cm ⁻²)*	F _{tu} ksi		F _{ty} ksi		e (2 inches) percent	
			A	B	A	B	A	B
120	RT	2.0 x 10 ¹⁹	33.1	36.7	26	29.1	4	6
120	RT	1.2 x 10 ²⁰	33.1	42.0	26	33.5	4	6
120	RT	5.6 x 10 ²⁰	33.1	45.9	26	42.4	4	6
120	RT	9.8 x 10 ²⁰	33.1	54.4	26	52.1	4	3

* Energy greater than 1.0 MeV
A not irradiated
B irradiated

3.014 MIL-A-21180B specified tensile properties for specimens cut from castings of A356, Table 3.014.

Al
7 Si
0.3 Mg

TABLE 3.014

Source	MIL-A-21180B (6)					
Alloy	A356					
Form	Special Mold, Permanent Mold, or Sand Mold With Chills					
Condition	T61					
Location in Casting	Designated Area			Any Area		
Class	1	2*	3*	10	11	12
F _{tu} , minimum - ksi	38.0	40.0	45.0	38.0	33.0	32.0
F _{ty} , minimum - ksi	28.0	30.0	34.0	28.0	27.0	22.0
e, minimum - percent	5.0	3.0	3.0	5.0	3.0	2.0

* Obtainable only in favorable casting configurations and must be negotiated with the foundry.

356, A356.

3. MECHANICAL PROPERTIES
3.01 Specified Mechanical Properties
3.011 AMS and producer's specified mechanical properties for 356 alloy, Table 3.011.

TABLE 3.011

Source	(7, p. 62)	(7, p. 62) (1)	(7, p. 62)	(5)	(7, p. 65) (3)	(7, p. 65)	(2) (4)	
Alloy	356							
Form	Sand Castings				Permanent Mold Castings			Investment and Centrifugal Castings
Condition	T51	T6	T7	T71	T51	T6	T7	T6
Specimen	Cast Test Bars	Cast Test Bars	From Castings Average*	Cast Test Bars	Cast Test Bars	From Castings Average*	Cast Test Bars	From Castings Average*
F _{tu} , min -ksi	23	30	22.5	31	25	18.8	33	24.75
F _{ty} , min -ksi	16	20	15.0	26	18	-	22	16.5
e(2 in), min - percent	-	3	-	-	3	-	3	-
e(4 D), min - percent	-	-	0.7	-	-	-	0.7	0.7
F _{cy} , min -ksi	17	20	-	27	19	-	22	-
F _{su} , min -ksi	17	25	-	21	17	-	25	-
F _{bry} , min (e/D = 2.0) -ksi	48	63	-	65	52	-	59	-
F _{bry} , min (e/D = 2.0) -ksi	32	40	-	52	36	-	40	-
Hardness, BHN (500 kg, 10 mm)								
min	-	-	65.0	-	-	65.0	-	65.0
max	-	-	95.0	-	-	-	-	95.0

* Average values for at least 4, preferably 10, specimens.

3.012 Producer's specified properties for A356 alloy, Table 3.012.

TABLE 3.012

Source	(7, p. 65) MIL (6)		
Alloy	A356		
Form	Permanent Mold Castings		
Condition	T61		
Specimen Type	From Castings		
	(a)	(b)	(c)
F _{tu} , minimum -ksi	33	38	40
F _{ty} , minimum -ksi	27	25	30
e(2 inches) minimum - percent	3	5	3
F _{cy} , minimum -ksi	27	-	-
F _{su} , minimum -ksi	23	-	-

(a) Individually cast specimen.
(b) Cut from designated location in casting.
(c) Must be negotiated with foundry.

- 3.02 Mechanical Properties at Room Temperature
3.021 Tension.
3.0211 Stress-strain diagrams (see Figure 2.043).
3.0212 Typical mechanical properties of 356 cast test bars at room temperature, Table 3.0212.

TABLE 3.0212

Source	(8) (27)						
Alloy	356						A356
Form	Sand Cast			Permanent Mold Cast			
Specimen	Cast Test Bars						
Condition	T51	T6	T7	T71	T6	T7	T61
F _{tu} -ksi	25	33.0	34	28.0	37	32	41
F _{ty} -ksi	20	24.0	30	21.0	27	24	30
e(2 inches)-percent	2	3.5	2	3.5	5	6	10
F _{cy} -ksi	21	25.0	31	22.0	27	24	32
F _{su} -ksi	20	26.0	24	20.0	30	25	28
Hardness, * BHN	60	70.0	75	60.0	80	70	90

* 500 kg load 10 mm ball.

3.013 AMS specified tensile properties for A356 alloy, Table 3.013.

TABLE 3.013

Source	AMS (19)	
Alloy	A356	
Form	Type of Mold Not Restricted	
Condition	Solution and Precipitation Heat Treated	
Specimen Type	(a)	(b)
F _{tu} , minimum -ksi	32	33
F _{ty} , minimum -ksi	22	27
e(2 inches) minimum - percent	2	3

(a) Specimen cut from any area of casting.
(b) Cast specimen.

3.0213 Effect of diameter of cylindrical 356-T6 castings on tensile properties, Table 3.0213.

Al
7 Si
0.3 Mg

TABLE 3.0213

Source	(9, p. 58)									
Alloy	356									
Form	Sand Cast									
Condition	T51					T6				
Section Thickness-Inches	Test Bar 0.505	3/4	1 1/4	1 3/4	Test Bar 0.505	3/4	1 1/4	1 3/4	2 1/4	
F _{tu} -ksi	27.2	21.9	17.15	14.4	34.1	28.3	23.0	19.4	15.1	
F _{ty} -ksi	-	16.7	13.45	12.7	24.3	23.0	22.5	-	-	
e -percent	1.6	1.5	1.3	1.2	4.6	2.0	1.0	0.7	0.5	

356, A356 3.0214 Typical tensile properties of specimens cut from 356-T6 sand and permanent mold castings of different thickness, Table 3.0214.

TABLE 3.0214

Source	(9, p. 57)											
Alloy	356											
Form	Sand Cast						Permanent Mold Cast					
Condition	T6											
Section thickness-inches	< 1/8	1/8 to 1/4	1/4 to 1/2	1/2 to 3/4	3/4 to 1.0	< 1/8	1/8 to 1/4	1/4 to 1/2	1/2 to 3/4	3/4 to 1.0	1.0 to 1.5	
F _{tu} -ksi	37.0	35.5	34.0	32.5	31.0	43.0	42.0	40.0	37.0	37.0	36.0	
F _{ty} -ksi	25.5	24.5	23.5	22.5	21.5	31.0	30.0	30.0	29.0	28.0	28.0	
e(4D) -percent	5.0	4.5	4.0	3.5	3.0	-	-	-	-	-	-	
e(2 inches) -percent	-	-	-	-	-	6.0	5.0	4.0	2.0	2.0	1.25	

3.0215 Typical tensile properties of specimens cut from premium strength A356 castings, Table 3.0215.

TABLE 3.0215

Source	(14, p. 4)			
Alloy	A356			
Form	Premium Strength Castings			
Condition	T61			
Specimen Type	From Castings			
	(a)	(a)	(b)	(b)
F _{tu} -ksi	41	43	45	
F _{ty} -ksi	31	33	35	
e -percent	8	9	6	
(a) Produced in either all or part of castings.				
(b) Must be negotiated with foundry.				

- 3.0216 Effect of exposure to elevated temperature on tensile properties of sand cast test bars in T51 condition, Figure 3.0216.
- 3.0217 Effect of exposure to elevated temperature on tensile properties of sand cast test bars in T7 condition, Figure 3.0217.
- 3.0218 Effect of iron content on properties of A356-T6 sand castings, Table 3.0218.

TABLE 3.0218

Source	(28)							
Alloy	A356-T6							
Type	Sand Castings (without chills)							
Iron Content percent	Room Temperature Tensile (a)			Charpy-V Impact (ft-lbs)			Notch to Unnotched Strength Ratio (-320F)	
	F _{tu} ksi	F _{ty} ksi	e(2 inches) percent	75 F	-320 F	-450 F		
0.13	37.3	24.4	7.5	2.8	2.0	2.4	1.14	
0.01	37.4	23.5	12.4	5.0	5.0	5.2	1.22	
(a) Machined cast test bars.								
(b) K _t = 6 for notched tensile samples.								

3.0219 Effect of iron content and section thickness on tensile properties of 356 and A356 castings, Table 3.0219.

TABLE 3.0219

Source	(29)			
Condition	T6			
Section Thickness (inches)	Test Data	356 (0.34 Fe)	A356 (0.18 Fe)	
1 1/4	F _{tu} -ksi	28.14	32.99	
	F _{ty} -ksi	20.52	25.71	
	e -percent	4.0	4.4	
3/4	F _{tu} -ksi	28.80	34.11	
	F _{ty} -ksi	21.37	26.85	
	e -percent	4.0	5.1	
3/8	F _{tu} -ksi	30.64	35.34	
	F _{ty} -ksi	22.11	26.91	
	e -percent	4.0	5.6	

- 3.022 Compression (see Tables 3.0212, 3.011 and 3.012).
- 3.0221 Stress-strain diagrams.
- 3.023 Impact (see Table 3.0218).
- 3.024 Bending.
- 3.025 Torsion and shear (see Tables 3.0212, 3.011 and 3.012).
- 3.026 Bearing (see Table 3.011).
- 3.027 Stress concentration.
- 3.0271 Notch properties (see Tables 2.042 and 3.0218).
- 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 exposure and test temperature on tensile properties of sand cast test bars in T51 condition, Figure 3.0312.
- 3.0313 Effect of exposure and test temperature on tensile properties of sand cast test bars in T6 condition, Figure 3.0313.
- 3.0314 Effect of exposure and test temperature on tensile properties of sand cast test bars in T7 condition, Figure 3.0314.
- 3.0315 Effect of exposure and test temperature on tensile properties of A356 permanent mold cast test bars in T61 condition, Figure 3.0315.
- 3.0316 Effect of test temperature on tensile properties of permanent mold castings in T6 and T7 conditions, Figure 3.0316.
- 3.0317 Effect of test temperature on tensile properties of sand castings in T6 and T7 conditions, Figure 3.0317.
- 3.0318 Effect of low temperatures on tensile properties of T6 castings, Figure 3.0318.
- 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 Creep and creep rupture curves at room temperature to 400F for sand cast test bars in T7 condition, Figure 3.041.
- 3.042 Creep and creep rupture curves at 300F for A356 permanent mold cast test bars in T61 condition, Figure 3.042.

- 3.05 Fatigue Properties
- 3.051 Typical fatigue strength of cast test bars at room temperature, Table 3.051.

TABLE 3.051
(S, p. 197) (10) (14, p. B)

Cast Test Bars-Room Temperature										
Alloy	Condi-tion	Method	Stress Ratio		Stress Concen-tration	Fatigue Strength - ksi at Cycles				
			A	R		10 ⁵	10 ⁶	10 ⁷	10 ⁸	5x10 ⁸
						Smooth K _t =1				
356 Sand cast	T51	Rot Beam	∞	-1		-	-	-	-	8.0
	T6		-	-		-	-	8.5		
	T7		21	14.5		10.5	9.5	9.5		
	T71		-	-		-	-	8.5		
356 Perm Mold	T6				-	-	-	-	13.0	
	T7				-	-	-	-	11.0	
A356	T61				29	23.0	17.0	14.0	13.0	

- 3.052 Endurance limit.
356-T6 13.0 ksi
A356-T61 13.0 ksi (27)
(Based on R. R. Moore rotating beam tests; 5.0 x 10⁸ cycles.)

- 3.06 Elastic Properties
- 3.061 Poisson's ratio, 0.33 (18).
- 3.062 Modulus of elasticity at various temperatures, Figure 3.062.
- 3.063 Modulus of rigidity at various temperatures, Figure 3.063.

4. FABRICATION

- 4.01 Formability
(see also Section 1.08)
- 4.011 General. 356 and A356 have excellent castability characteristics such as high fluidity, low solidification shrinkage tendencies, high resistance to hot cracking and good pressure tightness. These alloys are suitable for intricate castings containing thin sections and variable thicknesses (39).
- 4.012 Melting of these alloys is discussed in Section 1.08.
- 4.013 Hydrogen readily dissolves in molten aluminum from moisture in all forms and from hydrocarbons. It is liberated during solidification and can cause harmful porosity. Gas absorption increases with increasing temperature of the molten aluminum and with increasing time at temperature. Absorption of gas is also increased when the contact surface between molten metal and hydrogen forming gases is made larger.
- 4.014 Dross forms as a result of oxidation, and it may be trapped in the metal, causing defects in the casting because its density is slightly higher than the density of aluminum. The oxide film on the aluminum melt, however, gives an excellent protection against further oxidation and gas absorption. On casting, the metal should flow steadily and for a minimum distance to maintain the oxide layer and thus avoid dross inclusions.
- 4.015 Gaseous or solid fluxes are generally used to remove hydrogen and dross from the melt. Flushing with gaseous fluxes, such as chlorine or nitrogen, may be used

for this purpose. Solid fluxes are introduced into the melt to form a gas or liquid protective coating on top of the melt. Generally the metal is heated to 1250-1400F before adding flux. After fluxing, the melt should be allowed to settle for 10 to 20 minutes to allow the flux to float to the top, while the temperature of the liquid is adjusted to the pouring temperature.

	Al
7	Si
0.3	Mg

- 4.016 For thin sections of castings, it may be necessary to use a mold coating to increase fluidity. Hexachlorethane has been found to be effective in this respect. For example, it was reported that by spraying the mold with a saturated solution of hexachlorethane in ether, the fluidity of 356 alloy was increased 86 percent at 1320F and 96 percent at 1250F (38).

356, A356

4.02 Machining and Grinding

- 4.021 General. The machinability of these alloys is fair. Tool wear is greater for these alloys than for 355 alloy because of the higher silicon content. Carbide cutting tools and lubricants such as lard oil and kerosene are recommended for general machining. For tapping, pure lard oil is preferred.

4.03 Welding

- 4.031 General. These alloys are readily weldable by GTA techniques. Gas welding, metal arc, carbon arc, and atomic hydrogen techniques have also been used, usually with a furnace for preheating. Foundry welding of small defects, etc., usually employs filler metal of the same composition as the parent cast metal. For repair or assembly welding, 4043 filler metal is recommended to keep cracking sensitivity at a minimum (40).

- 4.032 Temperatures exceeding 400F during preheating or welding will affect the mechanical properties of heat treated castings. After welding, however, the castings can be reheat treated to restore their properties. A general rule during welding is to keep the heat of welding concentrated in a narrow region.

- 4.033 A more detailed discussion of the welding of aluminum castings is given in Reference 40.

- 4.034 Brazing of 356 and A356 is not normally recommended. However, it is possible to braze these alloys with special techniques (41).

4.04 Heat Treatment

4.05 Surface Treatment

- 4.051 General. The resistance of these alloys to normal atmospheric weathering is good, and protective coatings are not usually required. These alloys can be anodized to provide increased resistance to corrosion and abrasion. Other surface finishes such as electroplating, porcelain enameling, and painting can be applied for special purposes if desired (39).

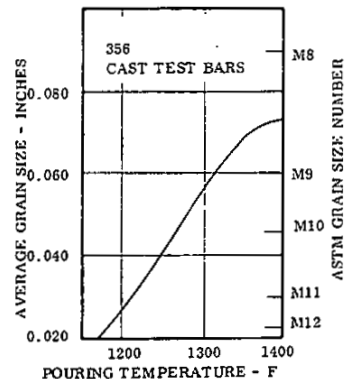


FIG. 1.084 EFFECT OF POURING TEMPERATURE ON GRAIN SIZE. (26)

Al
7 Si
0.3 Mg

356, A356

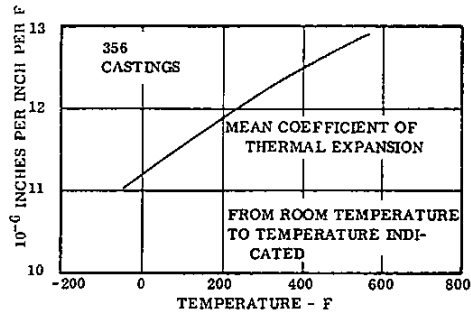


FIG. 2.014 THERMAL EXPANSION. (8, p. 205)

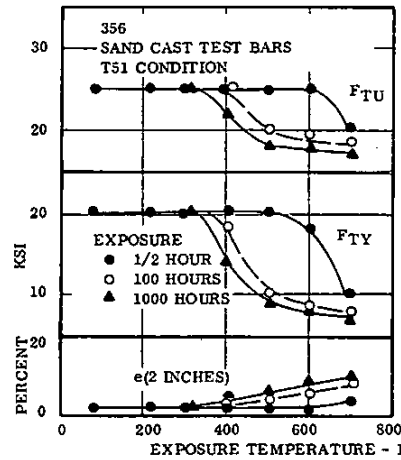


FIG. 3.0216 EFFECT OF EXPOSURE TO ELEVATED TEMPERATURE ON ROOM TEMPERATURE TENSILE PROPERTIES OF SAND CAST TEST BARS IN T51 CONDITION. (12)

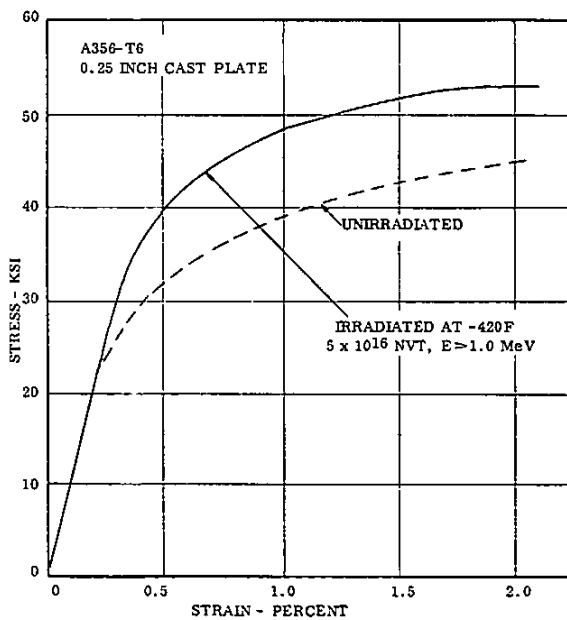


FIG. 2.043 EFFECT OF NUCLEAR RADIATION AT -420F ON STRESS-STRAIN CURVES OF PLATE (TYPICAL). (30)

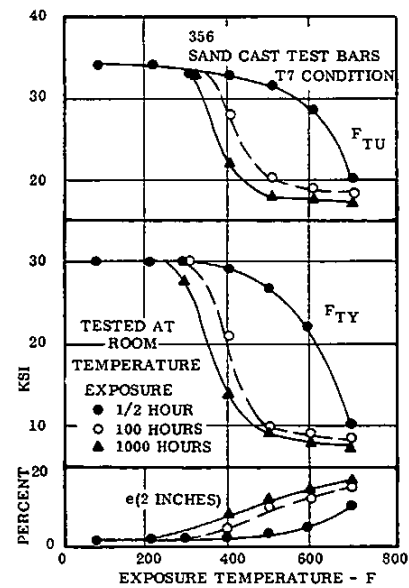


FIG. 3.0217 EFFECT OF EXPOSURE TO ELEVATED TEMPERATURE ON ROOM TEMPERATURE TENSILE PROPERTIES OF SAND CAST TEST BARS IN T7 CONDITION. (10)

	Al
7	Si
0.3	Mg

356, A356

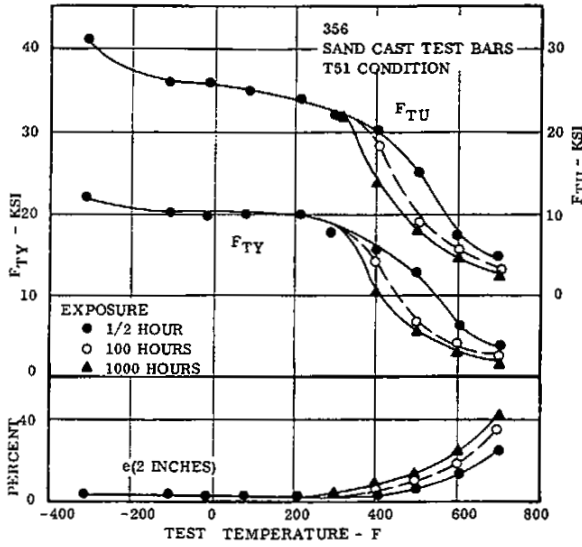


FIG. 3.0312 EFFECT OF EXPOSURE AND TEST TEMPERATURE ON TENSILE PROPERTIES OF SAND CAST TEST BARS IN T51 CONDITION. (12)

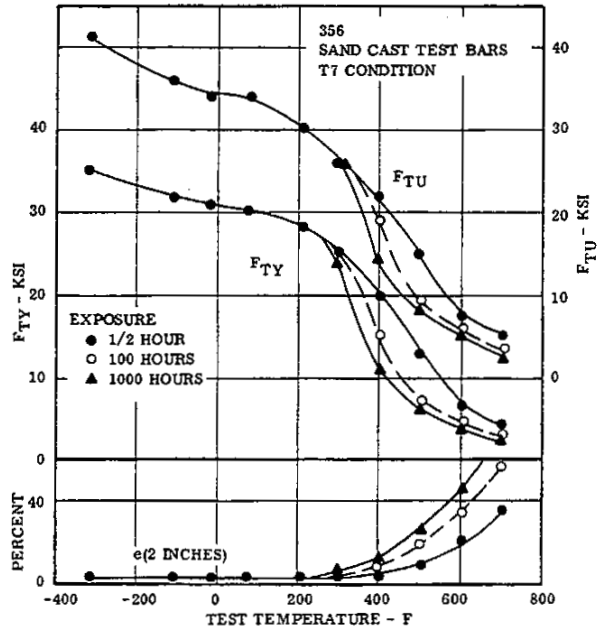


FIG. 3.0314 EFFECT OF EXPOSURE AND TEST TEMPERATURE ON TENSILE PROPERTIES OF SAND CAST TEST BARS IN T7 CONDITION. (10)

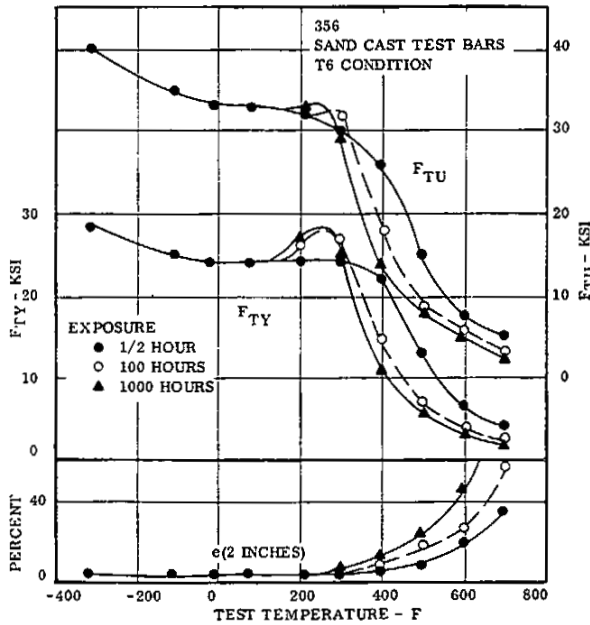


FIG. 3.0313 EFFECT OF EXPOSURE AND TEST TEMPERATURE ON TENSILE PROPERTIES OF SAND CAST TEST BARS IN T6 CONDITION. (16)

Al
7 Si
0.3 Mg

356, A356

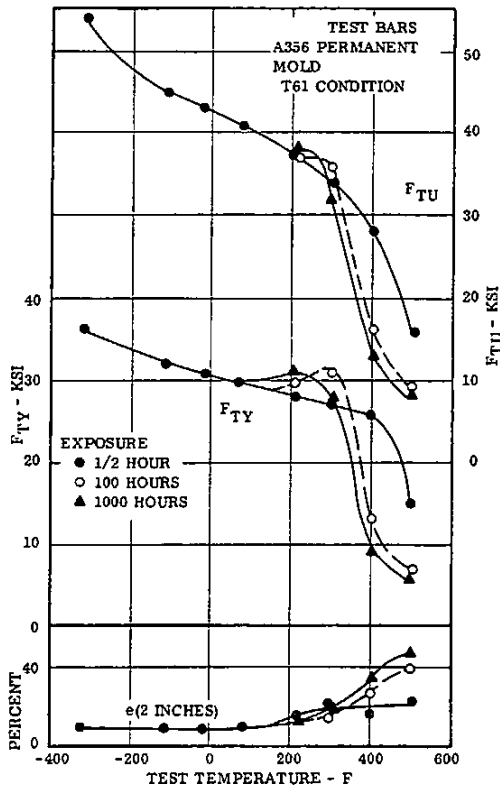


FIG. 3.0315 EFFECT OF EXPOSURE AND TEST TEMPERATURE ON TENSILE PROPERTIES OF A356 PERMANENT MOLD CAST TEST BARS IN T61 CONDITION. (14, p. B)

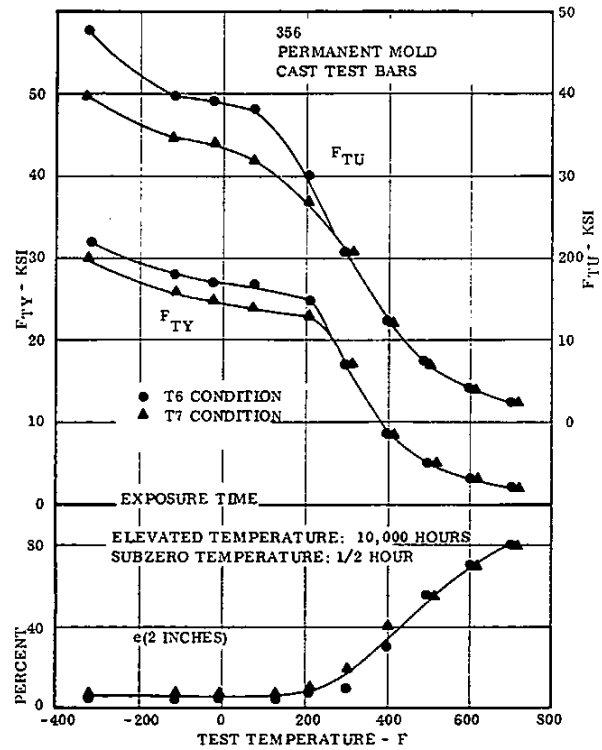


FIG. 3.0316 EFFECT OF TEST TEMPERATURE ON TENSILE PROPERTIES OF PERMANENT MOLD CASTINGS IN T6 AND T7 CONDITIONS. (27)

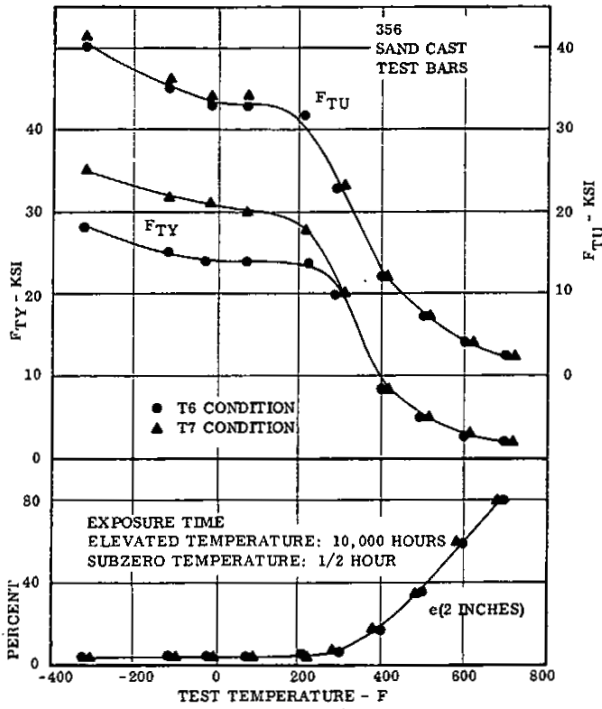


FIG. 3.0317 EFFECT OF TEST TEMPERATURE ON TENSILE PROPERTIES OF SAND CASTINGS IN T6 AND T7 CONDITIONS. (27)

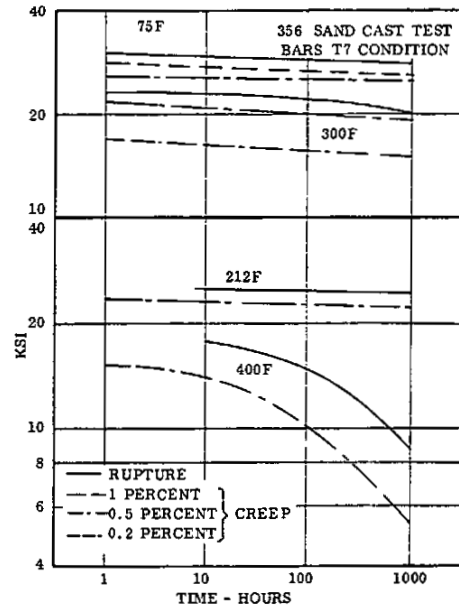
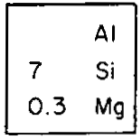


FIG. 3.041 CREEP AND CREEP RUPTURE CURVES AT ROOM TEMPERATURE TO 400F FOR SAND CAST TEST BARS IN T7 CONDITION. (10)



356, A356

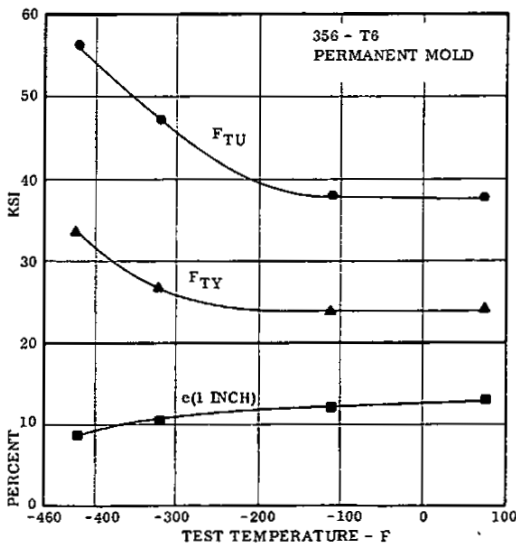


FIG. 3.0318 EFFECT OF LOW TEMPERATURE ON TENSILE PROPERTIES OF T6 CASTINGS. (22)

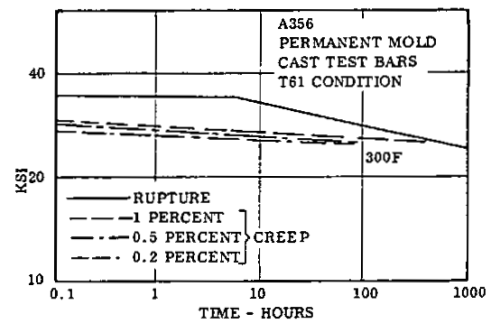


FIG. 3.042 CREEP AND CREEP RUPTURE CURVES AT 300F FOR A356 PERMANENT MOLD CAST TEST BARS IN T61 CONDITION. (14, p. B)

Al
7 Si
0.3 Mg

356, A356

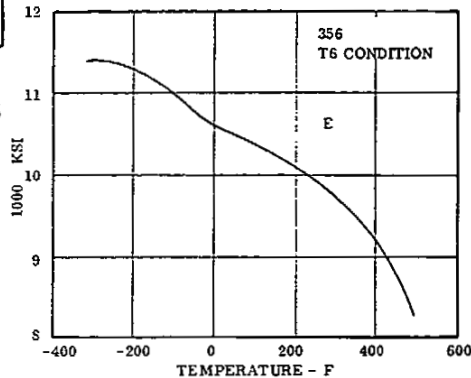


FIG. 3.062 MODULUS OF ELASTICITY AT VARIOUS TEMPERATURES. (13, p. 1-2-2.2)

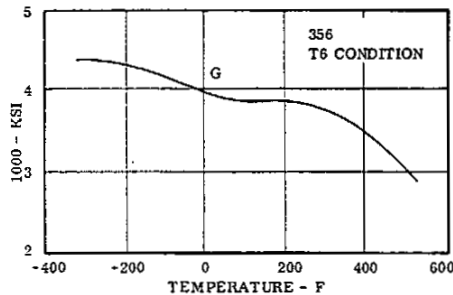


FIG. 3.063 MODULUS OF RIGIDITY AT VARIOUS TEMPERATURES. (13, p. 1-2-2.2)

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