1 GENERAL

This alloy has the highest strength of aluminum casting alloys coupled with relatively high toughness. Special attention must be given to casting methods to control hot tearing associated with relatively high shrinkage during solidification. The fully aged condition (-T6) should be avoided if integranular or stress corrosion may be a problem.

Weld repair of A201.0 castings is possible without cracking using carefully controlled techinques. B201 is an AMS designated aircraft quality grade with stronger quality assurance requirements, a reduced maximum on silver and iron content coupled with a slightly modified heat treatment.

Extensive investigations by Northrop (Ref. 9) showed that the properties obtained from cast plates could be used to sucessfully design large complex aerospace structures.

1.1 Commercial Designation - A201.0 (formerly KO-1)

1.2 Alternate Designations

1.2.1 *[Table]* Alternate designations.

1.3 Specifications

1.3.1 *[Table]* AMS specifications.

1.4 Composition

1.4.1 *[Table]* AMS and military specification compositions.

1.4.2 Effects of Alloying Elements. The addition of Ag to the base Al-Cu-Mg ternary (Ref. 18) has resulted in substantial increases in hardness and tensile strength. This modification of the aging response of Al-Cu-Mg casting by the addition of Ag is illustrated in Table 1.4.2.1 and Figure 1.4.2.2 which shows substantial increases in hardness and tensile strength are associated with the addition of a small amount of Ag.

As part of a program to establish the optimum foundry practices and design data for the cast Al-Cu-Mg-Ag alloy A201.0, Northrop (Ref. 6) attempted to systematically explore the influence of the major alloying elements (within the range of AMS 4223) and of the impurities Si and Fe on the tensile properties of sand and shell investment mold cast rectangular plates. These castings were produced using production equipment with procedures summarized in Table 1.4.2.3. The results were, in some cases, ambiguous and what follows presents the clearest examples. Increasing Mg resulted in increasing tensile and yield strengths of sand and investment castings and decreasing elongation (e.g., Figure 1.4.2.4). The tensile and yield strengths of both sand and investment castings increased with increasing Cu content but an unexpected increase in the elongation was obtained for the sand castings, Figure 1.4.2.5, while no effect on elongation was observed for the investment castings. As expected, additions of Ag produced substantial increases in the tensile strength properties coupled with a decrease in elongation for both types of castings (e.g., Figure 1.4.2.6). Iron contents above the maximum specified by AMS produced the expected decrease in tensile properties for the investment castings, Figure 1.4.2.7, but had only a small effect of the tensile and yield strength of the sand castings coupled with a large decrease in their elongation. Silicon compounds can promote eutectic melting during solution treatment (see Section 1.9.1). Increases above the 0.05 percent maximum silicon specified by AMS result in substantial reductions in the elongation of both types of castings, Figures 1.4.2.8 and 1.4.2.9, and increased tensile strength properties of sand castings, but Si had little effect on the tensile strength properties of investment castings.

	Al
4.5	**Cu**
0.7	**Ag**
0.3	**Mn**
0.25	**Mg**
0.25	**Ti**

Northrop also investigated the properties of castings made from "out of AMS 4242 Specification" melts using rectangular sand cast plates with either Cu or Fe chills.

The in-specification and out-of-specification tensile properties and grain size are compared in Table 1.4.2.10. The largest effects are noted for the Cu-Ag-Mg increases where the tensile strengths are increased and the elongation drastically reduced. These effects are associated with substantial increases in the grain size. Increased Ti also reduces the elongation but to a much smaller extent. The Cu chill tended to reduce the grain size.

1.4.2.1 *[Table]* Maximum hardness and tensile strengths produced by aging at three temperatures for Al-Cu-Mg and Al-Cu-Mg-Ag alloy castings.

1.4.2.2 *[Figure]* Effect of silver addition on aging response of a Al-Cu-Mg casting.

1.4.2.3 *[Table]* Casting and heat treatment details for investment and sand cast plates used in the investigation of composition and other factors controlling the mechanical properties of A201.0 castings.

1.2.4.4 *[Figure]* Effect of magnesium content on the tensile properties of a sand composite cast plate.

1.4.2.5 *[Figure]* Effect of copper content on tensile properties of a sand composite cast plate.

This section produced with the support of NASA-Lewis Research Center.

1.4.2.6 *[Figure]* Effect of silver content on the tensile properties of shell investment cast plates.

1.4.2.7 *[Figure]* Effect of iron content on the tensile properties of shell investment cast plates.

1.4.2.8 *[Figure]* Effect of silicon content on the tensile properties of shell investment cast plates.

1.4.2.9 *[Figure]* Effect of silicon content on the tensile properties of sand composite cast plates.

1.4.2.10 *[Table]* Effect of out of specification composition and mold cooling rate on tensile properties and grain size of sand composite cast plates.

1.5 Heat Treatment

General. The heat treatment consists of a solution phase designed to put the major alloying elements into solid solution in the aluminum matrix without encountering eutectic melting (see 1.9.1). Step solution treatments are given by AMS (see Table 1.5.6) to minimize eutectic melting. Room temperature aging produces the -T4 condition and some foundries prefer to age at room temperature up to 24 hrs. prior to artificial aging. A stabilized condition, -T43, is produced by aging at 310F for 1 to 2 hrs. A fully aged condition, -T6, is produced by aging at 310F for 20 hrs. Both the -T43 and the -T6 conditions are highly susceptible to intergranular and stress corrosion (see 2.3.2). The optimum condition (-T7) is an overage at 370F for 5 hrs.

Solution Treatment. Solution heat treatment times from 6 to 18 hrs. at 985F, Figures 1.5.1 and 1.5.2, had little effect on the tensile properties of sand and shell investment mold castings produced according to the processes outlined in Table 1.4.2.3. Generally, a water quench is used from the solution temperature. Quench water temperature up to 212F appears to have only a slight effect (e.g., Figure 1.5.3) on the tensile properties. (Refs. 6, 12) Quench delay time at room temperature up to 5 days had no significant effect on the tensile properties of sand or shell investment castings. (Ref. 6)

Aging. The tensile properties appear to be insensitive to the aging time between 3 to 7 hrs. at 370F for sand, Figure 1.5.4, and investment mold castings, Figure 1.5.5.

1.5.1 *[Figure]* Effect of solution heat treatment time on the tensile properties of shell investment cast plates.

1.5.2 *[Figure]* Effect of solution heat treatment time on the tensile properties of sand composite cast plates.

1.5.3 *[Figure]* Effect of quench water temperature on tensile properties of a shell investment cast plates.

1.5.4 *[Figure]* Effect of aging time at 370F on tensile properties of sand composite cast plates.

1.5.5 *[Figure]* Effect of aging time at 370F on tensile properties of a shell investment cast plates.

1.5.6 *[Table]* AMS and MIL Specification heat treatments.

1.6 Hardness (See Tables 1.4.2.1, 3.1.1, 3.2.1.5 and Figure 1.4.2.2)

1.7 Forms and Conditions Available. Investment and Sand Castings and Welding Wire

1.8 Melting and Casting Practice

1.8.1 General. The mechanical properties of a casting are complex functions of many variables including the mold design, placement of chills, gating and rising, grain refining techniques, melting crucible type and treatment, grain refinement additions and pouring temperature. In the case of castings for use in critical applications, all of these factors and the elimination of impurities are of prime concern. During the period from 1977 to 1984, the Air Force sponsored several programs to establish the techniques for producing high strength aluminum castings of complex design. Much of what follows is taken from the Northrop program to produce optimum properties in several alloys including A201.0. Information applicable to A201.0 concerning melting practice, degassing, holding time prior to degassing, mold design (for sand casting) and pouring temperature can be found in Code 3109 (Section 1.08) on A357, an Al-Si-Mg alloy.

In the Northrop program for establishing AMS specifications and design mechanical properties, use was made of a step plate sand casting shown in Figure 1.8.1.1. In other phases of the Nortrhrup program, specimens were removed from uniform thickness cast plates. Where available, the form of the casting is indicated on the Tables and Figures.

1.8.1.1 *[Figure]* Sand composite mold cast step plates for the Northrop investigation of manufacturing processes on design allowables.

1.8.1.2 *[Table]* Foundry practice in producing step plates.

1.8 2 Grain Refinement. While dendrite arm spacing (DAS) is important in controlling the mechanical properties of Al-Si-Mg alloys, this type of control is not possible in Al-Cu-Mg alloys, where dendrites are not discernible. In general, mechanical properties increase with a decrease in the grain size (e.g., Figure 1.8.2.1). Fine grain size minimizes the detrimental effects of grain boundary segregation of brittle phases which contribute to low energy grain boundary fractures. Grain size will decrease with increased cooling rate in a casting. However, control by this method is limited due to casting section size, microsegregation adjacent to chill faces, and mold-design factors necessary to prevent hot tearing (Ref. 12). The preferred method of grain size control is by inoculation with nucleating agents. A 5%Ti-1%B master alloy is the preferred inoculating agent. Upon cooling, crystals of $TiAl_3$ are nucleated on the stable TiB_2 particles. The $TiAl_3$ has a crystal structure close to that of pure Al and is effective in nucleating the growth of dendrites from the melt. (Ref. 12) The effect of the inoculation requires a conditioning period in which the TiB_2 particles become dispersed. As holding time increases, the particles tend to coalesce — resulting in grain size increases as shown in Figure 1.8.2.2. Relatively short holding times between 1 and 10 minutes are recommended with additions of 0.01% and 0.02% Ti using the T-B master alloy. (Ref. 12) However, considerable variation may be found among foundries. Generally, the melt is stirred immediately after the addition of the grain refining agent. As mentioned above, it is generally observed that the mechanical properties improve with a decrease in grain size. The expected behavior is observed in sand mold cast rectangular plates, Figure 1.8.2.1. However, this is not always the case and essentially no effect is observed in similar shaped investment cast plates, Figure 1.8.2.3. A lack of grain size effect was also found when the average grain size of the material producing the data shown in Table 3.2.1.3 was decreased from 0.0032 in. to 0.0011 in. (Ref. 9) These exceptions to the improvement of mechanical properties with decrease in grain size may be associated with the use of relatively simple castings resulting in a minimum of segregation

1.8.2.1 *[Figure]* Effect of grain size on the tensile properties of a sand cast composite plate.

1.8.2.2 *[Figure]* Effect of holding time and titanium content on grain size of melt inoculated with 5%Ti - 1%B.

1.8.2.3 *[Figure]* Tensile properties of shell investment cast plate at various grain sizes.

1.9 Special Considerations

1.9.1 Eutectic Melting. In the process of solidification, dendrites of Al became progressively enriched in alloying elements rejecting low temperature melting solute into interdendritic spaces. This solute eventually reaches eutectic composition and is trapped between dendrite arms or in the grain boundaries. A summary of possible phases which can form during the solidification of A201.0 are shown in Table 1.9.1.1. The lowest melting phases are $CuMgAl_2$ with a melting point of 945F and $(CuFeMg)_3Si_2\ Al_{15}$ with a melting point of 986F. It has been recommended (Ref. 12) that a step solution heat treatment be used to diffuse these phases into the matrix. This is accomplished by short times at temperatures between about 900 and 960F followed by longer times at a higher temperature. This high temperature should be limited to that which will not produce grain growth and generally does not exceed 990F. A two step solution treatment is in the AMS Specifications (see Table 1.5.6) and two and three step treatments were used in some portions of the Northrop program (see Table 1.8.1.2). The necessity for its use probably depends on the tendency of a particular casting design to promote segregation.

1.9.1.1 *[Table]* Possible grain boundary phases present in castings.

1.9.2 Shrinkage. A201.0 alloy is more prone to shrinkage during solidification than the Al-Si-Mg alloys A356.0 and A357.0. This shrinkage can cause hot tearing in casting regions involving pronounced changes in section size which inhibit contraction of the solidifying alloy. Hot tears may be open fissures or in some cases may be filled with a low melting eutectic. Regions containing hot tears possess poor mechanical properties because either the fissures act like cracks or tears filled with eutectic are brittle regions. Hot tears generally communicate with the surface and can be found by NDI techniques. If the fissures are filled with eutectic, X-ray examination may reveal Cu-rich regions associated with the fissures. Careful mold design and proper grain refinement, resulting in a small grain size, can eliminate hot tears. (Ref. 12) Hot isostatic pressing can close the fissures if they are empty. As shown in Table 1.9.2.1, A201.0 did not exhibit any significant decrease in tensile strength but a considerable loss in elongation occurred when shrinkage increased from radiographic grade AB to CD

1.9.2.1 *[Table]* Effect of casting defects on the tensile properties of shell investment and sand composite mold castings.

1.9.3 Porosity. Porosity results from the entrapment of gas and, depending on its severity, can cause substantial loss of gross deformation capacity which results in decreased ultimate tensile strength and elongation (see Table 1.9.3.1). Notch fatigue strength is substantially reduced by porosity (compare Figures 3.5.1.4 and 3.5.1.10). However, the fracture toughness (Table 1.9.3.1) is not affected by the same amount of porosity. This is probably due to the fact that the round pores do not act as crack extensions.

1.9.3.1 *[Table]* Effect of round gas porosity on the tensile properties and fracture toughness of defective step plates compared with grade B plates.

1.9.4 Dross. Dross generally results from the entrapment of material lighter than the melt, such as aluminum oxide, introduced by excessive agitation. Depending on its shape and concentration, substantial reduction in gross deformation capacity can result, as shown in Table 1.9.2.1, by the loss in ultimate tensile strength and elongation.

1.9.5 HIP. Hot isostatic pressing (HIP) has been shown to be effective in improving the mechanical properties of castings having poor radiographic quality associated with internal defects. Castings with porosity of Grade C were subjected to several HIP schedules as shown in

Table 1.9.5.1. The as-cast material had very poor properties — breaking before reaching the yield strain. A schedule of 950F/10 ksi/6 hr and 980F/10 ksi/6 hr produced some improvement in tensile ultimate strength but no significant improvement in ductility. Increasing the time from 6 to 12 hr at 950F/10ksi resulted in substantial improvement in all tensile properties. The best results were produced by the highest pressure of 15 ksi at 950F/6 hr; this material was reported as having a radiographic grade of A. It should be noted that elongation values shown for material breaking before the 0.2 percent offset are probably produced by the inability to match the halves of the broken specimens for elongation measurements.

1.9.5.1 *[Table]* Effect of hot isostatic pressing on specimens removed from rejected turbofan rim.

1.9.6 Squeeze Casting. This process applies a pressure of from 16 to 30 ksi to the solidifying metal in the mold. The purpose of this pressurized casting method is to minimize shrinkage and gas porosity. Squeeze-cast A201.0 is reported to have an absence of grain boundary intermetallics in the fully heat treated condition. Squeeze casting is claimed to be responsible for tensile strength and elongation values superior to that of conventionally cast A201.0 alloy.

1.9.6.1 *[Table]* Tensile properties of squeeze cast and permanent mold castings.

2 Physical Properties and Environmental Effects

2.1 Thermal Properties

2.1.1 Melting Range. 1300 to 1400F.

2.1.2 Phase Changes. The phase changes responsible for the age hardening of A201.0 and other Al-Cu-Mg alloys are extremely complex and not completely defined. A useful summary of the proposed mechanisms is found in Ref. 15 which is concerned with effects of Si on the hardening process. The generally accepted sequence, as proposed by Mondolfo (Ref. 14), is as follows: Saturated solid solution →GP + GPB →Intermediate Phases→$CuAl_2$ (θ) + $CuMgAl_2$, where, GP represents Guinier-Preston Cu zones and GPB represents Guinier-Preston Bagariatskij Cu/Mg zones. The intermetallic compounds, $CuAl_2$ and $CuMgAl_2$, are the equilibrium phases. The primary strengthening is associated with the GP and GPB zone formations and the intermediate phases. Nucleation and some formation of these strengthening phases occurs during room temperature aging. The effects of Ag as a minor alloying addition results in the precipitation of an Ω phase (Refs. 14, 15) which has the same structure and composition of the θ phase but different orientation relationship to the matrix. This phase is reported to have greater thermal stability and contributes significantly to the age hardening.

2.1.3 Thermal Conductivity. 70 Btu/ft/hr/F. (Ref. 17)

2.1.4 Thermal Expansion

2.1.4.1 *[Figure]* Thermal Expansion.

2.1.5 Specific Heat. 0.22 Btu/lb/deg F.

2.1.6 Thermal Diffusivity.

2.2 Other Physical Properties

2.2.1 Density. 0.101 lb/in.^{3}.

2.2.2 Electrical Properties.

2.2.3 Magnetic Properties.

2.2.4 Emmitance.

2.2.5 Damping Capacity.

2.3 Chemical Environments

2.3.1 General Corrosion.

2.3.2 Stress Corrosion.

General. Data reported in Ref. 11 show the -T4 (not aged) condition to be resistant to both intergranular and stress corrosion. Artificial aging at 300 to 330F produces conditions highly susceptible to both intergranular and stress corrosion. Overaging at 360 to 370F (-T7) resulted in conditions which showed no corrosion under the test conditions reported. This type of information has discouraged the use of the -T6 (fully aged) condition.

2.3.2.1 *[Table]* Integranular and stress corrosion behavior as a function of aging temperature and time.

2.4 Nuclear Environments

3 Mechanical Properties

3.1 Specified Mechanical Properties

3.1.1 *[Table]* AMS specified mechanical properties.

3.1.2 *[Table]* Tensile properties specified in MIL-A-21180D.

3.2 Mechanical Properties at Room Temperature

3.2.1 Tension Stress-strain Diagrams and Tensile Properties.

3.2.1.1 *[Figure]* Cyclic stress-strain curve for specimens from sand composite cast plate.

3.2.1.2 *[Table]* Tensile and compression properties of specimens removed from sand cast mold step plates.

3.2.1.3 *[Table]* Smooth and notch tensile results for specimens from sand composite cast plates from three foundries.

3.2.1.4 *[Table]* Tensile properties of sand cast bars aged to the -T6 and -T7 conditions.

3.2.1.5 *[Table]* Tensile and compressive strength, elastic modulus and Vickers hardness of three types of castings providing different cooling rates.

3.2.1.6 *[Figure]* Effect of exposure time at elevated temperatures on room temperature tensile properties of -T7 sand cast test bars.

3.2.2 Compression Stress-strain Diagrams and Compression Properties.

3.2.2.1 Compressive strength. (see Table 3.2.1.2.)

3.2.3 Impact.

3.2.4 Bending.

3.2.5 Torsion and Shear.

3.2.5.1 *[Table]* Shear strength of specimens removed from sand cast mold step plates.

3.2.6 Bearing.

3.2.6.1 *[Table]* Bearing strength of specimens removed from sand cast mold step plates.

3.2.7 Stress Concentration.

3.2.7.1 Notch Properties.

3.2.7.1.1 Sharp notch tensile strength. (see Table 3.2.1.3)

3.2.7.2 Fracture Toughness. There is a very limited data base for valid plane strain fracture roughness values. The K_{Ic} range, Table 3.2.7.2.1, is between about 23 to 33 ksi$\sqrt{in.}$ and appears to increase with decreasing tensile strength. The presence of substantial amounts of porosity did not reduce the plane strain fracture toughness. (see Table 1.9.3.1)

3.2.7.2.1 *[Table]* Plane strain fracture toughness of separately sand cast blocks.

3.2.8 Combined Loading.

3.3 Mechanical Properties at Various Temperatures

3.3.1 Tension Stress-strain Diagrams and Tensile Properties.

3.3.1.1 *[Figure]* Effect of test temperature on tensile properties of specimens from sand mold step plates from Foundry A.

3.3.1.2 *[Figure]* Effect of test temperature on tensile properties of specimens from sand mold step plates from Foundry B.

3.3.1.3 *[Figure]* Effect of exposure time and test temperature on -T7 sand cast bars tested at the exposure temperature.

3.3.2 Compression Stress-strain Diagrams and Compression Properties.

3.3.3 Impact.

3.3.4 Bending.

3.3.5 Torsion and Shear.

3.3.6 Bearing.

3.3.7 Stress Concentration.

3.3.7.1 Notch properties.

3.3.7.2 Fracture toughness.

3.3.8 Combined Loading.

3.4 Creep and Creep Rupture Properties

3.4.1 *[Figure]* Time for 0.25 percent total creep at several elevated temperatures for -T7 sand cast test bars.

3.4.2 *[Figure]* Time for 0.5 percent total creep at several elevated temperatures for -T7 sand cast test bars.

3.4.3 *[Figure]* Time for 1.0 percent total creep at several elevated temperatures for -T7 sand cast test bars.

3.4.4 *[Figure]* Rupture time at several elevated temperatures for -T7 sand cast test bars.

3.5 Fatigue Properties

3.5.1 Conventional High Cycle Fatigue.

3.5.1.1 *[Figure]* Rotating bending fatigue strength at room temperature and 400F for -T7 sand cast test bars.

3.5.1.2 *[Figure]* Effect of HIP processing on the fatigue strength of axially loaded specimens from a rejected turbofan rim.

3.5.1.3 *[Figure]* Fatigue strength of axially loaded specimens from sand cast plates from three foundries.

3.5.1.4 *[Figure]* Fatigue strength of axially loaded notched specimens from designated areas of sand cast step plates.

3.5.1.5 *[Figure]* Fatigue strength of axially loaded notched specimens from sand cast plates from three foundries.

3.5.1.6 *[Figure]* Fatigue strength (R = -1.0) of axially loaded -T6 notched (K_t = 3) specimens from individually cast test bars.

3.5.1.7 *[Figure]* Fatigue strength (R = 0.2) of axially loaded -T6 notched (K_t = 3) specimens from individually cast test bars.

3.5.1.8 *[Figure]* Fatigue strength (R = -1.0) of axially loaded -T7 notched (K_t = 3) specimens from individually cast test bars.

3.5.1.9 *[Figure]* Fatigue strength (R = 0.2) of axially loaded -T7 notched (K_t = 3) specimens from individually cast test bars.

3.5.1.10 *[Figure]* Fatigue strength of axially loaded notched (K_t = 3) specimens from sand cast step plates containing porosity.

3.5.2 Low Cycle Fatigue.

3.5.2.1 *[Figure]* Strain vs life data for specimens from sand cast plate from three foundries.

3.5.3 Fatigue Crack Propagation.

3.5.3.1 *[Figure]* Fatigue crack growth rates for specimens removed from sand cast step plates from two foundries.

3.5.3.2 *[Figure]* Fatigue crack growth rates for sand cast plates from three foundries.

3.6 Elastic Properties

3.6.1 Poisson's Ratio.

3.6.2 Modulus of Elasticity. The available data do not definitely establish a modulus for the different temper conditions of A201. Internal defects in cast material can alter the modulus and may account for some of the variation reported. Values are reported in Table 3.2.1.5 for various tempers and casting conditions. A value of 10,300 ksi appears reasonable for the -T7 condition.

3.6.3 Modulus of Rigidity.

3.6.4 Tangent Modulus.

3.6.5 Secant Modulus.

4 Fabrication

4.1 Forming

4.2 Machining and Grinding

No special problems arise in machining of A201.0 which machines easily.

4.3 Joining

4.3.1 Welding. Very limited data are available on welding and no general rules can be given at this time.

Repair welding is often used on castings and a review of the methods and precautions is given in Ref.19. This reference points out that A201.0 is rather difficult to weld without cracking. This problem is probably associated with the alloy's relative high shrinkage during solidification (see Table 1.9.2.1). GTA welding data have been reported (Ref. 6) using AMS 4233 composition wire. These welds were made in such a way as to simulate weld repairs of castings. Thus, the weld metal did not constitute the entire test section. Tensile and fracture toughness values for parent metal and welded specimens were essentially equal, as shown in Table 4.3.1.2, indicating the absense of cracking problems.

4.3.1.1 *[Figure]* Location of specimens in the designated areas of welded step plates.

4.3.1.2 *[Table]* Welding conditions used to produce welds in step plates.

4.3.1.3 *[Table]* Effect of GTA welding on the average tensile properties and fracture toughness of sand cast step plates.

4.4 Surface Treating

4.4.1 Small surface irregularities are easily removed by light machining. Electroplating and anodizing impart good finishes.

Table 1.2.1 Alternate designations

Alloy	UNS
A201.0-T4	A12010
A201.0-T7	A02010
B201.0-T7	A02010
201.0	A02010
SAE 382	—

Table 1.3.1 AMS Specifications (Refs. 1-4)

Alloy	AMS	Form
A201.0-T4	4223C (1)	Castings Solution Heat Treated and Naturally Aged
A201.0-T7	4229C (2)	High Strength Castings Solution Heat Treated and Overaged
B201.0-T7	4242(3)	Sand Composite Castings Solution Heat Treated and Overaged Aircraft Structural Quality
201	4233(4)	Weld Wire

Table 1.4.1 AMS and military specification compositions (Refs. 1-4, 8)

Alloy	A201.0		B201.0	
Form	See Table 1.3.1			
Source	AMS 4223[(1)], 4229[(2)], 4233[(4)] and MIL-A-28110D[(8)]		AMS 4242[(3)]	
Elements	Minimum	Maximum	Minimum	Maximum
Copper	4.0	5.0	4.0	5.0
Silver	0.40	1.0	0.40	0.80
Manganese	0.20	0.40	0.20	0.50
Magnesium	0.15	0.35	0.20	0.30
Titanium	0.15	0.35	0.15	0.35
Iron	—	0.10	—	0.05
Silicon	—	0.05	—	0.05
Other, each	—	0.03[a]	—	0.05
Other, total	—	0.10	—	0.15
Aluminum	Remainder		Remainder	

[a] AMS 4233 gives Beryllium = 0.0008 max.

Table 1.4.2.1 Maximum hardness and tensile strengths produced by aging at three temperatures for Al-Cu-Mg and Al-Cu-Mg-Ag alloy castings (Ref. 13, Table 1)

Alloy	A201.0					
Form	Castings					
Melting Practice	High Purity Stock, degas with Chlorine, no grain refiners, chill cast in iron molds to give ingots 9.4 x 4.3 x 1.1 inch					
Homogenize (F/hr)	932/24					
Solution Treat (F)	968					
Composition	Al - 4Cu - 0.25Mg			Al - 4.4Cu - 0.27Mg - 0.71Ag		
Age (F/hr)	266/480	338/7.2	446/1.2	266/480	338/7.2	446/1.2
Vickers Hardness	116	105	85	153	140	120
F_{tu} (ksi)		45	39		51	38
F_{ty} (ksi)		38	24		51	38

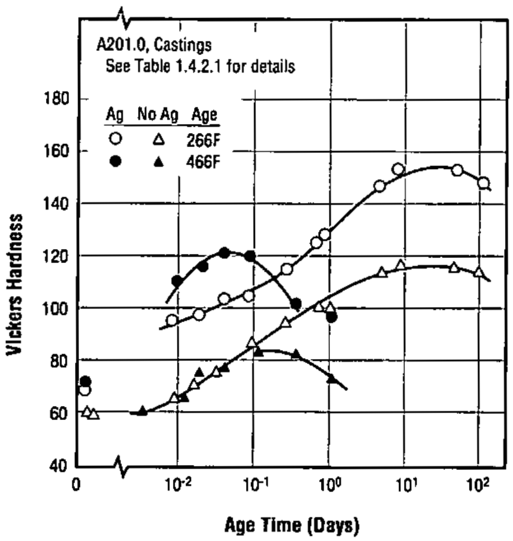

Figure 1.4.2.2 Effect of silver addition on aging response of a Al-Cu-Mg casting (Ref. 13, Fig. 1)

Table 1.4.2.3 Casting and heat treatment details for investment and sand cast plates used in investigation of composition and other factors controlling the mechanical properties of A201.0 castings (Ref. 6, pp. 32-39)

A201.0-T7

Shell investment[a] Plates 3 x 10 x 3/16-in. thick	Sand Composite[a] Plates 3 x 10 x 3/4-in. thick
↓ Six refractory coatings applied to wax pattern	↓ Cope and drag sand mold with chills in cope and drag
↓ Dewaxed with 100 psi steam	↓ 300-lb melt degassed with 90% Nitrogen + 10% Chlorine
↓ Shell cured at 1200F 4 hr	↓ Poured at 1375F into mold at RT
↓ 80-lb melt, grain refined with 5% Ti - 1% B at 1300F	↓ Clean-up by rough grinding
↓ Degassed 95% Nitrogen + 5% Freon 12	↓ ST 975F 2 hr + 985F 18 hr, 40F, WQ
↓ Poured at 1300F at 3-1/2 psi	↓ Age RT 12-14 hr + 370F 5 hr
↓ Clean with high velocity water	
↓ ST 965F 2 hr + 990F 16 hr, WQ + straighten	
↓ Age RT 12 hr + 370F 5 hr	

[a] Radiographic Grade B or better for heat treatment and composition studies; special plates were produced for effects of dross, shrinkage and porosity.

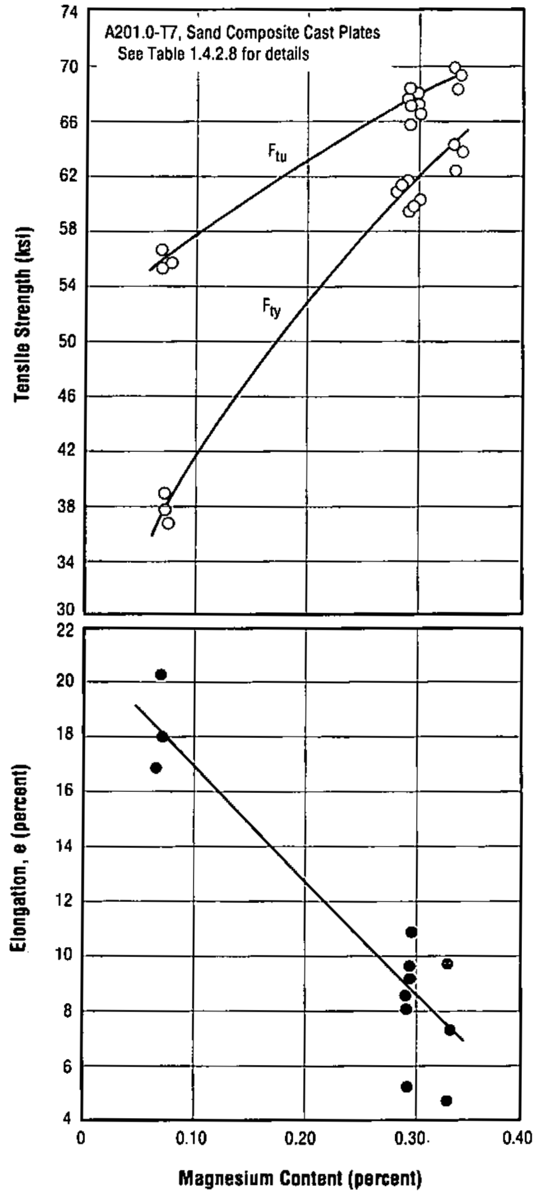

Figure 1.4.2.4 Effect of magnesium content on tensile properties of a sand composite cast plate (Ref. 13, Fig. 52)

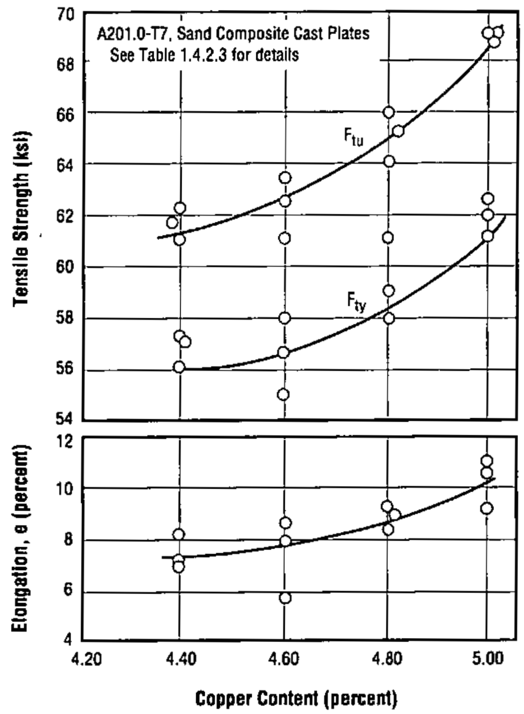

Figure 1.4.2.5 Effect of copper content on tensile properties of a sand composite cast plate (Ref. 6, Fig. 54)

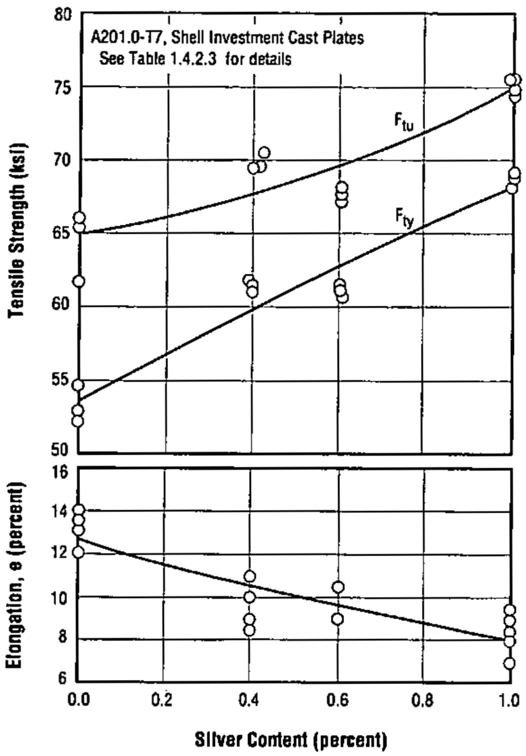

Figure 1.4.2.6 Effect of silver content on tensile properties of shell investment cast plates (Ref. 6, Fig. 56)

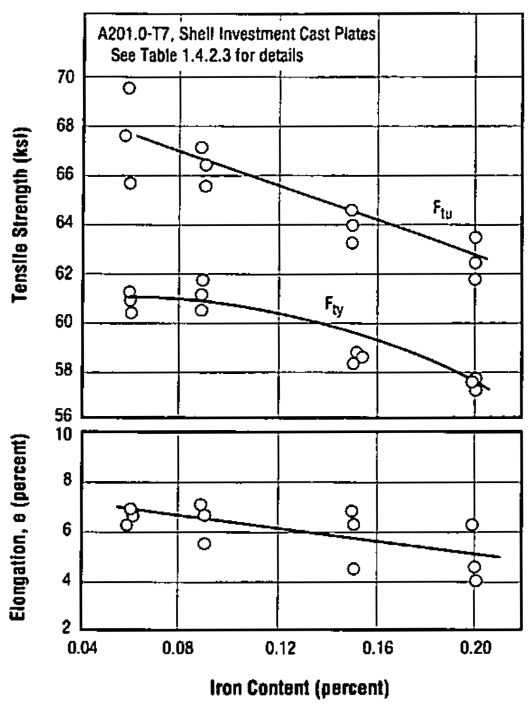

Figure 1.4.2.7 Effect of iron content on tensile properties of shell investment cast plates (Ref. 6, Fig. 58)

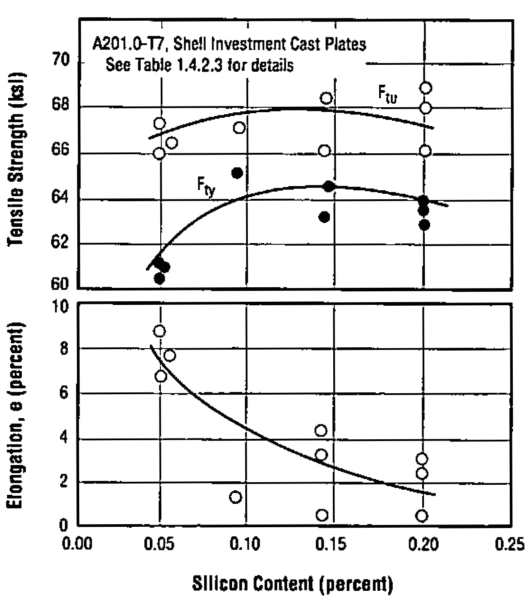

Figure 1.4.2.8 Effect of silicon content on tensile properties of shell investment cast plates (Ref. 6, Fig. 61)

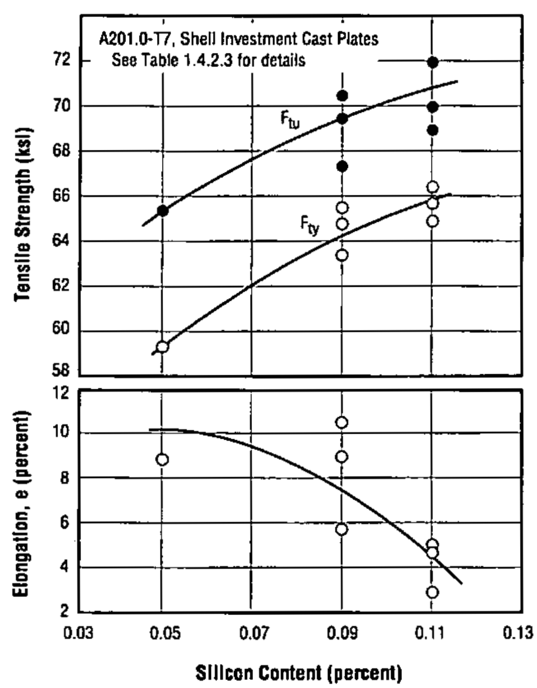

Figure 1.4.2.9 Effect of silicon content on tensile properties of sand composite cast plates (Ref. 13, Fig. 62)

Table 1.4.2.10 Effect of out-of-specification composition and mold cooling rate on tensile properties and grain size of sand composite cast plates (Ref. 9, Tables 33-36)

Alloy	A201.0-T7					
Form	0.75-in. Thick x 6-in. x 12-in. Cast Plates					
Heat Treat	ST 940F 2 hr + 960F 2 hr + 980F 16 hr + Age 360F 8 hr					
HIP	950F, 15 ksi, 3 hr					
Composition	AMS 4242 (See Table 1.4.1)		Outside AMS 4242			
			0.052 Ti		5.25Cu - 1.45Ag - 0.43Mg	
Pour Temperature/ Chill Material	1450F/Fe	1350F/Cu	1450F/Fe	1350F/Cu	1450F/Fe	1350F/Cu
F_{tu} (ksi)	65	67	69	69	74	77
F_{ty} (ksi)	60	60	64	64	73	72
e (percent)	6.3	9.4	3.0	3.2	1.4	5.7
Grain Size (10^{-4} in) at chill at edge	 42 52	 38 39	 47 56	 47 47	 90 75	 70 65

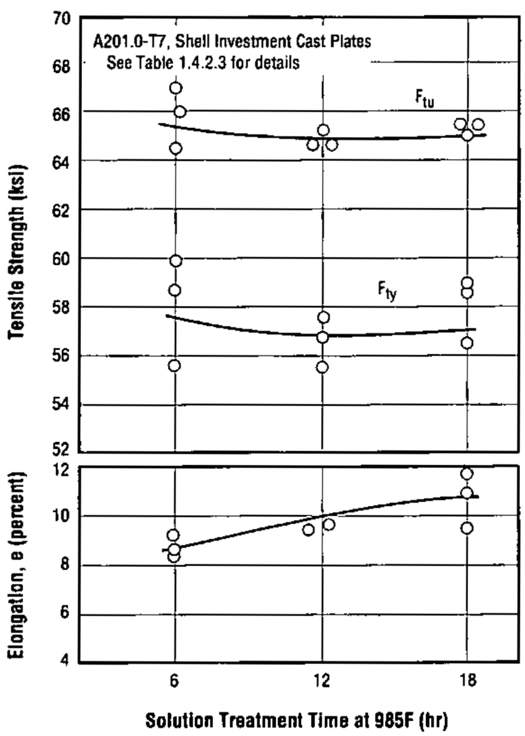

Figure 1.5.1 Effect of solution heat treatment time on tensile properties of shell investment cast plates (Ref. 6, Fig. 63)

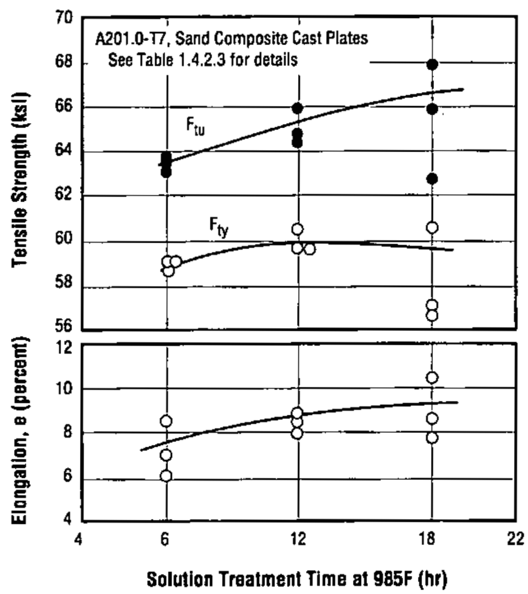

Figure 1.5.2 Effect of solution heat treatment time on tensile properties of sand composite cast plates (Ref. 6, Fig. 64)

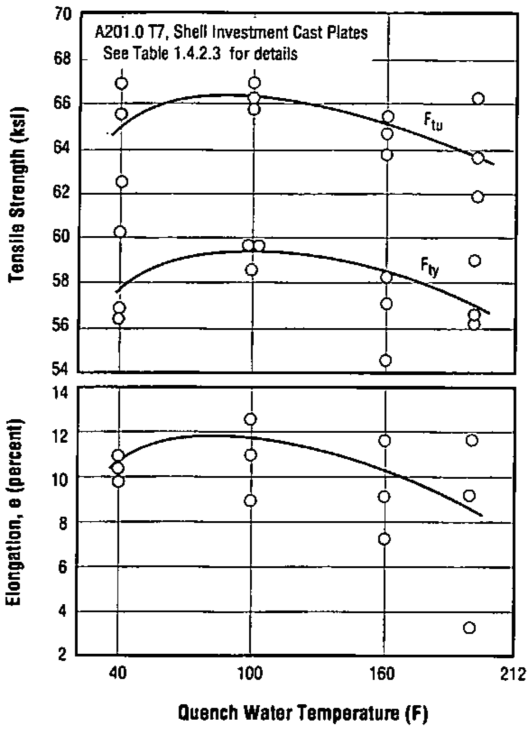

Figure 1.5.3 Effect of quench water temperature on tensile properties of shell investment cast plates (Ref. 6, Fig. 65)

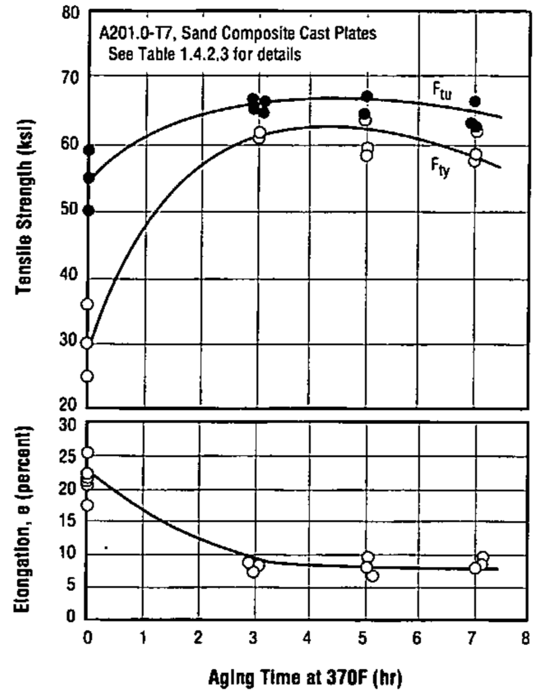

Figure 1.5.4 Effect of aging time at 370F on tensile properties of sand composite cast plates (Ref. 6, Fig. 70)

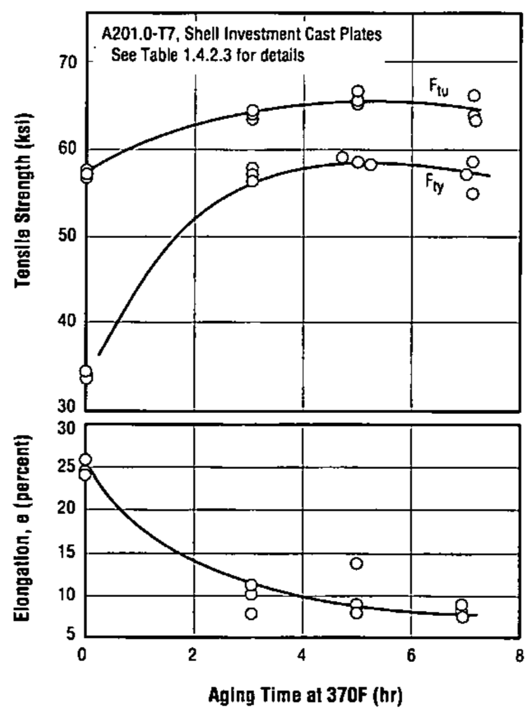

Figure 1.5.5 Effect of aging time at 370F on tensile properties of shell investment cast plates (Ref. 6, Fig. 69)

Table 1.5.6 AMS and MIL-Specification heat treatments (Refs. 1-3, 8)

Alloy	A201.0		B201.0	A201.0
Specification	AMS4223[1]	AMS 4229[2]	AMS 4242[3]	MIL-A-21180D[8]
Solution Treat	Heavy-wall castings 3/4-to 2-in. wall thickness 900 to 920F 2 hr + 980 to 990F 12 hr, quench	Heavy-wall castings as in 4223	All castings 945 to 965F 2 hr minimum + 970 to 990F 14 hr minimum	All castings 945 to 965F 2 hr minimum + 965 to 985F 8 to 24 hr[a]
	Thin-wall castings 940 to 960F, 2 hr + 980 to 990F 8 hr, quench	Thin-wall castings as in 4223	—	—
Age	RT 72 hr minimum	360 to 380F 5 hr	365 to 375F 5 hr minimum	360 to 380F 5 hr

[a] Soaking time varies with section thickness and grain size of the casting. Quench into a water bath at RT to 190F or into an aqueous solution of polyalkylene glycol.

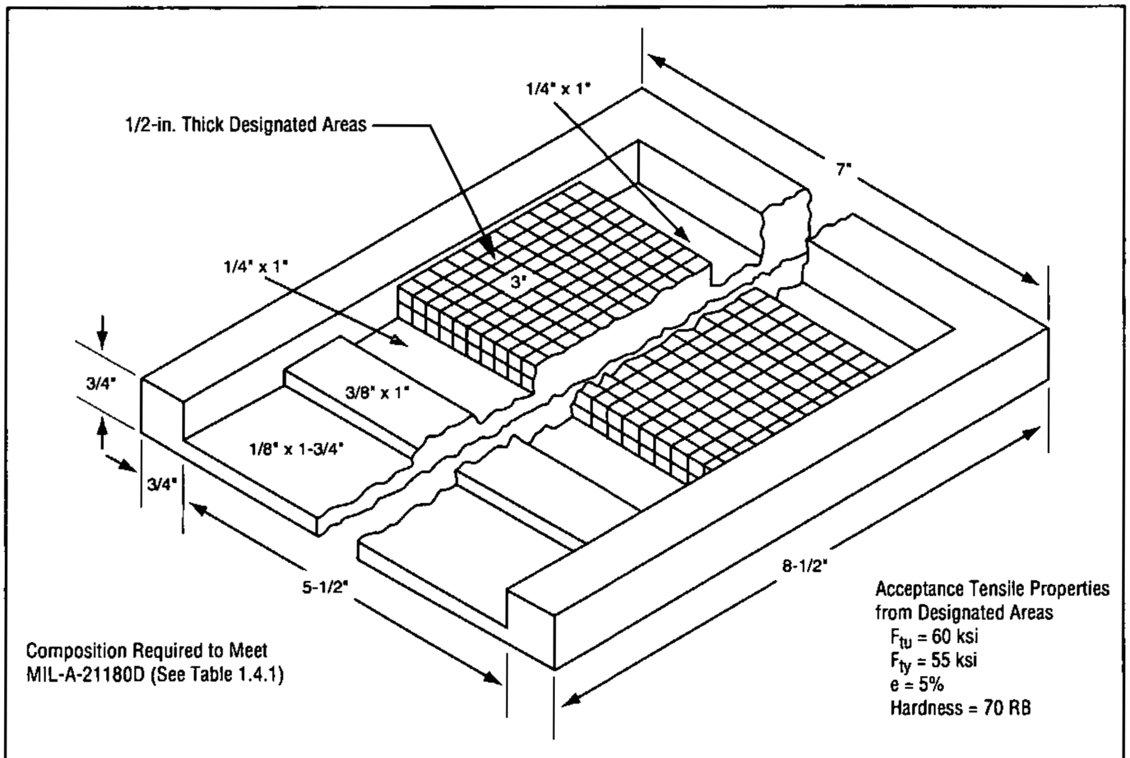

Figure 1.8.1.1 Sand composite mold cast step plates for Northrop Investigation of Manufacturing Processes on Design Allowables. (Ref. 6)

Table 1.8.1.2 Foundry practice in producing step plates (Ref. 6, p. 155 and Appendix E)

Alloy	A201.0	
Target Composition	4.5Cu, 0.50 - 1.0Ag, 0.25 - 0.35Mg otherwise as MIL-A-28110D	
Form	Sand Composite Mold Cast Step Plates	
Foundry	A	B
Degas	$N_2 + Cl_2$	Argon + Freon
Grain Size Control	5%Ti - 1%B pour within 30 minutes	Ti - B to give 0.02% Ti stir, wait 10 minutes, pour
Pouring Temperature (F)	1300	1400
Solution Treat (F/hr)	940/1	920/2
	960/1	950/2
	980/12	960/2
		980/18
Age (F/hr)	RT/12-24 + 370/5	RT/12 + 370/5

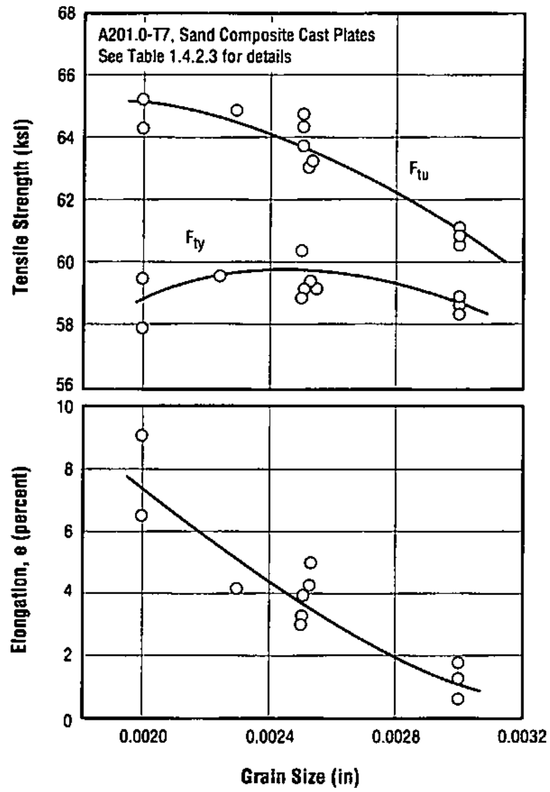

Figure 1.8.2.1 Effect of grain size on the tensile properties of a sand composite cast plate (Ref. 6, Fig. 75)

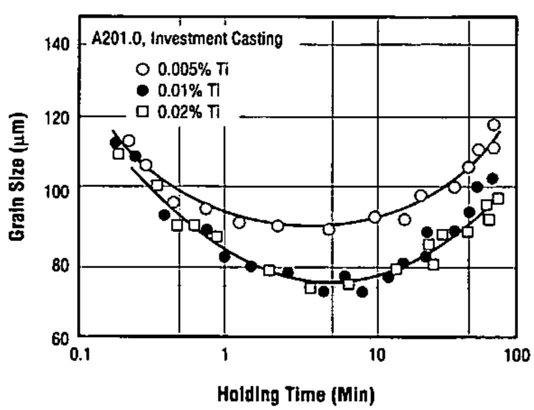

Figure 1.8.2.2 Effect on holding time and titanium content on grain size of melt inoculated with 5%Ti - 1%B (Ref. 12, Fig. F)

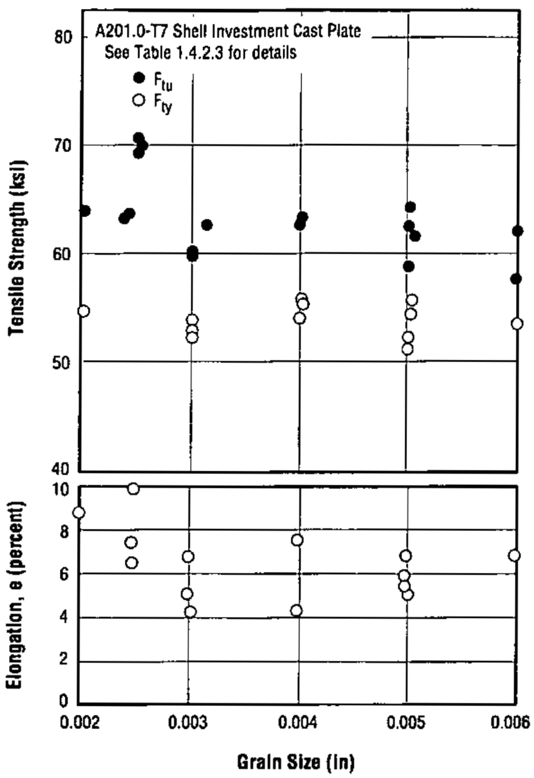

Figure 1.8.2.3 Tensile properties of shell investment cast plate at various grain sizes (Ref. 6, Fig. 74)

Table 1.9.1.1 Possible grain boundary phases present in castings (Ref. 12, Appendix B)

Alloy	A201.0
Form	Casting
Grain Boundary Phase	Melting Temperature (F)
$CuAl_2$	1096
$CuMgAl_2$	945
Ag_2Al	1340
$Cu_2Mn_3Al_{20}$	1141
$(CuFeMn)Al_6$	1209
$(CuFeMn)_3Si_2Al_{15}$	986
$FeSiAl_5$	1132
Mg_2Si	1103
$(FeMn)Al_6$	1213
$TiAl_3$	2338

Table 1.9.2.1 Effect of casting defects on the tensile properties of shell investment and sand composite mold castings (Ref. 6, Figs. 76, 77)

Alloy	A201.0-T7			
Condition[a]	For Casting and Heat Treat Details, See Table 1.4.2.3			
Form	Shell Investment		Sand Composite	
Defect Type	Shrinkage		Dross	
Radiographic Grade	AB	CD	B	D
F_{tu} (ksi) range	59.5 – 61.0	56.0 – 56.4	65.2 – 68.0	54.3 – 57.9
F_{ty} (ksi) range	51.6 – 53.0	51.2 – 51.8	57.6 – 60.2	51.4 – 53.5
e (percent) range	6.2 – 7.2	3.3 – 3.9	6.5 – 9.4	0.7 – 2.0

[a] Specially cast plates with defects.

Table 1.9.3.1 Effect of round gas porosity on the tensile properties and fracture toughness of defective step plates compared with Grade B plates (Ref. 6, pp. 267, 269)

Alloy	A201.0-T7	
Condition	Step Plates, See Figure 1.8.1.1	
Radiographic Grade	D[a]	B[b]
F_{tu} (ksi) Average Minimum Maximum n[c]	 58.2 56.7 69.3 4	 64
F_{ty} (ksi) Average Minimum Maximum n	 56.1 54.9 57.2 4	 56.1
e (percent) Average Minimum Maximum n	 1 1 1 4	 5.6
K_{Ic} (ksi $\sqrt{in.}$) Average[d] Minimum Maximum	 24.4 23.4 25.3	 24

a Round gas porosity No. 5 and 6.

b Average - specimens from designated areas.

c n = number of specimens.

d Round gas porosity No. 6.

Table 1.9.5.1 Effect of hot isostatic pressing on specimens removed from rejected turbofan rim (Ref. 7, Tables 6, 7)

Alloy	A201.0				
Form	Turbofan Engine Front Frame Rim				
Condition	HIP + 940F 2 hr + 970F 2 hr + 980F 6 hr, WQ + RT, 12 hr + 370F 5 hr, AC				
Grade	Porosity Radiographic Grade C Before HIP				
HIP Cycle	None	950F/10 ksi/6 hr	950F/10 ksi/12 hr	950F/15 ksi/6 hr	980F/10 ksi/6 hr
F_{tu} (ksi)					
n[a]	6	6	13	7	6
Mean	28.3	30.1	57.1	66.5	37.7
Sdev[b]	9.8	11.37	8.57	2.99	8.07
F_{ty} (ksi)					
n[a]	6	6	13	7	6
Mean	(c)	(c)	49.3	49.7	(c)
Sdev[b]			5.5	3.00	
RA (percent)					
n[a]	6	6	13	7	6
Mean	1.3	1.52	10.3	14	1.8
Sdev[b]	0.23	0.75	5.66	3.97	0.612
e (percent)					
n[a]	6	6	7	7	6
Mean	1.7	1.5	9.8	9.8	1.6
Sdev[b]	0.321	0.505	2.14	2.14	0.271

[a] n = number of tests.

[b] Standard deviation.

[c] Specimens failed before 0.2 percent strain.

Table 1.9.6.1 Tensile properties of squeeze cast and permanent mold castings (Ref. 20, Table 2)

Alloy	A201.0-T6	
Form	Castings[a]	
Composition	Within AMS 4223	
Cast Process	Squeeze 22 ksi	Permanent Mold
F_{tu} (ksi)	72	65
F_{ty} (ksi)	65	55
e (percent)	12.1	8
Grain Size (in.)	0.004	—

[a] Details concerning the mold design and size not given.

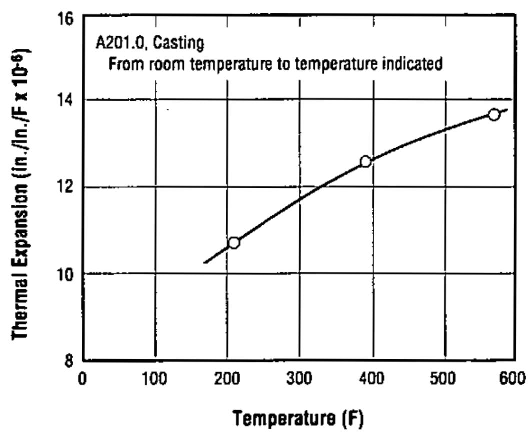

Figure 2.1.4 Thermal expansion (Ref. 17)

Table 2.3.2.1 Intergranular and stress corrosion behavior as a function of aging temperature and time (Ref. 11, Fig. 16)

Alloy	A201.0						
Composition	4.85Cu, 0.72Ag, 0.28Mg, 0.30Mg						
Form	Green Sand Cast Bars						
Condition	ST[a] + Age						
Age Temperature (F)	0	300	320	310(-T6)	330	360	370(-T7)
Age Time (hr)		1	2	20	10 - 32	12	5
Intergranular[b] Penetration (mils)	0	5	20	12.5	10	0	0
SCC Failure Time[c]	> 30 days	< 24 hr	< 24 hr	5 days	< 30 days	> 30 days	> 30 days

[a] Not given.

[b] Immersion for 6 hours at 86F in 57g NaCl + 10 mil 30% H_2O_2 in 1 liter distilled water.

[c] Alternate immersion at 75% F_{ty} in 3.5% NaCl solution 50 minutes + 10 minutes out.

Table 3.1.1 AMS Specified mechanical properties (Refs. 1-3)

Alloy	A201.0-T4			A201.0-T7			B201.0-T7[a]		
AMS[b]	4223[(1)]			4229[(2)]			4242[(3)]		
Specimens Location	Designated Areas	Other Areas	Separately Cast	Designated Areas	Other Areas	Separately Cast	Designated Areas	Other Areas	Integrally Attached Coupons
F_{tu} (ksi) min.	50	35	50	60	56	60	60	56	62
F_{ty} (ksi) min.	30	25	30	50	48	50	50	48	55
e (percent) min.	12	5	12	3	1.5	3	3	2	5
Hardness - BHN 10/500 10/1000	80 - 110 85 - 115			110 - 145 115 - 150					

[a] Specimens cut from designated area of a casting or from an attached coupon shall show no evidence of stress corrosion cracking when tested at 37.5 ksi for 30 days in accordance with ASTM G 44.

[b] AMS 4223 and 4229 also call out requirements for stress corrosion resistance but these are not specific as in AMS 4242.

Table 3.1.2 Tensile properties specified in MIL-A-21180D (Ref. 8)

Alloy	A201.0			
Condition	-T7			
Specimen Location	Designated Areas		Any Area	
Strength Class	1	2	10	11
F_{tu} (ksi)	60	60	60	56
F_{ty} (ksi)	50	50	56	48
e (percent)	3	5	3	1.5

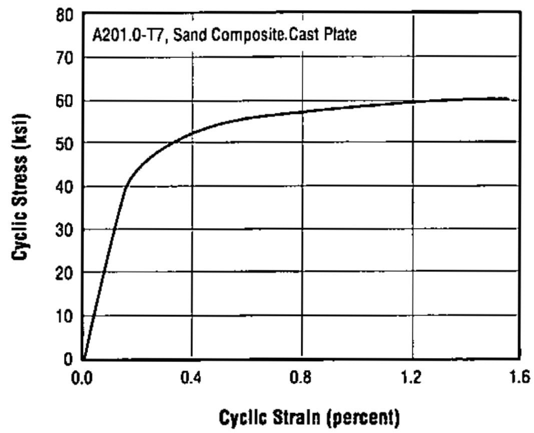

Figure 3.2.1.1 Cyclic stress-strain curve for specimen from sand composite cast plate (Ref. 9, Fig. 89)

Table 3.2.1.2 Tensile and compression properties of specimens removed from sand cast mold step plates (Ref. 6, pp. 226, 235)

Alloy	A201.0			
Form	Sand Mold Cast Step Plates, See Figure 1.8.1.1			
Condition	For Heat Treatment, See Table 1.8.1.2			
Foundry	A		B	
Step Plate Location	Designated Area	Areas Not Designated	Designated Area	Areas Not Designated
F_{tu} (ksi)				
Average	64.0	60.5	65.8	65.4
Minimum	59.9	55.4	62.8	62.9
Maximum	69.0	66.6	69.6	67.6
n[a]	51	32	52	33
F_{ty} (ksi)				
Average	58	55.3	60.2	61.2
Minimum	53.7	50.7	56.2	67.7
Maximum	62.7	58.7	63.4	63.5
n	51	32	52	33
e (percent)				
Average	6	4	6	3
Minimum	2	3	2	1
Maximum	11	8	9	9
n	51	32	52	33
F_{cy} (ksi)				
Average	64.7	55.3	64.2	68.9
Minimum	63.4	57.0	62.0	61.6
Maximum	65.5	54.5	64.2	63.9
n	5	5	5	5

[a] Number of tests.

Table 3.2.1.3 Smooth and notch tensile results for specimens from sand composite cast plates from three foundries (Ref. 9, Tables D1-D3)

Alloy	A201.0		
Composition	AMS 4242		
Form	16 x 6 x 1.25-in. Thick Cast Plates from Three Foundries Each Foundry used Metal Chills in Somewhat Different Rigging		
Grain Size	0.0032 in.		
HIP	950F, 15 ksi, 3 hr		
Supplier	Foundry A	Foundry B	Foundry C
Number of Tests	8	10	8
Solution Treat	940F 2 hr + 960F 2 hr + 980F 16 hr, RT WQ	940F 2 hr + 950F 2 hr + 980F 16 hr, RT WQ	920F 2 hr + 950F 2 hr + 970F 2 hr + 980F 16 hr, RT WQ
Age	380F 5 hr	360F 8 hr	RT 24 hr + 360F 8 hr
F_{tu} (ksi) Average Minimum Maximum	 66 65 67	 70 68 73	 67 64 70
F_{ty} (ksi) Average Minimum Maximum	 57 54 58	 63 60 66	 60 58 62
e (percent) Average Minimum Maximum	 9 8 11	 8 7 9	 8 7 10
NYS/F_{ty}[a] Average Minimum Maximum	 1.59 1.5 1.65	 1.32 1.27 1.38	 1.5 1.43 1.57

[a] ASTM E 602 0.5-inch diameter specimen.

Table 3.2.1.4 Tensile properties sand cast bars aged to the -T6 and -T7 conditions (Ref. 5, Table 1)

Alloy	A201.0	
Form	Green Sand Cast Bars	
Composition	As AMS 4223 except 0.16 - 0.35Mg	
Solution Treat	970F 2 hr + 985F 20 hr, WQ	
Age	310F 20 hr, -T6	370F 5 hr, -T7
F_{tu} (ksi) Average Minimum Maximum n[a]	 67.9 66.3 69.4 6	 65.7 65.3 66.0 3
F_{ty} (ksi) Average Minimum Maximum n	 58.4 55.7 67.7 6	 62.7 63.1 62.6 3
e (percent) Average Minimum Maximum n	 8.1 7 10.5 6	 2.7 2 4 3

[a] Number of bars tested.

Table 3.2.1.5 Tensile and compressive strength, elastic modulus and Vickers hardness for three types of castings providing different cooling rates (Ref. 16, Tables A1-A3)

Alloy	A201.0								
Composition	Within AMS 4223								
Solution Treat	955F 2 hr + 385F 14 hr, WQ + RT 24 hr								
Cast Form [a]	Permanent Mold			Sand Cast			Insulated		
Temper [b]	-T43	-T6	-T7	-T43	-T6	-T7	-T43	-T6	-T7
F_{tu} (ksi)	59	65	63	52	57	56	40	52	51
F_{ty} (ksi)	36	58	57	35	52	54	33	51	50
e (percent)	21	7	6	8	1	1.7	7	2	0.8
RA (percent)	21	11	8	10	3.4	1.7	6	1.8	1.3
F_{cy} (ksi)	39	63	62	58	58	59	35	35	55
E-Tension (1000 ksi)	9.25	10.8	11.2	8.0	9.4	9.1	8	9.5	8.4
E-Compression (1000 ksi)	9.94	10.6	10	10	8.2	10.3	10	9.1	10.4
Vickers Hardness	135	153	145	133	152	150	128	148	128

a Casting details not given.

b -T43 = Age 310F 1/2 hour, AC
-T6 = Age 310F 20 hours, AC
-T7 = Age 370F 5 hours, AC.

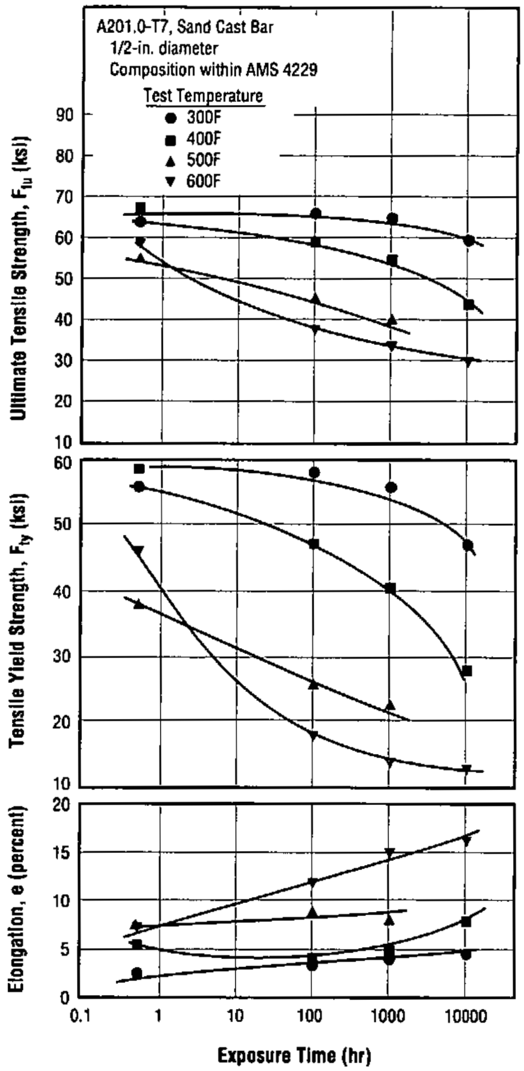

Figure 3.2.1.6 Effect of exposure time at elevated temperature on room temperature tensile properties of -T7 sand cast test bars (Ref. 10, Table 4)

Table 3.2.5.1 Shear strength of specimens removed from sand cast mold step plates (Ref. 6, p. 235)

Alloy	A201.0			
Form	See Figure 1.8.1.1			
Condition	See Table 1.8.1.2			
Foundry	A		B	
Step Plate Location	Designated Area	Areas Not Designated	Designated Area	Areas Not Designated
F_{su} (ksi)				
Average	41.0	38.8	40.2	39.4
Minimum	40.1	37.2	40.1	38.7
Maximum	41.3	39.9	41.3	39.9
n [a]	5	5	5	5

[a] Number of tests.

Table 3.2.6.1 Bearing strength of specimens removed from sand cast mold step plates (Ref. 6, p. 235)

Alloy	201			
Form	See Figure 1.8.1.1			
Condition	See Table 1.8.1.2			
Foundry	A		B	
Step Plate Location	Designated Area	Areas Not Designated	Designated Area	Areas Not Designated
e/D	1.5			
F_{bru} (ksi) Average Minimum Maximum n[a]	 99.5 93.2 103.6 6	 107.4 106.1 108.7 5	 110.0 110.2 111.4 5	 108.4 107.2 109.9 5
F_{bry} (ksi) Average Minimum Maximum n	 88.7 86.6 90.1 5	 87.8 87.1 88.2 5	 98.7 91.3 98.8 5	 90.4 89.1 92.8 5
e/D	2			
F_{bru} (ksi) Average Minimum Maximum n	 136.9 136.1 139.6 5	 127.5 125.5 129.7 5	 142.4 139.1 145.5 5	 129.7 105.3 136.5 5
F_{bry} (ksi) Average Minimum Maximum n	 111.1 103.8 131.4 5	 87.8 87.1 88.3 5	 112.6 106.1 115.4 4	 104.4 102.0 105.5 5

[a] Number of tests.

Table 3.2.7.2.1 Plane strain fracture toughness of separately sand cast blocks (Ref. 6, p. 247)

Alloy	A201.0-T7	
Condition	Separately Sand Cast Blocks	
Foundry	A	B
F_{tu} (ksi) Average Minimum Maximum n[a]	 61.3 59.4 63.2 2	 58 54.8 60.1 3
K_{Ic} (ksi $\sqrt{in.}$) Average Minimum Maximum n	 24.1 23.2 24.9 2	 32.2 30.7 33.2 3

[a] Number of tests.

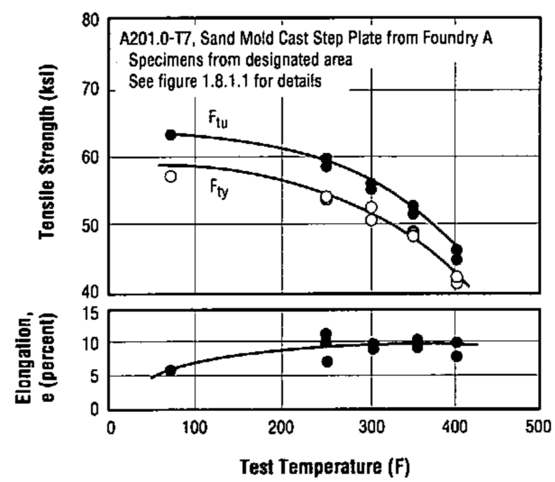

Figure 3.3.1.1 Effect of test temperature on tensile properties of specimens from sand mold step plates from Foundry A (Ref. 6, Table 47)

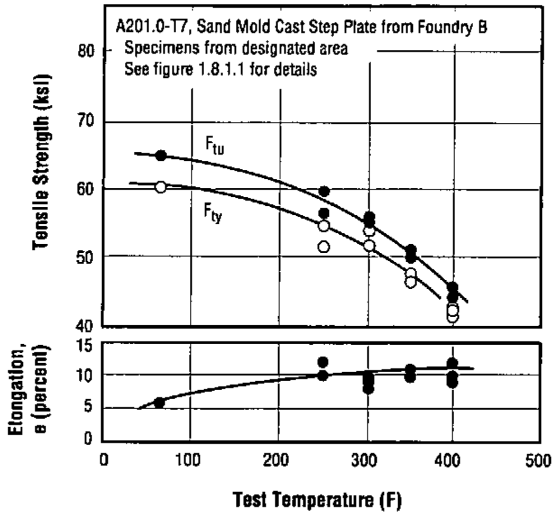

Figure 3.3.1.2 Effect of test temperature on tensile properties of specimens from sand mold step plates from Foundry B (Ref. 6, Table 48)

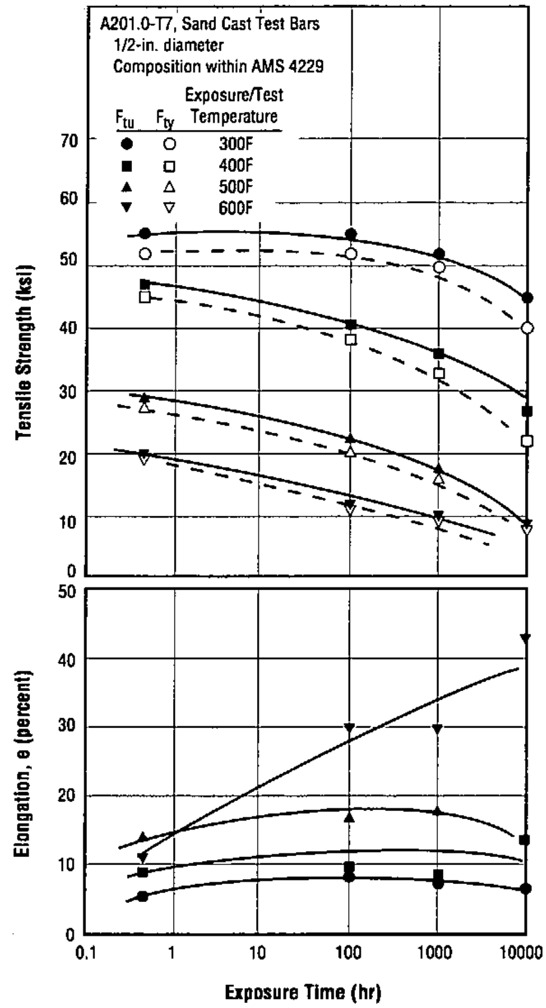

Figure 3.3.1.3 Effect of exposure time and test temperature on -T7 sand cast test bars tested at the exposure temperature (Ref. 10, Table 3)

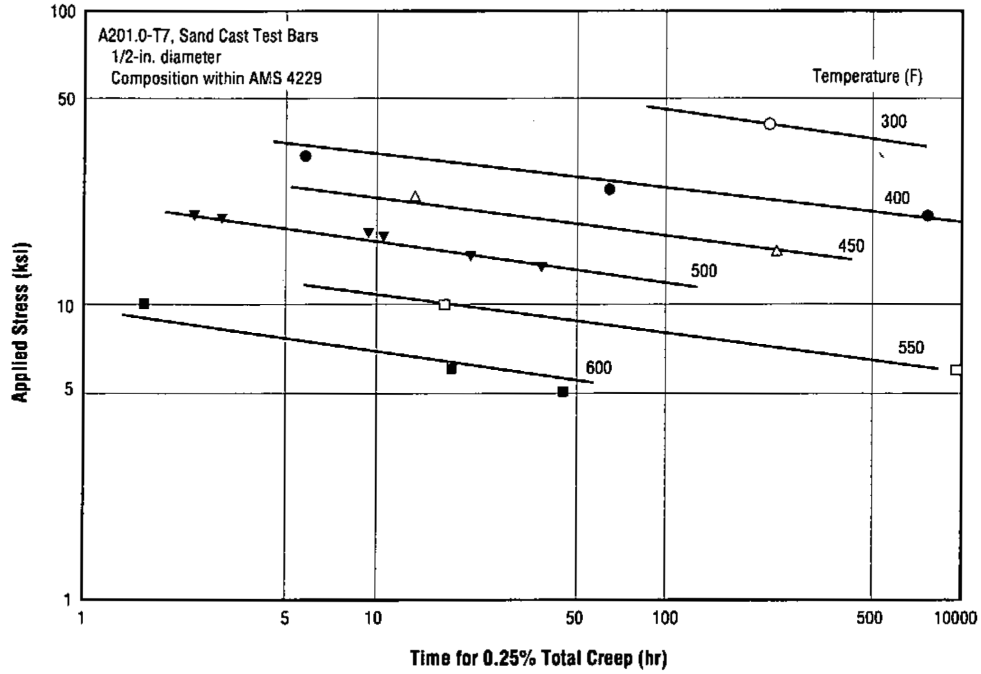

Figure 3.4.1 Time for 0.25 percent total creep at several elevated temperatures for -T7 sand cast test bars (Ref. 10, Fig. 5)

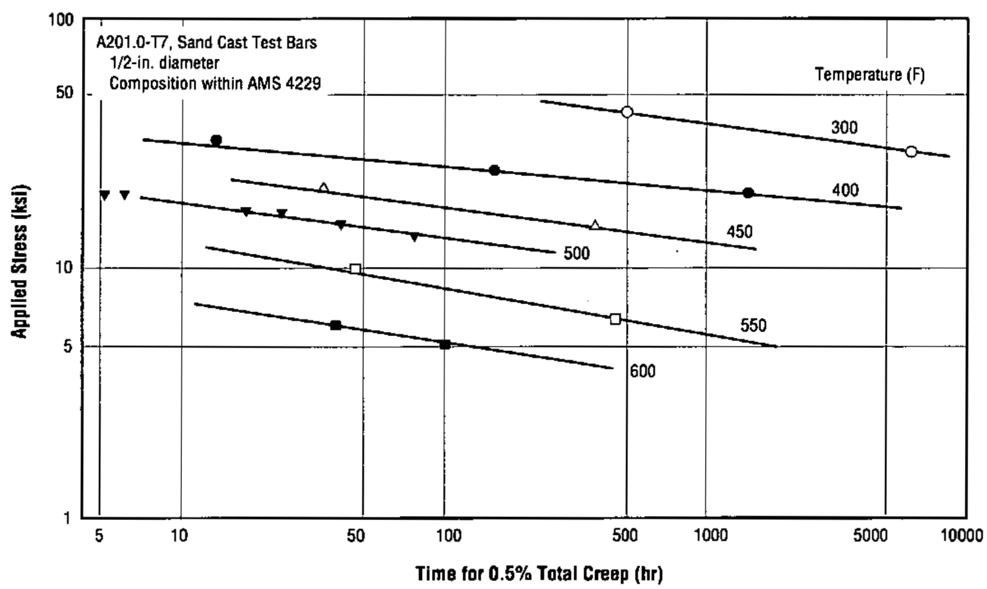

Figure 3.4.2 Time for 0.5 percent total creep at several elevated temperatures for -T7 sand cast test bars (Ref. 10, Fig. 4)

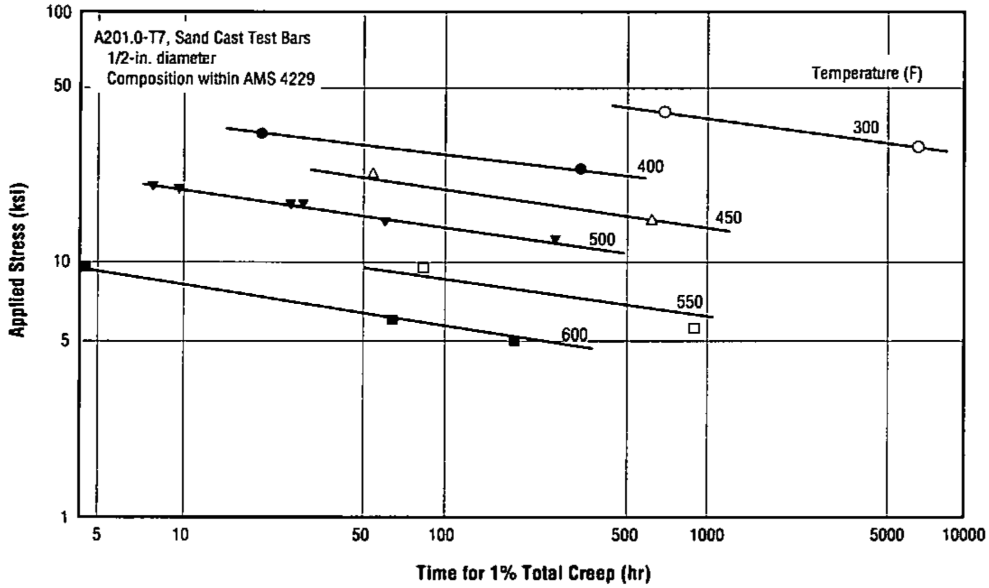

Figure 3.4.3 Time for 1.0 percent total creep at several elevated temperatures for -T7 sand cast test bars (Ref. 10, Fig. 3)

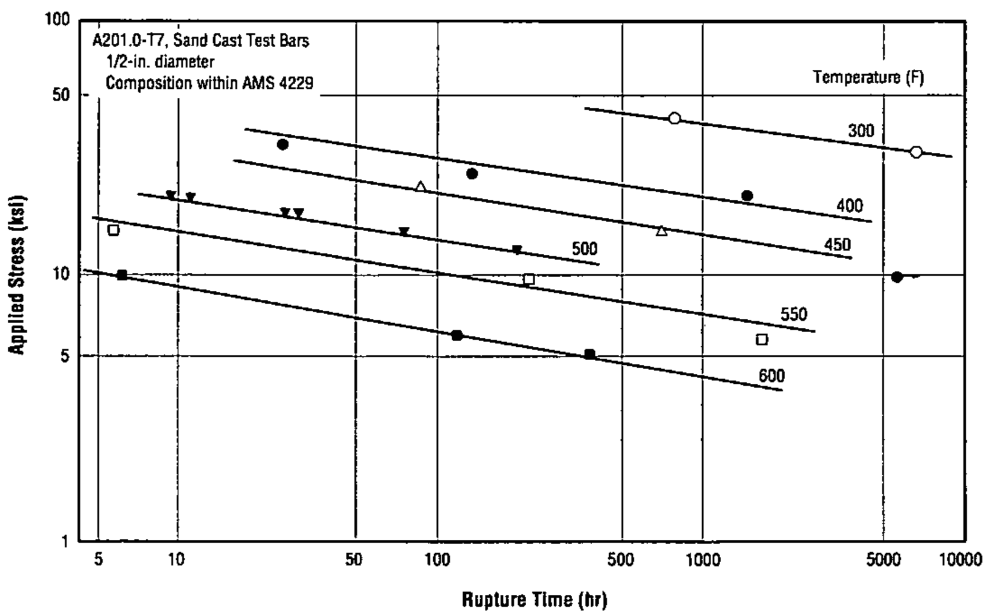

Figure 3.4.4 Rupture time at several elevated temperatures for sand cast test bars (Ref. 10, Fig. 1)

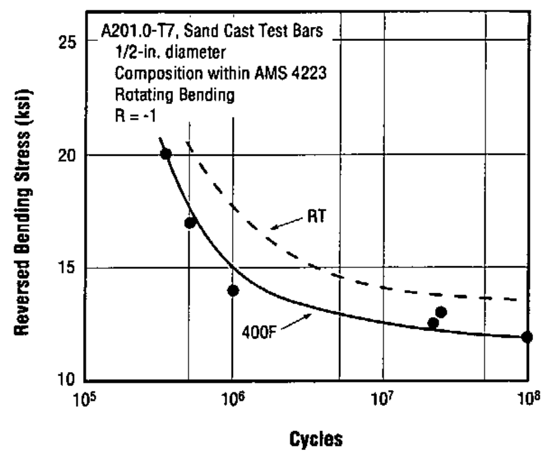

Figure 3.5.1.1 Rotating bending fatigue strength at room temperature and 400F for -T7 sand cast test bars (Ref. 10, Fig. 6)

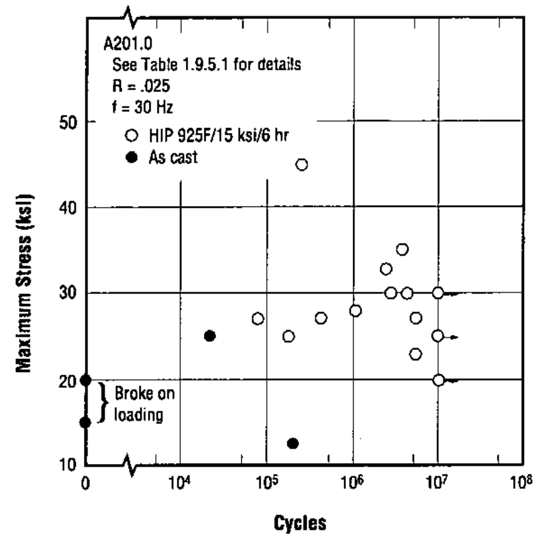

Figure 3.5.1.2 Effect of HIP processing on the fatigue strength of axially loaded specimens from a rejected turbofan rim (Ref. 7, Table 8)

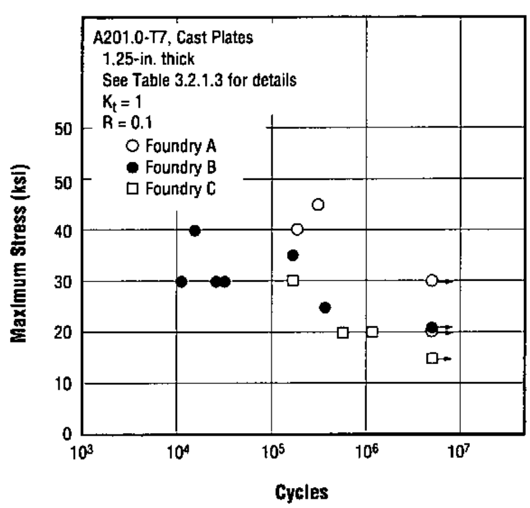

Figure 3.5.1.3 Fatigue strength of axially loaded specimens from sand cast plates from three foundries (Ref. 9, Table 8)

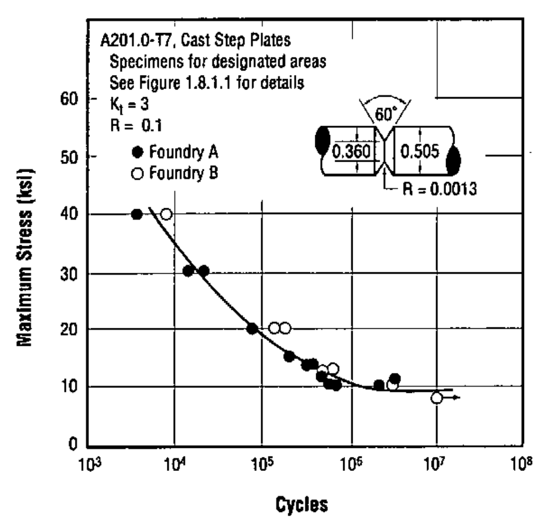

Figure 3.5.1.4 Fatigue strength of axially loaded notched specimens from designated areas of sand cast step plates (Ref. 6, Fig. 108)

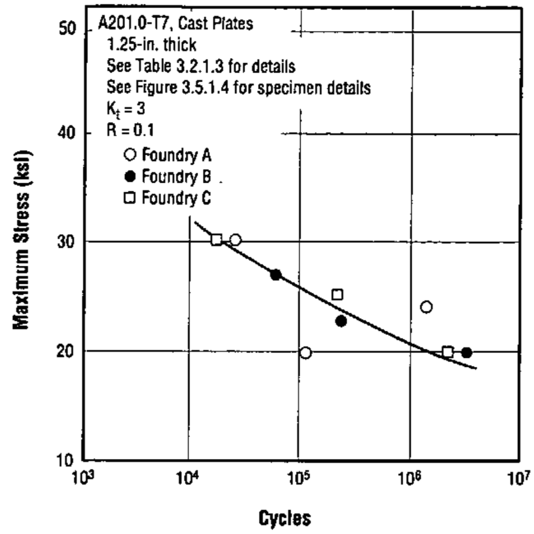

Figure 3.5.1.5 Fatigue strength of axially loaded notch specimens from sand cast plates from three foundries (Ref. 9, Table D5)

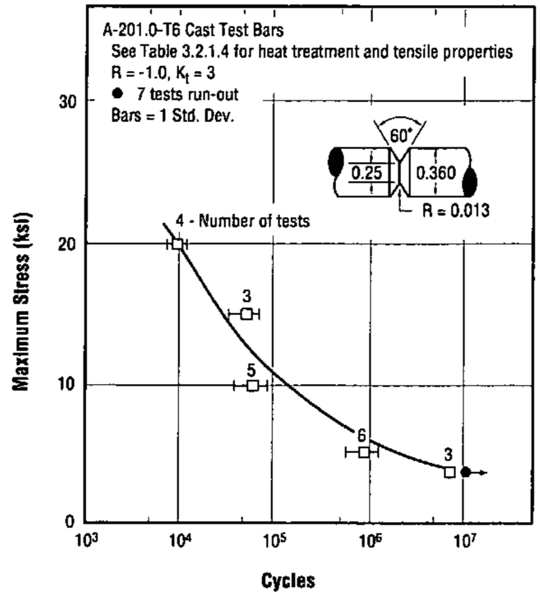

Figure 3.5.1.6 Fatigue strength (R = -1.0) of axially loaded -T6 notched (K_t = 3) specimens from individually cast test bars (Ref. 5, Table A2)

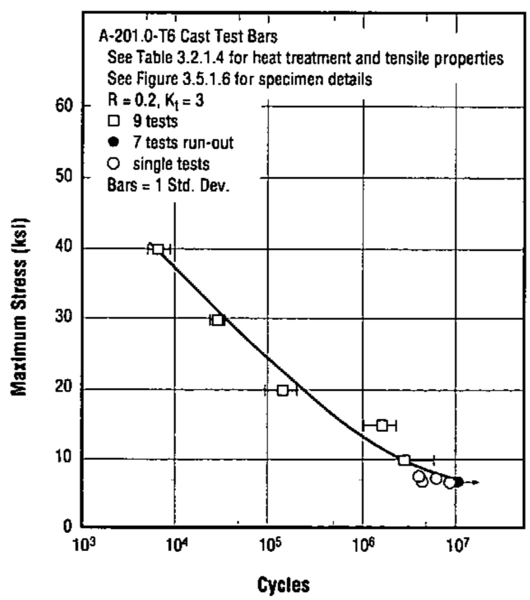

Figure 3.5.1.7 Fatigue strength (R = 0.2) of axially loaded -T6 notched (K_t = 3) specimens from individually cast test bars (Ref. 5, Table A1)

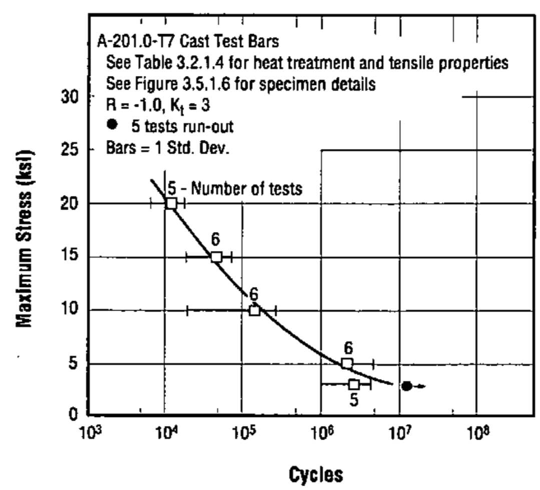

Figure 3.5.1.8 Fatigue strength (R = -1.0) of axially loaded -T7 notched (K_t = 3) specimens from individually cast test bars (Ref. 5, Table A6)

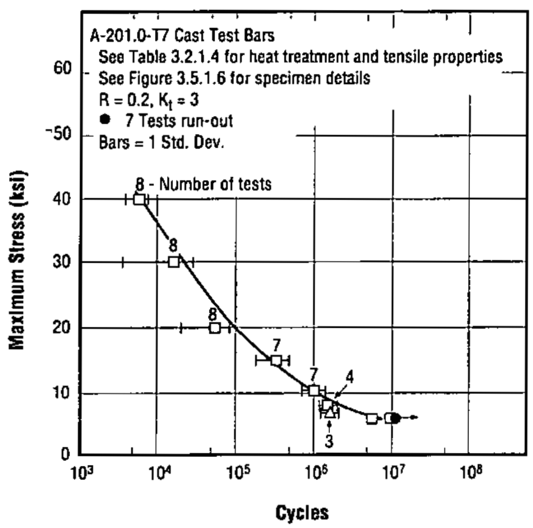

Figure 3.5.1.9 Fatigue strength (R = 0.2) of axially loaded -T7 notched (K_t = 3) specimens from individually cast test bars (Ref. 5, Table A4)

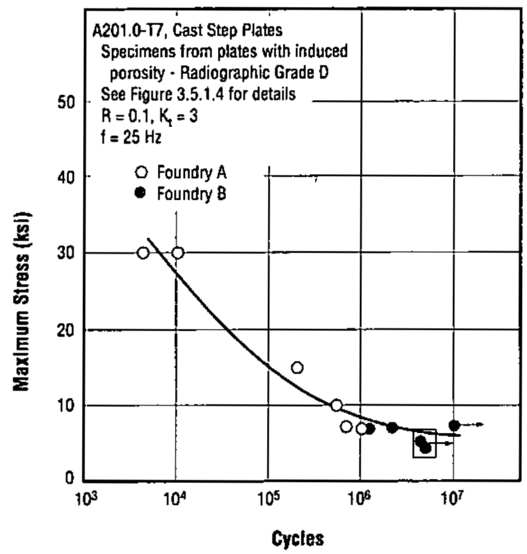

Figure 3.5.1.10 Fatigue strength of axially loaded notched (K_t = 3) specimens from sand cast step plates containing porosity (Ref. 6, Fig. 119)

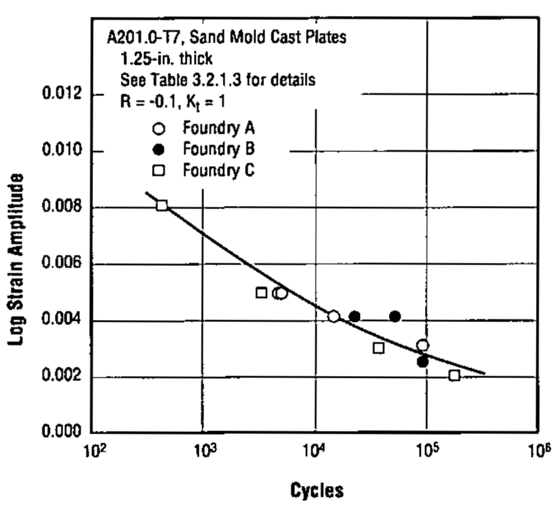

Figure 3.5.2.1 Strain vs life data for specimens from sand cast plate from three foundries (Ref. 9, Table D6)

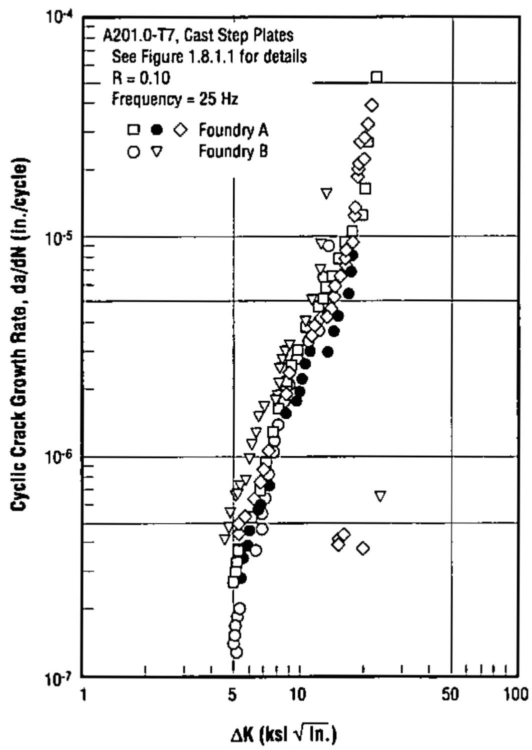

Figure 3.5.3.1 Fatigue crack growth rates for specimens removed from sand cast step plates from two foundries (Ref. 6, Fig. 109)

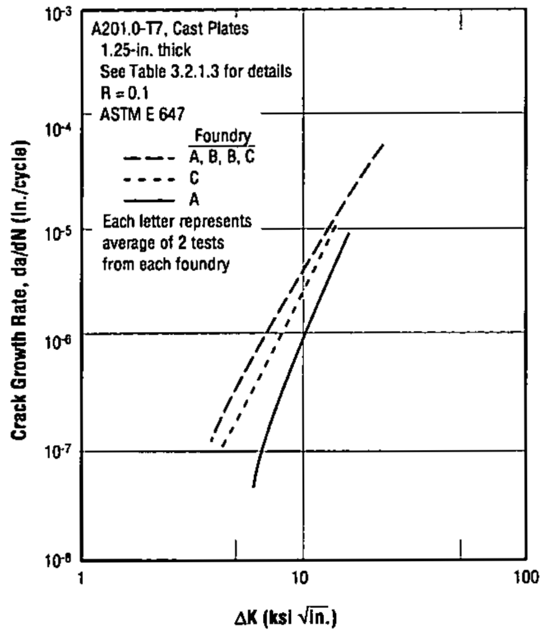

Figure 3.5.3.2 Fatigue crack growth rates for sand cast plates from three foundries (Ref. 9, Tables D1-D6)

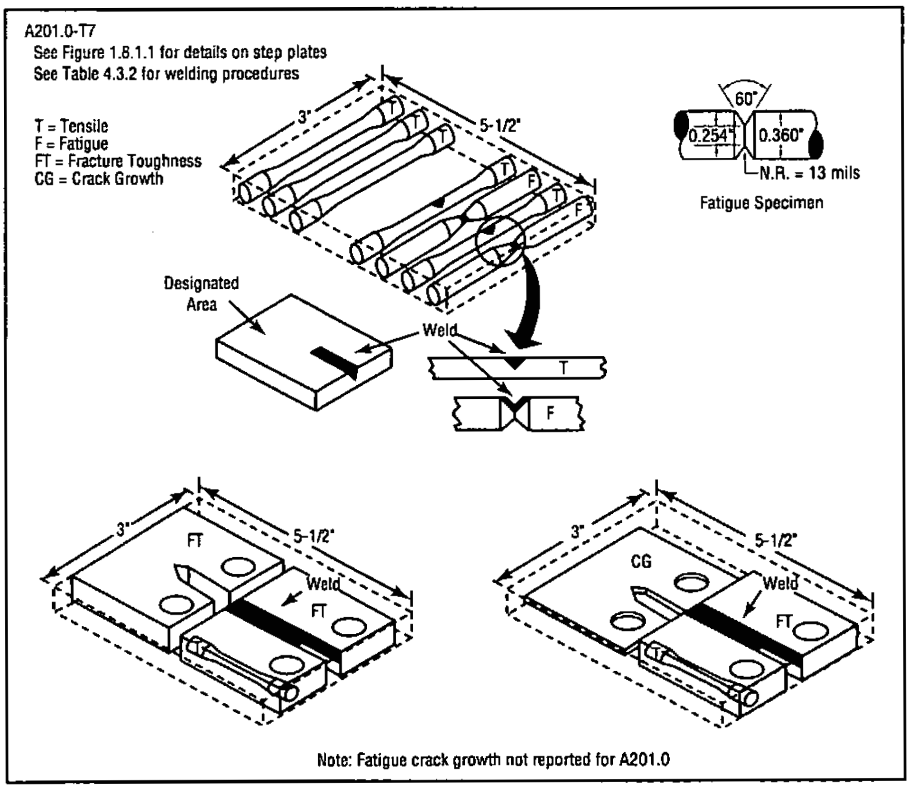

Figure 4.3.1.1 Location of specimens in the designated areas of welded step plates (Ref. 6, Fig. 110)

Table 4.3.1.2 Conditions used to produce welds in step plates (Ref. 6, pp. 251-252)

Alloy	A201.0
Condition	-T7
Coupon Location	Designated Areas of Step Plates (See Figure 4.3.1.1)
Weld Preperation	60° V-groove 0.25-in. deep with 3/32-in. radius, cleaned with 47% HNO_3 + 3% HF + 50% water + deionized water rinse + air dry
Filler Metal	0.094-inch diameter wire with AMS 4233 composition
Welds	4 pass GTA direct current, straight polarity, 100% He shielding, current 130-150 amps, voltage 18-22 v

Table 4.3.1.3 Effect of GTA welding on the average tensile properties and fracture toughness of sand cast step plates (Ref. 6, pp. 256-258)

Alloy	A201.0			
Form	Specimens from Welded Designated Areas of Step Plates See Figure 4.3.1.1 for Weld Locations and Table 4.3.1.2 for Welding Conditions			
Step Plate Source	Foundry A		Foundry B	
Specimen Location	Parent Metal	Weld	Parent Metal	Weld
F_{tu} (ksi)	64	66	66	66
F_{ty} (ksi)	58	59	60	60
e (percent)	5.6	5.3	5.6	5.6
K_Q (ksi $\sqrt{in}$)	27	37	29	—

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