REVISED: DECEMBER 1972
AUTHOR: W. F. BROWN, JR.

FERROUS ALLOYS

Fe
0.15 C
0.80 Mn
0.85 Ni
0.53 Cr
0.50 Mo
0.32 Cu
0.25 Si
0.05 V
+ B

T-1

Fe
0.16 C
0.85 Mn
0.53 Cr
0.27 Si
0.20 Mo
0.05 V
0.02 Ti
+ B

T-1A

Fe
0.16 C
1.12 Mn
0.52 Cr
0.50 Ni
0.27 Si
0.25 Mo
0.05 V
+ B

T-1B

1. GENERAL

T-1 steel is a low carbon quenched and tempered low alloy constructional steel with a high yield strength (90 to 100 ksi) and good toughness at room and moderately low temperatures. Its resistance to atmospheric corrosion is superior to that of the carbon steels. T-1A and T-1B are lower alloyed modifications of T-1 that are more economical but have somewhat lower toughness and hardenability. The service range of the T-1 steels should be restricted to -50F to 800F. The T-1 steels are normally supplied in the quenched and tempered condition, and unless otherwise stated the properties given in this chapter refer to that condition as defined in Section 1.05. All grades are weldable, however, the strength and toughness of the weld metal and the heat affected zone will depend on the welding conditions. These steels are not recommended for service conditions where tolerance for large plastic deformation is required under dynamic loads.

1.01 Commercial Designations
T-1, T-1 TypeA, T-1 Type B.

1.02 Alternate Designations
USS T-1, USS T-1 Type A, USS T-1 Type B.

1.03 Specifications
1.031 MIL-S-19795.
1.032 ASME SA 517, ASTM A 514-70 Types F, B and H, ASTM A 517-70a Types F, B and H.

1.04 Composition
1.041 Chemical composition of T-1, Table 1.041.
1.042 Chemical composition of T-1 Type A, Table 1.042.
1.043 Chemical composition of T-1 Type B, Table 1.043.

1.05 Heat Treatment
1.051 General. The strength and hardness of the T-1 steels are imparted by quenching and tempering. These alloys should not be used without heat treatment (2)(28).
1.052 Austenitize. 1650F to 1750F, water quench(15).
1.053 Temper. 1150F to 1275F. Quenching after tempering is desirable but not absolutely necessary (2)(8). Tempering temperature should not exceed 1275F (15).
1.054 To improve notch toughness of heavy sections over 2.5 inches, the following is recommended: 1750F, water quench, reheat to 1650F, water quench. Temper as in 1.053 (15).

1.06 Hardness
1.061 Typical hardness of heat treated plate for all types is approximately 258 BHN.
1.062 Effect of tempering temperature on hardness, Figure 1.062.
1.063 End quench hardenability bands, Figure 1.063.

1.07 Forms and Conditions Available
1.071 All types are available in the form of plates, structural shapes, bars, tubes. Non heat treated forms can be furnished under special conditions. Heat treated castings and rolled rings are available through a licensee of U.S. Steel.
1.072 Thickness ranges available for the three types under several specifications, Table 1.072.

1.08 Melting and Casting Practice

1.09 Special Considerations. (see also 2.03 and 4.03)
1.091 Blooms, billets, bars or ingots which have not been heat treated should never be gas cut. They should be sawed or hot sheared; or cold sheared if the size permits (15).
1.092 When heating to 1100F for forming, temperature should be accurately controlled.
1.093 Alloys must always be in the quenched and tempered condition before welding or gas cutting.
1.094 Alloys form an adherent scale; thus extremely high forging temperatures should be avoided.
1.095 High pressure hydrogen promotes crack growth in T-1 steel when the applied stress intensity is sufficiently high, (Table 1.095). Based on these results and on unpublished data the threshold K level for crack propagation has been estimated at 60 to 65 ksi-in$^{1/2}$ (32).
1.0951 Effect of high pressure hydrogen on crack propagation in T-1 plate, Table 1.0951.

2. PHYSICAL AND CHEMICAL PROPERTIES

2.01 Thermal Properties
2.011 Melting range.
2.012 Phase changes.
2.0121 Time-temperature transformation diagram, Figure 2.0121.
2.013 Thermal conductivity.
2.014 Thermal expansion, all types -50 to +150F = 6.5 x 10^{-6} in/in/F (1).
2.015 Specific heat.
2.016 Thermal diffusivity.

2.02 Other Physical Properties
2.021 Density. 0.284 lb per cu in. 7.85 gr per cu cm, (2).
2.022 Electrical properties.
2.0221 Resistivity 7.2 to 10.4 microhm-in.
2.023 Magnetic properties.
2.0231 Normal D-C magnetization curve for plate, Figure 2.0231.
2.024 Emissivity.
2.025 Damping capacity.

2.03 Chemical Properties
2.031 The atmospheric corrosion resistance of T-1 and T-1A are approximately four times and two times, respectively, that of structural carbon steels (15).
2.032 Weight loss in industrial, marine and semi-rural atmospheres for T-1 steel, Table 2.032.
2.033 Exposure of T-1 steel to various stress corrosion media, Table 2.033.
2.034 Results of four year exposure tests in sea water, Table 2.034.
2.035 No crack growth was observed when precracked DCB specimens of both T-1 plate metal and weld were loaded to 70% of the estimated K_{Ic} value in N_2O_4 (MIL-P-25539B) for up to 68 days at room temperature. Similar exposure of plate metals to unsymmetrical dimethylhydrazine (UDMH) (MIL-P-25604C) at 120F up to 33 days produced no crack growth (30).
2.036 In anhydrous ammonia service protection against stress corrosion can be obtained by the addition of a small amount of water (33).
2.037 Hydrogen sulfide promotes stress corrosion in the T-1 steels and for this reason they should not be used in construction of storage tanks for those oils containing detectable amounts of hydrogen sulfide (33).

2.04 Nuclear Properties
2.041 Effect of neutron irradiation on impact properties, Table 2.041.
2.042 Effect of neutron irradiation on tensile properties, Table 2.042.

3. MECHANICAL PROPERTIES

3.01 Specified Mechanical Properties
3.011 Producer's specified mechanical properties.
3.0111 Producer's specified tensile properties for T-1 plate, Table 3.0111.
3.0112 Producer's specified impact properties for T-1 plate, Table 3.0112.
3.0113 Producer's specified tensile properties for T-1 Type A plates and sheets and T-1 Type B plate, Table 3.0113.
3.0114 Producer's specified impact properties for T-1 Type A and T-1 Type B plate, Table 3.0114.
3.0115 Producer's specified tensile properties for heat treated bar, Table 3.0115.
3.0116 Producer's specified tensile properties for heat treated tubular products, Table 3.0116.
3.0117 Producer's bend test values for heat treated plate when specified, Table 3.0117.

T-1	T-1A	T-1B
Fe	Fe	Fe
0.15 C	0.16 C	0.16 C
0.80 Mn	0.85 Mn	1.12 Mn
0.85 Ni	0.53 Cr	0.52 Cr
0.53 Cr	0.27 Si	0.50 Ni
0.50 Mo	0.20 Mo	0.27 Si
0.32 Cu	0.05 V	0.25 Mo
0.25 Si	0.02 Ti	0.05 V
0.05 V	+ B	+ B
+ B		

3.02 Mechanical Properties at Room Temperature.
3.021 Tension (see also 3.01 and 3.031).
3.0212 Typical tensile values for wrought T-1 alloy, Table 3.0212.
3.0213 Effect of tempering temperature on tensile properties of T-1 steel, Figure 3.0213.
3.022 Compression.
3.0221 Typical compressive stress-strain diagram for T-1 steel at room temperature, Figure 3.0221.
3.023 Impact (see also 3.01 and 3.033).
3.0231 Effect of strain and strain plus aging on Charpy V ductility transition temperature, Table 3.0231.
3.024 Bending (see 3.0117).
3.025 Torsion and shear,
F_{su} = 75% of F_{tu} (approx.)
F_{sy} = 58% of F_{ty} (approx.)
3.026 Bearing
3.027 Stress concentration
3.0271 Notch properties
3.0272 Fracture toughness (See Appendix C)
3.028 Combined properties

3.03 Mechanical Properties at Various Temperatures
3.031 Tension.
3.0311 Stress-strain diagrams.
3.0312 Effect of test temperature on tensile properties for three thicknesses of T-1 plate, Figure 3.0312.
3.0313 Effect of test temperature on tensile properties for two thicknesses of T-1 Type A plate, Figure 3.0313.
3.0314 Effect of strain-rate on tensile properties of T-1 at various temperatures, Figure 3.0314.
3.0315 Effect of low temperature on the yield strength of plate, Figure 3.0315.
3.0316 Effect of test temperature on plane strain and axi-symmetric ductility of plate, Figure 3.0316.
3.032 Compression.
3.0321 Stress-strain diagrams.
3.033 Impact.
3.0331 Effect of test temperature on longitudinal Charpy V notch values of T-1 plate, Figure 3.0331.
3.0332 Effect of test temperature on transverse Charpy V notch values of T-1 plate, Figure 3.0332.
3.0333 Effect of temperature on Charpy V notch values for T-1 Type A plate, Figure 3.0333.
3.0334 Effect of test temperature on Charpy V impact and slow bend results for plate, Figure 3.0334.
3.0335 Effect of plate thickness on Charpy V-notch impact transition temperature, Figure 3.0335.
3.034 Bending (see 3.024).
3.035 Torsion and shear.
3.036 Bearing.
3.037 Stress concentration.
3.0371 Notch properties.
3.0372 Fracture toughness.
3.03721 General. The plane strain fracture toughness cannot be measured at room temperature at a thickness of two inches (25) but from the trend of the data in Figure 3.03722 and 3.03723 should be in excess of 140 ksi-in$^{1/2}$. The plane strain fracture toughness decreases with decreasing test temperature to a value of about 35 ksi-in$^{1/2}$ at -320F. The effect of increasing loading rate is to reduce the apparent plane strain fracture toughness (Figure 3.0723) and a corresponding effect is noted for the Charpy V impact values (see Figure 3.0334). See Section 4.03 for the fracture toughness of weldments.
3.03722 Effect of temperature on the plane strain fracture toughness of T-1 plate of several thicknesses, Figure 3.03722.
3.03723 Effect of temperature on the plane strain fracture toughness of 2 inch T-1 plate, Figure 3.03723.
3.03724 Effect of test temperature and strain rate on apparent plane strain fracture toughness of plate, Figure 3.03724.
3.038 Combined properties.

3.04 Creep and Creep Rupture Properties
3.041 Creep rupture strength of T-1 alloy at various temperatures, Figure 3.041.

3.05 Fatigue Properties
3.051 Stress range diagram for T-1 plate, Table 3.051.

3.06 Elastic Properties
3.061 Poisson's ratio.
3.062 Modulus of elasticity at room and elevated temperatures, Figure 3.062.
3.0621 Compressive modulus.
30 x 10^3 ksi (approx.) (15).
3.063 Modulus of rigidity.
3.064 Typical compression tangent modulus curve for T-1 steel, Figure 3.064.

4. FABRICATION

4.01 Formability
4.011 General. T-1 steels may be hot or cold formed, sheared, punched, gas cut and machined using conventional equipment. Wherever possible fabrication should be done in the heat treated condition. Hot working operations can alter the as heat treated properties and in these cases complete reheat treatment is necessary. Stress relief is desirable prior to surface machining (15).
4.012 Forging. Steels may be forged by usual methods at a temperature about 50F lower than that used for plain carbon steels. A blast of compressed air or steam should be used on the forging to prevent the formation of scale pits. Forgings over 16 inches square cross section should be cooled in lime, dry sand or other medium to prevent cracking. All forged pieces must be heat treated to provide adequate mechanical properties (15). (See also 1.094).
4.013 Cold forming. Steels may be readily cold formed or angle bent if sufficient power and suitable bend radii are used. Suggested minimum bend radii for plates up to 1.0 inch is 2 T, and for plates from 1.0 inch to 2.0 inch is 3 T. For brake press forming, the lower die span should be at least 16 times the plate thickness. Air bends are preferable to closed-die bends. Mutiple bits should be used where possible (15).
4.014 Hot forming. Hot forming can be employed when plate sizes are too heavy for cold forming. Forming temperature should not exceed 1100F and heating should preferably be done in a controlled atmosphere furnace. If this temperature is exceeded for severe formations (never higher than 1800F) the steel must be subsequently quenched and tempered to restore mechanical properties (15).
4.015 Punching and blanking. Steels may be satisfactorily punched in thickness to 0.5 inch.
For circle-blanking of plate, die clearances should be as close as possible.
4.016 Shearing. Steels may be sheared in thicknesses up to 1.0 inch if sufficient shear capacity and blade strength are available.
4.017 Gas cutting. T-1 steels can be readily gas cut by hand or machine. No preheating is necessary for sections up to 4 inches in thickness, but sections larger than 4 inches should be preheated 300 to 400F (not higher than 400F). Stack cutting of light plates should be avoided. The gas cut edge will be hard (about 415 Brinell) but will also be tough. The gas cut surface can be softened to facilitate machining but the softening temperature must not exceed 1100F (15).

4.02 Machining and Grinding
4.021 Carbide tools are recommended for all machining operations although high speed steel tools may also be satisfactory. Tools should be kept sharp and considerable coolant should be used. In general, machining speeds are reduced about 40 percent as compared to steels such as ASTM-A36. For drilling, two-flute drills with included point angle of 135 degrees have been successfully employed with speeds of 30-50 sfpm and feeds 15-25 percent less than those used for mild steel. Positive feed must be used to prevent glazing ahead of the drill point.
4.022 It is recommended that plates or other sections of T-1 steels be stress-relieved after heat treatment to reduce residual stresses and prevent excessive movement during machining (15).

4.03 Welding

4.031 General. The T-1 steels can be welded by the SMA, sub arc, GMA and GTA processes with 100 percent tensile joint efficiency. Oxyacetylene gas and electroslag welding are not recommended. The strength and toughness of the weld metal and HAZ are a function of the welding conditions. Satisfactory weld performance can only be obtained by following recommended procedures. These have been outlined in detail (9)(33) and the fabricator should consult these references as a guide in all welded construction using T-1 steels. If service conditions are expected to be particularly severe or highly restrained welds are unavoidable or when post weld heat treatment is required, technical assistance should be requested from the alloy developer (U.S. Steel Corp.). What follows is a brief summary of the recommended welding procedures, precautions and weld properties.

4.032 Welding procedures. Filler metals satisfactory for use with the T-1 steels are listed in Table 4.0321. It should be noted that sub arc welding with carbon steel wire and alloy flux is generally not recommended because very close control of the welding conditions are necessary to avoid composition gradients in the weld which could lead to local cracking. It is necessary to keep the moisture content of SMA electrode coating below 0.2 percent in order to avoid hydrogen embrittlement of the weld metal and heat affected zone. Likewise it is important that the total hydrogen content of bare wire electrodes not exceed 5 ppm. Recommended preheat temperatures are a function of thickness (Table 4.0322). The use of preheats less than 100F requires close control of environmentally induced moisture. No welding should be done when the ambient temperature is below 0F. The strength and toughness of the weld metal and the heat affected zone are controlled by their microstructure which is in turn a function of the cooling rate. To achieve the minimum cooling rate necessary to produce the desired microstructure it is necessary to control the heat input during welding as a function of the preheat temperature and the metal thickness. Recommendations are given in Tables 4.0323 and 4.0324. The stringer bear technique is preferred since it permits better control of the heat input. Good practice requires the use of multiple beads to take advantage of the improved toughness associated with the grain refining and tempering action of subsequent passes.

4.0321 Recommended filler metals for use in various welding processes for T-1 steels, Table 4.0321.

4.0322 Recommended preheat temperatures for several welding processes used with T-1 steels, Table 4.0322.

4.0323 Recommended maximum welding heat inputs for T-1 steel, Table 4.0323.

4.0324 Recommended maximum welding heat input for T-1A and T-1B steels, Table 4.0324.

4.033 As welded HAZ toughness. Dynamic fracture tests on the heat affected zone in T-1A weldments show reduced toughness in this zone as compared with that of the parent plate. (Table 4.0331 and Figure 4.0332). In multiple shot explosion bulge tests at 30F on SMA and sub arc welded one and two inch T-1 plate (17) and in similar tests at 0F on SMA welded T-1 plate (16), fractures were frequently observed near the weld reinforcement in the HAZ but rarely did any fracture occur on the first shot. This behavior in the explosion bulge test is characteristic of this class of steels which are not intended for service conditions characterized by dynamic loads and high plastic deformation.

In contrast to the behavior in dynamic tests, plane strain fracture toughness tests on the heat affected zone of sub arc welded T-1 plate give K_{Ic} values higher than those of the parent metal, (Figure 4.0333 and Figure 4.0334).

4.0331 Tensile properties and drop weight test data for parent plate and weldments, Table 4.0331.

4.0332 Dynamic tear values for T-1A (A517B with 0.25 Ni) parent plate and weld heat affected zone, Figure 4.0332.

4.0333 Effect of test temperature on the plane strain fracture toughness of sub arc plate welds (heat input 35 kjoules per inch), Figure 4.0333.

4.0334 Effect of test temperature on plane strain fracture toughness of sub arc plate welds (heat input 70 kjoules per inch), Figure 4.0334.

4.034 Post weld treatments. The use of post weld stress relief treatments should be avoided where possible. Application of a post weld treatment above about 900F can produce a heat affected zone microstructure which is prone to cracking during the stress relief operation (24). For example, the unexpected catastrophic failure of a large experimental T-1 pressure vessel was traced to microcracks in highly restrained stress relieved weldments (29). In addition, the application of post weld thermal treatments in the range from 900 to 1200F can impair the heat affected zone toughness (see Tables 4.0341 through 4.0344 and Figures 4.0333 and 4.0334). These problems and some remedial measures are discussed further in Reference 24.

4.0341 Results from crack starter explosion bulge tests on welded plate of T-1 and T-1A, Table 4.0341.

4.0342 Transition temperatures determined from Kinzel notch bend tests on parent plate and weldments, Figure 4.0342

4.0343 Notch bend, drop weight and explosion bulge data for T-1 plate and weldments, Table 4.0343.

4.0344 Transition temperatures determined on weldments using notch bend and drop weight tests. Table 4.0344.

4.04 Heat Treatment

4.05 Surface Treatment

4.051 Scale and rust may be removed by acid pickling, grit or shot blasting or wire brushing. If flame descaling is used, the surface of the scale should never show a red color, even in the dark (15).

4.052 T-1 Type A usually will pickle faster and cleaner than T-1 steel.

4.053 The improved corrosion resistance of T-1 steels will result in better paint life than can be obtained with structural carbon steels. Prime and finish coats should be applied in accordance with the paint manufacturers instructions. Electro-deposited coatings while not commonly used on the T-1 steels may be applied if the usual steps to avoid hydrogen embrittlement are adopted. Baking for removal of hydrogen will not affect the properties of T-1 steels. Any sprayed metal coating may be used without special practices (15).

4.054 Carburizing.

4.0541 Hardness results obtained following various pack carburizing cycles are reported by Vettraino (28). Case depths of about 0.040 in and hardnesses of 62 to 64 Rc were produced in one-half inch thick sections by carburizing at 1650F, 4 to 8 hours. Quenching from carburizing temperature and tempering at 350F reduced the case hardness to approximately 57 Rc. Quenching from carburizing followed by cold treating (-100F) plus tempering produced case hardnesses of about 62 to 63 Rc. For all treatments the core remained at 35 to 37 Rc.

Source	(1, p.1)(14) A514-70 Type F, A517-70a Type F	
Alloy	T-1	
	Percent	
	Min	Max
Carbon	0.10	0.20
Chromium	0.40	0.65
Manganese	0.60	1.00
Molybdenum	0.40	0.60
Nickel	0.70	1.00
Phosphorous	-	0.035
Sulphur	-	0.040
Vanadium	0.03	0.08
Silicon	0.15	0.35
Boron	0.002	0.006
Copper	0.15	0.50

TABLE 1.041 CHEMICAL COMPOSITION OF T-1.

T-1	
	Fe
0.15	C
0.80	Mn
0.85	Ni
0.53	Cr
0.50	Mo
0.32	Cu
0.25	Si
0.05	V
+	B

T-1A	
	Fe
0.16	C
0.85	Mn
0.53	Cr
0.27	Si
0.20	Mo
0.05	V
0.02	Ti
+	B

T-1B	
	Fe
0.16	C
1.12	Mn
0.52	Cr
0.50	Ni
0.27	Si
0.25	Mo
0.05	V
+	B

Fe
0.15 C
0.80 Mn
0.85 Ni
0.53 Cr
0.50 Mo
0.32 Cu
0.25 Si
0.05 V
+ B

T-1

Source	(1, p.3) A514-70 Type B, A517-70a Type B	
Alloy	T-1 Type A	
	percent	
	Min.	Max.
Carbon (a)	0.12	0.21
Chromium	0.40	0.65
Manganese	0.70	1.00
Molybdenum	0.15	0.25
Phosphorous	-	0.035
Sulphur	-	0.040
Silicon	0.20	0.35
Vanadium	0.03	0.08
Titanium	0.01	0.03
Boron	0.0005	0.005
Copper (b)	0.20	0.040

(a) Carbon 0.15 to 0.21 furnished for orders specifying ASTM A517 Grade B or ASME SA517 Grade B.
(b) Optional addition for increased corrosion resistance.

TABLE 1.042 CHEMICAL COMPOSITION OF T-1 TYPE A.

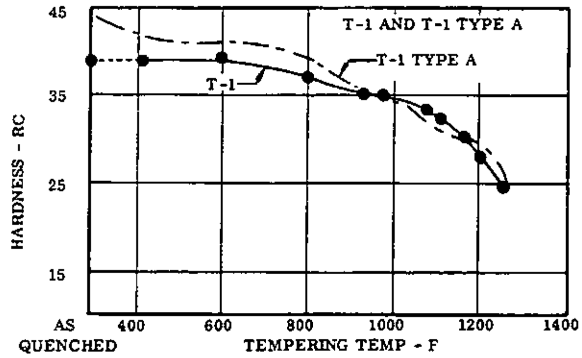

FIG 1.062 EFFECT OF TEMPERING TEMPERATURE ON HARDNESS (15)

Fe
0.16 C
0.85 Mn
0.53 Cr
0.27 Si
0.20 Mo
0.05 V
0.02 Ti
+ B

T-1A

Source	(1, p.5) A514-70 Type H, A517-70a Type H	
Alloy	T-1 Type B	
	percent	
	Min	Max
Carbon	0.12	0.21
Chromium	0.40	0.65
Manganese	0.95	1.30
Molybdenum	0.20	0.30
Nickel	0.30	0.70
Phosphorous	-	0.035
Sulphur	-	0.040
Silicon	0.20	0.35
Vanadium	0.030	0.080
Boron	0.0005	-
Copper (1)	0.20	0.40

(1) Optional addition for increased corrosion resistance.

TABLE 1.043 CHEMICAL COMPOSITION OF T-1 TYPE B.

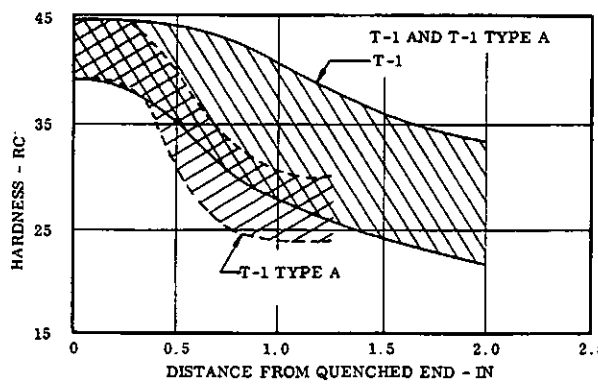

FIG 1.063 END - QUENCH HARDENABILITY BANDS (15)

Fe
0.16 C
1.12 Mn
0.52 Cr
0.50 Ni
0.27 Si
0.25 Mo
0.05 V
+ B

T-1B

Source	(1)		
Type (a)	T-1	T-1 Type A	T-1 Type B
Specification	Thickness	Thickness	Thickness
None (Structural quality)	3/16 - 7 in	-	-
ASTM A514 (Welded structure)	Grade F 4 in	Grade B 3/16 - 1-1/4 in	Grade H 3/16 - 2 in
ASTM A517 (Pressure vessel)	Grade F 3/16 - 2-1/2 in	Grade B 3/16 - 1-1/4 in	Grade H 3/16 - 2 in
Min. BHN plates			
321	3/16 - 4 in	3/16 - 1-1/4 in	3/16 - 2 in
340	3/16 - 2 in	3/16 - 1 in	3/16 - 1-1/2 in
360	3/16 - 1-1/2 in	3/16 - 1/2 in	3/16 - 1 in

(a) 200 in width max for all types.

TABLE 1.072 THICKNESS RANGES AVAILABLE FOR THE THREE TYPES UNDER SEVERAL SPECIFICATIONS.

Source	(32)			
Alloy	T-1			
Form	2 inch plate			
Condition	1660F, 1 hr WQ + 1230F, 1-1/2 hr WQ, F_{tu} = 121 ksi, F_{ty} = 110 ksi			
Exposure	10,000 psi hydrogen (electrolytic grade) 65F (a)			
Exposure time days	28	63		105
Applied K-ksi- in.	92	67	92	61
Crack extension - in.	0.448	.115	.076	0

(a) Bolt loaded WOL specimen one inch thick, 5 percent face notches.

TABLE 1.0951 EFFECT OF HIGH PRESSURE HYDROGEN ON CRACK PROPAGATION IN T-1 PLATE.

Fe
0.15 C
0.80 Mn
0.85 Ni
0.53 Cr
0.50 Mo
0.32 Cu
0.25 Si
0.05 V
+ B

T-1

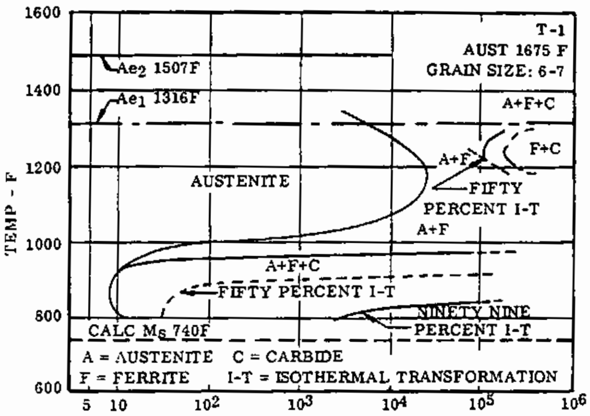

FIG. 2.0121 TIME-TEMPERATUE TRANSFORMATION DIAGRAM (15)

Source	(15)			
Alloy	T-1			
Test	Atmospheric corrosion			
Form	4 in x 6 in flat			
Atmosphere	Weight loss-grams			
	0.5 years	1.5 years	3.5 years	7.5 years
Industrial	5.0	8.2	9.4	11.3
Marine	2.8	5.9	10.4	15.4
Semi-rural	-	7.1	9.6	11.4

TABLE 2.032 WEIGHT LOSS IN INDUSTRIAL, MARINE AND SEMI-RURAL ATMOSPHERES FOR T-1 STEEL.

Fe
0.16 C
0.85 Mn
0.53 Cr
0.27 Si
0.20 Mo
0.05 V
0.02 Ti
+ B

T-1A

Fe
0.16 C
1.12 Mn
0.52 Cr
0.50 Ni
0.27 Si
0.25 Mo
0.05 V
+ B

T-1B

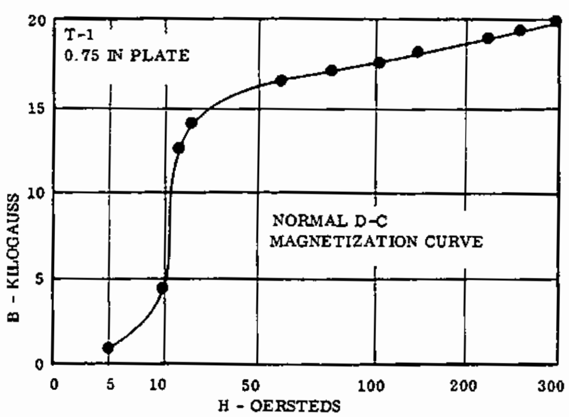

FIG. 2.0231 NORMAL D-C MAGNETIZATION CURVE FOR PLATE. (15)

Source	(15)
Alloy	T-1
Test	Exposure to stress-corrosion media
Test Medium	Susceptibility to cracking
Pickling acid, 12 percent H_2SO_4 at 160F	No
3 percent NaCl solution (aerated)	No
3 percent NaCl solution (aerated with cathodic protection at 300 amps per sq cm	No
Sea water	No
Marine atmosphere	No
Water, H_2S saturated	Yes
Molten sulfur with small amounts of H_2S	No
Molten sulfur with small amounts of H_2S and water	No
Sour crude oil (containing H_2S)	Yes
Uncontaminated ammonia	No
Agricultural ammonia, contaminated with air	Yes
Agricultural ammonia, contaminated with air and inhibited 0.2 percent water	No

TABLE 2.033 EXPOSURE OF T-1 STEEL TO VARIOUS STRESS CORROSION MEDIA.

Fe
0.15 C
0.80 Mn
0.85 Ni
0.53 Cr
0.50 Mo
0.32 Cu
0.25 Si
0.05 V
+ B

T-1

Source	(13)	
Alloy	T-1	
Form	16 ft strip	
Location in sea water (a)	Feet from top of strip	Corrosion rate mils per yr
Splash zone	1	0.9
	2	0.7
	3	1.0
Tidal zone	4	0.4
	5	-
	6	0.3
Immersed zone	7	0.9
	8	5.1
	9	4.3
	10	3.9
	11	4.6
	12	5.2
	13	4.5
	14	5.0
	15	4.5
	16	2.4
(a) Four year exposures.		

TABLE 2.034 RESULTS OF FOUR YEAR EXPOSURE TESTS IN SEA WATER.

Source		(6)(11)			
Alloy		T-1			
Specimen		V-notch impact, 0.187 to 0.2 in, cantilever			
Test		Effect of irradiation on impact properties			
Irradiation Conditions		Transition Temp- F (a)		Max energy absorption in-lb (b)	
Temp- F	Exposure, nvt (c)	Control	Irradiated	Control	Irradiated
< 100	$1.3x10^{21}$	-165	+167	67	22
< 200	$5x10^{18}$	-240	- 40	48	40
< 200	$7x10^{19}$	-240	+150	48	23
575	$5x10^{18}$	-240	-115	48	48
< 200	$2.3x10^{19}$	-214	+ 19	86	52
< 200	$3.3x10^{19}$	-214	+ 68	86	52

(a) Taken from transition curve, criterion: 50 percent of maximum impact energy.
(b) Taken from transition curve.
(c) > 1 Mev

TABLE 2.041 EFFECT OF NEUTRON IRRADIATION ON IMPACT PROPERTIES.

Fe
0.16 C
0.85 Mn
0.53 Cr
0.27 Si
0.20 Mo
0.05 V
0.02 Ti
+ B

T-1A

Source	(13)										
Alloy	T-1										
Atmosphere	Industrial				Marine				Semi-rural		
Exposure Time - yrs	0.5	1.5	3.5	7.5	0.5	1.5	3.5	7.5	1.5	3.5	7.5
Weight loss gms (a)	5.0	8.2	9.4	11.3	2.8	5.9	10.4	15.4	7.1	9.6	11.4

(a) Total grams per 4 x 6 inch specimen.

TABLE 2.035 RESULTS OF LONG TIME EXPOSURES TO VARIOUS ATMOSPHERES.

Source		(6)					
Alloy		T-1 Steel					
Test		Effect of irradiation on tensile properties					
Irrad Cond		F_{tu} ksi		F_{ty} ksi		e (1 in)-percent	
Temp F	nvt Exposure	Control	Irrad	Control	Irrad	Control	Irrad
<100	1.3×10^{21}	116.0	180)	100.0(a)	180.0(a)	20.0	4.7
<200	1.7×10^{19}	129.0	171.0	120.0	170.0	14.0	4.5
<200	1.0×10^{20}	129.0	187.2	120.0	186.0	14.0	3.8
<200	2.3×10^{19}	139.7	186.4	129.3	184.0	15.0(b)	9.0(b)
<200	3.3×10^{19}	139.7	189.4	129.3	186.8	15.0(b)	8.6(b)

(a) 0.1 percent offset yield strength
(b) 0.275 inch gage length

TABLE 2.042 EFFECT OF NEUTRON IRRADIATION ON TENSILE PROPERTIES.

Fe
0.16 C
1.12 Mn
0.52 Cr
0.50 Ni
0.27 Si
0.25 Mo
0.05 V
+ B

T-1B

Source	(1)					
Alloy type	T-1					
Form	Plate					
Thickness-in	3/16 to 2-1/2		>2-1/4 to 4 incl.		>4 to 6 incl.	
Direction (2)	L	T	L	T	L	T
F_{tu}-ksi (max)	135	135	135	135	135	135
(min)	115	115	105	105	105	105
F_{ty}-ksi (min)	100	100	90	90	90	90
e (2 in)-percent(min)(1)	18	16	17	15	16	-
R.A.-percent (min) ≤3/4 in (3)	40	35	-	-	-	-
>3/4 in >1/2 in dia spec.(4) >1-1/2 in wide	50	45	50	45	45	
Full thick spec. (3)	40	35				-

(1) Deduct 1.25 percent for each 1/32 in decrease in thickness under 5/16, not to exceed 3 percent.
(2) Transverse may be specified for any thickness up to 4 in. Transverse values shown are required by ASTM A517 Grade F (ASME SA517, Grade F).
(3) Specimens according to ASTM A370, Fig. 4.
(4) ASTM 370, Fig. 6.

TABLE 3.0111 PRODUCER'S SPECIFIED TENSILE PROPERTIES FOR T-1 PLATE.

Source	(1)	
Alloy Type	T-1	
Form	Plate	
Thickness - in	7/16 to 2-1/4 inch	
Direction	L	T
Impact (a) IE Charpy V ft-lb (min.)		
0 F or higher	30	20
<0 to -50 F	20	15

(a) Applicable to pressure vessel quality and higher.

TABLE 3.0112 PRODUCER'S SPECIFIED IMPACT PROPERTIES FOR T-1 PLATE.

Source	(2)(15)(7)			
Alloy	T-1			T-1A
Test	Tensile			
Condition	HT			
Form	Bar(b)			
Size-in	Up thru 4.0 Flats to 2.5	4.0 thru 7.0 Flats > 2.5	7.0 thru 9.5	Up to 1.75
F_{tu} - max-ksi	140	135	135	140
min-ksi	115	105	105	115
F_{ty} - max-ksi	-	-	-	-
min-ksi	100	95	90	100
e(2in) min-percent	18	16	16	18
RA - min-percent	55(a)	45	45	55(a)

(a) Reduction of area for flats 0.75 inch and under is 45 percent.
(b) Longitudinal properties.

TABLE 3.0115 PRODUCER'S SPECIFIED TENSILE PROPERTIES FOR HEAT TREATED BAR.

T-1

Fe
0.15 C
0.80 Mn
0.85 Ni
0.53 Cr
0.50 Mo
0.32 Cu
0.25 Si
0.05 V
+ B

Source	(1)					
Alloy Type	T-1A				T-1B	
Form	Plates and Sheets				Plates	
Thickness-in	<3/4	0.180 to 3/4 incl.	>3/4 to 1-1/4 incl.		3/16 to 2 incl.	
Direction (a)	L	T	L	T	L	T
F_{tu}-ksi (max)	135	135	135	135	135	135
(min)	115	115	115	115	115	115
F_{ty}-ksi (min)	100	100	100	100	100	100
e (2 in) percent (min)						
Plates	18(b)	16(b)	18	16	18(b)	16(b)
Sheet or strip	10					
R.A. percent (min)						
Plates (c)	40	35	40(d)	35(d)	40 (e)	35(e)

(a) Tranverse tensile values shown are mandatory for plates to ASTM A517, Grade B (ASME SA517, Grade B).
(b) Deduct 1.25 percent for each 1/32 inch decrease in thickness under 5/16, not to exceed 3 percent.
(c) Specimens according to ASTM A370, Figure 4.
(d) For 1/2 in diameter specimen RA = 50 percent L and 45 percent T.
(e) Over 3/4 in thick: using 1/2 in diameter specimen RA = 50 percent L and 45 percent T.

TABLE 3.0113 PRODUCER'S SPECIFIED TENSILE PROPERTIES FOR T-1 TYPE A PLATES AND SHEETS AND T-1 TYPE B PLATE.

Source	(7)(15)
Alloy	T-1 and T-1 type A
Test	Tensile
Condition	HT
Form	Seamless tubing (b)
Thickness-in	(a)
F_{tu} - max-ksi	145
min-ksi	115
F_{ty} - max-ksi	-
min-ksi	100
e (2 in) - min-percent	18
RA - min-percent	-

(a) All wall thicknesses for round, square, and rectangular tubing.
(b) On strip specimens ≤ 0.25 inch, e is reduced accordingly.

TABLE 3.0116 PRODUCER'S SPECIFIED TENSILE PROPERTIES FOR HEAT TREATED TUBULAR PRODUCTS.

T-1A

Fe
0.16 C
0.85 Mn
0.53 Cr
0.27 Si
0.20 Mo
0.05 V
0.02 Ti
+ B

Source	(1)			
Alloy Type	T-1A		T-1B	
Form	Plate		Plate	
Thickness-in	7/16 - 1-1/4		7/16 to 2	
Direction	L	T	L	T
Impact (a) IE Charpy V ft-lbs (min.)				
-50 F	15	15	-	-
> 10 F	-	-	20	15
<10 to -50 F	-	-	15	-

(a) Applicable to pressure vessel quality and higher.

TABLE 3.0114 PRODUCER'S SPECIFIED IMPACT PROPERTIES FOR T-1 TYPE A AND T-1 TYPE B PLATE.

Source	(7)(15)			
Alloy	T-1		T-1 type A	
Condition	HT		HT	
Form	Plate			
Test	ASTM bend test (a)			
Quality	Structural	Pressure Vessel	Structural	Pressure Vessel
Orientation	L	T	L	T
Thickness-in				
to 1.0	2t	2t	2t	2t
1.0 to 1.25	-	-	3t	3t
1.0 to 2.5	3t	3t	-	-
2.5 to 4.0	4t	4t	-	-
over 4.0	None	-	-	-

(a) 180 degree bend.

TABLE 3.0117 PRODUCER'S BEND TEST VALUES FOR HEAT TREATED PLATE WHEN SPECIFIED.

T-1B

Fe
0.16 C
1.12 Mn
0.52 Cr
0.50 Ni
0.27 Si
0.25 Mo
0.05 V
+ B

Fe
0.15 C
0.80 Mn
0.85 Ni
0.53 Cr
0.50 Mo
0.32 Cu
0.25 Si
0.05 V
+ B

T-1

Fe
0.16 C
0.85 Mn
0.53 Cr
0.27 Si
0.20 Mo
0.05 V
0.02 Ti
+ B

T-1A

Fe
0.16 C
1.12 Mn
0.52 Cr
0.50 Ni
0.27 Si
0.25 Mo
0.05 V
+ B

T-1B

Source	(15)
Alloy	T-1
Condition	HT
F_{tu} typ-ksi	122
F_{ty} typ-ksi	111
Uniform e (2 in)-percent	8.2
Total e (2 in)-percent	18.5
RA -percent	62
Strain hardening exponent	0.07

TABLE 3.0212 TYPICAL TENSILE VALUES FOR WROUGHT T-1 ALLOY.

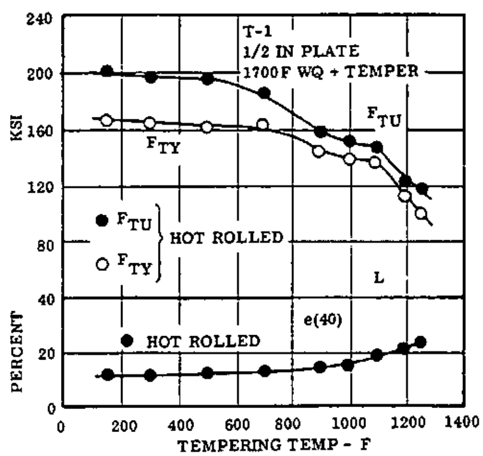

FIG. 3.0213 EFFECT OF TEMPERING TEMPERATURE ON TENSILE PROPERTIES OF T-1 PLATE. (33, fig. 1)

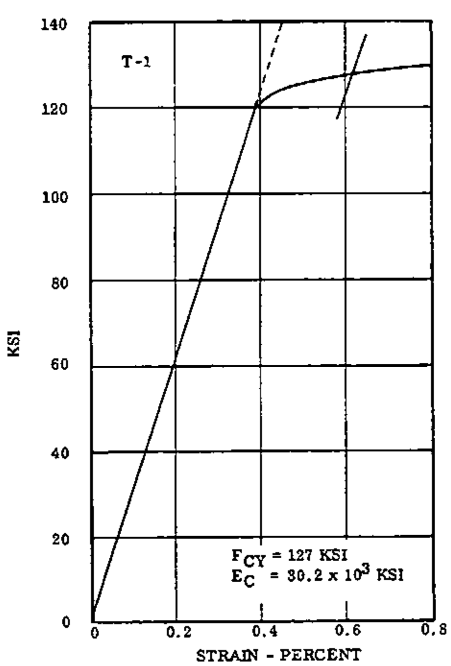

FIG 3.0221 TYPICAL COMPRESSIVE STRESS-STRAIN DIAGRAM FOR T-1 STEEL AT ROOM TEMPERATURE (15)

Source	(15)	
Test	Effect of strain and strain + age	
Specimen	Charpy V (a)	
Alloy	T-1	T-1 type A
Condition	Ductility transition temp- F(b)	
Unstrained	-225	-95
Strain 5 percent	-170	-50
Strain 5 percent + age	-150	-50
Strain 5 percent + age + stress relieve	-180	-100
(a) Longitudinal specimens		
(b) 15 ft-lb		

TABLE 3.0231 EFFECT OF STRAIN AND STRAIN PLUS AGING ON CHARPY V DUCTILITY TRANSITION TEMPERATURE.

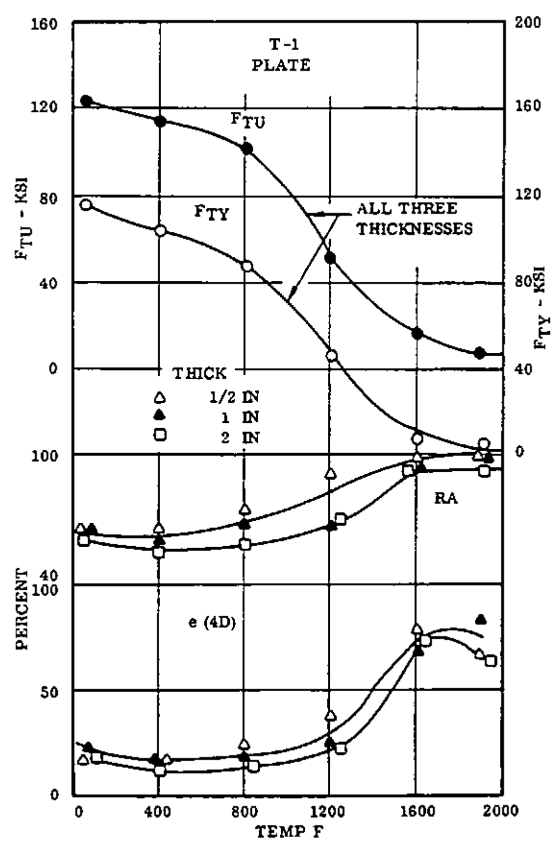

FIG 3.0312 EFFECT OF TEST TEMPERATURE ON TENSILE PROPERTIES FOR THREE THICKNESSES OF T-1 PLATE. (13)

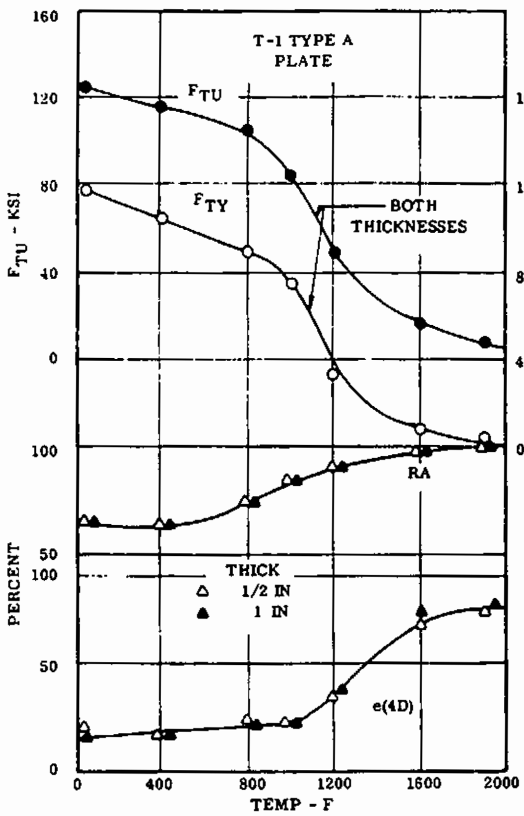

FIG 3.0313 EFFECT OF TEST TEMPERATURE ON TENSILE PROPERTIES FOR TWO THICKNESSES OF T-1 TYPE A PLATE (13)

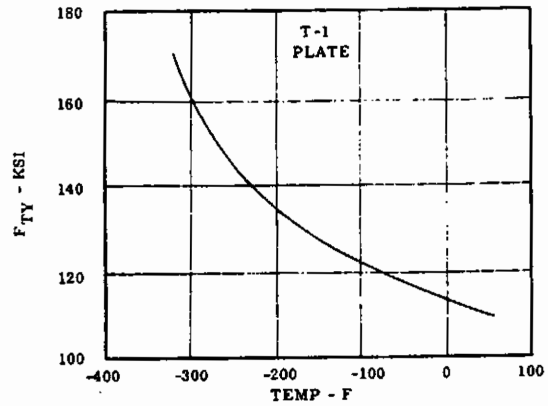

FIG 3.0315 EFFECT OF LOW TEMPERATURE ON YIELD STRENGTH OF PLATE (26) FIG 16

T-1
Fe
0.15 C
0.80 Mn
0.85 Ni
0.53 Cr
0.50 Mo
0.32 Cu
0.25 Si
0.05 V
+ B

T-1A
Fe
0.16 C
0.85 Mn
0.53 Cr
0.27 Si
0.20 Mo
0.05 V
0.02 Ti
+ B

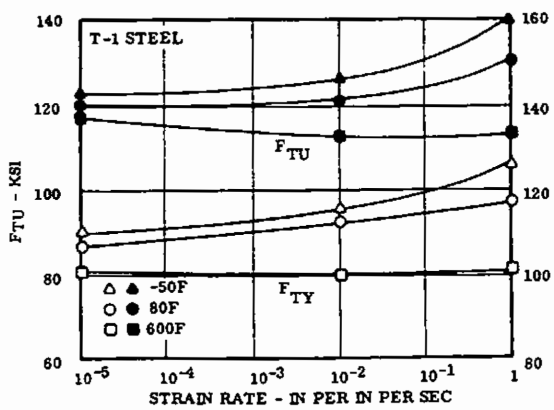

FIG. 3.0314 EFFECT OF STRAIN RATE ON TENSILE PROPERTIES OF T-1 AT VARIOUS TEMPERATURES. (15)

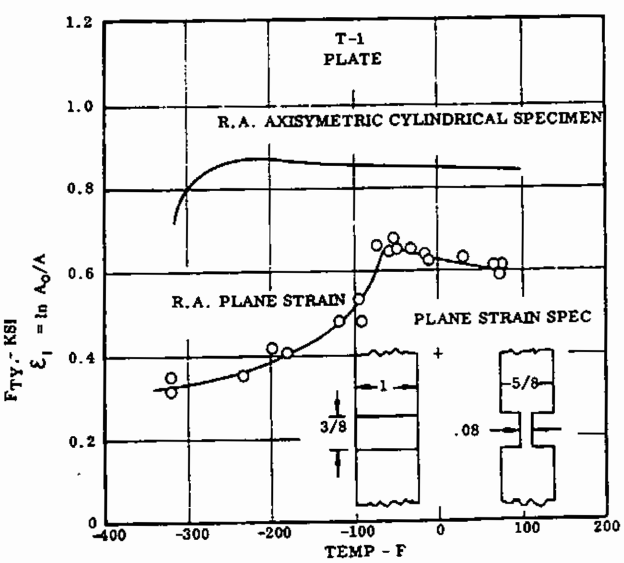

FIG 3.0316 EFFECT OF TEST TEMPERATURE ON PLANE STRAIN AND AXISYMETRIC DUCTILITY OF PLATE (26) FIG 10

T-1B
Fe
0.16 C
1.12 Mn
0.52 Cr
0.50 Ni
0.27 Si
0.25 Mo
0.05 V
+ B

Fe
0.15 C
0.80 Mn
0.85 Ni
0.53 Cr
0.50 Mo
0.32 Cu
0.25 Si
0.05 V
+ B

T-1

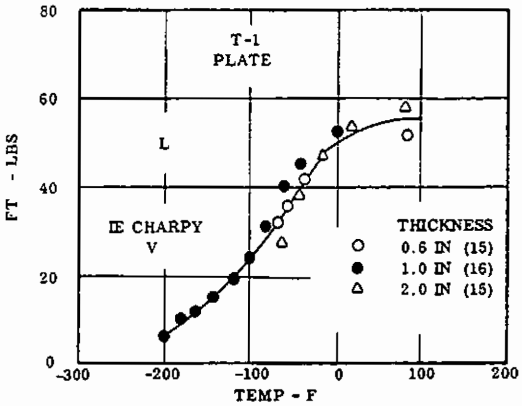

FIG. 3.0331 EFFECT OF TEST TEMPERATURE ON LONGITUDINAL CHARPY V NOTCH VALUES OF T-1 PLATE. (16, p.3)(15)

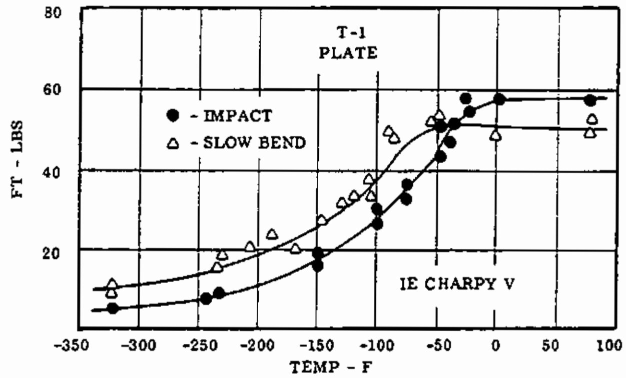

FIG 3.0334 EFFECT OF TEST TEMPERATURE ON CHARPY V IMPACT AND SLOW BEND RESULTS FOR PLATE (25, fig.14)

Fe
0.16 C
0.85 Mn
0.53 Cr
0.27 Si
0.20 Mo
0.05 V
0.02 Ti
+ B

T-1A

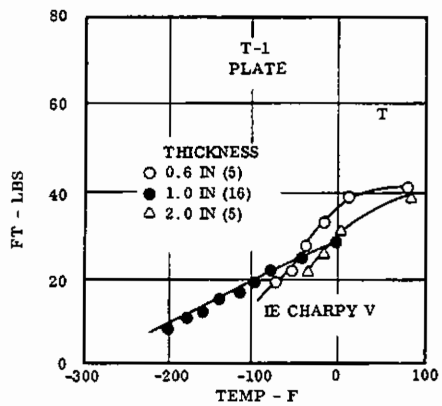

FIG. 3.0332 EFFECT OF TEST TEMPERATURE ON TRANSVERSE CHARPY V NOTCH VALUES OF T-1 PLATE (16 p.3)(15)

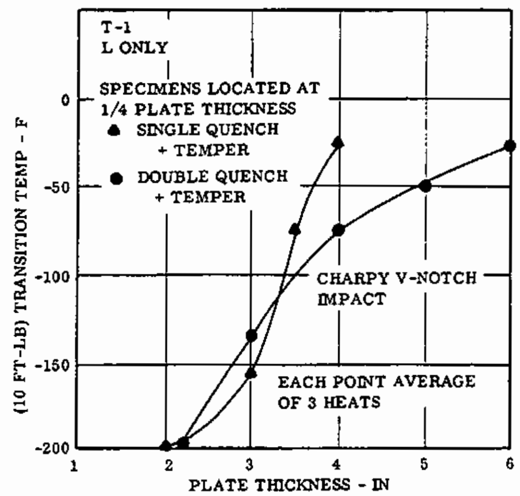

FIG. 3.0335 EFFECT OF PLATE THICKNESS ON CHARPY V-NOTCH IMPACT TRANSITION TEMPERATURE. (15)

Fe
0.16 C
1.12 Mn
0.52 Cr
0.50 Ni
0.27 Si
0.25 Mo
0.05 V
+ B

T-1B

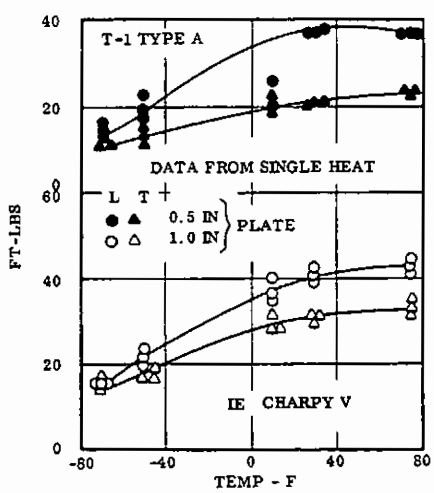

FIG 3.0333 EFFECT OF TEMPERATURE ON CHARPY V - NOTCH VALUES FOR T-1 TYPE A PLATE (15)

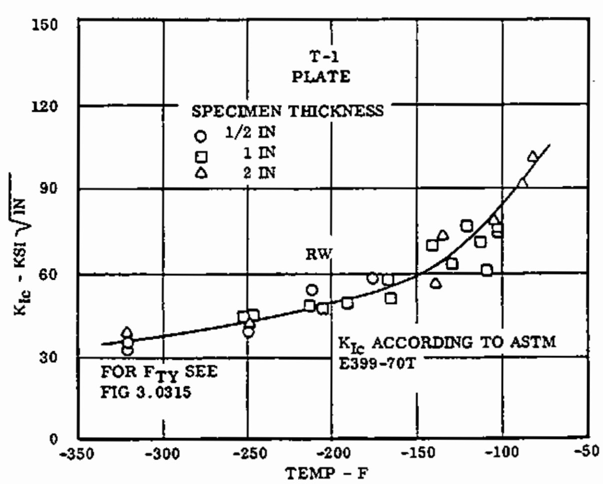

FIG 3.03722 EFFECT OF TEMPERATURE ON PLANE STRAIN FRACTURE TOUGHNESS OF PLATE OF SEVERAL THICKNESSES. (25, fig. 5)

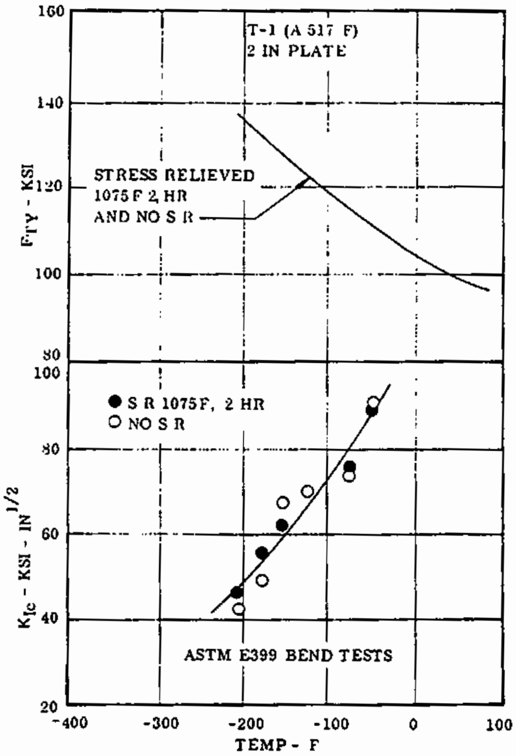

FIG. 3.03723 EFFECT OF TEMPERATURE ON PLANE STRAIN FRACTURE TOUGHNESS OF 2 IN T-1 PLATE. (31, table 2, fig. 21)

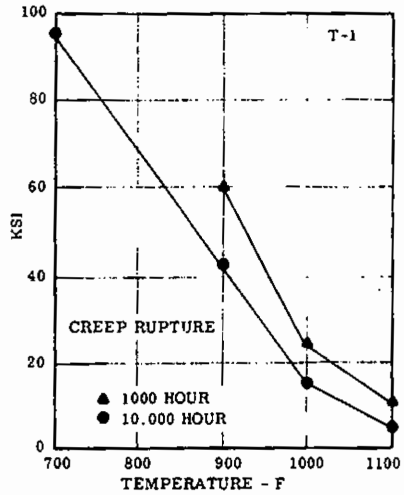

FIG. 3.041 CREEP RUPTURE STRENGTH OF T-1 STEEL AT VARIOUS TEMPERATURES. (15)

Source	(5, p. 230)								
Alloy	T-1								
Form	3/4 in plate F_{tu} = 121 ksi F_{ty} = 112 ksi								
Stress Ratio	R = -1 A = ∞			R = 0 A = 1			R = 0.5 A = .33		
Cycles to Failure	10^5	$6x10^5$	$2x10^6$	10^5	$6x10^5$	$2x10^6$	10^5	$6x10^5$	$2x10^6$
F_{max} - ksi	55	35	30	90	50	40	115	80	60

TABLE 3.051 STRESS RANGE RESULTS FOR T-1 PLATE.

	Fe
0.15	C
0.80	Mn
0.85	Ni
0.53	Cr
0.50	Mo
0.32	Cu
0.25	Si
0.05	V
+	B

T-1

	Fe
0.16	C
0.85	Mn
0.53	Cr
0.27	Si
0.20	Mo
0.05	V
0.02	Ti
+	B

T-1A

	Fe
0.16	C
1.12	Mn
0.52	Cr
0.50	Ni
0.27	Si
0.25	Mo
0.05	V
+	B

T-1B

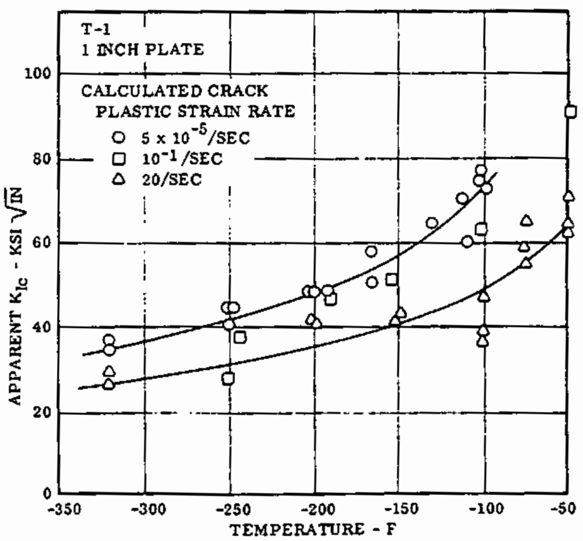

FIG. 3.03724 EFFECT OF TEST TEMPERATURE AND STRAIN RATE ON APPARENT PLANE STRAIN FRACTURE TOUGHNESS OF PLATE. (27, fig. 5)

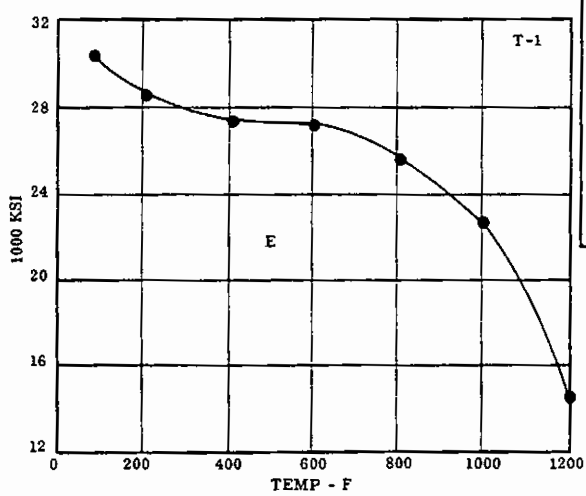

FIG. 3.062 MODULUS OF ELASTICITY AT ROOM AND ELEVATED TEMPERATURES (15)

Fe
0.15 C
0.80 Mn
0.85 Ni
0.53 Cr
0.50 Mo
0.32 Cu
0.25 Si
0.05 V
+ B

T-1

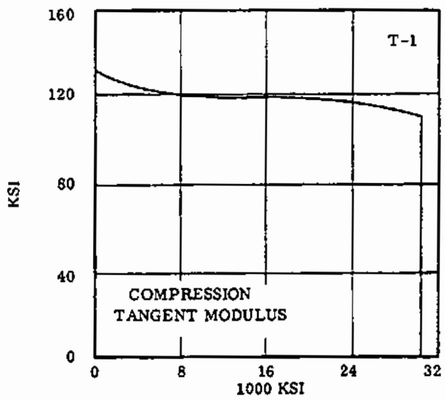

FIG 3.064 TYPICAL COMPRESSION TANGENT MODULUS CURVE FOR T-1 STEEL (15)

Source	(33) Table 4		
Alloy	T-1 (A517)		
Weld process	SMA	Sub arc	GMA
Filler metal	E11018G (a)(b)	Mn-Ni-Cr-Mo wire + neutral flux or carbon steel wire + alloy flux (c)	Mn-Ni-Cr-Mo-wire + Argon-O_2 gas

(a) Lower strength, low H_2 electrodes may be used.
(b) Higher strength electrode (e.g. E120186) may be necessary for thin plates of T-1A (A517B).
(c) Very close control of welding conditions required to avoid composition variations and cracking.

TABLE 4.0321 RECOMMENDED FILLER METALS FOR USE IN VARIOUS WELDING PROCESSES USED WITH T-1 STEELS.

Fe
0.16 C
0.85 Mn
0.53 Cr
0.27 Si
0.20 Mo
0.05 V
0.02 Ti
+ B

T-1A

Source	(33 Table 6) (a)			
Alloy	T-1, T-1A and T-1B			
Weld process	SMA	GMA	Sub Arc	Sub Arc
Plate thick (in.)				
≤ 1/2	100F	100F	100F	100F
> 1/2 to 1	100	100	100	200
> 1 to 2	150	150	150	300
> 2	200	200	200	400

TABLE 4.0322 RECOMMENDED PREHEAT TEMPERATURES FOR SEVERAL WELDING PROCESSES USED WITH T-1 STEELS.

Fe
0.16 C
1.12 Mn
0.52 Cr
0.50 Ni
0.27 Si
0.25 Mo
0.05 V
+ B

T-1B

Source	(33 Table 9)							
Alloy	T-1							
Welding condition	Max. heat input in Kjoules/in. for various thicknesses							
Thickness - in.	3/16	1/4	1/2	3/4	1	1-1/4	1-1/2	2
Preheat and interpass temp-F								
70	27	36	70	121	Any	Any	Any	Any
200	21	29	56	99	173	Any	Any	Any
300	17	24	47	82	126	175	Any	Any
400	13	19	40	65	93	127	165	Any

4.0323 RECOMMENDED MAXIMUM WELDING HEAT INPUTS FOR T-1 STEEL.

Source	(33 Table 8)							
Alloy	T-1A and T-1B							
Welding condition	Max. heat input in Kjoules/in. for various thicknesses							
Thickness - in.	3/16	1/4	3/8	1/2	5/8	3/4	1	1-1/4
Preheat and interpass temp-F								
70	17.5	23.7	35	47.4	64.5	88.6	Any	Any
150	15.3	20.9	30.7	41.9	57.4	77.4	120.0	Any
200	14	19.2	28	35.5	53.0	69.9	110.3	154.0
300	11.5	15.8	23.5	31.9	42.5	55.7	86.0	120.0
400	9.0	12.3	18.5	25.9	33.5	41.3	65.6	94.0

TABLE 4.0324 RECOMMENDED MAXIMUM WELDING HEAT INPUT FOR T-1A AND T-1B STEELS.

Source	(18, p.5) (19, p.3)			
Alloy	T-1		T-1A (0.25%Ni)	
Form	1 in. plate		1 in. plate	
Condition	Austenitize + 1150F	Austenitize + 900F	As Rec'd. Q & T	As Rec'd. + Welded (b)(c)
F_{tu} - ksi	125	153	121	-
F_{ty} - ksi	119	143	113	-
RA - percent	48	40	55	-
NDT - F(a)	-65	+10	-80	+10
DWTT at 30F ft-lbs				
TL	-	-	1478	-
LT	-	-	3633	-

(a) ASTM E208-69
(b) See Figure 4.0332 for welding conditions.
(c) NDT specimen notched in HAZ.

TABLE 4.0331 TENSILE PROPERTIES AND DROP WEIGHT TEST FOR PARENT PLATE AND WELDMENTS.

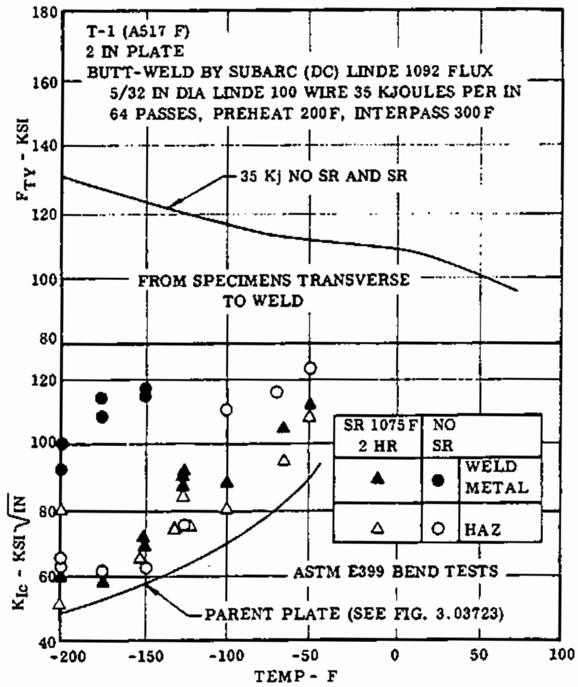

FIG. 4.0333 EFFECT OF TEST TEMPERATURE ON PLANE STRAIN FRACTURE TOUGHNESS OF SUBARC PLATE WELDS. (31, table 2)

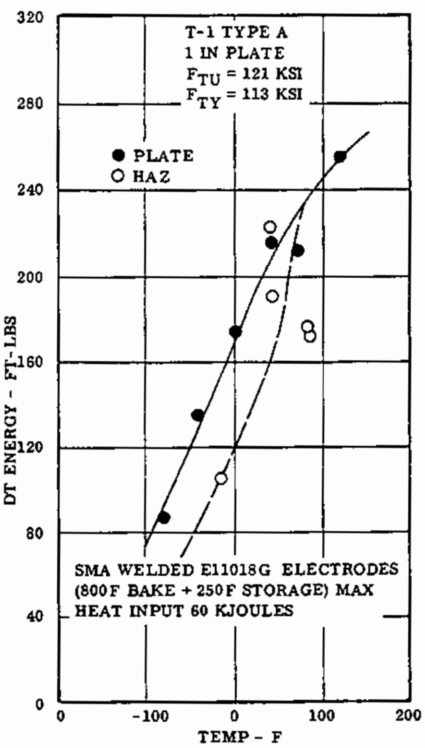

FIG. 4.0332 DYNAMIC TEAR VALUES FOR T-1A (A517B WITH 0.25 Ni) PARENT PLATE AND WELD HEAT AFFECTED ZONE. (23, table 7)

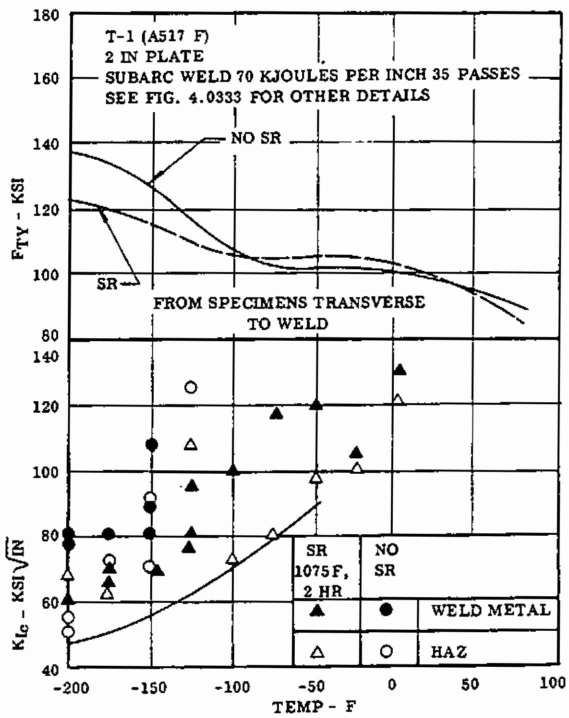

FIG. 4.0334 EFFECT OF TEST TEMPERATURE ON PLANE STRAIN FRACTURE TOUGHNESS OF SUBARC PLATE WELDS. (31, table 2, fig. 21)

T-1
Fe
0.15 C
0.80 Mn
0.85 Ni
0.53 Cr
0.50 Mo
0.32 Cu
0.25 Si
0.05 V
+ B

T-1A
Fe
0.16 C
0.85 Mn
0.53 Cr
0.27 Si
0.20 Mo
0.05 V
0.02 Ti
+ B

T-1B
Fe
0.16 C
1.12 Mn
0.52 Cr
0.50 Ni
0.27 Si
0.25 Mo
0.05 V
+ B

Fe
0.15 C
0.80 Mn
0.85 Ni
0.53 Cr
0.50 Mo
0.32 Cu
0.25 Si
0.05 V
+ B

T-1

Source	(14)(17)							
Alloy	T-1				T-1A			
Thickness-in	1				1		1-3/8	
Condition (a)	A	SMA	SMA +SR	SA	A	SMA	A	SMA
Test temp. for transition to elastic fracture (FTE) -F	-40	-30 to -40	-10 to -30	-10 to -30	-60	-15	-10	-25

(a) A - as received Q and T; SMA - shielded metal arc SA - submerged arc; SR - stress relief 1100F, 1 hr.

TABLE 4.0341 RESULTS FROM CRACK STARTER EXPLOSION BULGE TESTS ON WELDED PLATE OF T-1 AND T-1A.

Source	(15)(10)			
Alloy	T-1			
Form	Plate			
Thickness-in	0.5			
Test	Notch toughness			
	Specimen Orientation	Condition of Specimen	Ductility Transition Temp-F(a)	Fracture Appearance Transition Temp-F(b)
Kinzel Notch-bend	L	unwelded	-68	-67
	T	unwelded	-62	-59
	L	welded	-42	-42
	T	welded	-50	-47
	L	welded + stress rel. (c)	-30	-27
NRL drop-weight	L	welded (d)	-80	-
	T	welded (d)	-80	-
NRL bulge-explosion	-	welded (d)	-	-50 (e)

(a) Ductility transition temperature at middle of band for Kinzel notch-bend and total failure at 3 percent angle for NRL drop-weight test.
(b) Fracture appearance transition temperature selected at 50 percent shear for Kinzel notch-bend and failure across plate for NRL bulge-explosion test.
(c) Stress relieved at 1100F for 1 hour.
(d) Hard facing electrodes.
(e) Fracture-arrest transition temperature.

TABLE 4.0343 NOTCH BEND, DROP WEIGHT AND EXPLOSION BULGE DATA FOR T-1 PLATE AND WELDMENTS.

Fe
0.16 C
0.85 Mn
0.53 Cr
0.27 Si
0.20 Mo
0.05 V
0.02 Ti
+ B

T-1A

Source	(15)				
Alloy	T-1				
Form	1/2 in plate				
Type	T-1			T-1A	
Condition	A (a)	A + Weld	A + Weld + 1100F, 1 hr	A	A + Weld + 1100F, 1 hr
Ductility Transition Temp - F (b)	-68	-42	-30	-56	-40
50 percent shear transition Temp - F (b)	-67	-42	-27	-44	-12

(a) Q and T as received.
(b) Kinzel notch bend test

TABLE 4.0342 TRANSITION TEMPERATURES DETERMINED FROM KINZEL NOTCH BEND TESTS ON PARENT PLATE AND WELDMENTS.

Fe
0.16 C
1.12 Mn
0.52 Cr
0.50 Ni
0.27 Si
0.25 Mo
0.05 V
+ B

T-1B

Source	(15)(10)			
Alloy	T-1 Type A			
Form	Plate			
Thickness-in	0.5			
Test	Notch Toughness			
	Specimen Orientation	Condition of Specimen	Ductility Transition Temp-F(a)	Fracture Appearance Transition Temp-F(b)
Kinzel notch-bend	L	welded	-56	-44
	L	welded + stress rel(c)	-40	-12
NRL drop-weight	L	welded (d)	-60	-

(a)(b)(c)(d) see Table 4.038

TABLE 4.0344 TRANSITION TEMPERATURES DETERMINED ON WELDMENTS USING NOTCH BEND AND DROP WEIGHT TESTS.

REFERENCES

1. Properties Card, "U.S.S. T-1 Constructional Alloy", U.S. Steel Corporation (March 1969).
2. Alloy Digest, "USS T-1 Type A", Filing Code: SA-157, Steel Alloy (November 1963).
3. Bennett, E. V., "Super-Strength Structural Steel", prepared for the Climax Molybdenum Company.
4. United States Steel Corporation, "New Steels, New Shapes, New Concepts" (1961).
5. Brockenbrough, R. L. and Johnston, B. G., "USS Steel Design Manual", USS ADUSS 27-3400-02 (November 1968).
6. Porter, L. F., "Radiation Effects in Steel", ASTM Special Technical Publication No. 276, Materials in Nuclear Applications (June 1960).
7. United States Steel Corporation, "Availabilities Guide, Qualities, Forms, Sizes and Properties, USS T-1 and T-1 Type A Steels" (May 1963).
8. Alloy Digest, "Carilloy T-1", Filing Code: SA-25, Steel Alloy (January 1955).
9. United States Steel Corporation, "How to Weld T-1 and T-1 Type A Steels", Publication No. ADUCO 01006 (latest revision).
10. Puzak, P. P. and Pellini, W.S., "Evaluation of the Significance of Charpy Tests for Quench and Tempered Steels", The Welding Journal , Vol. 35 (6), Research Suppl. 275-S to 290-S (1956).
11. Balai, N., Kettles, T.L. and Bailey, R.E., "Reactor Pressure Vessel Design for Nuclear Reactions", Symposium on Radiation Effects on Materials, Vol. 3, ASTM STP No. 233 (1958).
12. McDonnell Aircraft Corporation, "Mechanical Properties and Weldability of Cast T-1 Steel", from First Quarterly Progress Report on Unpublished Materials Research and Development Programs, Rep. No. 8743, Vol. IV, Ser. 1 (April 1962).
13. Reichold, H.M., U. S. Steel Corporation, personal communication with W. F. Brown, Jr. (February 29, 1972).
14. Doty, W.D., "Welding of Quenched and tempered Alloy Steels", Metals Engineering Quarterly (February 1969).
15. Carney, D.J., U.S. Steel Corporation, personal communication with W. F. Brown, Jr. (January 27, 1972)
16. Puzak, P. P., "Explosion Bulge Test Performance of Low Carbon Ni-Cr-Mo-B Quenched and Tempered Steel Weldments", NRL Report 4919 (May 17, 1957).
17. Doty, W.D., Benten, W.P. and Manning, R.D., "Performance Tests of a High Yield Strength Steel for Ships", The Welding Journal, Vol. 47, No. 12, Res. Supp. (1968) p. 534s.
18. Puzak, P.P. and Babecki, A.J., "Explosion Tear Test Studies of High Strength Q and T Steels", NRL Report 5836 (September 6, 1962).
19. McGeady, L.J., "Fracture Properties of Quenched and Tempered Steel Weldment Specimens", NRL Report 6602, (October 10, 1967).
20. Pellini, W.S., et al, "Review of Concepts and Status of Procedures for Fracture Safe Design of Complex Welded Structures Involving Metals of Low to Ultra High Strength Levels", NRL Report 6300 (June 1965).
21. Pellini, W.S. and Puzak, P.P., "Practical Considerations in Applying Laboratory Fracture Criteria to the Fracture Safe Design of Pressure Vessels", NRL Report 6030 (November 5, 1963).
22. Pellini, W.S., "Advances in Fracture Toughness Characterization Procedures and in Quantitative Interpretations to Fracture Safe Design for Structural Steels", NRL Report 6713 (April 3, 1968).
23. McGeady, L.J., "Procedures for the Evaluation of the Fracture Toughness of Heat Affected Zones", Welding Journal, Vol. 51, No. 12, (December 12, 1972), Res. Supp. p. 569s.
24. Doty, W.D., "Weldability of Steels and Selection of Welding Procedures", Paper presented during 37th Midyear Meeting of American Petroleum Institute's Division of Refining (May 11, 1972).
25. Barsom, J.M., "Relationship Between Plane Strain Ductility and K_{Ic} for Various Steels", Ind. Eng. for Industry (November 1971) p. 1209.
26. Barsom, J.M. and Rolfe, S.T., "K_{Ic} Transition Behavior of A517-F Steel", U.S. Steel Applied Research Lab Report No. 89.018-022 (1), Contract Nobs-94535 (FBM) (November 29, 1968).
27. Shoemaker, A.K. and Rolfe, S.T., "The Static and Dynamic Low Temperature Crack-Toughness Performance of Seven Structural Steels", Eng. Fracture Mechs. Vol. 2 (1971) p.319.
28. Vettraino, J., "T-1 Steel Investigation," Army Tank Automotive Center, Detroit Arsenal, Report 7139, AD 477546L (November 1961).
29. Lange, E.A., Pickett, A.G. and Wylie, R.D., "Failure Analysis of PVRC Vessel No. 5. Part I, A Study of Materials Properties and Fracture Development", Welding Research Council Bulletin No. 98 (August 1964).
30. Raymond, L. and Usell, R.J. Jr., "The Effect of N_2O_4 and UDMH on Subcritical Crack Growth in Various High Toughness Low-Strength Steels", Aerospace Corporation Report No. TR-0059 (6250-10)-8 (June 15, 1971).
31. Gentlicore, V.C., Pense, A.W. and Stout, R.D., "Fracture Toughness of Pressure Vessel Steel Weldments", The Welding Journal, Vol. 49, No. 8 (August 1970), Res. Supp. p. 341s.
32. Loginow, A.W., U. S. Steel Research Laboratory, Personal Communication with W. F. Brown, Jr. (January 1972).
33. Doty, W.D., "Welding of Quenched and Tempered Alloy Steels", Metals Engineering Quarterly, ASM (February 1969).