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PLANE STRAIN FRACTURE TOUGHNESS (KIC) DATA HANDBOOK  
FOR METALS

ARMY MATERIALS AND MECHANICS RESEARCH CENTER

DECEMBER 1973

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ABSTRACT

A compilation of plane strain  $K_{IC}$  data is presented for metals manufactured in the USA and Europe, including 50 steels, 21 titanium alloys, 38 aluminum alloys, and one beryllium material. The data corresponds to static loading in neutral laboratory environment. The effect of temperature is included in the tables along with the direction of testing, the form and size of the material, its composition and heat treatment, and the specimen type and size. (Author)

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## INTRODUCTION

The plane strain fracture toughness values presented in this compilation are expressed in terms of linear elastic fracture mechanics. These  $K_{IC}$  values have been obtained by the ASTM E399-72 "Standard Method of Test for Plane Strain Fracture Toughness Testing of Metallic Materials" or a similar method. This data compilation includes materials manufactured in the USA and Europe. The following factors are involved in the selection and interpretation of the  $K_{IC}$  values.

### Testing Conditions

The material values shown correspond to quasi-static loading of approximately one to three minutes duration. The environment is a neutral laboratory environment in which no aggressive chemicals or extreme of humidity are intentionally introduced.

### Specimen Types

$K_{IC}$  values shown have been obtained from ASTM recommended bend and compact tensile specimens and from a variety of other specimens: four-point bend, double cantilever beam, wedge opening loading, side edge notched, center cracked specimens and a few double edge cracked and notched round specimens. Surface cracked specimen data is not included in the appendix since, although this configuration is extremely important in applications, criteria for validity of  $K_{IC}$  measurements of surface cracked specimens have not been established.

### Criteria for Validity of Typical $K_{IC}$ Values

The ASTM E399-72 requirements are taken as the general guide for validity. However, since complete details of factors cited by ASTM are usually not available, personal judgment must be exercised. For example, although all data listed pertain to fatigue-cracked specimens, the range of imposed  $K_I$  during fatiguing is usually not reported. In addition, the crack front curvature and the orientation of the crack plane with respect to the loading axis are also unknown. Other typical unknowns are the critical crack length, the details of selection of the critical load value, the appearance of the fracture surfaces, the details of fixture design to minimize friction and the linearity of the displacement gage. Therefore, it is often necessary to assume that in general the test measurements have been carried out according to good practice. In terms of specific criteria for inclusion in this tabulation the ASTM requirement of thickness greater than  $2.5 (K_{IC}/\sigma_{YS})^2$ , was applied. Virtually all of the data satisfied this requirement. Although it would be desirable to require that crack length exceed  $2.5 (K_{IC}/\sigma_{YS})^2$ , this criterion was not rigidly imposed. The minimum reported crack length for data presented in this appendix is  $1.25 (K_{IC}/\sigma_{YS})^2$ .

### Accuracy of $K_{IC}$ Values

In general the  $K_{IC}$  values shown are averages of several tests. The range of typical data may be interpreted to be the average shown  $\pm 10\%$ . In cases where the range of toughness values was large, either the entire range is shown or the extremely high values were excluded before computing the average. It should be recognized that these accuracy limits refer only to the specific results obtained and may not be appropriate in general for material of the same nominal composition, form, and size which is processed and tested elsewhere.

### Parameters Influencing $K_{IC}$

Where available, the influence, whether significant or negligible, of material form and thickness, composition, heat treatment, testing temperature and material anisotropy and yield strength upon  $K_{IC}$  is shown by the series of data entered in the tables. In most cases where a particular heat treatment produces both the highest yield strength and toughness, data for other heat treatments are omitted. It is important to note that for some materials, data from the combination of composition and processing which leads to the highest toughness is not included in this compilation. In those instances it is not possible to obtain valid  $K_{IC}$  measurements for the particular material thickness of interest. There are additional parameters which may also influence  $K_{IC}$  values which are not shown in these tables since they are rather infrequently reported. These include melting practice, heat treating practice such as the size of quenching bath relative to the material size, and the amount of material straining during forging.

## DEFINITION OF SYMBOLS AND UNITS

### Units, Symbols and Nomenclature

Data is presented in the customary units used in the United States with accompanying International System Units (SI) in parentheses. The definition of units and symbols for specimen orientation and type are given preceding the tabulations.

#### a) Composition and Heat Treatment Codes

Code Form: Letter, Number

Letter - Identifies Composition

Number - Identifies Heat Treatment

Detailed descriptions of composition and heat treatment are at the bottom of each table. The compositional values are measured values in terms of percentage by weight, except when designated ppm (parts per million).

When only specified composition is available, the nominal specified levels are followed by the letter "N" and the maximum levels of other elements are followed by "F".

b) Orientation of Specimens

Code: First letter: Direction of Loading

Second letter: Direction of Crack Propagation

L: Direction Parallel to Primary Grain Flow Direction of Plate, Forging or Extrusion

T: Direction Parallel to Largest Dimension in Plane Transverse to L Direction

S: Direction Parallel to Smallest Dimension in Plane Transverse to L Direction

ST4: Direction 45° Between Directions of Largest and Smallest Dimension in Plane Transverse to L Direction

R: Radial Direction

C: Circumferential Direction

If a direction is ambiguous in terms of two of the above definitions, then both directions are shown.

c) Specimen Identification

Bend: 3-point Bend Specimen

Bend (4 pt): 4-point Bend Specimen

CT: ASTM Compact Tensile Specimen

WJL: Similar to CT, but with different dimensions

CC: Remotely Loaded Flat Tensile Specimen with Center Notch

DEC: Remotely Loaded Flat Tensile Specimen with Double Edge Cracks

SEN: Remotely Loaded Flat Tensile Specimen with a Single Edge Crack

NR: Round Tensile Specimen, Circumferentially Notched

DCB: Double Cantilever Beam Specimen

d) Units

Temperature: F - Degrees Fahrenheit

K - Degrees Kelvin

Stress: KSI - Kips per Square Inch

MN/m<sup>2</sup> - Mega Newtons per Square Meter

Stress Intensity: KSI  $\sqrt{\text{in}}$  - Kips per Square Inch Times Square Root Inches

MN m<sup>3/2</sup> - Mega Newtons times (Meters)<sup>3/2</sup>

Length: in, mm - Inches, Millimeters

ft, m - Feet, Meters

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Steel, Low Alloy: AISI 4330M, EN30B

Table 1

| Form                                                                                                                     | Composition, Heat Treatment | Test Orientation | Temp.<br>°F (°K) | Yield Strength<br>KSI (MN/m <sup>2</sup> ) | Typical<br>K <sub>IC</sub><br>KSI/√in (MN m <sup>-3/2</sup> ) | 2.5<br>K <sub>IC</sub><br>(σ <sub>YS</sub> ) <sup>2</sup><br>in (mm) | Specimen            |                      |                  |                         | Ref.  |      |      |      |      |
|--------------------------------------------------------------------------------------------------------------------------|-----------------------------|------------------|------------------|--------------------------------------------|---------------------------------------------------------------|----------------------------------------------------------------------|---------------------|----------------------|------------------|-------------------------|-------|------|------|------|------|
|                                                                                                                          |                             |                  |                  |                                            |                                                               |                                                                      | Type                | Thickness<br>in (mm) | Width<br>in (mm) | Crack Length<br>in (mm) |       |      |      |      |      |
| AISI 4330M<br>Cylindrical Forging<br>15.5 in. (394 mm) OD<br>6.5 in. (165 mm) ID<br>35 ft (10.7 m) Long                  | A,1                         | C-R              | 70(294)          | 181(1248)                                  | 120(131)                                                      | 1.10(27.9)                                                           | WOL 1.0             | (25.4)               | 2.75(69.8)       | ---                     | 1     |      |      |      |      |
|                                                                                                                          | A,1                         | C-R              | -20(244)         | ---                                        | 120(131)                                                      | ---                                                                  | WOL 1.0             | (25.4)               | 2.75(69.8)       | ---                     |       |      |      |      |      |
|                                                                                                                          | A,2                         | C-R              | 70(294)          | 157(1110)                                  | 120(131)                                                      | 1.47(37.3)                                                           | WOL 1.0             | (25.4)               | 2.75(69.8)       | ---                     |       |      |      |      |      |
|                                                                                                                          | A,2                         | C-R              | -60(222)         | ---                                        | 45(49)                                                        | ---                                                                  | WOL 1.0             | (25.4)               | 2.75(69.8)       | ---                     |       |      |      |      |      |
|                                                                                                                          | B,3                         | L-T              | 70(294)          | 210(1448)                                  | 55(60)                                                        | 0.17(4.3)                                                            | NR D=               | 0.353(19.9)          | ---              | ---                     | 2     |      |      |      |      |
| Plate: 1 in. (25.4 mm)<br>Thick                                                                                          |                             | L-T              | -100(200)        | ---                                        | 40(44)                                                        | ---                                                                  | NR D=               | 0.353(19.9)          | ---              | ---                     |       |      |      |      |      |
|                                                                                                                          | C,4                         | L-T              | 70(294)          | 198(1365)                                  | 84(92)                                                        | 0.45(11.4)                                                           | Bend0.48 (12.2) 1.5 | (38.1) 0.3           | (7.6)            | 3                       |       |      |      |      |      |
| Forging: 3 in. (76.2 mm)<br>Thick                                                                                        |                             | L-T              | -65(219)         | ---                                        | 64(70)                                                        | ---                                                                  | Bend0.48 (12.2) 1.5 | (38.1) 0.3           | (7.6)            | 4 pt                    |       |      |      |      |      |
|                                                                                                                          |                             |                  |                  |                                            |                                                               |                                                                      |                     |                      |                  |                         |       |      |      |      |      |
| EN30B<br>Bar: 0.56 in. (14.2 mm)<br>Square                                                                               | D,5                         | L-ST             | 70(294)          | 198(1365)                                  | 68(75)                                                        | 0.29(7.5)                                                            | Bend0.313(7.8)      | 0.5                  | (12.7) 0.25      | (6.4)                   | 5     |      |      |      |      |
|                                                                                                                          | D,6                         | L-ST             | 70(294)          | 207(1427)                                  | 65(72)                                                        | 0.247(6.3)                                                           | Bend0.315(8.0)      | 0.5                  | (12.7) 0.26      | (6.6)                   |       |      |      |      |      |
|                                                                                                                          | D,7                         | L-ST             | 70(294)          | 216(1489)                                  | 56(62)                                                        | 0.168(4.3)                                                           | Bend0.315(8.0)      | 0.5                  | (12.7) 0.21      | (5.3)                   |       |      |      |      |      |
|                                                                                                                          | D,8                         | L-ST             | 70(294)          | 232(1600)                                  | 74(81)                                                        | 0.254(6.5)                                                           | Bend0.315(8.0)      | 0.5                  | (12.7) 0.25      | (6.4)                   |       |      |      |      |      |
|                                                                                                                          | D,9                         | L-ST             | 70(244)          | 243(1710)                                  | 68(75)                                                        | 0.188(4.7)                                                           | Bend0.315(8.0)      | 0.5                  | (12.7) 0.22      | (5.6)                   |       |      |      |      |      |
| COMPOSITION                                                                                                              |                             |                  |                  |                                            |                                                               |                                                                      |                     |                      |                  |                         |       |      |      |      |      |
|                                                                                                                          |                             |                  |                  |                                            |                                                               | C                                                                    | Si                  | Mn                   | S                | P                       | Mo    | Ni   | Cu   | V    |      |
|                                                                                                                          |                             |                  |                  |                                            |                                                               | A                                                                    | 0.34                | 0.22                 | 0.50             | 0.011                   | 0.012 | 0.58 | 3.08 | 1.15 | 0.13 |
|                                                                                                                          |                             |                  |                  |                                            |                                                               | B                                                                    | 0.31                | 1.59                 | ---              | ---                     | ---   | 0.40 | 1.80 | 2.04 | 0.07 |
|                                                                                                                          |                             |                  |                  |                                            |                                                               | C                                                                    | 0.28                | 0.36                 | 0.80             | 0.007                   | 0.009 | 0.44 | 1.84 | 0.90 | 0.09 |
|                                                                                                                          |                             |                  |                  |                                            |                                                               | D                                                                    | 0.32                | 0.20                 | 0.49             | 0.009                   | 0.012 | 0.24 | 4.09 | 1.22 | ---  |
| HEAT TREATMENT                                                                                                           |                             |                  |                  |                                            |                                                               |                                                                      |                     |                      |                  |                         |       |      |      |      |      |
| 1. 1550F (8117K) Oil Quench; Temper 1050F (839K), 4 Hr                                                                   |                             |                  |                  |                                            |                                                               |                                                                      |                     |                      |                  |                         |       |      |      |      |      |
| 2. 1550F (8117K), Salt Quench to 600F (589K); Temper 1050F (839K), 4 Hr                                                  |                             |                  |                  |                                            |                                                               |                                                                      |                     |                      |                  |                         |       |      |      |      |      |
| 3. 1700F (1200K), 1 Hr, Oil Quench; Temper 600F (589K), 1 Hr, Air Cool                                                   |                             |                  |                  |                                            |                                                               |                                                                      |                     |                      |                  |                         |       |      |      |      |      |
| 4. 175F (1130K), 1 Hr, Oil Quench; Temper 500F (533K), 3 Hr, Air Cool                                                    |                             |                  |                  |                                            |                                                               |                                                                      |                     |                      |                  |                         |       |      |      |      |      |
| 5. Hot Rolled, Air Cooled; 1525F (1103K), 1 Hr, Oil Quench; Temper 391F (473K), 1 Hr                                     |                             |                  |                  |                                            |                                                               |                                                                      |                     |                      |                  |                         |       |      |      |      |      |
| 6. Heated at 54F (30K)/sec to A <sub>c3</sub> Temp, Quench; Temper 661F (623K), 1 Hr                                     |                             |                  |                  |                                            |                                                               |                                                                      |                     |                      |                  |                         |       |      |      |      |      |
| 7. Heated at 54F (30K)/sec to A <sub>c3</sub> Temp, Quench; Temper 391F (473K), 1 Hr                                     |                             |                  |                  |                                            |                                                               |                                                                      |                     |                      |                  |                         |       |      |      |      |      |
| 8. 1796F (1253K), 1 Hr, Quench in Lead Bath 931F (773K); Ausformed, 70% Reduction, Air Cooled; Temper 750F (672K), 1 Hr. |                             |                  |                  |                                            |                                                               |                                                                      |                     |                      |                  |                         |       |      |      |      |      |
| 9. 1796F (1253K), 1 Hr, Quench in Lead Bath 931F (773K); Ausformed, 70% Reduction, Air Cooled; Temper 391F (473K), 1 Hr  |                             |                  |                  |                                            |                                                               |                                                                      |                     |                      |                  |                         |       |      |      |      |      |

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## HEAT TREATMENT

1. 1550F (811K) Oil Quench; Temper 1050F (566K), 4 Hr
2. 1550F (811K), Salt Quench to 600F (316K); Temper 1050F (566K), 4 Hr
3. 1700F (927K), 1 Hr, Oil Quench; Temper 600F (316K), 1 Hr, Air Cool
4. 1750F (955K), 1 Hr, Oil Quench; Temper 500F (260K), 3 Hr, Air Cool
5. Hot Rolled, Air Cooled; 1525F (835K), 1 Hr, Oil Quench; Temper 391F (200K), 1 Hr
6. Heated at 54F (30K)/sec to A<sub>c3</sub> Temp, Quench; Temper 661F (350K), 1 Hr
7. Heated at 54F (30K)/sec to A<sub>c3</sub> Temp, Quench; Temper 391F (200K), 1 Hr
8. 1796F (986K), 1 Hr, Quench in Lead Bath 931F (500K); Ausformed, 70% Reduction, Air Cooled; Temper 750F (405K), 1 Hr
9. 1796F (986K), 1 Hr, Quench in Lead Bath 931F (500K); Ausformed, 70% Reduction, Air Cooled; Temper 391F (200K), 1 Hr

Steel Low Alloy: 1. 2D16, EN40C

Table 2

| Form                                                                                                                    | Composition, Heat Treatment | Test Orientation | Temp °F (°K) | Yield Strength KSI (MN/m <sup>2</sup> ) | Typical K <sub>IC</sub> KSI/√in (MN m <sup>3/2</sup> ) | 2.5 (K <sub>IC</sub> <sup>2</sup> / σ <sub>ys</sub> ) in (mm) | Specimen        |                   |               | Ref.  |
|-------------------------------------------------------------------------------------------------------------------------|-----------------------------|------------------|--------------|-----------------------------------------|--------------------------------------------------------|---------------------------------------------------------------|-----------------|-------------------|---------------|-------|
|                                                                                                                         |                             |                  |              |                                         |                                                        |                                                               | Type            | Thickness in (mm) | Width in (mm) |       |
| 35NCD16                                                                                                                 |                             |                  |              |                                         |                                                        |                                                               |                 |                   |               |       |
| Bar: Vac. Arc. Remelt                                                                                                   | A, 1                        | L-R              | 70(294)      | 191(1317)                               | 72(79)                                                 | 0.355 (9.0)                                                   | (a)             | ---               | ---           | 67    |
|                                                                                                                         | A, 2                        | L-R              | 70(294)      | 202(1393)                               | 72(79)                                                 | 0.318 (8.1)                                                   | (a)             | ---               | ---           |       |
|                                                                                                                         | A, 3                        | L-R              | 70(294)      | 211(1455)                               | 67(74)                                                 | 0.252 (6.4)                                                   | (a)             | ---               | ---           |       |
|                                                                                                                         | C, -                        | T-S              | 70(294)      | 208(1344)                               | 74(81)                                                 | 0.316 (8.04)                                                  | Bend 0.5 (12.7) | 1.0 (25.4)        | ---           | 60    |
|                                                                                                                         | C, -                        | T-S              | 70(294)      | 216(1489)                               | 72(79)                                                 | 0.278 (7.1)                                                   | Bend 0.5 (12.7) | 1.0 (25.4)        | ---           |       |
|                                                                                                                         | C, -                        | T-S              | 20(294)      | 222(1521)                               | 71(78)                                                 | 0.256 (6.5)                                                   | Bend 0.5 (12.7) | 1.0 (25.9)        | ---           |       |
| EN40C                                                                                                                   |                             |                  |              |                                         |                                                        |                                                               |                 |                   |               |       |
| Bar: 0.56 in (14.2 mm) sq.                                                                                              | B, 4                        | L-R              | 70(294)      | 218(1503)                               | 60(66)                                                 | 0.189 (4.8)                                                   | Bend 0.313(8)   | 0.5 (12.7)        | 0.23(5.8)     | 5     |
|                                                                                                                         | B, 5                        | L-R              | 70(294)      | 239(1648)                               | 59(65)                                                 | 0.152 (3.9)                                                   | Bend 0.313(8)   | 0.5 (12.7)        | 0.15(3.8)     |       |
|                                                                                                                         | , 6                         | L-R              | 70(294)      | 260(1793)                               | 55(61)                                                 | 6.112 (2.8)                                                   | Bend 0.313(8)   | 0.5 (12.7)        | 0.21(5.3)     |       |
|                                                                                                                         | B, 7                        | L-R              | 70(294)      | 317(2186)                               | 44(48)                                                 | 0.048 (1.2)                                                   | Bend 0.313(8)   | 0.5 (12.7)        | 0.12(3.0)     |       |
| (a) Specimen in accordance with ASTM Recommendations.                                                                   |                             |                  |              |                                         |                                                        |                                                               |                 |                   |               |       |
| COMPOSITION                                                                                                             |                             |                  |              |                                         |                                                        |                                                               |                 |                   |               |       |
|                                                                                                                         | C                           | Si               | Mn           | Ni                                      | Cr                                                     | Mo                                                            | V               | S                 | P             | Al    |
| A                                                                                                                       | 0.35                        | 0.27             | 0.33         | 3.99                                    | 1.69                                                   | 0.44                                                          | 0.05            | 0.009             | 0.009         | 0.026 |
| B                                                                                                                       | 0.37                        | 0.26             | 0.54         | 0.13                                    | 2.98                                                   | 0.90                                                          | 0.23            | 0.013             | 0.015         | ---   |
| C                                                                                                                       | 0.35N                       | 0.4M             | 0.35N        | 4.0N                                    | 1.75N                                                  | 0.45N                                                         | -               | 0.03M             | 0.03M         | ---   |
| HEAT TREATMENT                                                                                                          |                             |                  |              |                                         |                                                        |                                                               |                 |                   |               |       |
| 1. 1705 (1203K), Air Cool; 1606F (1148K), Air Cool; -95F(203K); Temper 751F (673K), 2 Hr                                |                             |                  |              |                                         |                                                        |                                                               |                 |                   |               |       |
| 2. 1705 (1203K), Air Cool; 1606F (1148K), Air Cool; -95F (203K); Temper 661F (623K), 2 Hr                               |                             |                  |              |                                         |                                                        |                                                               |                 |                   |               |       |
| 3. 1705 (1203K), Air Cool; 1606F (1148K), Air Cool; -95F (203K); Temper 42°F (493K), 2 Hr                               |                             |                  |              |                                         |                                                        |                                                               |                 |                   |               |       |
| 4. 1650F (1172K), Oil Quench; Temper 571F (573K), 1 Hr                                                                  |                             |                  |              |                                         |                                                        |                                                               |                 |                   |               |       |
| 5. Heated at 54F (30K)/sec to A <sub>3</sub> Temp, Immediate Quench to 70F (294K); Temper 571F (570K), 1 Hr             |                             |                  |              |                                         |                                                        |                                                               |                 |                   |               |       |
| 6. 1796F (1253K), 1 Hr, Quench in Lead Bath 1021F (823K); Ausformed 70% Reduction, Air Cooled; Temper 391F (473K), 1 Hr |                             |                  |              |                                         |                                                        |                                                               |                 |                   |               |       |
| 7. 1796F (1253K), 1 Hr, Quench in Lead Bath 1021F (823K); Ausformed 70% Reduction, Air Cooled; Temper 571F (573K), 1 Hr |                             |                  |              |                                         |                                                        |                                                               |                 |                   |               |       |

## Table 3

Table 3

| Form                            | C'-'po-<br>sition,<br>Heat<br>Treat-<br>ment | Test<br>Orienta-<br>tion | Temp<br>of (K) | Yield<br>Strength<br>KSI (MN/m <sup>2</sup> ) | Typical<br>K <sub>IC</sub><br>KSI/√in (MN m <sup>1/2</sup> ) | 2.5 (K <sub>IC</sub><br>σ <sub>ys</sub> ) <sup>2</sup><br>in (mm) | Specimen     |                      |                  |                            | Ref. |
|---------------------------------|----------------------------------------------|--------------------------|----------------|-----------------------------------------------|--------------------------------------------------------------|-------------------------------------------------------------------|--------------|----------------------|------------------|----------------------------|------|
|                                 |                                              |                          |                |                                               |                                                              |                                                                   | Type         | Thickness<br>in (mm) | Width<br>in (mm) | Crack<br>Length<br>in (mm) |      |
| Plate: 0.0085 in (2.2 mm) Thick | A, 1                                         | L-T                      | 75(297)        | 243(1675)                                     | 40(44)                                                       | 0.068( 1.7)                                                       | CC           | 0.085( 2.2)          | 1.75( 4.44)      | 0.7 (17.8)                 | 54   |
|                                 |                                              | L-T                      | -103(200)      | 257(1760)                                     | 35(38)                                                       | 0.046( 1.2)                                                       | CC           | 0.085( 2.2)          | 1.75( 4.44)      | 0.7 (17.8)                 |      |
|                                 | A, 2                                         | L-T                      | 75(297)        | 231(1590)                                     | 35(38)                                                       | 0.057( 1.4)                                                       | CC           | 0.065( 2.2)          | 1.75( 4.44)      | 0.7 (17.8)                 |      |
|                                 |                                              | L-T                      | -100(200)      | 240(1555)                                     | 31(34)                                                       | 0.042( 1.1)                                                       | CC           | 0.085( 2.2)          | 1.75( 4.44)      | 0.7 (17.8)                 |      |
| Plate: 0.5 in (12.7 mm) Thick   | B, 3                                         | L-T                      | 200(367)       | 202(1393)                                     | 55(60)                                                       | 0.195( 4.7)                                                       | Bend         | 0.5 (12.7)           | 1.3 (25.5)       | 0.23( 5.8)                 | 7    |
|                                 |                                              | L-T                      | 75(297)        | 212(1462)                                     | 34(37)                                                       | 0.064( 1.6)                                                       | Bend         | 0.5 (12.7)           | 1.0 (25.5)       | 0.28( 7.1)                 |      |
|                                 |                                              | T-L                      | 75(297)        | 204(1407)                                     | 32(35)                                                       | 0.061( 1.5)                                                       | Bend         | 0.5 (12.7)           | 1.0 (25.5)       | 0.26( 6.6)                 |      |
|                                 |                                              | L-T                      | -50(238)       | 216(1489)                                     | 23(25)                                                       | 0.028( 0.7)                                                       | Bend         | 0.5 (12.7)           | 1.0 (25.5)       | 0.26( 6.6)                 |      |
|                                 |                                              | L-T                      | -100(200)      | 228(1572)                                     | 21(23)                                                       | 0.021( 0.5)                                                       | Bend         | 0.5 (12.7)           | 1.0 (25.5)       | 0.23( 5.8)                 |      |
| Bar: 1 in (25.4 mm) Thick       | C, 4                                         | L-T                      | 200(367)       | 198(1365)                                     | 81(89)                                                       | 0.418(10.6)                                                       | Bend         | 1.03 (26.2)          | 0.94(23.8)       | 0.24( 6.1)                 |      |
|                                 |                                              | L-T                      | -50(238)       | 210(1448)                                     | 25(28)                                                       | 0.035( 0.9)                                                       | Bend         | 0.75 (19.1)          | 0.75(19.1)       | 0.13( 3.3)                 |      |
|                                 |                                              | L-T                      | -100(200)      | 220(1517)                                     | 23(25)                                                       | 0.027( 0.7)                                                       | Bend         | 1.0 (25.4)           | 1.0 (25.4)       | 0.28( 7.0)                 |      |
| Forging: 3 in (76.1 mm) Thick   | D, 5                                         | T-L                      | 70(294)        | 189(1303)                                     | 45(49)                                                       | 0.142( 3.6)                                                       | Bend<br>4 pt | 0.18 (12.2)          | 1.5 (38.1)       | 0.3 ( 7.6)                 | 3    |
|                                 |                                              | T-L                      | -65(219)       | ---                                           | 35(38)                                                       | ---                                                               | Bend<br>4 pt | 0.48 (12.2)          | 1.5 (38.1)       | 0.3 ( 7.6)                 |      |
| Forging: 8 in (203 mm) Square   | E, 1                                         | T-L                      | 70(294)        | 225(1551)                                     | 38(41)                                                       | 0.071( 1.8)                                                       | Bend         | 0.75 (19.1)          | 0.75(19.1)       | 0.15( 3.8)                 | 12   |
|                                 | E, 2                                         | T-L                      | 70(294)        | 194(1338)                                     | 73(80)                                                       | 0.35 ( 8.9)                                                       | Bend         | 0.75 (19.1)          | 0.75(19.1)       | ---                        |      |

COMPOSITION

HEAT TREATMENT

|   |                                                                               |
|---|-------------------------------------------------------------------------------|
| A | 1850F (1263K), 20 min; Temper 2 Hr + 2 Hr, 1050F (839K)                       |
| B | 2. 1850F (1283K), 20 min; Temper 2 Hr + 2 Hr, 1100F (867K)                    |
| C | 3. 1850F (1283K), in Salt, Oil Quench; Temper 1 Hr + 1 Hr, 1080F (856K)       |
| D | 4. 1850F (1283K), in Salt, Oil Quench; Temper 1 Hr + 1 Hr, 1100F (867K)       |
| E | 5. 1550F (1117K), 1 Hr, Oil Quench; Temper 2 Hr + 2 Hr, 950F (783K), Air Cool |

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### COMPOSITION

## HEAT TREATMENT

1. 1850F (1253K), 20 min; Temper 2 Hr + 2 Hr, 1050F (839K)
2. 1850F (1253K), 20 min; Temper 2 Hr + 2 Hr, 1100F (867K)
3. 1850F (1253K), in Salt, Oil Quench; Temper 1 Hr + 1 Hr, 1080F (856K)
4. 1850F (1253K), in Salt, Oil Quench; Temper 1 Hr + 1 Hr, 1100F (867K)
5. 1550F (1117K), 1 Hr, Oil Quench; Temper 2 Hr + 2 Hr, 950F (763K), Air Cool

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Steel, Low Alloy: AISI 4140

Table 4

| Form                               | Composition, Heat Treatment | Test Orientation | Temp<br>°F (°K) | Yield Strength<br>KSI (MPa) | Typical<br>$K_{IC}$<br>KSI $\sqrt{in}$ (MN $\sqrt{m}$ ) | $2.5 \left( \frac{K_{IC}}{\sigma_{ys}} \right)^2$<br>in (mm) | Specimen  |                      |                  | Ref.                    |
|------------------------------------|-----------------------------|------------------|-----------------|-----------------------------|---------------------------------------------------------|--------------------------------------------------------------|-----------|----------------------|------------------|-------------------------|
|                                    |                             |                  |                 |                             |                                                         |                                                              | Type      | Thickness<br>in (mm) | Width<br>in (mm) | Crack Length<br>in (mm) |
| Bar:<br>1 in (25.4 mm)<br>Thick    | A, 1                        | L-T              | 200 (367)       | 173 (1193)                  | 65 (72)                                                 | 0.553 (9.0)                                                  | Bend      | 1.03 (26.2)          | 1.0 (25.4)       | 0.321 (8.2)             |
|                                    | A, 1                        | L-T              | 75 (297)        | 196 (1310)                  | 72 (79)                                                 | 0.559 (9.1)                                                  | 4 pt Bend | 1.03 (26.2)          | 1.0 (25.4)       | 0.225 (5.7)             |
|                                    | B, 1                        | T-L              | 75 (297)        | ---                         | 70 (77)                                                 | ---                                                          | Bend      | 1.02 (25.9)          | 1.0 (25.4)       | 0.3 (7.6)               |
|                                    | B, 1                        | L-T              | -50 (228)       | 200 (1379)                  | 65 (72)                                                 | 0.324 (8.2)                                                  | 4 pt Bend | 1.02 (25.9)          | 1.0 (25.4)       | 0.33 (8.4)              |
|                                    | B, 1                        | L-T              | -100 (200)      | 205 (1413)                  | 52 (57)                                                 | 0.161 (4.1)                                                  | 4 pt Bend | 1.02 (25.9)          | 1.0 (25.4)       | 0.24 (6.1)              |
|                                    | C, 2                        | T-L              | 70 (294)        | 177 (1220)                  | 90 (99)                                                 | 0.782 (19.9)                                                 | SIX       | 1.0 (25.9)           | 4.5 (114)        | 1.6 (40.6)              |
| Plate:<br>1 in (25.4 mm)<br>Thick  | D, 3                        | L-T              | 75 (297)        | 66 (455)                    | 55 (60)                                                 | 1.736 (44.1)                                                 | WOL       | 4.0 (102)            | 10.22 (260)      | 4.0 (102)               |
| Plate:<br>4 in (101.6 mm)<br>Thick |                             | L-T              | 0, -60          | 82 (565)                    | 52 (57)                                                 | 1.005 (25.5)                                                 | WOL       | 4.0 (102)            | 10.22 (260)      | 3.1 (78.7)              |

## COMPOSITION

|   | C    | Mn   | P     | S     | Si   | Cr   | Mo   | Ni   | V     | Cu   |
|---|------|------|-------|-------|------|------|------|------|-------|------|
| A | 0.37 | 0.75 | 0.010 | 0.019 | 0.26 | 0.85 | 0.15 | ---  | ---   | ---  |
| B | 0.38 | 0.81 | 0.008 | 0.025 | 0.27 | 0.91 | 0.17 | ---  | ---   | ---  |
| C | 0.43 | 0.98 | 0.013 | 0.030 | 0.19 | 1.04 | 0.21 | 0.01 | 0.08  | ---  |
| D | 0.42 | 0.78 | 0.007 | 0.023 | 0.23 | 0.89 | 0.21 | 0.22 | <0.01 | 0.25 |

## HEAT TREATMENT

1. Austenitize 1550F (1117K) in Salt, Oil Quench, Temper 800F (700K), 2 hr
2. Austenitize 1550F (1117K), 1 Hr, Oil Quench, Temper 900F (756K), 2 Hr, Air Cool
3. Austenitize 1550F (1117K), 6 Hr, Oil Quench; Temper 1200F (922K), 6 Hr, Furnace Cool

STEEL, Low Alloy: AISI 4140 (Sheet 1 of 2)

Table 5

| Form                                                   | Compo-<br>sition,<br>Heat<br>Treat-<br>ment | Test<br>Orienta-<br>tion | Temp<br>°F (°K) | Yield<br>Strength<br>KSI (MN/m <sup>2</sup> ) | Typical<br>K <sub>IC</sub><br>KSI√in (MN m <sup>3/2</sup> ) | 2.5<br>/K <sub>IC</sub> <sup>2</sup><br>(σ <sub>ys</sub><br>in (mm)) | Specimen |                      |                  |                            | Ref. |
|--------------------------------------------------------|---------------------------------------------|--------------------------|-----------------|-----------------------------------------------|-------------------------------------------------------------|----------------------------------------------------------------------|----------|----------------------|------------------|----------------------------|------|
|                                                        |                                             |                          |                 |                                               |                                                             |                                                                      | Type     | Thickness<br>in (mm) | Width<br>in (mm) | Crack<br>Length<br>in (mm) |      |
| Plate: 0.125 in (3.2 mm)<br>Thick                      | A,1                                         | L-T                      | 200(367)        | 220(1517)                                     | 40(44)                                                      | 0.083 (2.1)                                                          | CC       | 0.10 (2.5)           | 3.0 (76.2)       | 1.2 (30.5)                 | 8    |
|                                                        | A,2                                         | L-T                      | -100(200)       | 220(1517)                                     | 40(44)                                                      | 0.083 (2.1)                                                          | CC       | 0.10 (2.5)           | 3.0 (76.2)       | 1.2 (30.5)                 |      |
| Plate: 0.375 in (9.5 mm)<br>Thick                      | B,3                                         | L-T                      | 200(367)        | 208(1435)                                     | 60(66)                                                      | 0.208 (5.3)                                                          | Bend     | 0.390(9.9)           | 1.0 (25.4)       | 0.4 (10.1)                 | 7    |
|                                                        | E,3                                         | L-T                      | 75(297)         | 226(1517)                                     | 52(57)                                                      | 0.140 (3.6)                                                          | Bend     | 0.390(9.9)           | 1.0 (25.4)       | 0.4 (10.1)                 |      |
|                                                        | F,3                                         | T-L                      | 75(297)         | 223(1538)                                     | 53(58)                                                      | 0.141 (3.6)                                                          | Bend     | 0.377(9.6)           | 0.9 (22.9)       | 0.37 (9.4)                 |      |
|                                                        | E,3                                         | L-L                      | -50(228)        | 235(1620)                                     | 40(44)                                                      | 0.072 (1.8)                                                          | Bend     | 0.390(9.9)           | 1.0 (25.4)       | 0.4 (10.1)                 |      |
|                                                        | E,3                                         | L-T                      | -100(200)       | 240(1655)                                     | 32(35)                                                      | 0.044 (1.1)                                                          | Bend     | 0.390(9.9)           | 1.0 (25.4)       | 0.4 (10.1)                 |      |
| Plate: 0.500 in (12.6 mm)<br>Thick                     | H,10                                        | T-L                      | 75(297)         | 231(1593)                                     | 68(75)                                                      | 0.217 (5.5)                                                          | Bend     | 0.500(12.7)          | 1.0 (25.4)       | --- ---                    | 80   |
| Plate: 0.625 in (15.9 mm)<br>Thick                     | C,4                                         | L-T                      | 75(297)         | 204(1504)                                     | 78(86)                                                      | 0.371 (9.4)                                                          | SEN      | 0.523(13.3)          | 2.0 (50.8)       | 0.67 (17.6)                | 12   |
| Plate: 1 in (25.4 mm)<br>Thick                         | D,5                                         | L-T                      | 70(294)         | 182(1255)                                     | 106(116)                                                    | 0.850 (21.6)                                                         | Bend     | 1.0 (25.4)           | 2.0 (50.8)       | 1.0 (25.4)                 | 6    |
|                                                        | D,6                                         | L-T                      | 70(294)         | 213(1469)                                     | 68(75)                                                      | 0.255 (6.5)                                                          | Bend     | 1.0 (25.4)           | 1.0 (25.4)       | 0.5 (12.7)                 |      |
|                                                        | B,7                                         | L-T                      | -50(228)        | 203(1380)                                     | 65(71)                                                      | 0.256 (6.5)                                                          | Bend     | 1.0 (25.4)           | 1.0 (25.4)       | 0.2 (5.1)                  | 7    |
|                                                        |                                             | L-T                      | -100(200)       | 206(1400)                                     | 50(55)                                                      | 0.148 (3.8)                                                          | Bend     | 1.0 (25.4)           | 1.0 (25.4)       | 0.2 (5.1)                  |      |
|                                                        | D,8                                         | L-T                      | 70(294)         | 230(1586)                                     | 52(57)                                                      | 0.128 (3.3)                                                          | Bend     | 0.25 (6.3)           | 1.0 (25.4)       | 0.5 (12.7)                 | 9    |
|                                                        | D,7                                         | L-T                      | 75(297)         | 206(1400)                                     | 80(88)                                                      | 0.38 (9.7)                                                           | Bend     | 0.95 (24.2)          | 2.0 (50.8)       | 1.0 (25.4)                 | 44   |
| Billet: 4x4.5 in (102x<br>114 mm) Vac.<br>Arc Remelted | G,9                                         | L-T                      | 72(296)         | 241(1662)                                     | 53(58)                                                      | 0.121 (3.1)                                                          | Bend     | 0.90 (22.9)          | 1.8 (45.7)       | 0.9 (22.9)                 | 79   |
|                                                        |                                             | T-L                      | 72(296)         | 240(1655)                                     | 54(59)                                                      | 0.127 (3.2)                                                          | Bend     | 0.90 (22.9)          | 1.8 (45.7)       | 0.9 (22.9)                 |      |
|                                                        |                                             | T-S                      | 72(296)         | 240(1655)                                     | 56(62)                                                      | 0.136 (3.5)                                                          | Bend     | 0.90 (22.9)          | 1.8 (45.7)       | 0.9 (22.9)                 |      |
| Forged Bar: 5 in (127 mm)<br>Thick                     | I,11                                        | T-S                      | 70(294)         | 191(1317)                                     | 80(88)                                                      | 0.439 (11.1)                                                         | (a)      | ---                  | ---              | ---                        | 69   |
|                                                        | I,12                                        | T-S                      | 70(294)         | 230(1586)                                     | 49(53)                                                      | 0.113 (2.9)                                                          | (a)      | ---                  | ---              | ---                        |      |

(a) Specimen in accordance with ASTM Recommendations

Table 5 (Cont.)

| Form                                                                                                                                             | Composition, Heat Treatment |      |       |       |      |      |      |      | Temp<br>°F<br>(°K) | Yield<br>Strength<br>KSI (MN/m <sup>2</sup> ) | Typical<br>K <sub>IC</sub><br>KSI√in (MN m <sup>-3/2</sup> ) | 2.5 (K <sub>IC</sub><br>σ <sub>ys</sub> ) <sup>2</sup><br>in (mm) | Specimen |                      |                  | Ref. |
|--------------------------------------------------------------------------------------------------------------------------------------------------|-----------------------------|------|-------|-------|------|------|------|------|--------------------|-----------------------------------------------|--------------------------------------------------------------|-------------------------------------------------------------------|----------|----------------------|------------------|------|
|                                                                                                                                                  | C                           | Mn   | P     | S     | Si   | Ni   | Cr   | Mo   |                    |                                               |                                                              |                                                                   | Type     | Thickness<br>in (mm) | Width<br>in (mm) |      |
| COMPOSITION:                                                                                                                                     |                             |      |       |       |      |      |      |      |                    |                                               |                                                              |                                                                   |          |                      |                  |      |
| A                                                                                                                                                | 0.41                        | 0.72 | 0.015 | 0.009 | 0.33 | 1.83 | 0.78 | 0.26 |                    |                                               |                                                              |                                                                   |          |                      |                  |      |
| B                                                                                                                                                | 0.43                        | 0.84 | 0.006 | 0.005 | 0.27 | 1.78 | 0.78 | 0.26 |                    |                                               |                                                              |                                                                   |          |                      |                  |      |
| C                                                                                                                                                | 0.43                        | 0.65 | 0.010 | 0.005 | 0.30 | 1.85 | 0.82 | 0.26 |                    |                                               |                                                              |                                                                   |          |                      |                  |      |
| D                                                                                                                                                | 0.42                        | 0.71 | 0.010 | 0.012 | 0.25 | 1.77 | 0.80 | 0.23 |                    |                                               |                                                              |                                                                   |          |                      |                  |      |
| E                                                                                                                                                | 0.40                        | 0.75 | 0.005 | 0.010 | 0.29 | 1.77 | 0.79 | 0.25 |                    |                                               |                                                              |                                                                   |          |                      |                  |      |
| F                                                                                                                                                | 0.41                        | 0.69 | 0.018 | 0.012 | 0.29 | 1.87 | 0.78 | 0.22 |                    |                                               |                                                              |                                                                   |          |                      |                  |      |
| G                                                                                                                                                | 0.42                        | 0.84 | 0.008 | 0.005 | 0.25 | 1.71 | 0.82 | 0.24 |                    |                                               |                                                              |                                                                   |          |                      |                  |      |
| H                                                                                                                                                | 0.38                        | 0.74 | 0.001 | 0.005 | 0.28 | 1.86 | 0.84 | 0.26 |                    |                                               |                                                              |                                                                   |          |                      |                  |      |
| I                                                                                                                                                | 0.43                        | 0.63 | 0.013 | 0.004 | 0.24 | 1.56 | 1.03 | 0.30 |                    |                                               |                                                              |                                                                   |          |                      |                  |      |
| HEAT TREATMENT                                                                                                                                   |                             |      |       |       |      |      |      |      |                    |                                               |                                                              |                                                                   |          |                      |                  |      |
| 1. Normalize 1600F (1144K), 1 Hr; Austenitize 1550K (1117K), 1 Hr, Oil Quench; Temper 1 Hr, 400F (478K)                                          |                             |      |       |       |      |      |      |      |                    |                                               |                                                              |                                                                   |          |                      |                  |      |
| 2. Normalize 1600F (1144K), 1 Hr, Austenitize 1550F (1117K), 1 Hr, Oil Quench; Temper 1 Hr, 700F (664K)                                          |                             |      |       |       |      |      |      |      |                    |                                               |                                                              |                                                                   |          |                      |                  |      |
| 3. 1550F (1117K) Salt; Oil Quench; Temper 1 Hr + 1 Hr, 500F (533K)                                                                               |                             |      |       |       |      |      |      |      |                    |                                               |                                                              |                                                                   |          |                      |                  |      |
| 4. 1500F (1089K), 1 Hr; Temper 1 Hr + 1 Hr, 700F (644K)                                                                                          |                             |      |       |       |      |      |      |      |                    |                                               |                                                              |                                                                   |          |                      |                  |      |
| 5. 1500F (1089K), 0.5 Hr; Oil Quench; Temper 1 Hr, 925F (770K)                                                                                   |                             |      |       |       |      |      |      |      |                    |                                               |                                                              |                                                                   |          |                      |                  |      |
| 6. 1500F (1089K), 0.5 Hr; Oil Quench; Temper 1 Hr, 750F (672K)                                                                                   |                             |      |       |       |      |      |      |      |                    |                                               |                                                              |                                                                   |          |                      |                  |      |
| 7. 1550F (1117K) Salt, Oil Quench; Temper 1 Hr + 1 Hr, 800F (700K)                                                                               |                             |      |       |       |      |      |      |      |                    |                                               |                                                              |                                                                   |          |                      |                  |      |
| 8. 1500F (1089K), 0.5 Hr, Oil Quench; Temper 1 Hr, 600F (589K)                                                                                   |                             |      |       |       |      |      |      |      |                    |                                               |                                                              |                                                                   |          |                      |                  |      |
| 9. 1650F (1172K), 1 Hr, Air Cool; 1550F (1089K), 1 Hr, Oil Quench; -321F (77K), 0.5 Hr Min; 400F (478K), 2 Hrs                                   |                             |      |       |       |      |      |      |      |                    |                                               |                                                              |                                                                   |          |                      |                  |      |
| 10. 1600F (1144K), 0.5 Hr, Air Cool; 1500F (1089K), 0.5 Hr, Oil Quench; -320F, 0.5 Hr, 400F (478K), 6 Hr, Air Cool; 250F (394K), 24 Hr, Air Cool |                             |      |       |       |      |      |      |      |                    |                                               |                                                              |                                                                   |          |                      |                  |      |
| 11. 1543F (1113K), 0.5 Hr, Oil Quench; Temper 841F (723K), 0.75 Hr                                                                               |                             |      |       |       |      |      |      |      |                    |                                               |                                                              |                                                                   |          |                      |                  |      |
| 12. 1543F (1113K), 0.5 Hr, Oil Quench; Temper 571F (573K), 1 Hr                                                                                  |                             |      |       |       |      |      |      |      |                    |                                               |                                                              |                                                                   |          |                      |                  |      |

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STEEL, Low Alloy: 30QM (Sheet 1 of 2)

Table 6

| Form                                                  | Composition,<br>Heat Treatment | Test Orientation | Temp.<br>°F (°K) | Yield Strength<br>KSI (MN/m <sup>2</sup> ) | Typical<br>$K_{IC}$<br>KSI $\sqrt{in}$ (MN $\sqrt{m}$ ) | $2.5 \left( \frac{K_{IC}}{\sigma_{ys}} \right)^2$<br>in (mm) | Specimen |                      |                  |                         | Ref. |
|-------------------------------------------------------|--------------------------------|------------------|------------------|--------------------------------------------|---------------------------------------------------------|--------------------------------------------------------------|----------|----------------------|------------------|-------------------------|------|
|                                                       |                                |                  |                  |                                            |                                                         |                                                              | Type     | Thickness<br>in (mm) | Width<br>in (mm) | Crack Length<br>in (mm) |      |
| Forging: 5 x 10 in (152 x 254 mm)                     | A,1                            | L-T              | 70(294)          | 246(1703)                                  | 69(75)                                                  | 0.195 (5.0)                                                  | Bend     | ---                  | ---              | ---                     | 19   |
| Forging: 4.5 x 4.5 in (114 x 114 mm)                  | B,2                            | L-T              | 70(294)          | 243(1675)                                  | 60(65)                                                  | 0.152 (3.9)                                                  | Bend     | 0.50 (12.7)          | 1.0 (25.4)       | 0.5 (12.7)              | 16   |
| Forging: 1 x 13 x 34 in (25.4 x 330.2 x 863.6 mm)     | C,3                            | L-T              | 70(294)          | 240(1655)                                  | 88(96)                                                  | 0.336 (8.5)                                                  | CC       | 0.372(9.4)           | 5.0 (127)        | 1.90 (1.90)             | 18   |
|                                                       | C,4                            | L-T              | 70(294)          | 234(1613)                                  | 74(81)                                                  | 0.250 (6.4)                                                  | CC       | 0.370(9.4)           | 5.0 (127)        | 2.05 (52.1)             |      |
|                                                       | C,5                            | L-T              | 70(294)          | 205(1413)                                  | 74(81)                                                  | 0.336 (8.3)                                                  | CC       | 0.370(9.4)           | 5.0 (127)        | 1.75 (44.4)             |      |
| Forging: 3 x 9 in (76.2 x 229.6 mm)                   | D,6                            | T-L              | 70(294)          | 233(1606)                                  | 79(87)                                                  | 0.287 (7.3)                                                  | Bend     | 0.480(12.2)          | 1.5 (38.1)       | 0.30 (7.6)              | 3    |
| Hot Rolled                                            |                                |                  |                  |                                            |                                                         |                                                              | 4 pt     |                      |                  |                         |      |
| 2300F (1533K)                                         |                                |                  |                  |                                            |                                                         |                                                              | Bend     | 0.480(12.2)          | 1.5 (38.1)       | 0.30 (7.6)              |      |
| Forged 2100F (1422K)                                  |                                | T-L              | -65(219)         | 233(1606)                                  | 53(58)                                                  | ---                                                          | 4 pt     |                      |                  |                         |      |
| Forging: 20 in (508 mm) dia Ingot                     | E,6                            | T-L              | 70(294)          | 236(1627)                                  | 68(74)                                                  | 0.208 (5.3)                                                  | Bend     | 0.480(12.2)          | 1.5 (38.1)       | 0.30 (7.6)              |      |
| Forged at 2125F (1436K) to 3 x 9 in (76.2 x 228.6 mm) |                                | T-L              | -65(219)         | ---                                        | 45(49)                                                  | ---                                                          | Bend     | 0.480(12.2)          | 1.5 (38.1)       | 0.30 (7.6)              |      |
| Billet: 3 in (76.2 mm)                                | F,7                            | L-TS             | 70(294)          | 142(976)                                   | 111(122)                                                | 1.33 (38.8)                                                  | (a)      | ---                  | ---              | ---                     | 57   |
|                                                       | F,8                            | L-TS             | 70(294)          | 185(1275)                                  | 111(122)                                                | 0.9 (22.9)                                                   | (a)      | ---                  | ---              | ---                     |      |
|                                                       | F,9                            | L-TS             | 70(294)          | 206(1418)                                  | 78(86)                                                  | 0.358 (9.1)                                                  | (a)      | ---                  | ---              | ---                     |      |
|                                                       | F,10                           | L-R              | 70(294)          | 238(1643)                                  | 68(75)                                                  | 0.209 (5.3)                                                  | (a)      | ---                  | ---              | ---                     | 67   |
| Bar: Vacuum Arc Remelted 1 in (25.4 mm) Dia           | G,11                           | C-R              | 70(294)          | 255(1755)                                  | 45(50)                                                  | 0.078 (2.0)                                                  | (a)      | ---                  | ---              | ---                     | 68   |
| Forged Bar: Vacuum Arc Remelted 5 in (127 mm) Dia     | H,12                           | L-T              | 72(296)          | 259(1785)                                  | 52(57)                                                  | 0.101 (2.6)                                                  | Bend     | 0.9(22.9)            | 1.8 (45.7)       | 0.9 (22.9)              | 79   |
| Billet: 4 x 4.5 in (101 x 114 mm)                     |                                | T-L              | 72(296)          | 255(1758)                                  | 56(62)                                                  | 0.121 (3.1)                                                  | Bend     | 0.9(22.9)            | 1.8 (45.7)       | 0.9 (22.9)              | 79   |
|                                                       |                                | T-L              | 72(296)          | 255(1758)                                  | 58(64)                                                  | 0.129 (3.3)                                                  | Bend     | 0.9(22.9)            | 1.3 (45.7)       | 0.9 (22.9)              | 79   |

(a) Specimen in accordance with ASTM Recommendations

Table 6 (Cont.)

| Form                           | Compo-<br>sition,<br>Heat<br>Treat-<br>ment                                                                                                                              | Test<br>Orienta-<br>tion | Temp<br>(°K) | Yield<br>Strength<br>KSI (N/m <sup>2</sup> ) | Typical<br>K <sub>IC</sub><br>KSI√in (MJ/m <sup>3/2</sup> ) | 2.5( $\frac{K_{IC}}{\sigma_{ys}}$ )<br>in (mm) | Specimen |                      |                  |                            |     |
|--------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------|--------------------------|--------------|----------------------------------------------|-------------------------------------------------------------|------------------------------------------------|----------|----------------------|------------------|----------------------------|-----|
|                                |                                                                                                                                                                          |                          |              |                                              |                                                             |                                                | Type     | Thickness<br>in (mm) | Width<br>in (mm) | Crack<br>Length<br>in (mm) | Ref |
| Plate: 0.56 in (14.2 mm) Thick |                                                                                                                                                                          |                          |              |                                              |                                                             |                                                |          |                      |                  |                            |     |
|                                | J,13                                                                                                                                                                     | L-T                      | 70(294)      | 248(1710)                                    | ≤0(66)                                                      | 0.146(3.7)                                     | Bend 0.5 | 12.7                 | 1.5 (38.1)       | -                          | 123 |
|                                | J,14                                                                                                                                                                     | L-T                      | 70(294)      | 233(1606)                                    | 60(72)                                                      | 0.2(5.1)                                       | Bend 0.5 | 12.7                 | 1.5 (38.1)       | -                          |     |
| COMPOSITION                    |                                                                                                                                                                          |                          |              |                                              |                                                             |                                                |          |                      |                  |                            |     |
|                                | C                                                                                                                                                                        | Si                       | Mn           | S                                            | P                                                           | Ni                                             | Cr       | V                    | Al               |                            |     |
| A                              | 0.43                                                                                                                                                                     | 1.68                     | 0.70         | 0.010                                        | 0.010                                                       | 0.39                                           | 1.93     | 0.79                 | 0.07             | 0.15                       |     |
| B                              | 0.41                                                                                                                                                                     | 1.77                     | 0.81         | 0.003                                        | 0.007                                                       | 0.40                                           | 1.85     | 0.83                 | 0.08             | -                          |     |
| C                              | 0.40                                                                                                                                                                     | 1.60                     | 0.83         | 0.006                                        | 0.007                                                       | 0.41                                           | 1.82     | 0.83                 | 0.09             | -                          |     |
| D                              | 0.39                                                                                                                                                                     | 1.55                     | 0.82         | 0.009                                        | 0.012                                                       | 0.43                                           | 1.73     | 0.86                 | 0.09             | -                          |     |
| E                              | 0.43                                                                                                                                                                     | 1.62                     | 0.85         | 0.006                                        | 0.014                                                       | 0.41                                           | 1.74     | 0.94                 | 0.08             | -                          |     |
| F                              | 0.42                                                                                                                                                                     | 1.45                     | 0.73         | 0.006                                        | 0.009                                                       | 0.40                                           | 1.82     | 0.98                 | 0.11             | 0.029                      |     |
| G                              | 0.44                                                                                                                                                                     | 1.63                     | 0.81         | 0.006                                        | 0.005                                                       | 0.38                                           | 1.34     | 0.85                 | 0.09             | -                          |     |
| H                              | 0.42                                                                                                                                                                     | 1.59                     | 0.80         | 0.006                                        | 0.006                                                       | 0.37                                           | 1.81     | 0.79                 | 0.08             | -                          |     |
| J                              | 0.43                                                                                                                                                                     | 1.72                     | 0.84         | 0.004                                        | 0.010                                                       | 0.39                                           | 1.72     | 0.77                 | 0.08             | -                          |     |
| HEAT TREATMENT                 |                                                                                                                                                                          |                          |              |                                              |                                                             |                                                |          |                      |                  |                            |     |
| 1.                             | 1600F (1144K), Quenched Warm Oil; Double Temper 2 + 2 Hr, 575F (575K)                                                                                                    |                          |              |                                              |                                                             |                                                |          |                      |                  |                            |     |
| 2.                             | 1700F (1200K), 3 1/2 Hr, Air Cool; 1600F (1144K), 1 1/2 Hr; Salt Quenched to 1000F, Hold 1 Hr; Oil Quenched; 110F, 1/2 Hr; Double Tempered 575F(575K), 2 + 2 Hr Air Cool |                          |              |                                              |                                                             |                                                |          |                      |                  |                            |     |
| 3.                             | 1700F (1200K), 1 1/2 Hr, Air Cool; 1600F(1144K), 1 1/2 Hr, Oil Quenched; Double Temper, 2 + 2 Hr, 500F(533K)                                                             |                          |              |                                              |                                                             |                                                |          |                      |                  |                            |     |
| 4.                             | 1700F (1200K), 1 1/2 Hr, Air Cool; 1600F (1144K), 1 1/2 Hr, Oil Quenched, Double Temper, 2 + 2 Hr, 675F(630K)                                                            |                          |              |                                              |                                                             |                                                |          |                      |                  |                            |     |
| 5.                             | 1700F (1200K), 1 1/2 Hr, Air Cool; 1600F(1144K), 1 1/2 Hr, Oil Quenched, Double Temper, 2 + 2 Hr, 975F(797K)                                                             |                          |              |                                              |                                                             |                                                |          |                      |                  |                            |     |
| 6.                             | 1600F (1144K), 1 Hr, Oil Quenched; Double Temper, 3 + 3 Hr, 600F(589K), Air Cool                                                                                         |                          |              |                                              |                                                             |                                                |          |                      |                  |                            |     |
| 7.                             | 1705F (1203K), Air Cool; 1777F (1243K), Oil Quench; 1200F (922K), 2 + 2 Hr                                                                                               |                          |              |                                              |                                                             |                                                |          |                      |                  |                            |     |
| 8.                             | 1705F (1203K), Air Cool; 1777F (1243K), Oil Quench; 1111F (873K), 2 + 2 Hr                                                                                               |                          |              |                                              |                                                             |                                                |          |                      |                  |                            |     |
| 9.                             | 1705F (1203K), Air Cool; 1777F (1243K), Oil Quench; 1021F (823K), 2 + 2 Hr                                                                                               |                          |              |                                              |                                                             |                                                |          |                      |                  |                            |     |
| 10.                            | 1705F (1203K), Air Cool; 1777F (1243K), Oil Quench; 481F (523K), 2 + 2 Hr                                                                                                |                          |              |                                              |                                                             |                                                |          |                      |                  |                            |     |
| 11.                            | 1705F (1203K), Air Cool; 1615F (1153K), Oil Quench; 571F (573K), 5 + 5 Hr                                                                                                |                          |              |                                              |                                                             |                                                |          |                      |                  |                            |     |
| 12.                            | 1700F (1200K), 1 Hr, Air Cool; 1600F (1144K), 1 Hr, Oil Quench, -321F (77K), 0.5 Hr Min; 600F (589K), 2 + 2 Hr                                                           |                          |              |                                              |                                                             |                                                |          |                      |                  |                            |     |
| 13.                            | 1550F (1117K), Oil Quench; 550F (561K), 2 + 2 Hr                                                                                                                         |                          |              |                                              |                                                             |                                                |          |                      |                  |                            |     |
| 14.                            | 1600F (1144K), Oil Quench; 550F (561K), 2 + 2 Hr                                                                                                                         |                          |              |                                              |                                                             |                                                |          |                      |                  |                            |     |

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STEEL, Low Alloy: D6AC (Sheet 1 of 2)

Table 7

| Form                                   | Composition, Heat Treatment | Test Orientation | Temp °F (°C) | Yield Strength KSI (MN/m <sup>2</sup> ) | Typical K <sub>IC</sub> KSI/√in (MN m <sup>-3/2</sup> ) | 2.5 $\frac{K_{IC}}{\sigma_{ys}}$ in (mm) | Specimen |                   |               |                      | Ref. |
|----------------------------------------|-----------------------------|------------------|--------------|-----------------------------------------|---------------------------------------------------------|------------------------------------------|----------|-------------------|---------------|----------------------|------|
|                                        |                             |                  |              |                                         |                                                         |                                          | Type     | Thickness in (mm) | Width in (mm) | Crack Length in (mm) |      |
| Plate: 0.095 in (2.4 mm) Thick         | A,1                         | T-L              | 75(297)      | 236(1628)                               | 46(50)                                                  | 0.095( 2.4)                              | CC       | 0.095( 2.4)       | 1.75 (44.4)   | 0.7 (17.8)           | 12   |
|                                        |                             | L-T              | -100(200)    | 253(1745)                               | 37( 41)                                                 | 0.063( 1.3)                              | CC       | 0.095( 2.4)       | 1.75 (44.4)   | 0.7 (17.8)           |      |
|                                        |                             | L-T              | -200(144)    | 263(1815)                               | 36( 40)                                                 | 0.047( 1.2)                              | CC       | 0.095( 2.4)       | 1.75 (44.4)   | 0.7 (17.8)           |      |
| Plate: 0.5 in (12.7 mm) Thick          | B,2                         | L-S              | 70(294)      | 203(1400)                               | 110(120)                                                | 0.734(18.6)                              | Bend     | 0.75 (19.1)       | 1.5 (38.1)    | 0.368( 9.3)          | 20   |
|                                        |                             | L-S              | 70(294)      | 231(1523)                               | 61( 66)                                                 | 0.174( 4.4)                              | Bend     | 0.257( 6.5)       | 0.486(12.3)   | 0.245( 6.2)          |      |
| Plate: 0.75 in (19.1 mm) Thick         | B,1                         | ---              | 70(294)      | 247(1703)                               | 67( 74)                                                 | 0.735(18.7)                              | Bend     | 0.75 (19.1)       | 0.75 (19.1)   | ---                  | 46   |
| Plate: 0.8 in (20.3 mm) Thick          | C,3                         | ---              | 175(353)     | 211(1455)                               | 92(101)                                                 | 0.475 (12.1)                             | CT       | 0.75 (19.1)       | 1.5 (38.1)    | 0.75 (19.1)          | 51   |
|                                        |                             | ---              | 70(294)      | 217(1496)                               | 94(103)                                                 | 0.469 (11.9)                             | CT       | 0.75 (19.1)       | 1.5 (38.1)    | 0.75 (19.1)          |      |
| Plate: 1.5-1.8 in (38.1-45.7 mm) Thick |                             | ---              | -20(244)     | 226(1558)                               | 72(79)                                                  | 0.254 (6.4)                              | CT       | 0.75 (19.1)       | 1.5 (38.1)    | 0.75 (19.1)          |      |
|                                        |                             | ---              | 175(353)     | 211(1455)                               | 92(101)                                                 | 0.475 (12.1)                             | CT       | 0.75 (19.1)       | 1.5 (38.1)    | 0.75 (19.1)          |      |
|                                        |                             | ---              | 70(294)      | 217(1496)                               | 79(87)                                                  | 0.331 (8.4)                              | CT       | 0.75 (19.1)       | 1.5 (38.1)    | 0.75 (19.1)          |      |
|                                        |                             | ---              | -20(244)     | 226(1558)                               | 50(55)                                                  | 0.122 (3.1)                              | CT       | 0.75 (19.1)       | 1.5 (38.1)    | 0.75 (19.1)          |      |
|                                        |                             | ---              | -65(219)     | 228(1572)                               | 46(51)                                                  | 0.102 (2.6)                              | CT       | 0.75 (19.1)       | 1.5 (38.1)    | 0.75 (19.1)          |      |
| Forging: 0.8 in (20.3 mm) Thick        |                             | ---              | 70(294)      | 214(1476)                               | 97(107)                                                 | 0.514 (13.0)                             | CT       | 0.75 (19.1)       | 1.5 (38.1)    | 0.75 (19.1)          |      |
| 1.5-1.8 in (38.1-45.7 mm) Thick        |                             | ---              | 70(294)      | 214(1476)                               | 90(99)                                                  | 0.442 (11.2)                             | CT       | 0.75 (19.1)       | 1.5 (38.1)    | 0.75 (19.1)          |      |
|                                        |                             | ---              | -65(219)     | 225(1551)                               | 45(50)                                                  | 0.100 (2.5)                              | CT       | 0.75 (19.1)       | 1.5 (38.1)    | 0.75 (19.1)          |      |
| Billet: 3 in (72.6 mm) Dia             | D,4                         | LR               | 70(294)      | 208(1454)                               | 105(115)                                                | 0.637 (16.2)                             | CT       | 0.75 (19.1)       | 1.5 (38.1)    | 0.75 (19.1)          | 67   |
|                                        | D,5                         | LR               | 70(294)      | 215(1482)                               | 84(92)                                                  | 0.382 (9.7)                              | CT       | 0.75 (19.1)       | 1.5 (38.1)    | 0.75 (19.1)          |      |

COMPOSITION

|   | C      | Mn    | P      | S      | Si    | Ni    | Cr   | Mo   | V     | Al    |
|---|--------|-------|--------|--------|-------|-------|------|------|-------|-------|
| A | 0.47   | 0.85  | 0.007  | 0.005  | 0.20  | 0.57  | 1.07 | 1.01 | 0.08  | 0.06  |
| B | 0.45   | 0.69  | 0.008  | 0.006  | 0.026 | 0.55  | 1.08 | 1.01 | 0.08  | 0.07  |
| C | 0.475N | 0.75N | 0.015M | 0.015M | 0.22M | 0.55N | 1.0N | 1.0N | 0.12N | ---   |
| D | 0.47   | 0.90  | 0.010  | 0.007  | 0.30  | 0.55  | 1.0  | 0.92 | 0.10  | 0.026 |

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## COMPOSITION

|   | C      | Mn    | P      | S      | Si    | Ni    | Cr   | Mo   | V     | Al    |
|---|--------|-------|--------|--------|-------|-------|------|------|-------|-------|
| A | 0.47   | 0.85  | 0.007  | 0.005  | 0.20  | 0.57  | 1.07 | 1.01 | 0.08  | 0.06  |
| B | 0.45   | 0.69  | 0.008  | 0.006  | 0.026 | 0.55  | 1.08 | 1.01 | 0.08  | 0.07  |
| C | 0.475N | 0.75N | 0.015M | 0.015M | 0.22N | 0.55N | 1.0N | 1.0N | 0.12N | ---   |
| D | 0.47   | 0.90  | 0.010  | 0.007  | 0.30  | 0.55  | 1.0  | 0.92 | 0.10  | 0.026 |

Table 7 (Cont.)

| Form | Composition,<br>Heat Treatment | Test Orientation | Temp<br>°F (°K) | Yield Strength<br>KSI (MN/m <sup>2</sup> ) | Typical<br>K <sub>IC</sub><br>KSI√in (MN m <sup>-3/2</sup> ) | 2.5 (K <sub>IC</sub> ) <sup>2</sup><br>in (mm) | Specimen |                      |                  | Ref.                    |
|------|--------------------------------|------------------|-----------------|--------------------------------------------|--------------------------------------------------------------|------------------------------------------------|----------|----------------------|------------------|-------------------------|
|      |                                |                  |                 |                                            |                                                              |                                                | Type     | Thickness<br>in (mm) | Width<br>in (mm) | Crack Length<br>in (mm) |

## HEAT TREATMENT

- 1650F (1172K); 1550F (1117K), Oil Quenched 150F (339K); Temper 1 Hr + 1 Hr, 500F (533K)
- 1550F (1117K) in Salt, 20 min, Oil Quench, Temper 1 Hr + 1 Hr, 500F (533K)
- 1700F (1200K); Quench in Furnace to 975 + 25F (797 + 14K), at 6F (3.3K) per minute from 1350 to 1150F (1006 to 894K), Oil, Quench 140F<sup>-</sup> (334K); Temper 1000-1025F (811-823K), 1 Hr + 1 Hr
- 1705F (1203K), Air Cool; 1615F (1153K), Oil Quench at 363F (457K), 1 Hr;
- Temper 841F (723K), 2 Hr
- 1705 (1203K), Air Cool; 1615 F (1153K), Oil Quench at 363F (457K), 1 Hr; Temper 1021F (823K), 2 Hr

SILFEL, Low Alloy: EN24, Ni-Cr-Mo-V

| Form                     |                                                                                                                      | Composition, Heat Treatment | Test Orientation | Temp °F (°K) | Yield Strength KSI (MN/m <sup>2</sup> ) | Typical K <sub>IC</sub> KSI/√in (MN m <sup>-3/2</sup> ) | 2.5 (K <sub>IC</sub> <sup>2</sup> / σ <sub>ys</sub> ) in (mm) | Specimen |                   |               | Ref.  |                      |      |
|--------------------------|----------------------------------------------------------------------------------------------------------------------|-----------------------------|------------------|--------------|-----------------------------------------|---------------------------------------------------------|---------------------------------------------------------------|----------|-------------------|---------------|-------|----------------------|------|
|                          |                                                                                                                      |                             |                  |              |                                         |                                                         |                                                               | Type     | Thickness in (mm) | Width in (mm) |       | Crack Length in (mm) |      |
| EN24                     |                                                                                                                      |                             |                  |              |                                         |                                                         |                                                               |          |                   |               |       |                      |      |
| Ingot: 5 in (127 mm) Sq. |                                                                                                                      |                             |                  |              |                                         |                                                         |                                                               |          |                   |               |       |                      |      |
|                          |                                                                                                                      | A, 1                        | L-ST             | 70(294)      | 231(1590)                               | 64(70)                                                  | 0.192 (4.9)                                                   | Bend     | 0.492 (12.5)      | 0.984 (25)    | 91    |                      |      |
|                          |                                                                                                                      | A, 2                        |                  | 70(294)      | 220(1520)                               | 37(41)                                                  | 0.071 (1.8)                                                   | Bend     | 0.482 (12.5)      | 0.984 (25)    |       |                      |      |
|                          |                                                                                                                      | A, 3                        |                  | 70(294)      | 206(1420)                               | 75(83)                                                  | 0.331 (8.4)                                                   | Bend     | 0.482 (12.5)      | 0.984 (25)    |       |                      |      |
|                          |                                                                                                                      | A, 4                        |                  | 70(294)      | 206(1420)                               | 41(45)                                                  | 0.099 (2.5)                                                   | Bend     | 0.482 (12.5)      | 0.984 (25)    |       |                      |      |
|                          |                                                                                                                      | A, 5                        |                  | 70(294)      | 186(1285)                               | 71(78)                                                  | 0.364 (9.3)                                                   | Bend     | 0.482 (12.5)      | 0.984 (25)    |       |                      |      |
| Ni-Cr-Mo-V               |                                                                                                                      |                             |                  |              |                                         |                                                         |                                                               |          |                   |               |       |                      |      |
| Bar                      | 1.0 x 3.312 in (25.4 x 7.9 mm)                                                                                       | B, 6                        | L                | 70(294)      | 263(1837)                               | 45(46)                                                  | 0.074 (1.9)                                                   | Bend     | 0.187 (4.7)       | 0.75 (19.1)   | 47    |                      |      |
|                          |                                                                                                                      | B, 7                        | L                | 70(294)      | 251(1753)                               | 49(53)                                                  | 0.096 (2.4)                                                   |          |                   |               |       |                      |      |
|                          |                                                                                                                      | B, 8                        | L                | 70(294)      | 241(1683)                               | 51(56)                                                  | 0.112 (2.8)                                                   |          |                   |               |       |                      |      |
|                          |                                                                                                                      | B, 9                        | L                | 70(294)      | 247(1725)                               | 67(73)                                                  | 0.185 (4.7)                                                   |          |                   |               |       |                      |      |
|                          |                                                                                                                      | B, 10                       | L                | 70(294)      | 236(1648)                               | 63(69)                                                  | 0.180 (4.6)                                                   |          |                   |               |       |                      |      |
| COMPOSITION              |                                                                                                                      |                             |                  |              |                                         |                                                         |                                                               |          |                   |               |       |                      |      |
|                          | C                                                                                                                    | Mn                          | Si               | P            | S                                       | Al                                                      | Fe                                                            | Ni       | Mo                | Sn            | Cu    | Al                   | V    |
| A                        | 0.39                                                                                                                 | 0.57                        | 0.28             | 0.021        | 0.038                                   | 1.76                                                    | 1.10                                                          | 0.24     | 0.023             | 0.16          | 0.020 | -                    | -    |
| B                        | 0.45                                                                                                                 | 0.44                        | 0.79             | 0.012        | 0.008                                   | 1.72                                                    | 1.31                                                          | 0.88     | -                 | -             | -     | 0.23                 | -    |
| C                        | 0.39                                                                                                                 | 1.15                        | 1.45             | 0.008        | 0.006                                   | 1.90                                                    | 0.09                                                          | 0.30     | -                 | -             | -     | -                    | 0.24 |
| HEAT TREATMENT           |                                                                                                                      |                             |                  |              |                                         |                                                         |                                                               |          |                   |               |       |                      |      |
| 1.                       | 1545K (1113K), Hold 40 Sec, Oil Quench, 7 cycles; 1506F (1133K), Hold 1 min, Oil Quench, 2 cycles; 661F (623K), 4 Hr |                             |                  |              |                                         |                                                         |                                                               |          |                   |               |       |                      |      |
| 2.                       | 1561F (1123K), 4 Hr, Oil Quench; 181F (523K), 1 Hr                                                                   |                             |                  |              |                                         |                                                         |                                                               |          |                   |               |       |                      |      |
| 3.                       | 1561F (1123K), Hold 1 min, Oil Quench, 1 cycle; 661F (623K), 4 Hr                                                    |                             |                  |              |                                         |                                                         |                                                               |          |                   |               |       |                      |      |
| 4.                       | 1561F (1123K), 1 Hr, Oil Quench; 661F (623K), 1 Hr                                                                   |                             |                  |              |                                         |                                                         |                                                               |          |                   |               |       |                      |      |
| 5.                       | 1561F (1123K), 1 Hr, Oil Quench, 841F (723K), 1 Hr                                                                   |                             |                  |              |                                         |                                                         |                                                               |          |                   |               |       |                      |      |
| 6.                       | 1690F (1193K), Oil Quench; refrigerated at -95F (203K); Tempered 481F (523K)                                         |                             |                  |              |                                         |                                                         |                                                               |          |                   |               |       |                      |      |
| 7.                       | 1690F (1193K), Oil Quench; refrigerated at -95F (203K); Tempered 571F (573K)                                         |                             |                  |              |                                         |                                                         |                                                               |          |                   |               |       |                      |      |
| 8.                       | 1690F (1193K), Oil Quench; refrigerated at -95F (203K); Tempered 661F (623K)                                         |                             |                  |              |                                         |                                                         |                                                               |          |                   |               |       |                      |      |
| 9.                       | 1561F (1123K), Oil Quench; temper 706F (648K)                                                                        |                             |                  |              |                                         |                                                         |                                                               |          |                   |               |       |                      |      |
| 10.                      | 1561F (1123K), Oil Quench; Temper 481F (523K)                                                                        |                             |                  |              |                                         |                                                         |                                                               |          |                   |               |       |                      |      |

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Table 9

| Form                          | Composition, Heat Treatment | Orientation | Loss of temp of (°K) | Yield Strength ksi (N/mm <sup>2</sup> ) | Typical K <sub>IC</sub> ASIV/in (MN/m <sup>3/2</sup> ) | 2σ <sub>ys</sub> ( $\frac{K_{IC}}{\sigma_{ys}}$ ) <sup>2</sup> in (mm) | Specimen |                 |               |                      | Ref |
|-------------------------------|-----------------------------|-------------|----------------------|-----------------------------------------|--------------------------------------------------------|------------------------------------------------------------------------|----------|-----------------|---------------|----------------------|-----|
|                               |                             |             |                      |                                         |                                                        |                                                                        | Type     | Thickness in mm | Width in (mm) | Crack Length in (mm) |     |
| Plate: 1.5 in (38.1 mm) Thick | A,1                         | I-L         | -100 (200)           | 98 (1365)                               | 132 (145)                                              | 1.11 (28.2)                                                            | Bend     | 1.4 (35.5)      | 2.8 (7.1)     | 1.4 (35.5)           | 4   |
|                               |                             |             | -321 (78)            | 240 (1655)                              | 49 (54)                                                | 0.10 (2.6)                                                             | Bend     | 1.4 (35.5)      | 2.8 (7.1)     | 1.4 (35.5)           |     |
| Plate: 2.5 in (63.5 mm) Thick | A,2                         | I-L         | 73 (246)             | 150 (1310)                              | 142 (156)                                              | 1.53 (38.9)                                                            | CT       | 2.0 (50.8)      | 6.0 (152)     | 2.9 (73.7)           | 110 |
| Plate: 4 in (101.6 mm) Thick  | B,2                         | S-L         | 85 (302)             | 186 (1283)                              | 122 (136)                                              | 0.98 (24.9)                                                            | CT       | 1.0 (25.4)      | 3 (76.2)      | 1.5 (38.1)           |     |

COMPOSITION:

|   | C    | Si   | Co   | Mn   | Pb   | Cr   | V    | P     | S     | Se   | Cu   |
|---|------|------|------|------|------|------|------|-------|-------|------|------|
| A | 0.21 | 8.90 | 4.24 | 0.20 | 0.02 | 0.74 | 0.07 | 0.008 | 0.007 | 0.01 | -    |
| B | 0.19 | 9.40 | 1.52 | 0.29 | 0.90 | 0.85 | 0.10 | 0.005 | 0.005 | 0.06 | 0.17 |

HEAT TREATMENT

1. Normalize 1650f (899°C), 1.5 hr, Air (cool), Austenitize 1500f (816°C), 1.5 hr Water Quench; Temper 1025f (552°C), 6 hr.
2. 1525f (835°C), 0.1 hr Quench; -100f (240K), 1 hr; 1025f (552°C), 6 hr

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STEEL, Nickel: 9Ni-4Co-.3C

Table 10

| Form                                     | Composition, Heat Treatment | Test Orientation | Temp $\phi_F$ (°C) | Yield Strength KSI (MN/m <sup>2</sup> ) | Typical $K_{IC}$ (KSI/in (MN m <sup>-3/2</sup> )) | 2.S. ( $\frac{K_{IC}}{\sigma_{ys}}$ ) in (mm) | Specimen |                   |               |                      | Ref. |
|------------------------------------------|-----------------------------|------------------|--------------------|-----------------------------------------|---------------------------------------------------|-----------------------------------------------|----------|-------------------|---------------|----------------------|------|
|                                          |                             |                  |                    |                                         |                                                   |                                               | Type     | Thickness in (mm) | Width in (mm) | Crack Length in (mm) |      |
| Plate: 3 in (76.2 mm) Thick              | A,1                         | T-L              | 82 (300)           | 215 (1482)                              | 88 (5.0)                                          | 0.44 (11.2)                                   | CT       | 1.0 (25.4)        | 3.0 (76.2)    | 1.5 (38.1)           | 110  |
| Forging: 4.5 x 4.5 in (114.3 x 114.3 mm) | B,2                         | L-T              | 70 (294)           | 223 (1535)                              | 99 (110)                                          | 0.49 (12.5)                                   | DEC      | 5.0 (12.7)        | 3.0 (76.1)    | 0.5 (12.7)           | 16   |
| Forging: 3 in (76.2 mm) Thick            | C,3                         | L-T              | -100 (200)         | 202 (1392)                              | 64 (69)                                           | 0.25 (6.4)                                    | DEC      | 0.50 (12.7)       | 3.0 (76.1)    | 0.5 (12.7)           | 11   |
|                                          |                             | T-L              | 150 (339)          | 175 (1366)                              | 108 (123)                                         | 0.95 (24.2)                                   | WOL      | 2.0 (50.8)        | 5.1 (130)     | 1.8 (45.7)           |      |
|                                          |                             | T-L              | 70 (294)           | 177 (1220)                              | 177 (1366)                                        | 1.61 (41.0)                                   | WOL      | 2.0 (50.8)        | 2.25 (57.3)   | 1.0 (25.4)           |      |
|                                          |                             | T-L              | 70 (294)           | 177 (1220)                              | 100 (110)                                         | 0.78 (20.3)                                   | WOL      | 2.0 (50.8)        | 5.1 (130)     | 1.8 (45.7)           |      |
|                                          |                             | T-L              | 0 (355)            | 187 (1289)                              | 105 (114)                                         | 0.788 (20.0)                                  | WOL      | 2.0 (50.8)        | 5.1 (130)     | 1.8 (45.7)           |      |
|                                          |                             | T-L              | -40 (233)          | 188 (1296)                              | 111 (121)                                         | 0.871 (22.1)                                  | WOL      | 2.0 (50.8)        | 5.1 (130)     | 1.8 (45.7)           |      |
|                                          |                             | T-L              | -75 (214)          | 188 (1296)                              | 112 (122)                                         | 0.888 (22.6)                                  | WOL      | 2.0 (50.8)        | 5.1 (130)     | 1.8 (45.7)           |      |

# COMPOSITION

|   | C    | Ni   | Co   | Mn   | Mo   | Cr   | V    | P     | S     | Si   |
|---|------|------|------|------|------|------|------|-------|-------|------|
| A | 0.21 | 8.90 | 4.24 | 0.20 | 0.92 | 0.74 | 0.07 | 0.009 | 0.007 | 0.01 |
| B | 0.32 | 7.62 | 4.25 | 0.16 | 0.94 | 1.03 | 0.08 | 0.005 | 0.007 | 0.01 |
| C | 0.26 | 8.41 | 3.9  | 0.33 | 0.48 | 0.40 | 0.07 | 0.008 | 0.008 | 0.01 |

# HEAT TREATMENT

- 1525 (1103K), Oil Quench; -100F (200K), 3 Hr; 1000F (811K), 5 Hr
- 1125F (602V) 16 Hr, Air Cool; 1700F (1200K) 1 Hr, Air Cool; 1550F (1115K), 0.5 Hr, Salt Quench to 460F (512K); Hold 7 Hr; Temper 1000F (811K) 2 Hr, Air Cool
- 1550F (1175K), 2 Hr; Double Temper, 2 Hr + 2 Hr, 1000F (811K)

## STEEL, NICKEL: 9Ni-4Co-.45C

Table 11

| Form                                              | Composition, Heat Treatment | Test Orientation | Temp °F (°K) | Yield Strength KSI (MN/m <sup>2</sup> ) | Typical $K_{IC}$ KSI√in (MN m <sup>-3/2</sup> ) | 2.5 ( $\frac{K_{IC}}{\sigma_{ys}}$ ) <sup>2</sup> in (mm) | Specimen  |                   |               | Ref.                 |
|---------------------------------------------------|-----------------------------|------------------|--------------|-----------------------------------------|-------------------------------------------------|-----------------------------------------------------------|-----------|-------------------|---------------|----------------------|
|                                                   |                             |                  |              |                                         |                                                 |                                                           | Type      | Thickness in (mm) | Width in (mm) | Crack Length in (mm) |
| Plate: 0.95 in (2.4 mm) Thick                     | A,1                         | L-T              | 75(297)      | 220(1510)                               | 50( 55)                                         | 0.125( 3.2)                                               | CC        | 0.095( 2.4)       | 1.75 ( 44.4)  | 0.7 (17.8)           |
|                                                   |                             | T-L              | 75(297)      | 224(1545)                               | 50( 55)                                         | 0.124( 3.2)                                               | CC        | 0.095( 2.4)       | 1.75 ( 44.4)  | 0.7 (17.8)           |
|                                                   |                             | L-T              | -100(200)    | 223(1540)                               | 51( 56)                                         | 0.131( 3.3)                                               | CC        | 0.095( 2.4)       | 1.75 ( 44.4)  | 0.7 (17.8)           |
|                                                   |                             | L-T              | -200(144)    | 226(1575)                               | 47( 52)                                         | 0.106( 2.7)                                               | CL        | 0.095( 2.4)       | 1.75 ( 44.4)  | 0.7 (17.8)           |
|                                                   |                             | T-L              | 75(297)      | 233(1610)                               | 86( 95)                                         | 0.34 ( 8.6)                                               | Bend      | 0.875(22.2)       | 0.875( 22.2)  | ---                  |
| Plate: 1 in (25.4 mm) Thick                       | B,2                         | T-L              | 75(297)      | 233(1610)                               | 86( 95)                                         | 0.34 ( 8.6)                                               | Bend      | 0.875(22.2)       | 0.875( 22.2)  | ---                  |
|                                                   |                             | L-T              | 70(294)      | 198(1365)                               | 109(120)                                        | 0.755(19.2)                                               | CC        | 1.0 (25.4)        | 9.0 (228.6)   | 2.6 (60 )            |
| Forging: 9 x 9 x 24 in (228.6 x 228.6 x 609.6 mm) | C,3                         | L-T              | -110(194)    | 211(1453)                               | 55( 60)                                         | 0.172( 4.3)                                               | CC        | 1.0 (25.4)        | 9.0 (228.6)   | 2.6 (60 )            |
|                                                   |                             | T-L              | 70(294)      | 225(1550)                               | 90( 98)                                         | 0.4 (10.2)                                                | Bend      | 0.480(12.2)       | 1.5 ( 38.1)   | 0.31( 7.9)           |
| Forging: 3 x 9 x 24 in (76.2 x 228.6 x 609.6 mm)  | D,4                         | T-L              | -65(219)     | ---                                     | 68( 75)                                         | ---                                                       | 4 pt Bend | 0.480(12.2)       | 1.5 ( 38.1)   | 0.33( 8.4)           |
|                                                   |                             | T-L              | 300(422)     | 195(1344)                               | 83( 90)                                         | 0.453(11.5)                                               | 4 pt Bend | 0.480(12.2)       | 1.5 ( 38.1)   | 0.36( 9.1)           |
| Forging: 3 x 9 x 24 in (76.2 x 228.6 x 609.6 mm)  | E,5                         | T-L              | 75(257)      | 225(1550)                               | 89( 97)                                         | 0.392(10.0)                                               | 4 pt Bend | 0.480(12.2)       | 1.5 ( 38.1)   | 0.31(17.9)           |
|                                                   |                             | L-T              | -65(219)     | 246(1655)                               | 89( 97)                                         | 0.344( 8.7)                                               | 4 pt Bend | 0.480(12.2)       | 1.5 ( 38.1)   | 0.32( 8.1)           |
|                                                   |                             | T-L              | -65(219)     | ---                                     | 68( 75)                                         | ---                                                       | 4 pt Bend | 0.480(12.2)       | 1.5 ( 38.1)   | 0.33( 8.4)           |
|                                                   |                             | S-L              | -64(219)     | ---                                     | 79( 87)                                         | ---                                                       | 4 pt Bend | 0.480(12.2)       | 1.5 ( 38.1)   | 0.36( 9.1)           |
|                                                   |                             | T-L              | -110(194)    | 243(1675)                               | 62( 68)                                         | 0.163( 4.1)                                               | 4 pt Bend | 0.480(12.2)       | 1.5 ( 38.1)   | 0.35( 8.9)           |

## COMPOSITION

|   | C    | Ni   | Co   | Mn   | Mo   | Cr   | V    | P     | S     | Si   |
|---|------|------|------|------|------|------|------|-------|-------|------|
| A | 0.45 | 8.76 | 3.76 | 0.12 | 0.30 | 0.30 | 0.06 | 0.005 | 0.009 | 0.01 |
| B | 0.43 | 8.00 | 4.0  | 0.02 | 0.08 | 0.09 | 0.12 | ---   | ---   | 0.01 |
| C | 0.43 | 8.09 | 3.81 | 0.13 | 0.11 | 0.13 | 0.09 | 0.005 | 0.009 | 0.01 |
| D | 0.45 | 7.90 | 4.26 | 0.09 | 0.22 | 0.33 | 0.10 | 0.003 | 0.011 | 0.05 |
| E | 0.44 | 7.79 | 4.03 | 0.19 | 0.29 | 0.32 | 0.08 | 0.010 | 0.009 | 0.05 |

## HEAT TREATMENT

1. 1450F (1060K), Oil Quench; Temper 1 hr + 1 hr, 600F (589K)
2. 1600F (1144K), Air Cool; 1450F (1061K) 0.5 hr, Salt Bath
3. 1600F (1144K), 6 hr, Air Cool
4. 1600F (1144K), 1 hr, Air Cool; 1450F (1061K), 30 min; Salt Quench, 450F (505K), 6 hr, Air Cool; Double Temper 1 hr + 1 hr, 700F (644K)
5. 1500F (1089K), 1 hr, Salt Quench 475F (519K) 6 hr
6. 1550 - 1650F (1117-1172K) 1 hr, Air Cool; 1150F (894K), 30 min; 1500F (1089K) 1 hr; 465F (514K) Salt Bath, 6 hr, Air Cool

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## STEEL: 10 Nickel

Table 12

| Table 12                      |                             |                  |              |                                         |                                                         |                                                               |          |                    |               |                      |      |
|-------------------------------|-----------------------------|------------------|--------------|-----------------------------------------|---------------------------------------------------------|---------------------------------------------------------------|----------|--------------------|---------------|----------------------|------|
| Form                          | Composition, Heat Treatment | Test Orientation | Temp °F (°K) | Yield Strength KSI (MN/m <sup>2</sup> ) | Typical K <sub>IC</sub> KSI/√in (MN m <sup>-3/2</sup> ) | 2.S (K <sub>IC</sub> <sup>2</sup> / σ <sub>ys</sub> ) in (mm) | Specimen |                    |               |                      | Ref. |
|                               |                             |                  |              |                                         |                                                         |                                                               | Type     | Thickness in. (mm) | Width in (mm) | Crack Length in (mm) |      |
| Plate: 0.5 in (12.7 mm) Thick | A, 1                        | L-T              | 70(294)      | 257(1772)                               | 51(56)                                                  | 0.98 (2.5)                                                    | Bend     | 0.5 (12.7)         | 1.0 (25.4)    | 0.5 (12.7)           | 80   |
|                               |                             | T-L              | 70(294)      | 256(1765)                               | 52(57)                                                  | 0.103 (2.6)                                                   | Bend     | 0.5 (12.7)         | 1.0 (25.4)    | 0.5 (12.7)           |      |
|                               | B, 2                        | T-L              | 70(294)      | 256(1765)                               | 87(96)                                                  | 0.352 (8.9)                                                   | Bend     | 0.5 (12.7)         | 1.0 (25.4)    | 0.5 (12.7)           |      |
|                               | C, 2                        | T-L              | 70(294)      | 272(1875)                               | 73(80)                                                  | 0.216 (5.5)                                                   | Bend     | 0.5 (12.7)         | 1.0 (25.4)    | 0.5 (12.7)           |      |
|                               | D, 5                        | T-L              | 70(294)      | 257(1772)                               | 77(85)                                                  | 0.618 (15.7)                                                  | Bend     | 0.5 (12.7)         | 1.0 (25.4)    | 0.5 (12.7)           |      |

## COMPOSITION

|   | C    | Mn   | P     | S     | Si   | Ni    | Cr   | Mo   | Al    | N     | O     | Co   |
|---|------|------|-------|-------|------|-------|------|------|-------|-------|-------|------|
| A | 0.26 | 0.15 | 0.001 | 0.003 | 0.12 | 10.08 | 2.00 | 0.98 | 0.008 | 0.002 | 0.01  | 15.2 |
| B | 0.23 | 0.13 | 0.001 | 0.002 | 0.13 | 9.68  | 1.94 | 0.98 | 9.002 | 0.003 | 0.001 | 12.3 |
| C | 0.25 | 0.14 | 0.002 | 0.003 | 0.11 | 10.10 | 1.99 | 1.01 | 0.004 | 0.002 | 0.001 | 14.6 |
| D | 0.25 | 0.11 | 0.001 | 0.003 | 0.12 | 10.0  | 1.57 | 0.79 | 0.004 | 0.001 | 0.002 | 12.6 |

## HEAT TREATMENT

- 1650F (1172K), 1 Hr, Water Quenched; 1500F (1089K), 1 Hr., Water Quench; Temper 950F (783K), 1 Hr, Water Quench.
- Heat to 1350F (839K), Hold, Heat to 1550F (1117K), Hold, Water Quench, Repeat Cycle 4 Times, Temper 950F (783K), 5 Hr
- Heat to 1120F (879K), Hold 6 Sec, Heat to 1450F (1060K), Hold 8 Sec, Water Quench, Repeat Cycle 4 Times, Temper 400F (478K), 5 Hr

## STEEL: Maraging 12 Nickel

Table 13

| Form                           | Compo-<br>sition,<br>Heat<br>Treat-<br>ment | Test<br>Orienta-<br>tion | Temp<br>°F<br>(°K) | Yield<br>Strength<br>KSI (MN/m <sup>2</sup> ) | Typical<br>K <sub>IC</sub><br>KSI/√in (MN m <sup>-3/2</sup> ) | 2.5<br>( $\frac{K_{IC}}{\sigma_y}$ ) <sup>2</sup><br>in (mm) | Specimen     |                      |                  |                            | Ref.       |    |
|--------------------------------|---------------------------------------------|--------------------------|--------------------|-----------------------------------------------|---------------------------------------------------------------|--------------------------------------------------------------|--------------|----------------------|------------------|----------------------------|------------|----|
|                                |                                             |                          |                    |                                               |                                                               |                                                              | Type         | Thickness<br>in (mm) | Width<br>in (mm) | Crack<br>Length<br>in (mm) |            |    |
| Plate: 1 in (25.4 mm)<br>Thick | A,1                                         | L-T                      | 70(294)            | 171(1179)                                     | 100(110)                                                      | 0.86 (21.8)                                                  | SEN          | 1                    | (25.4)           | 4.5 (114.3)                | 1.6 (40.7) | 21 |
|                                | B,1                                         | T-L                      | 70(294)            | 185(1276)                                     | 120(132)                                                      | 1.175 (29.9)                                                 | SEN          | 1                    | (25.4)           | 4.5 (114.3)                | 1.6 (40.7) |    |
| Plate: 2 in (50.8 mm)<br>Thick | C,1                                         | L-T                      | 20(294)            | 175(1207)                                     | 125(138)                                                      | 1.28 (32.5)                                                  | Bend         | 2                    | (50.8)           | 5.95(151)                  | 1.6 (40.7) | 85 |
|                                | D,2                                         | -                        | 70(294)            | 186(1282)                                     | 147(162)                                                      | 1.56 (39.6)                                                  | 4 pt<br>Bend | 2                    | (50.8)           | 2 (50.8)                   | -          | 85 |

## COMPOSITION

|   | C     | Mn    | P     | S     | Si    | Ni    | Cr   | Mo   | Ti   | Al   |
|---|-------|-------|-------|-------|-------|-------|------|------|------|------|
| A | 0.033 | 0.08  | 0.007 | 0.005 | 0.07  | 12.5  | 4.81 | 3.55 | 0.21 | 0.16 |
| B | 0.033 | 0.08  | 0.007 | 0.005 | 0.07  | 12.5  | 4.71 | 3.65 | 0.21 | 0.16 |
| C | 0.23  | 0.088 | 0.004 | 0.008 | 0.094 | 12.1  | 5.21 | 2.86 | 0.24 | -    |
| D | 0.24  | 0.044 | 0.007 | 0.013 | 0.042 | 11.72 | 5.38 | 3.18 | 0.30 | 0.47 |

## HEAT TREATMENT

1. 1500F (1089K); Temper 900F (756K), 3 hr
2. 1500F (1089K); Temper 900F (756K), 30 hr

STEEL: 18Ni: Maraging: 200 Grade

Table 14

| Form                                                                                   | Composition,<br>Heat<br>Treat-<br>ment | Test<br>Ori-<br>en-<br>ta-<br>tion | Temp<br>°F (°K) | Yield<br>Strength<br>KSI (MN/m <sup>2</sup> ) | Typical<br>K <sub>IC</sub><br>KSI√in (MN <sup>3/2</sup> /in <sup>3/2</sup> ) | 2.5<br>/K <sub>IC</sub> <sup>2</sup><br>(in <sup>3/2</sup> /K <sup>2</sup> ) | Specimen |                      |                  | Ref.                       |
|----------------------------------------------------------------------------------------|----------------------------------------|------------------------------------|-----------------|-----------------------------------------------|------------------------------------------------------------------------------|------------------------------------------------------------------------------|----------|----------------------|------------------|----------------------------|
|                                                                                        |                                        |                                    |                 |                                               |                                                                              |                                                                              | Type     | Thickness<br>in (mm) | Width<br>in (mm) | Crack<br>Length<br>in (mm) |
| Plate: 1 in (25.4 mm)<br>Thick                                                         | A,1                                    | L-T                                | -321(18)        | 241(1662)                                     | 115(127)                                                                     | 0.569 (14.5)                                                                 | Bend     | 1.0 (25.4)           | 3.0 (76.2)       | 1.6 (40.6)                 |
| Plate: 2 in (50.8 mm)<br>Thick                                                         | -2                                     | L-T                                | 75(297)         | 187(1289)                                     | 152(167)                                                                     | 1.65 (42.0)                                                                  | Bend     | 2.0 (50.8)           | 4.0 (101.6)      | 1.5 (38.1)                 |
| Plate: 2 in (50.8 mm)<br>Thick                                                         | D,3                                    | L-S                                | 70(294)         | 197(1356)                                     | 104(114)                                                                     | 0.697 (17.7)                                                                 | (a)      | ---                  | ---              | ---                        |
|                                                                                        |                                        | L-T                                | 70(294)         | 192(1324)                                     | 100(110)                                                                     | 0.687 (17.2)                                                                 | (a)      | ---                  | ---              | ---                        |
|                                                                                        |                                        | T-S                                | 70(294)         | 194(1334)                                     | 78(86)                                                                       | 0.404 (10.3)                                                                 | (a)      | ---                  | ---              | ---                        |
|                                                                                        |                                        | T-L                                | 70(294)         | 195(1347)                                     | 75(83)                                                                       | 0.370 (9.4)                                                                  | (a)      | ---                  | ---              | ---                        |
|                                                                                        |                                        | S-L                                | 70(294)         | 198(1365)                                     | 70(75)                                                                       | 0.312 (7.9)                                                                  | (a)      | ---                  | ---              | ---                        |
| Plate: 2.13 in (54mm)<br>Thick                                                         | B,4                                    | T-L                                | 75(297)         | 206(1420)                                     | 170(187)                                                                     | 1.7 (43.2)                                                                   | Bend     | 2.0 (50.8)           | 4.0(101.6)       | 2.0(50.8)                  |
|                                                                                        |                                        | T-L                                | -100(200)       | 229(1580)                                     | 164(179)                                                                     | 1.28 (32.5)                                                                  | Bend     | 2.0 (50.8)           | 4.0(101.6)       | 2.0(50.8)                  |
|                                                                                        |                                        | T-L                                | -321(78)        | 271(1870)                                     | 79(87)                                                                       | 0.21 (5.3)                                                                   | Bend     | 2.0 (50.8)           | 4.0(101.6)       | 2.0(50.8)                  |
| Plate: 4.25 in (108 mm)<br>Thick Con.E1. Vac<br>Remelt, Hot Rolled<br>at 2300F (1553K) | C,5                                    | L-T                                | 75(297)         | 234(1613)                                     | 92(101)                                                                      | 0.386 (9.8)                                                                  | Bend     | 3.94 (100)           | 7.89(200)        | 4.0 (102)                  |
|                                                                                        | C,6                                    | L-T                                | 75(297)         | 211(1455)                                     | 103(113)                                                                     | 0.596 (15.1)                                                                 | CT       | 3.94 (100)           | 6.31(160)        | 3.22 (81.6)                |
|                                                                                        | C,7                                    | L-T                                | 75(297)         | 190(1310)                                     | 129(142)                                                                     | 1.152 (2.93)                                                                 | Bend     | 3.94 (100)           | 7.87(200)        | 3.92 (99.6)                |
|                                                                                        | C,8                                    | L-T                                | 75(297)         | 174(1200)                                     | 180(198)                                                                     | 2.675 (68.0)                                                                 | Bend     | 3.93 (100)           | 7.86(200)        | 3.98 (101)                 |
|                                                                                        | C,9                                    | L-T                                | 75(297)         | 166(1145)                                     | 187(206)                                                                     | 3.173 (80.6)                                                                 | CT       | 3.93 (100)           | 6.31(160)        | 3.20 (81.3)                |

HEAT TREATMENT

- 1500F (1089K), 93 Min, Water Cooled; 1160F (399K), 93 Min, Water Quench
- 1500F (1089K), Aged 900F (756K), 3 Hr
- Aged 895F (753K), 3 Hr
- 1650F (1172K), 2 Hr, Air Cool; 1450F (1060K), 2 Hr, Air Cool;
- Aged 900F (756K), 2 Hr
- 1650F (1172K), 4.5 Hr, Air Cool; 850F (728K), 100 Hr
- 1650F (1172K), 4.5 Hr, Air Cool; 1000F (811K), 6 Hr
- 1650F (1172K), 4.5 Hr, Air Cool; 1050F (839K), 6 Hr
- 1650F (1172K), 4.5 Hr, Air Cool; 1100F (867K), 6 Hr
- 1650F (1172K), 4.5 Hr, Air Cool; 1100F (867K), 24 Hr

(a) Specimen in accordance with ASTM Recommendations

COMPOSITION

|   | C     | Mn    | P     | S     | Si    | Ni    | Co   | Mo    | Ti    | Al   | CT   |
|---|-------|-------|-------|-------|-------|-------|------|-------|-------|------|------|
| A | 0.003 | 0.02  | 0.003 | 0.007 | 0.005 | 17.90 | 7.75 | 2.96  | 0.20  | -    | -    |
| B | 0.005 | 0.03  | 0.005 | 0.008 | 0.02  | 18.40 | 8.50 | 3.34  | 0.20  | 0.07 | -    |
| C | 0.02  | 0.07  | 0.001 | 0.009 | 0.08  | 17.78 | 7.07 | 4.46  | 0.185 | -    | -    |
| D | 0.034 | 0.124 | 0.014 | 0.014 | 0.124 | 18.4  | 7.58 | 3.258 | 0.285 | 0.14 | 0.54 |

STEEL, 18 Ni Maraging: (250 Grade), DTD S212, G100, G110, Garval 18 (Sheet 1 of 3) Table 15

| Form                                                             | Compo-<br>sition,<br>Heat<br>Treat-<br>ment | Test<br>Orienta-<br>tion | Temp<br>°F (°K) | Yield<br>Strength<br>KSI (MN/m <sup>2</sup> ) | Typical<br>K <sub>IC</sub><br>KSI√in (MN m <sup>3/2</sup> ) | 2.5<br>( $\frac{K_{IC}}{\sigma_{ys}}$ ) <sup>2</sup><br>in (mm) | Specimen     |                           |                  |                            | Ref. |
|------------------------------------------------------------------|---------------------------------------------|--------------------------|-----------------|-----------------------------------------------|-------------------------------------------------------------|-----------------------------------------------------------------|--------------|---------------------------|------------------|----------------------------|------|
|                                                                  |                                             |                          |                 |                                               |                                                             |                                                                 | Type         | Thick-<br>ness<br>in (mm) | Width<br>in (mm) | Crack<br>Length<br>in (mm) |      |
| 250 Grade                                                        |                                             |                          |                 |                                               |                                                             |                                                                 |              |                           |                  |                            |      |
| Plate: 1 in (25.4 mm) Thick                                      | A,1                                         | L-T                      | 70(294)         | 259(1786)                                     | 68(74)                                                      | 0.172(4.3)                                                      | Bend         | 0.250( 6.4)               | 2.0 (50.8)       | ---                        | 14   |
| Rolled to 2 in (50.8 mm) thick-<br>ness from Press Forged Slab   | B,2                                         | L-T                      | 70(294)         | 227(1565)                                     | 96(105)                                                     | 0.447(11.3)                                                     | Bend         | 1.8 (45.7)                | 3.75(95.3)       | ---                        | 15   |
|                                                                  | B,2                                         | L-T                      |                 | 232(1600)                                     | 85( 93)                                                     | 0.336( 8.5)                                                     | Bend         | 1.8 (45.7)                | 3.75(95.3)       | ---                        |      |
|                                                                  | B,3                                         | L-T                      |                 | 259(1786)                                     | 84( 92)                                                     | 0.263( 6.7)                                                     | Bend         | 1.8 (45.7)                | 3.75(95.3)       | ---                        |      |
|                                                                  | B,4                                         | L-T                      |                 | 259(1786)                                     | 80( 87)                                                     | 0.239( 6.1)                                                     | Bend         | 1.8 (45.7)                | 3.75(95.3)       | ---                        |      |
| Forging: 3 in (76.2 mm) Thick                                    | C,5                                         | T-L                      | 70(294)         | 243(1675)                                     | 99(108)                                                     | 0.415(10.5)                                                     | Bend<br>4 pt | 0.480(12.2)               | 1.5 (38.1)       | 0.3 ( 7.6)                 | 3    |
|                                                                  |                                             | T-L                      | -65(219)        | ---                                           | 90( 98)                                                     | ---                                                             | Bend<br>4 pt | 0.480(12.2)               | 1.5 (38.1)       | 0.3 ( 7.6)                 |      |
| Plate: 1 in (25.4 mm) Thick                                      | D,6                                         | -                        | 70(294)         | 246(1696)                                     | 105(114)                                                    | 0.455(11.6)                                                     | Bend         | 1.00 (25.4)               | 3.0 (76.2)       | ---                        | 10   |
|                                                                  |                                             | -                        | 0(255)          | 250(1724)                                     | 72( 78)                                                     | 0.207( 5.3)                                                     | Bend         | 1.00 (25.4)               | 3.0 (76.2)       | ---                        |      |
|                                                                  |                                             | -                        | -100(200)       | 300(2068)                                     | 75( 82)                                                     | 0.156( 4.0)                                                     | Bend         | 1.00 (25.4)               | 3.0 (76.2)       | ---                        |      |
|                                                                  |                                             | -                        | -200(144)       | 260(1834)                                     | 52( 57)                                                     | 0.100( 2.5)                                                     | Bend         | 1.00 (25.4)               | 3.0 (76.2)       | ---                        |      |
|                                                                  |                                             | -                        | -385( 75)       | 230(1586)                                     | 40( 44)                                                     | 0.075( 1.9)                                                     | Bend         | 1.00 (25.4)               | 3.0 (76.2)       | ---                        |      |
| Forging: 4.5 x 4.5 in (114.3 x<br>114.3 mm)<br>Vacuum Arc Remelt | E,7                                         | L-T                      | -110(194)       | 273(1882)                                     | 86( 94)                                                     | 0.248( 6.3)                                                     | SEN          | 0.250( 6.4)               | 1.0 (25.4)       | 0.500(12.7)                | 16   |
|                                                                  |                                             | T-L                      | -110(194)       | 272(1875)                                     | 80( 87)                                                     | 0.216( 5.6)                                                     | SLN          | 0.250( 6.4)               | 1.0 (25.4)       | 0.500(12.7)                |      |
| Forging: 13 x 13 in (330.2 x<br>330.2 mm) Vacuum Arc<br>Remelted | E,7                                         | L-S                      | -110(194)       | 259(1786)                                     | 82(89)                                                      | 0.251(6.4)                                                      | SEN          | 0.250( 6.4)               | 1.0(25.4)        | 1.500(12.7)                | 16   |
|                                                                  |                                             | TL                       | -110(194)       | 260(1793)                                     | 80(87)                                                      | 0.237(6.0)                                                      | SEN          | 0.250( 6.4)               | 1.0(25.4)        | 0.500(12.7)                |      |
|                                                                  |                                             | S-T                      | -110(194)       | 262(1806)                                     | 82(89)                                                      | 0.245(6.2)                                                      | SEN          | 0.250( 6.4)               | 1.0(25.4)        | 0.500(12.7)                |      |
|                                                                  |                                             | ST4-ST4                  | -110(194)       | 262(1806)                                     | 72(78)                                                      | 0.189(4.8)                                                      | SEN          | 0.250( 6.4)               | 1.0(25.4)        | 0.500(12.7)                |      |

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STEEL: 18 Ni Maraging (250 Grade), DTD 5212, G100, G110, Marval 18 (Sheet 2 of 3) Table 15 (Cont.)

SHEET: 18 N1 Maraging (250 Grade), DTD 5212, G100, G110, Marval 18 (cont.)

| Form                                                                             | Composition, Heat Treatment | Test Orientation                | Temp<br>°F (°K) | Yield Strength<br>KSI (N/m <sup>2</sup> ) | Typical<br>K <sub>IC</sub><br>KSI/√in (MN m <sup>-3/2</sup> ) | 2.5 (K <sub>IC</sub><br>σ <sub>ys</sub> ) <sup>2</sup><br>in (mm) | Specimen     |                      |                  |                         | Ref. |    |
|----------------------------------------------------------------------------------|-----------------------------|---------------------------------|-----------------|-------------------------------------------|---------------------------------------------------------------|-------------------------------------------------------------------|--------------|----------------------|------------------|-------------------------|------|----|
|                                                                                  |                             |                                 |                 |                                           |                                                               |                                                                   | Type         | Thickness<br>in (mm) | Width<br>in (mm) | Crack Length<br>in (mm) |      |    |
| Plate: 1.5 x 23 in (38.1 x 330.2 mm)                                             |                             | LS                              | -110(194)       | 262(1806)                                 | 83(90)                                                        | 0.251(6.4)                                                        | SEN          | 0.250( 6.4)          | 1.0(25.4)        | 0.500(12.7)             | 16   |    |
|                                                                                  |                             | TL                              | -110(194)       | 267(1841)                                 | 73(80)                                                        | 0.187(4.7)                                                        | SEN          | 0.250( 6.4)          | 1.0(25.4)        | 0.500(12.7)             |      |    |
|                                                                                  |                             | ST                              | -110(194)       | 267(1841)                                 | 69(75)                                                        | 0.167(4.2)                                                        | CT           | 0.500(12.7)          | 1.0(25.4)        | 0.500(12.7)             |      |    |
|                                                                                  |                             | TL                              | -110(194)       | 264(1820)                                 | 84(92)                                                        | 0.253(6.4)                                                        | SEN          | 0.250( 6.4)          | 1.0(25.4)        | 0.500(12.7)             |      |    |
| <div> <div>DTD 5212</div> <div>Forged Plate: 2.5 in (63.5 mm) Thick</div> </div> |                             |                                 |                 |                                           |                                                               |                                                                   |              |                      |                  |                         |      |    |
| G100                                                                             | F, 8                        | L-T                             | 70(294)         | 246(1696)                                 | 91(100)                                                       | 0.542(8.7)                                                        | (a)          | ---                  | ---              | ---                     | 65   |    |
|                                                                                  |                             |                                 |                 |                                           |                                                               |                                                                   |              |                      |                  |                         |      |    |
|                                                                                  |                             | Forged Bar: 5 in (127 mm) Thick | T-S             | 70(294)                                   | 204(1407)                                                     | 88(97)                                                            | 0.465 (11.8) | (a)                  | ---              | ---                     | ---  | 69 |
|                                                                                  |                             |                                 | T-S             | 20(294)                                   | 225(1551)                                                     | 82(90)                                                            | 0.332 (8.4)  | (a)                  | ---              | ---                     | ---  |    |
| G110                                                                             | G, 9                        | T-S                             | 70(294)         | 248(1706)                                 | 83(92)                                                        | 0.280 (7.1)                                                       | (a)          | ---                  | ---              | ---                     |      |    |
|                                                                                  |                             |                                 |                 |                                           |                                                               |                                                                   |              |                      |                  |                         |      |    |
|                                                                                  |                             | L-ST                            | 70(294)         | *262(*1806)                               | 92(101)                                                       | ---                                                               | (a)          | ---                  | ---              | ---                     | 70   |    |
|                                                                                  |                             | ST-L                            | 70(294)         | *260(*1793)                               | 85(93)                                                        | ---                                                               | (a)          | ---                  | ---              | ---                     |      |    |
| Bar: 8 in (203) Sq Double Vac. Melted                                            | G, 9                        | ST-L                            | 70(294)         | *265(1834)                                | 82(90)                                                        | ---                                                               | (a)          | ---                  | ---              | ---                     |      |    |
|                                                                                  |                             |                                 |                 |                                           |                                                               |                                                                   |              |                      |                  |                         |      |    |
| Plate:                                                                           | G, --                       | ---                             | 70(294)         | 235(1620)                                 | 80(88)                                                        | 0.290 (7.4)                                                       | Bend         | 0.715(18.2)          | 1.0(25.4)        | 0.47(11.9)              | 57   |    |
| <div> <div>Marval 18</div> <div></div> </div>                                    |                             |                                 |                 |                                           |                                                               |                                                                   |              |                      |                  |                         |      |    |
|                                                                                  | --                          | T-S                             | 70(294)         | 245(1689)                                 | 100(110)                                                      | 0.416(10.6)                                                       | Bend         | 0.5 (12.7)           | 1.0 (25.4)       | ---                     | 60   |    |

(a) Specimen in accordance with ASTM Recommendations

\* tensile Ultimate Values

STEEL: 18 Ni Maraging (250 Grade), DTD 5212, G100, G110, Marval 18 (Sheet 3 of 3) Table 15 (Cont.)

| Form                                                                                                        | Composition,<br>Heat<br>Treat-<br>ment | Test<br>Orienta-<br>tion | Temp<br>(°K) | Yield<br>Strength<br>KSI (MN/m <sup>2</sup> ) | Typical<br>K <sub>IC</sub><br>$\left( \frac{3}{\sqrt{Wt}} \right)$<br>KSI√in (MN√m) | $2.5 \left( \frac{K_{IC}}{\sigma_{ys}} \right)^2$<br>in (mm) | Specimen |                      |                  |                            |       | Ref.  |      |
|-------------------------------------------------------------------------------------------------------------|----------------------------------------|--------------------------|--------------|-----------------------------------------------|-------------------------------------------------------------------------------------|--------------------------------------------------------------|----------|----------------------|------------------|----------------------------|-------|-------|------|
|                                                                                                             |                                        |                          |              |                                               |                                                                                     |                                                              | Type     | Thickness<br>in (mm) | Width<br>in (mm) | Crack<br>Length<br>in (mm) |       |       |      |
|                                                                                                             |                                        |                          |              |                                               |                                                                                     |                                                              |          |                      |                  |                            |       |       |      |
| C                                                                                                           | Mn                                     | Si                       | P            | S                                             | Ni                                                                                  | Mo                                                           | Co       | Al                   | Ti               | B                          | Zr    | Cr    | V    |
| A                                                                                                           | 0.020                                  | 0.05                     | 0.09         | 0.006                                         | 0.005                                                                               | 18.35                                                        | 5.32     | 7.18                 | 0.04             | 0.32                       | -     | -     | -    |
| B                                                                                                           | 0.006                                  | 0.06                     | 0.01         | 0.006                                         | 0.007                                                                               | 18.47                                                        | 4.81     | 7.40                 | 0.11             | 0.40                       | 0.002 | 0.01  | 0.05 |
| C                                                                                                           | 0.030                                  | 0.10                     | 0.10         | 0.005                                         | 0.008                                                                               | 18.05                                                        | 5.08     | 7.66                 | 0.15             | 0.40                       | -     | -     | -    |
| D                                                                                                           | 0.003                                  | 0.002                    | 0.003        | 0.002                                         | 0.004                                                                               | 17.1                                                         | 4.65     | 7.60                 | -                | 0.50                       | -     | -     | -    |
| E                                                                                                           | 0.020                                  | 0.05                     | 0.03         | 0.003                                         | 0.003                                                                               | 18.20                                                        | 4.71     | 7.58                 | 0.14             | 0.42                       | 0.003 | 0.016 | 0.05 |
| F                                                                                                           | 0.015                                  | 0.10                     | 0.010        | 0.010                                         | 0.010                                                                               | 18.00                                                        | 4.90     | 7.75                 | 0.10             | 0.45                       | -     | -     | 0.25 |
| G                                                                                                           | 0.010                                  | 0.05                     | 0.05         | 0.005                                         | 0.005                                                                               | 17.50                                                        | 4.85     | 8.00                 | -                | 0.50                       | -     | -     | 0.10 |
| H                                                                                                           | 0.003                                  | 0.05                     | 0.05         | 0.005                                         | 0.004                                                                               | 18.3                                                         | 4.72     | 7.64                 | 0.11             | 0.8                        | -     | -     | 0.05 |
| HEAT TREATMENT                                                                                              |                                        |                          |              |                                               |                                                                                     |                                                              |          |                      |                  |                            |       |       |      |
| 1. Mill Anneal; 900F (756K) 3 hr                                                                            |                                        |                          |              |                                               |                                                                                     |                                                              |          |                      |                  |                            |       |       |      |
| 2. 1500F (1089K), Air Cool; Aged 800F (700K) 6 hrs                                                          |                                        |                          |              |                                               |                                                                                     |                                                              |          |                      |                  |                            |       |       |      |
| 3. 1500F (1089K), Air Cool; Aged 1000F (811K) 6 hrs                                                         |                                        |                          |              |                                               |                                                                                     |                                                              |          |                      |                  |                            |       |       |      |
| 4. 1500F (1089K), Air Cool; Aged 900F (756K) 6 hrs                                                          |                                        |                          |              |                                               |                                                                                     |                                                              |          |                      |                  |                            |       |       |      |
| 5. 1500F (1089K), Air Cool; Aged 900F (756K) 24 hrs                                                         |                                        |                          |              |                                               |                                                                                     |                                                              |          |                      |                  |                            |       |       |      |
| 6. 1650F (1172K), 1 hr, Water Quench; 1525F (1103K) 1 hr, Water Quench; Aged 900F (750K) 5 hr, Water Quench |                                        |                          |              |                                               |                                                                                     |                                                              |          |                      |                  |                            |       |       |      |
| 7. 1500F (1089K), Air Cool; Aged 950F (783K) 3 hr, Air Cool                                                 |                                        |                          |              |                                               |                                                                                     |                                                              |          |                      |                  |                            |       |       |      |
| 8. 1489-1525F (1083-1103K), Air Cool; 904F (758K), 3 hr, Air Cool                                           |                                        |                          |              |                                               |                                                                                     |                                                              |          |                      |                  |                            |       |       |      |
| 9. 1507F (1093K), Air Cool; 895F (753K), 3 hr, Air Cool                                                     |                                        |                          |              |                                               |                                                                                     |                                                              |          |                      |                  |                            |       |       |      |
| 10. 1507F (1093K), Aged 913F (763K)                                                                         |                                        |                          |              |                                               |                                                                                     |                                                              |          |                      |                  |                            |       |       |      |
| 11. 1471-1650F (1073-1173K), Air Cool; 796F (698K), 1.5 hr                                                  |                                        |                          |              |                                               |                                                                                     |                                                              |          |                      |                  |                            |       |       |      |
| 12. 1471-1650F (1073-1173K), Air Cool; 895F (753K), 1.25 hr                                                 |                                        |                          |              |                                               |                                                                                     |                                                              |          |                      |                  |                            |       |       |      |
| 13. 1471-1650F (1073-1173K), Air Cool; 895F (753K), 2.5 hr                                                  |                                        |                          |              |                                               |                                                                                     |                                                              |          |                      |                  |                            |       |       |      |

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STEEL, 18 Ni Maraging. 300 Grade and G125

Table 16

| STEEL, 18 Ni Maraging. 300 Grade and G125                                                           |                             |                  |              |                                         |                                                       |                                                              |                   |               |                      |               |                           |      |       |       |       |       |       |
|-----------------------------------------------------------------------------------------------------|-----------------------------|------------------|--------------|-----------------------------------------|-------------------------------------------------------|--------------------------------------------------------------|-------------------|---------------|----------------------|---------------|---------------------------|------|-------|-------|-------|-------|-------|
| Form                                                                                                | Composition, Heat Treatment | Test Orientation | Temp °F (°K) | Yield Strength KSI (MN/m <sup>2</sup> ) | Typical K <sub>IC</sub> KSI√in (MN m <sup>3/2</sup> ) | 2.5 /K <sub>IC</sub> <sup>2</sup> (σ <sub>ys</sub> ) in (mm) | Specimen          |               |                      | Ref.          |                           |      |       |       |       |       |       |
|                                                                                                     |                             |                  |              |                                         |                                                       |                                                              | Thickness in (mm) | Width in (mm) | Crack Length in (mm) |               |                           |      |       |       |       |       |       |
| 300 Grade                                                                                           |                             |                  |              |                                         |                                                       |                                                              |                   |               |                      |               |                           |      |       |       |       |       |       |
| Plate: 0.5 in (2.7 mm) Thick                                                                        | A,1                         | T-L              | 600(589)     | 236(1627)                               | 80(87)                                                | 0.287 (7.3)                                                  | CC                | 0.25 (6.4)    | 3.0 (76.2)           | 1.0 (25.4) 53 |                           |      |       |       |       |       |       |
|                                                                                                     |                             | T-L              | 70(294)      | 280(1931)                               | 68(74)                                                | 0.147 (3.7)                                                  | CC                | 0.25 (6.4)    | 3.0 (76.2)           | 1.0 (25.4)    |                           |      |       |       |       |       |       |
|                                                                                                     |                             | T-L              | -100(200)    | 305(2103)                               | 42(46)                                                | 0.047 (1.2)                                                  | CC                | 0.25 (6.4)    | 3.0 (76.2)           | 1.0 (25.4)    |                           |      |       |       |       |       |       |
| Plate: 1 in (25.4 mm) Thick                                                                         | B,2                         | I-ST             | 70(294)      | 285(1965)                               | 52(57)                                                | 0.083 (2.1)                                                  | Bend              | 0.25(6.4)     | 1.0 (25.4)           | 14            |                           |      |       |       |       |       |       |
|                                                                                                     |                             |                  |              |                                         |                                                       |                                                              |                   |               |                      |               |                           |      |       |       |       |       |       |
| Forging: 8 in (203) Dia Con. Elec. Vac. Remelt                                                      | C,3                         | I-T              | 70(2 94)     | 299(2062)                               | 68(75)                                                | 0.129 (3.3)                                                  | Bend              | 0.5(12.7)     | 1.0 (25.4)           | 0.5 (12.7) 59 |                           |      |       |       |       |       |       |
|                                                                                                     |                             | T-L              | 70(294)      | 300(2068)                               | 68(75)                                                | 0.128 (3.3)                                                  | Bend              | 0.5(12.7)     | 1.0 (25.4)           | 0.5 (12.7)    |                           |      |       |       |       |       |       |
|                                                                                                     | D,3                         | T-L              | -65(219)     | ---                                     | 54(59)                                                | ---                                                          | Bend              | 0.5(12.7)     | 1.0 (25.4)           | 0.5 (12.7)    |                           |      |       |       |       |       |       |
|                                                                                                     |                             | I-T              | 70(294)      | 280(1931)                               | 83(91)                                                | 0.326 (8.3)                                                  | Bend              | 0.5(12.5)     | 1.0 (25.4)           | 0.5 (12.7)    |                           |      |       |       |       |       |       |
|                                                                                                     |                             | I-L              | 70(294)      | 280(1931)                               | 77(85)                                                | 0.189 (4.8)                                                  | Bend              | 0.5(12.5)     | 1.0 (25.4)           | 0.5 (12.7)    |                           |      |       |       |       |       |       |
| G125                                                                                                |                             |                  |              |                                         |                                                       |                                                              |                   |               |                      |               |                           |      |       |       |       |       |       |
| Plate: 0.75 in (19 mm) Thick                                                                        | E,4                         | L-T              | 70(294)      | *296(2020)*                             | 63(69)                                                | ---                                                          | (a)               | ---           | ---                  | 70            |                           |      |       |       |       |       |       |
|                                                                                                     |                             | T-L              | 70(294)      | *296(2020)*                             | 60(66)                                                | ---                                                          | (a)               | ---           | ---                  | 40            |                           |      |       |       |       |       |       |
| COMPOSITION                                                                                         |                             |                  |              |                                         |                                                       |                                                              |                   |               |                      |               |                           |      |       |       |       |       |       |
|                                                                                                     |                             |                  |              | C                                       | Mn                                                    | Si                                                           | P                 | S             | Ni                   | Mo            | Ti                        | B    | Zr    | Cu    | V     |       |       |
| A                                                                                                   |                             |                  |              | 0.03                                    | 0.06                                                  | 0.07                                                         | 0.003             | 0.007         | 18.00                | 4.77          | 9.16                      | 0.12 | 0.70  | 0.005 | 0.01  | -     | -     |
| B                                                                                                   |                             |                  |              | 0.03                                    | 0.021                                                 | 0.06                                                         | 0.003             | 0.010         | 18.53                | 4.64          | 8.89                      | 0.15 | 0.69  | -     | -     | -     | -     |
| C                                                                                                   |                             |                  |              | 0.003                                   | 0.002                                                 | 0.01                                                         | 0.004             | 0.004         | 18.51                | 4.84          | 9.15                      | 0.15 | 0.84  | 0.002 | 0.011 | 0.002 | 0.01  |
| D                                                                                                   |                             |                  |              | 0.014                                   | 0.05                                                  | 0.02                                                         | 0.004             | 0.004         | 18.25                | 4.79          | 8.87                      | 0.10 | 0.60  | 0.004 | 0.010 | -     | -     |
| E                                                                                                   |                             |                  |              | 0.01N                                   | 0.05M                                                 | 0.05H                                                        | 0.005M            | 0.005M        | 18.5N                | 4.85N         | 9.0N                      | -    | 0.75M | -     | -     | -     | 0.10M |
| HEAT TREATMENT                                                                                      |                             |                  |              |                                         |                                                       |                                                              |                   |               |                      |               | * Tensile Ultimate Values |      |       |       |       |       |       |
| 1. 1650F (1172K), 1 Hr, Air Cool; Age 850F (728K), 3 Hr                                             |                             |                  |              |                                         |                                                       |                                                              |                   |               |                      |               |                           |      |       |       |       |       |       |
| 2. 1500F (1089K), Age 900F (756K), 3 Hr                                                             |                             |                  |              |                                         |                                                       |                                                              |                   |               |                      |               |                           |      |       |       |       |       |       |
| 3. Double Anneal, 1700F (1200K), 1 Hr, Fan Cool to 200F (367K), 1 Hr, Fan Cool to 200F (367K), 6 Hr |                             |                  |              |                                         |                                                       |                                                              |                   |               |                      |               |                           |      |       |       |       |       |       |
| 4. 1507F (1093K), Air Cool; 895F (753K), 3 Hr, Air Cool                                             |                             |                  |              |                                         |                                                       |                                                              |                   |               |                      |               |                           |      |       |       |       |       |       |

\* Tensile Ultimate Values

## COMPOSITION

|   | C     | Mn    | Si    | P      | S      | Ni    | Mo    | Cu   | Zr   | Ti    | B     | Cu    | V     |
|---|-------|-------|-------|--------|--------|-------|-------|------|------|-------|-------|-------|-------|
| A | 0.03  | 0.06  | 0.07  | 0.003  | 0.007  | 18.00 | 4.77  | 9.16 | 0.12 | 0.70  | 0.005 | 0.01  | -     |
| B | 0.03  | 0.021 | 0.06  | 0.003  | 0.010  | 18.53 | 4.64  | 8.89 | 0.15 | 0.69  | -     | -     | -     |
| C | 0.003 | 0.002 | 0.01  | 0.002  | 0.004  | 18.51 | 4.84  | 9.11 | 0.15 | 0.84  | 0.002 | 0.011 | -     |
| D | 0.014 | 0.05  | 0.02  | 0.004  | 0.004  | 18.25 | 4.79  | 8.87 | 0.10 | 0.60  | 0.004 | 0.010 | -     |
| E | 0.01N | 0.05N | 0.05N | 0.005N | 0.005N | 18.5N | 4.85N | 9.0N | -    | 0.75N | -     | -     | 0.10N |

## HEAT TREATMENT

- 1650F (1172K), 1 hr, Air Cool; Age 850F (728K), 3 Hr
- 1500F (1089K), Age 900F (756K), 3 Hr
- Double Anneal, 1700F (1200K), 1 hr, Fan Cool to 200F (367K), 1500F (1089K), 1 hr, Fan Cool to 200F (367K), Aged 900F (756K), 6 Hr
- 1507F (1093K), Air Cool; 895F (753K), 3 Hr, Air Cool

Table 17

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## STAINLESS STEEL: 17-4 PH

Table 18

| Form                                                                  | Composition,<br>Heat<br>Treat-<br>ment | Test<br>Orienta-<br>tion | $\sigma_F$ (ksi) | Yield<br>Strength<br>ksi (MN/m <sup>2</sup> ) | Typical<br>$K_{IC}$<br>ksi√in (MN/m <sup>3/2</sup> ) | $2.5\left(\frac{K_{IC}}{\sigma}\right)^2$<br>in (mm) | Specimen |                      |                  | Ref                        |
|-----------------------------------------------------------------------|----------------------------------------|--------------------------|------------------|-----------------------------------------------|------------------------------------------------------|------------------------------------------------------|----------|----------------------|------------------|----------------------------|
|                                                                       |                                        |                          |                  |                                               |                                                      |                                                      | Type     | Thickness<br>in (mm) | Width<br>in (mm) | Crack<br>Length<br>in (mm) |
| Plate: 0.5 in (12.7 mm) Thick                                         | B, 1                                   | L-T                      | 200 (367)        | 161 (1110)                                    | 81 (88)                                              | 0.633 (16.1)                                         | Bend     | 0.510 (13)           | 1.0 (25.4)       | ---                        |
|                                                                       | A, 1                                   | L-T                      | 70 (294)         | 168 (1158)                                    | 46 (50)                                              | 0.187 (4.7)                                          | Bend     | 0.510 (13)           | 1.0 (25.4)       | ---                        |
|                                                                       | A, 1                                   | T-L                      | ---              | ---                                           | 36 (40)                                              | ---                                                  | Bend     | 0.510 (13)           | 1.0 (25.4)       | ---                        |
|                                                                       | B, 1                                   | L-T                      | 70 (294)         | 170 (1172)                                    | 37 (41)                                              | 0.118 (3.0)                                          | Bend     | 0.510 (13)           | 1.0 (25.4)       | ---                        |
|                                                                       | B, 1                                   | T-L                      | 70 (294)         | ---                                           | 40 (44)                                              | ---                                                  | Bend     | 0.510 (13)           | 1.0 (25.4)       | ---                        |
|                                                                       | B, 1                                   | L-T                      | -50 (228)        | 189 (1303)                                    | 28 (31)                                              | 0.055 (1.4)                                          | Bend     | 0.510 (13)           | 1.0 (25.4)       | ---                        |
|                                                                       | A, 1                                   | L-T                      | -50 (228)        | 183 (1262)                                    | 29 (32)                                              | 0.063 (1.6)                                          | Bend     | 0.510 (13)           | 1.0 (25.4)       | ---                        |
|                                                                       | A, 1                                   | L-T                      | -100 (200)       | 190 (1310)                                    | 23 (25)                                              | 0.037 (1.0)                                          | Bend     | 0.510 (13)           | 1.0 (25.4)       | ---                        |
|                                                                       | B, 1                                   | L-T                      | -100 (200)       | 195 (1344)                                    | 27 (29)                                              | 0.048 (1.2)                                          | Bend     | 0.510 (13)           | 1.0 (25.4)       | ---                        |
|                                                                       | C, 1                                   | L-T                      | 70 (294)         | 209 (1441)                                    | 52 (57)                                              | 0.177 (4.5)                                          | Bend     | 0.635 (16.0)         | 0.635 (15.1)     | ---                        |
| Bar: 1/2 in (12.7 mm) Thick                                           | E, 3                                   | L-R                      | 70 (294)         | 186 (1292)                                    | 48 (53)                                              | 0.166 (4.2)                                          | Bend     | 0.75 (19.1)          | 1.5 (38.1)       | 0.75 (19.1) 120            |
| Bar: 3/32 in (83.3 μm) Thick<br>Electroslag remelted                  | D, 2                                   | L-R                      | 70 (294)         | 168 (1158)                                    | 85 (93)                                              | 0.640 (16.3)                                         | Bend     | 1.0 (25.4)           | 2.0 (50.8)       | 1.0 (25.4) 116             |
| COMPOSITION                                                           |                                        |                          |                  |                                               |                                                      |                                                      |          |                      |                  |                            |
|                                                                       | C                                      | Mn                       | P                | S                                             | Si                                                   | Cr                                                   | Ni       | Cu                   | Ta               | Ch                         |
| A                                                                     | 0.036                                  | 0.24                     | 0.018            | 0.016                                         | 0.58                                                 | 15.8                                                 | 1.31     | 3.46                 | 0.02             | 0.21                       |
| B                                                                     | 0.037                                  | 0.28                     | 0.019            | 0.013                                         | 0.60                                                 | 15.7                                                 | 4.37     | 3.29                 | 0.01             | 0.21                       |
| C                                                                     | 0.038                                  | 0.22                     | 0.018            | 0.018                                         | 0.64                                                 | 15.7                                                 | 4.27     | 3.46                 | 0.01             | 0.21                       |
| D                                                                     | 0.030                                  | 0.28                     | -                | 0.55                                          | 15.6                                                 | 15.6                                                 | 4.52     | 3.39                 | -                | 0.24                       |
| L                                                                     | 0.04                                   | 0.70                     | 0.15             | 0.08                                          | 0.41                                                 | 15.9                                                 | 4.45     | 3.45                 | -                | 0.23                       |
| HEAT TREATMENT                                                        |                                        |                          |                  |                                               |                                                      |                                                      |          |                      |                  |                            |
| 1. 1400F, (1033K) 1 1/2 Hr; Cool to 55F (286K), Age 900F (756K), 1 Hr |                                        |                          |                  |                                               |                                                      |                                                      |          |                      |                  |                            |
| 2. 11975 Condition                                                    |                                        |                          |                  |                                               |                                                      |                                                      |          |                      |                  |                            |
| 3. 900F (756K), 1 Hr, (11900 Condition)                               |                                        |                          |                  |                                               |                                                      |                                                      |          |                      |                  |                            |

Table 19

STAINLESS STEEL. 17-7 PH

TABLE 19

| Form                          | Composition, Heat Treatment | Test Orientation | Temp.<br>°F. (°K.) | Yield Strength<br>KSI (N/mm <sup>2</sup> ) | Typical<br>K <sub>IC</sub><br>KSI√in (MN m <sup>3/2</sup> ) | 2.5 /K <sub>IC</sub> <sup>2</sup><br>in (mm) | Specimen  | Ref.                 |                  |                         |   |
|-------------------------------|-----------------------------|------------------|--------------------|--------------------------------------------|-------------------------------------------------------------|----------------------------------------------|-----------|----------------------|------------------|-------------------------|---|
|                               |                             |                  |                    |                                            |                                                             |                                              | Type      | Thickness<br>in (mm) | Width<br>in (mm) | Crack Length<br>in (mm) |   |
| Plate: 0.5 in (12.7 mm) Thick |                             |                  |                    |                                            |                                                             |                                              |           |                      |                  |                         |   |
|                               | A, 1                        | L-T              | 75(297)            | 164(1131)                                  | 66(72)                                                      | 0.405(10.3)                                  | Bend 4 pt | 0.5 (12.7)           | 1.0 (25.4)       | 0.374(9.5)              | 7 |
|                               | A, 1                        | T-L              | 75(297)            | 153(1055)                                  | 64(70)                                                      | 0.436(11.1)                                  | Bend 4 pt | 0.5 (12.7)           | 1.0 (25.4)       | 0.203(1.9)              |   |
|                               | B, 2                        | L-T              | 75(297)            | 183(1262)                                  | 63(69)                                                      | 0.295( 7.5)                                  | Bend 4 pt | 0.5 (12.7)           | 1.0 (25.4)       | 0.269(6.8)              |   |
|                               | C, 2                        | L-T              | 75(297)            | 176(1212)                                  | 67(74)                                                      | 0.363( 9.2)                                  | Bend 4 pt | 0.5 (12.7)           | 1.0 (25.4)       | 0.236(6.0)              |   |
|                               | A, 1                        | L-T              | -50(228)           | 178(1227)                                  | 43(47)                                                      | 0.146( 3.7)                                  | Bend 4 pt | 0.5 (12.7)           | 1.0 (25.4)       | 0.260(6.6)              |   |
|                               | C, 1                        | L-T              | -50(228)           | 155(1069)                                  | 51(56)                                                      | 0.271( 6.9)                                  | Bend 4 pt | 0.5 (12.7)           | 1.0 (25.4)       | 0.223(5.7)              |   |
|                               | D, 1                        | L-T              | -50(228)           | 179(1254)                                  | 45(99)                                                      | 0.159( 4.0)                                  | Bend 4 pt | 0.5 (12.7)           | 1.0 (25.4)       | 0.252(6.4)              |   |
|                               | A, 1                        | L-T              | -100(200)          | 180(1241)                                  | 43(47)                                                      | 0.143( 3.6)                                  | Bend 4 pt | 0.5 (12.7)           | 1.0 (25.4)       | 0.206(5.2)              |   |
|                               | C, 1                        | L-T              | -100(200)          | 180(1241)                                  | 47(52)                                                      | 0.170( 4.3)                                  | Bend 4 pt | 0.5 (12.7)           | 1.0 (25.4)       | 0.211(5.4)              |   |
|                               | D, 1                        | L-T              | -100(200)          | 190(1310)                                  | 45(49)                                                      | 0.141( 3.6)                                  | Bend 4 pt | 0.5 (12.7)           | 1.0 (25.4)       | 0.234(5.9)              |   |
|                               | E, 2                        | L-T              | 75(297)            | 164(1130)                                  | 56(61)                                                      | 0.291( 7.4)                                  | Bend 4 pt | 0.223(5.7)           | 1.0 (25.4)       | 0.246(6.2)              |   |
|                               | E, 2                        | L-T              | -50(228)           | 165(1158)                                  | 38(42)                                                      | 0.128( 3.3)                                  | Bend 4 pt | 0.223(5.7)           | 1.0 (25.4)       | 0.242(6.1)              |   |
|                               | E, 2                        | L-T              | -100(200)          | 175(1207)                                  | 32(35)                                                      | 0.084( 2.1)                                  | Bend 4 pt | 0.223(5.7)           | 1.0 (25.4)       | 0.252(6.4)              |   |
|                               | F, 2                        | L-T              | -100(200)          | 186(1283)                                  | 47(52)                                                      | 0.159( 4.0)                                  | Bend 4 pt | 0.197(5.0)           | 0.910(23.1)      | 0.263(6.7)              |   |
|                               | G, 2                        | L-T              | -100(200)          | 168(1158)                                  | 49(54)                                                      | 0.212( 5.4)                                  | Bend 4 pt | 0.202(5.1)           | 0.930(23.6)      | 0.216(5.5)              |   |
|                               | H, 2                        | L-T              | 75(297)            | 206(1420)                                  | 69(76)                                                      | 0.292( 7.5)                                  | Bend 4 pt | 0.610(15.5)          | 0.616(16.6)      | 0.153(6.0)              |   |
| Plate: 0.188 in 4.8 mm Thick  |                             |                  |                    |                                            |                                                             |                                              |           |                      |                  |                         |   |
| Bar: 1 in (25.4 mm) Thick     |                             |                  |                    |                                            |                                                             |                                              |           |                      |                  |                         |   |

COMPOSITION

|   | C     | Cr   | Ni   | Al   | Nb   | Si   | P     | S     |
|---|-------|------|------|------|------|------|-------|-------|
| A | 0.080 | 16.9 | 6.85 | 1.30 | 0.75 | 0.26 | 0.011 | 0.013 |
| B | 0.080 | 16.9 | 7.85 | 1.30 | 0.75 | 0.26 | 0.011 | 0.013 |
| C | 0.078 | 16.9 | 7.38 | 1.36 | 0.62 | 0.25 | 0.023 | 0.008 |
| D | 0.076 | 17.0 | 7.17 | 1.22 | 0.66 | 0.32 | 0.019 | 0.007 |
| E | 0.073 | 16.7 | 7.20 | 1.05 | 0.72 | 0.43 | 0.028 | 0.005 |
| F | 0.069 | 17.2 | 7.29 | 1.08 | 0.63 | 0.36 | 0.017 | 0.012 |
| G | 0.077 | 16.7 | 6.56 | 1.11 | 0.78 | 0.50 | 0.032 | 0.013 |
| H | 0.072 | 17.3 | 7.10 | 0.90 | 0.68 | 0.54 | 0.028 | 0.005 |

HEAT TREATMENT

1. 1400F (1035K), 1.5 hr; Cool to 550F (288K), 1.5 hr
2. 1750F (1228K), 10 min; Cool to -110F (194K), 3 hr; Age 950F (783K), 1 hr

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HEAT TREATMENT

1. 1400F (1035K), 1.5 hr; Cool to 550F (564K); Age 1050F (832K), 1.5 hr
2. 1750F (1228K), 10 min; Cool to -110F (194K), 3 hr; Age 950F (783K), 1 hr

Table 20

| Form                          | Composition,<br>Heat Treatment | Test Orientation | Temp<br>°F (°K) | Yield Strength<br>KSI (MN/m <sup>2</sup> ) | Typical<br>K <sub>IC</sub><br>KSI/√in (MN m <sup>3/2</sup> ) | 2.5<br>( $\frac{K_{IC}}{\sigma_{ys}}$ ) <sup>2</sup><br>in (mm) | Specimen     |                      |                  | Ref.       |                         |
|-------------------------------|--------------------------------|------------------|-----------------|--------------------------------------------|--------------------------------------------------------------|-----------------------------------------------------------------|--------------|----------------------|------------------|------------|-------------------------|
|                               |                                |                  |                 |                                            |                                                              |                                                                 | Type         | Thickness<br>in (mm) | Width<br>in (mm) |            | Crack Length<br>in (mm) |
| Plate: 0.5 in (12.7 mm) Thick | A,1                            | L-T              | +200(367)       | 196(1551)                                  | 88( 96)                                                      | 0.504(12.8)                                                     | Bend<br>4 pt | 0.520(13.2)          | 1.0(25.4)        | 0.300(7.6) | 7                       |
|                               | B,1                            | L-T              | +200(367)       | 191(1517)                                  | 65( 71)                                                      | 0.290( 7.4)                                                     | Bend<br>4 pt | 0.520(13.2)          | 1.0(25.4)        | 0.317(8.8) |                         |
|                               | A,1                            | L-T              | 70(294)         | 207(1427)                                  | 45( 49)                                                      | 0.118( 3.0)                                                     | Bend<br>4 pt | 0.520(13.2)          | 1.0(25.4)        | 0.257(6.5) |                         |
|                               | B,1                            | L-T              | 70(294)         | 205(1400)                                  | 50( 55)                                                      | 0.152( 3.9)                                                     | Bend<br>4 pt | 0.520(13.2)          | 1.0(25.4)        | 0.276(7.0) |                         |
|                               | A,2                            | L-T              | 70(294)         | 195(1344)                                  | 76( 83)                                                      | 0.569(14.4)                                                     | Bend<br>4 pt | 0.510(13.0)          | 1.0(25.4)        | 0.238(6.0) |                         |
|                               | A,2                            | L-T              | 70(294)         | 183(1262)                                  | 74( 81)                                                      | 0.409(10.4)                                                     | Bend<br>4 pt | 0.510(13.0)          | 1.0(25.4)        | 0.287(7.3) |                         |
|                               | A,2                            | L-T              | -50(228)        | 203(1400)                                  | 53( 58)                                                      | 0.170( 4.3)                                                     | Bend<br>4 pt | 0.510(13.0)          | 1.0(25.4)        | 0.381(9.7) |                         |
|                               | A,1                            | L-T              | -50(228)        | 218(1503)                                  | 28( 31)                                                      | 0.041( 1.0)                                                     | Bend<br>4 pt | 0.510(13.0)          | 1.0(25.4)        | 0.160(4.1) |                         |
|                               | B,2                            | L-T              | -50(228)        | 184(1250)                                  | 46( 50)                                                      | 0.625(15.9)                                                     | Bend<br>4 pt | 0.510(13.0)          | 1.0(25.4)        | 0.269(6.8) |                         |
|                               | B,1                            | L-T              | -100(200)       | 232(1630)                                  | 29( 32)                                                      | 0.039( 1.0)                                                     | Bend<br>4 pt | 0.510(13.0)          | 1.0(25.4)        | 0.300(7.6) |                         |
|                               | B,2                            | L-T              | -100(200)       | 205(1400)                                  | 46( 50)                                                      | 0.13 ( 3.3)                                                     | Bend<br>4 pt | 0.510(13.0)          | 1.0(25.4)        | 0.282(7.2) |                         |
|                               | A,2                            | L-T              | -100(200)       | 200(1379)                                  | 47( 51)                                                      | 0.138( 3.5)                                                     | Bend<br>4 pt | 0.510(13.0)          | 1.0(25.4)        | 0.281(7.2) |                         |
|                               | C,3                            | L-T              | -75(297)        | 173(1193)                                  | 53( 58)                                                      | 0.236(6.0)                                                      | Bend<br>4 pt | 0.750(19.1)          | 0.750(19.1)      | 0.3 (7.6)  |                         |
|                               | D,3                            | L-T              | 75(297)         | 178(1228)                                  | 50( 55)                                                      | 0.197(5.0)                                                      | Bend<br>4 pt | 0.750(19.1)          | 0.750(19.1)      | 0.236(6.0) |                         |
| Bar: 1 in (25.4 mm) Thick     |                                |                  |                 |                                            |                                                              |                                                                 |              |                      |                  |            |                         |

## COMPOSITION:

|   | C     | Cr   | Ni   | Mo   | Al   | Mn   | Si   | P     | S     |
|---|-------|------|------|------|------|------|------|-------|-------|
| A | 0.070 | 15.3 | 7.71 | 2.30 | 1.28 | 0.61 | 0.60 | 0.012 | 0.009 |
| B | 0.070 | 15.1 | 7.31 | 2.37 | 1.19 | 0.52 | 0.26 | 0.018 | 0.012 |
| C | 0.055 | 14.5 | 7.33 | 2.16 | 1.15 | 0.75 | 0.39 | 0.018 | 0.016 |
| D | 0.060 | 14.6 | 7.43 | 2.21 | 1.22 | 0.74 | 0.38 | 0.019 | 0.013 |

## HEAT TREATMENT:

1. 1400F (1033K) 1.5 Hr; Cool to 55F (286K); Age to 1650F (899K), 1 Hr
2. 1400F (1033K) 1.5 Hr; Cool to 55F (286K); Age to 1130F (616K), 1.5 Hr
3. 1400F (1033K) 1.5 Hr; Cool to 55F (286K); Age to 1080F (594K), 1.5 Hr

Table 21

STAINLESS STEEL: PH13-8 MO and PV 520R

| Table 21                                                                                         |                             |                  |              |                                         |                                                        |                                                               |          |                   |               |             |                     |
|--------------------------------------------------------------------------------------------------|-----------------------------|------------------|--------------|-----------------------------------------|--------------------------------------------------------|---------------------------------------------------------------|----------|-------------------|---------------|-------------|---------------------|
| Form                                                                                             | Composition, Heat Treatment | Test Orientation | Temp °F (°K) | Yield Strength KSI (MN/m <sup>2</sup> ) | Typical K <sub>IC</sub> KSI√in (MN m <sup>-3/2</sup> ) | 2.5 (K <sub>IC</sub> / σ <sub>ys</sub> ) <sup>2</sup> in (mm) | Specimen |                   |               | Ref.        |                     |
|                                                                                                  |                             |                  |              |                                         |                                                        |                                                               | Type     | Thickness in (mm) | Width in (mm) |             | Gage Length in (mm) |
| <b>PH13-8MO</b>                                                                                  |                             |                  |              |                                         |                                                        |                                                               |          |                   |               |             |                     |
| Forging: 4.5 x 4.5 in (114.3 x 114.3 mm)<br>Double Vacuum Melted                                 | A,1                         | L-T              | 70(204)      | 206(1420)                               | 92(100)                                                | 0.500(12.7)                                                   | DEC      | 0.500(12.7)       | 3.0(76.2)     | 0.500(12.7) | 16                  |
|                                                                                                  |                             | L-T              | -110(194)    | 229(1579)                               | 43(47)                                                 | 0.088(2.2)                                                    | SEN      | 0.250(6.4)        | 1.0(25.4)     | 0.500(12.7) |                     |
|                                                                                                  |                             | T-L              | -110(194)    | 227(1565)                               | 41(45)                                                 | 0.081(2.1)                                                    | SEN      | 0.250(6.4)        | 1.0(25.4)     | 0.500(12.7) |                     |
| Forging: 15 x 15 in (380.2 x 380.2 mm)                                                           |                             | L-T              | -110(194)    | 224(1544)                               | 53(58)                                                 | 0.146(3.7)                                                    | SEN      | 0.250(6.4)        | 1.0(25.4)     | 0.500(12.7) |                     |
|                                                                                                  |                             | T-L              | -110(194)    | 218(1503)                               | 57(62)                                                 | 0.171(4.3)                                                    | SEN      | 0.250(6.4)        | 1.0(25.4)     | 0.500(12.7) |                     |
| Plate: 1.5 x 15 in (38.1 x 380.2 mm)                                                             |                             | L-T              | -110(194)    | 219(1510)                               | 47(51)                                                 | 0.115(2.9)                                                    | SEN      | 0.250(6.4)        | 1.0(25.4)     | 0.500(12.7) |                     |
|                                                                                                  |                             | T-L              | -110(194)    | 226(1558)                               | 47(51)                                                 | 0.108(2.7)                                                    | SEN      | 0.250(6.4)        | 1.0(25.4)     | 0.500(12.7) |                     |
| Forging: 9 x 9 in (229 x 229 mm)                                                                 | B,2                         | L-TS             | 70(294)      | 205(1412)                               | 89(98)                                                 | 0.468(11.9)                                                   | CN       | 1.0(25.4)         | 8.6(21.8)     | ---         | 50                  |
|                                                                                                  |                             | L-TS             | -110(194)    | 219(1510)                               | 42(46)                                                 | 0.092(2.3)                                                    | CN       | 1.0(25.4)         | 8.6(21.8)     | ---         |                     |
| <b>PV520R</b>                                                                                    |                             |                  |              |                                         |                                                        |                                                               |          |                   |               |             |                     |
| Bar: 6 in (152 mm) Dia                                                                           | C,2                         | L-R              | 70(294)      | 170(1172)                               | 119(131)                                               | 1.225(31.1)                                                   | (a)      | ---               | ---           | ---         | 65                  |
| (a) Specimen in accordance with ASTM Recommendations                                             |                             |                  |              |                                         |                                                        |                                                               |          |                   |               |             |                     |
| COMPOSITION                                                                                      |                             |                  |              |                                         |                                                        |                                                               |          |                   |               |             |                     |
|                                                                                                  |                             |                  | C            | Si                                      | Mn                                                     | P                                                             | Mo       | Ni                | Cr            | Al          | Cu                  |
| A                                                                                                |                             |                  | 0.012        | 0.02                                    | 0.02                                                   | 0.001                                                         | 0.003    | 2.06              | 8.07          | 12.58       | 1.11                |
| B                                                                                                |                             |                  | 0.015        | 0.52                                    | 0.10                                                   | 0.003                                                         | 0.003    | 2.14              | 8.40          | 12.72       | 0.96                |
| C                                                                                                |                             |                  | 0.070        | 0.69                                    | 1.04                                                   | 0.025M                                                        | 0.035M   | 1.6N              | 5.4N          | 13.7N       | 1.6N                |
| PH 13-8MO                                                                                        |                             |                  |              |                                         |                                                        |                                                               |          |                   |               |             |                     |
| 1. 1700(1200) 1 Hr, Air Cool; Refrigerated at -110(194), 16 Hrs; Aged 1000(811K), 1 Hr, Air Cool |                             |                  |              |                                         |                                                        |                                                               |          |                   |               |             |                     |
| 2. 1921(1579), 150(112) 84H (723K), 3 Hr.                                                        |                             |                  |              |                                         |                                                        |                                                               |          |                   |               |             |                     |

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(a) Specimen in accordance with ASTM Recommendations

## COMPOSITION

|   | C     | Si   | Mn   | S     | P     | Mo   | Ni   | Cr    | Al   | Cu         |
|---|-------|------|------|-------|-------|------|------|-------|------|------------|
| A | 0.042 | 0.02 | 0.02 | 0.001 | 0.003 | 2.06 | 8.07 | 12.58 | 1.11 | -          |
| B | 0.045 | 0.32 | 0.10 | 0.004 | 0.003 | 2.14 | 8.40 | 12.72 | 0.96 | -          |
| C | 0.073 | 0.69 | 1.04 | 0.025 | 0.035 | 1.6N | 5.4N | 13.7N | -    | 1.6N 0.35N |

## PH 13-8MO

1. 1700F (927C) 1 Hr, Air Cool; Refrigerated at -110F (194K), 16 Hrs; Aged 1000F (538C), 1 Hr, Air Cool
2. 1921F (1052C), 150 x (112 x) 8411 (723K), 3 Hr.

STAINLESS STEEL: AISC 77, AISC 266 (Sheet 1 of 2)

Table 22

| Form                               | Composition, Heat Treatment                                                                                                                  | Test Orientation | Temp °F (°K) | Yield Strength ksi (N/m <sup>2</sup> ) | Typical K <sub>IC</sub> ksi√in (MN/m <sup>3/2</sup> ) | 2.5( $\frac{K_{IC}}{\sigma_{ys}}$ ) in (mm) | Specimen |                   |               | Crack Length in (mm) | Ref  |      |
|------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------|------------------|--------------|----------------------------------------|-------------------------------------------------------|---------------------------------------------|----------|-------------------|---------------|----------------------|------|------|
|                                    |                                                                                                                                              |                  |              |                                        |                                                       |                                             | Type     | Thickness in (mm) | Width in (mm) |                      |      |      |
| A1355                              |                                                                                                                                              |                  |              |                                        |                                                       |                                             |          |                   |               |                      |      |      |
| Plate: 0.5 in (12.7 mm) Thick      | A,1                                                                                                                                          | L-T              | -50(228)     | 178(1227)                              | 80(88)                                                | 0.505 (12.8)                                | Bend     | 0.775(19.7)       | 0.793(20.1)   | 0.22 (5.6)           | 7    |      |
|                                    |                                                                                                                                              | L-T              | -100(200)    | 180(1241)                              | 54(59)                                                | 0.225 (5.7)                                 | Bend     | 0.775(19.7)       | 0.793(20.1)   | 0.22 (5.6)           |      |      |
| Plate: 0.625 in (15.9 mm) Thick    | A,2                                                                                                                                          | L-T              | 70(294)      | 201(1386)                              | 74(81)                                                | 0.359 (8.6)                                 | Bend     | 0.625(15.9)       | 1.0 (25.4)    | ---                  | 50   |      |
| Forging: 9x9 in (230 x 230 mm)     | B,3                                                                                                                                          | L-T              | 70(294)      | 167(1151)                              | 63(69)                                                | 0.356 (9.0)                                 | CC       | 1.0 (25.4)        | 9.0 (229)     | 1.5 (38.1)           |      |      |
|                                    |                                                                                                                                              | L-T              | -110(193)    | 203(1400)                              | 24(70)                                                | 0.35 (8.9)                                  | CC       | 0.375(9.5)        | 6.0 (152)     | 0.5 (12.7)           |      |      |
| A1357                              |                                                                                                                                              |                  |              |                                        |                                                       |                                             |          |                   |               |                      |      |      |
| Bar: 3 in (76.2 mm) Dia Air Melted | C,4                                                                                                                                          | L-R              | 70(294)      | 222(1531)                              | 74(81)                                                | 0.278 (7.1)                                 | Bend     | 0.48 (12.2)       | 1.5 (38.1)    | ---                  | 90   |      |
|                                    |                                                                                                                                              | R-L              | 70(294)      | 210(1448)                              | 50(76)                                                | 0.270 (6.9)                                 | Bend     | 0.59 (1)          | 0.39 (1)      |                      |      |      |
|                                    | C,5                                                                                                                                          | L-R              | 70(294)      | 277(1917)                              | 106(117)                                              | 0.366 (9.3)                                 | Bend     | 0.48 (12.2)       | 1.5 (38.1)    |                      |      |      |
| Plate: 0.56 in (14.2 mm) Thick     | C,6                                                                                                                                          | L-T              | 70(294)      | 290(1379)                              | 110(121)                                              | 0.75 (19.1)                                 | Bend     | 0.5 (12.7)        | 1.5 (38.1)    | 0.5 (12.7)           | 77   |      |
| A1360                              |                                                                                                                                              |                  |              |                                        |                                                       |                                             |          |                   |               |                      |      |      |
| Plate: 0.55 in (14 mm) Thick       | D,7                                                                                                                                          | L-T              | 75(297)      | 206(1420)                              | 90(99)                                                | 0.477 (12.1)                                | Bend     | 0.5 (12.7)        | 1.5 (38.1)    | ---                  | 114  |      |
| COMPOSITION                        |                                                                                                                                              |                  |              |                                        |                                                       |                                             |          |                   |               |                      |      |      |
|                                    | C                                                                                                                                            | Si               | Mn           | S                                      | P                                                     | Ni                                          | Cr       | Mo                | V             | Co                   | N    | Cl   |
| A                                  | 0.113                                                                                                                                        | 0.32             | 1.08         | 0.006                                  | 0.012                                                 | 4.06                                        | 15.08    | 2.82              | -             | -                    | -    | -    |
| B                                  | 0.12                                                                                                                                         | 0.44             | 1.21         | 0.009                                  | 0.015                                                 | 4.49                                        | 15.02    | 2.76              | -             | -                    | -    | -    |
| C                                  | 0.16                                                                                                                                         | 0.13             | 0.18         | 0.021                                  | 0.015                                                 | 0.21                                        | 14.0     | 5.02              | 0.23          | 13.41                | 0.04 | -    |
| D                                  | 0.07                                                                                                                                         | 0.30             | 0.34         | 0.012                                  | 0.015                                                 | 1.94                                        | 15.4     | 4.3               | -             | 13.0                 | 0.04 | 0.14 |
| HEAT TREATMENT                     |                                                                                                                                              |                  |              |                                        |                                                       |                                             |          |                   |               |                      |      |      |
| 1.                                 | 1750F (1206K), Water Quench; -100F (200K), 3 hr; Age 1000F (811K), 3 hr                                                                      |                  |              |                                        |                                                       |                                             |          |                   |               |                      |      |      |
| 2.                                 | 1710F (1206K), 10 min; Temper 925F (770K), 3 hr                                                                                              |                  |              |                                        |                                                       |                                             |          |                   |               |                      |      |      |
| 3.                                 | 1925F (1325K), 0.5 hr; Oil Quench; -100F (200K), 3 hr; Temper 850F (728K), 2 hr; Oil Quench; -100F (200K), 3 hr; 850F (728K), 1 hr; Air Cool |                  |              |                                        |                                                       |                                             |          |                   |               |                      |      |      |
| 4.                                 | 1900F (1311K), 1 hr; Oil Quench; -100F (200K), 0.5 hr; Temper 800F (700K), 2 hr + 2 hr, Air Cool                                             |                  |              |                                        |                                                       |                                             |          |                   |               |                      |      |      |

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Table 22 (Cont.)

| Form                                                                                                                                                                                                                   | Composition, Heat Treatment | Test Orientation | Temp, °F (°K) | Yield Strength KSI (N/mm <sup>2</sup> ) | Typical $K_{IC}$ KSI√in (MN/m <sup>3/2</sup> ) | $2.5 \left( \frac{K_{IC}}{\sigma_{ys}} \right)^2$ in (mm) | Specimen |                   |               |                      |
|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----------------------------|------------------|---------------|-----------------------------------------|------------------------------------------------|-----------------------------------------------------------|----------|-------------------|---------------|----------------------|
|                                                                                                                                                                                                                        |                             |                  |               |                                         |                                                |                                                           | Type     | Thickness in (mm) | Width in (mm) | Crack Length in (mm) |
| HEAT TREATMENT                                                                                                                                                                                                         |                             |                  |               |                                         |                                                |                                                           |          |                   |               |                      |
| 5. 2000F (1067K), 1 hr, Oil Quench; -100F (200K), 0.5 hr; Temper 500F (533K), 2 hr, 10% Cold Reduction by Rolling; Temper 700F (644K), 2 hr + 2 hr, Air Cool                                                           |                             |                  |               |                                         |                                                |                                                           |          |                   |               |                      |
| 6. Cold Rolled from 1.12 in (28.5 mm) Plate to 0.56 in (14.2 mm) in 5 stages with Intermediate Anneal, 1400F (1033K); 1800-1875F (1255-1297K), 1 hr, Oil Quench; -100F (200K), 0.5 hr, Temper 500F (533K), 2 hr + 2 hr |                             |                  |               |                                         |                                                |                                                           |          |                   |               |                      |
| 7. 2000F (1067K), 1 hr; 1900F (1311K), 1 hr, Oil Quench; -320F (76K), 1 hr, 1000F (811K), 2 hr + 2 hr                                                                                                                  |                             |                  |               |                                         |                                                |                                                           |          |                   |               |                      |

STELL: ABS-C, ASIN A203 Grade A & B

Table 23

| Form                                                                                | Compo-<br>sition,<br>Heat<br>Treat-<br>ment | Test<br>Orien-<br>tation | Temp<br>°F (°K) | Yield<br>Strength<br>KSI (MN/m <sup>2</sup> ) | Typical<br>K <sub>IC</sub><br>KSI√in (MN/m <sup>3/2</sup> ) | 2.5( $\frac{K_{IC}}{\sigma_{ys}}$ ) <sup>2</sup><br>in (mm) | Specimen        |                      |                  | Ref   |
|-------------------------------------------------------------------------------------|---------------------------------------------|--------------------------|-----------------|-----------------------------------------------|-------------------------------------------------------------|-------------------------------------------------------------|-----------------|----------------------|------------------|-------|
|                                                                                     |                                             |                          |                 |                                               |                                                             |                                                             | Type            | Thickness<br>in (mm) | Width<br>in (mm) |       |
| AISI-C<br>Plate: 1 in (25.4 mm) Thick.<br>Open Heart<br>Si-Al Killed                |                                             |                          |                 |                                               |                                                             |                                                             |                 |                      |                  |       |
|                                                                                     | A,1                                         | L-T                      | 70(293)         | 39(269)                                       |                                                             |                                                             |                 |                      |                  | 10    |
|                                                                                     |                                             | L-T                      | -210(138)       | 60(414)                                       | 43(47)                                                      | 1.28 (32.6)                                                 | Bend 1.0 (25.4) | 3.0 (76.2)           | 1.6 (40.6)       |       |
|                                                                                     |                                             | L-T                      | -275(103)       | 94(648)                                       | 25(27)                                                      | 0.177(4.5)                                                  | Bend 1.0 (25.4) | 3.0 (76.2)           | 1.6 (40.6)       |       |
|                                                                                     |                                             | L-T                      | -221(77.2)      | 116(809)                                      | 23(25)                                                      | 0.098(2.5)                                                  | Bend 1.0 (25.4) | 3.0 (76.2)           | 1.6 (40.6)       |       |
| A203 Grade A<br>Plate: 1.65 in (42 mm) Thick                                        |                                             |                          |                 |                                               |                                                             |                                                             |                 |                      |                  |       |
|                                                                                     | B,2                                         | L-T                      | -200(144)       | 65(448)                                       | 51(56)                                                      | 1.54 (39.1)                                                 | CT              | 1.645(41.8)          | ---              | 102   |
|                                                                                     |                                             | L-T                      | -250(112)       | 77(531)                                       | 39(43)                                                      | 0.641(16.3)                                                 | CT              | 1.645(41.8)          | ---              |       |
|                                                                                     |                                             | L-T                      | -250(112)       | 90(621)                                       | 57(62)                                                      | 1.002(25.5)                                                 | CT              | 1.645(41.8)          | ---              |       |
|                                                                                     |                                             | L-T                      | -300(88)        | ---                                           | 41(45)                                                      | ---                                                         | CT              | 1.645(41.8)          | ---              |       |
| A203 Grade B<br>Plate: 2 in (50.8 mm) Thick                                         |                                             |                          |                 |                                               |                                                             |                                                             |                 |                      |                  |       |
|                                                                                     | C,2                                         | L-T                      | -150(172)       | 61(421)                                       | 38(42)                                                      | 0.970(24.6)                                                 | CT              | 2.0 (50.8)           | ---              | 102   |
|                                                                                     |                                             | L-T                      | -250(144)       | 70(483)                                       | 37(41)                                                      | 0.698(17.7)                                                 | CT              | 2.0 (50.8)           | ---              |       |
|                                                                                     |                                             | L-T                      | -300(88)        | ---                                           | 39(43)                                                      | ---                                                         | CT              | 2.0 (50.8)           | ---              |       |
|                                                                                     |                                             | COMPOSITION              |                 |                                               |                                                             |                                                             |                 |                      |                  |       |
| C                                                                                   | Mn                                          | P                        | S               | Si                                            | Ni                                                          | Cr                                                          | Mo              | Cu                   | Al               |       |
| A                                                                                   | 0.20                                        | 0.60                     | 0.009           | 0.016                                         | 0.023                                                       | 0.02                                                        | 0.07            | 0.01                 | 0.03             | 0.057 |
| B                                                                                   | 0.14                                        | 0.51                     | 0.014           | 0.022                                         | 0.18                                                        | 2.55                                                        | -               | -                    | -                | -     |
| C                                                                                   | 0.11                                        | 0.45                     | 0.010           | 0.023                                         | 0.23                                                        | 3.35                                                        | -               | -                    | -                | -     |
| HEAT TREATMENT                                                                      |                                             |                          |                 |                                               |                                                             |                                                             |                 |                      |                  |       |
| 1. 1650F (1172K), 1 Hr, Air Cool                                                    |                                             |                          |                 |                                               |                                                             |                                                             |                 |                      |                  |       |
| 2. Normalized                                                                       |                                             |                          |                 |                                               |                                                             |                                                             |                 |                      |                  |       |
| 3. 1650F (1172K), 2 Hr, Water Spray Quenched; Tempered 1150F (894K), 2 Hr, Air Cool |                                             |                          |                 |                                               |                                                             |                                                             |                 |                      |                  |       |

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STEEL: Low Strength: AISI 1015

Table 24

| Form                                               | Composition, Heat Treatment | Test Orientation | $\sigma_F$ (ksi) | Yield Strength (ksi) | Typical $K_{IC}$ (ksi $\sqrt{in}$ ) | $2.5 \left( \frac{K_{IC}}{\sigma_y} \right)^2$ in (mm) | Specimen |                   |               |                      |
|----------------------------------------------------|-----------------------------|------------------|------------------|----------------------|-------------------------------------|--------------------------------------------------------|----------|-------------------|---------------|----------------------|
|                                                    |                             |                  |                  |                      |                                     |                                                        | Type     | Thickness in (mm) | Width in (mm) | Crack Length in (mm) |
| Plate: 4 in (101.6 mm) Thick                       | A, 1                        | L-T              | 25 (269)         | 39 (439)             | 46 (50)                             | 3.5 (88.9)                                             | NOL      | 4.0 (101.6)       | 10.22 (260)   | 4.08 (104)           |
|                                                    |                             | L-T              | 0 (256)          | 40 (276)             | 46 (50)                             | 3.7 (84.1)                                             | NOL      | 4.0 (101.6)       | 10.22 (260)   | 4.08 (104)           |
| COMPOSITION                                        |                             |                  |                  |                      |                                     |                                                        |          |                   |               |                      |
| C                                                  | Mn                          | P                | S                | Si                   | Ni                                  | Cr                                                     | Mo       | Cu                | V             | Ti                   |
| A 0.52                                             | 0.83                        | 0.006            | 0.028            | 0.25                 | 0.12                                | <0.10                                                  | 0.03     | 0.29              | <0.01         | <0.01                |
| HEAT TREATMENT                                     |                             |                  |                  |                      |                                     |                                                        |          |                   |               |                      |
| 1. Normalized; Heated to 1700F (1200K), Air Cooled |                             |                  |                  |                      |                                     |                                                        |          |                   |               |                      |

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## STEEL: ASTM A216

Table 25

| Form                                                                                                                                                                                                                                  | Compo-<br>sition,<br>Heat<br>Treat-<br>ment | Test<br>Orienta-<br>tion | Temp<br>°F (°K) | Yield<br>Strength<br>KSI (N/m <sup>2</sup> ) | Typical<br>K <sub>IC</sub><br>KSI√in (MPa/m <sup>3/2</sup> ) | 2.5( $\frac{K_{IC}}{\sigma_{ys}}$ ) <sup>2</sup><br>in (mm) | Specimen |                      |                  |                            | Ref |
|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|---------------------------------------------|--------------------------|-----------------|----------------------------------------------|--------------------------------------------------------------|-------------------------------------------------------------|----------|----------------------|------------------|----------------------------|-----|
|                                                                                                                                                                                                                                       |                                             |                          |                 |                                              |                                                              |                                                             | Type     | Thickness<br>in (mm) | Width<br>in (mm) | Crack<br>Length<br>in (mm) |     |
| A216 WCC Grade<br>Casting: 20" x 20 x 48 in<br>(508 x 508 x 219 mm)                                                                                                                                                                   |                                             |                          |                 |                                              |                                                              |                                                             |          |                      |                  |                            |     |
|                                                                                                                                                                                                                                       | A, 1                                        | -                        | -50(228)        | 55(379)                                      | 90(59)                                                       | 6.694(170)                                                  | WOL      | 6 (152)              | 15.3 (389)       | 6.5 (165)                  | 103 |
|                                                                                                                                                                                                                                       |                                             |                          | -100(200)       | 61(421)                                      | 49(54)                                                       | 1.613 (41)                                                  | WOL      | 2 (50.8)             | 5.1 (130)        | 2.08 (53)                  |     |
|                                                                                                                                                                                                                                       |                                             |                          | -150(172)       | 67(462)                                      | 48(53)                                                       | 1.283(32.6)                                                 | WOL      | 2 (50.8)             | 5.1 (130)        | 2.12 (54)                  |     |
|                                                                                                                                                                                                                                       |                                             |                          | -200(144)       | 77(531)                                      | 33(36)                                                       | 0.459(11.7)                                                 | WOL      | 2 (50.8)             | 5.1 (130)        | 2.11 (54)                  |     |
| COMPOSITION                                                                                                                                                                                                                           |                                             |                          |                 |                                              |                                                              |                                                             |          |                      |                  |                            |     |
|                                                                                                                                                                                                                                       | C                                           | Mn                       | P               | S                                            | Si                                                           | Ni                                                          | Cr       | Mo                   | Al               |                            |     |
| A                                                                                                                                                                                                                                     | 0.24                                        | 1.15                     | 0.008           | 0.011                                        | 0.44                                                         | 0.37                                                        | 0.09     | 0.02                 | 0.06             |                            |     |
| HEAT TREATMENT                                                                                                                                                                                                                        |                                             |                          |                 |                                              |                                                              |                                                             |          |                      |                  |                            |     |
| 1. 1650F (1172K), 8 hr, Furnace Cool 600F (589K); 1125F (881K), Furnace Cool 650° (589K);<br>1750F (1228K), 8 hr, Furnace Cool to 1650F (1172K), Equalize; Accelerated Cooling to<br>200F (367K), Temper 1300F (922K), 8 hr, Air Cool |                                             |                          |                 |                                              |                                                              |                                                             |          |                      |                  |                            |     |

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STILL: ASTM A302B

Table 26

| Form                        | Composition, Heat Treatment | Test Orientation | Temp of test, °K | Yield Strength<br>ksi (N/mm <sup>2</sup> ) | Typical<br>K <sub>IC</sub><br>ksi√in (MN/m <sup>3/2</sup> ) | 2.5( $\frac{K_{IC}}{\sigma_{ys}}$ ) <sup>2</sup><br>in (mm) | Specimen |                   |               |                      | Ref |
|-----------------------------|-----------------------------|------------------|------------------|--------------------------------------------|-------------------------------------------------------------|-------------------------------------------------------------|----------|-------------------|---------------|----------------------|-----|
|                             |                             |                  |                  |                                            |                                                             |                                                             | Type     | Thickness in (mm) | Width in (mm) | Crack Length in (mm) |     |
| Plate: 1 in (25.4 mm) thick | A, 1                        | L-T              | -150 (172)       | 65 (448)                                   | 47 (52)                                                     | 1.31 (33.2)                                                 | Bend     | 1.0 (25.4)        | 3.0 (76.2)    | 1.6 (40.6)           | 10  |
|                             |                             | L-T              | -200 (144)       | 73 (503)                                   | 32 (35)                                                     | 0.48 (12.2)                                                 | Bend     | 1.0 (25.4)        | 3.0 (76.2)    | 1.6 (40.6)           |     |
|                             |                             | L-T              | -250 (112)       | 89 (614)                                   | 25 (27)                                                     | 0.197 (5.0)                                                 | Bend     | 1.0 (25.4)        | 3.0 (76.2)    | 1.6 (40.6)           |     |
|                             |                             | L-T              | -321 (77)        | 123 (848)                                  | 23 (25)                                                     | 0.087 (2.2)                                                 | Bend     | 1.0 (25.4)        | 3.0 (76.2)    | 1.6 (40.6)           |     |
| Plate: 7 in (178 mm) thick  | B, 2                        | T-L              | 0 (256)          | 50 (345)                                   | 53 (58)                                                     | 2.8 (71.3)                                                  | WOL      | 4.0 (101.6)       | 4.5 (114.3)   | 2.0 (50.8)           | 11  |
|                             |                             | T-L              | -100 (200)       | 63 (434)                                   | 45 (49)                                                     | 1.28 (32.4)                                                 | WOL      | 4.0 (101.6)       | 4.5 (114.3)   | 2.0 (50.8)           |     |
|                             |                             | T-L              | -200 (144)       | 85 (586)                                   | 34 (37)                                                     | 0.40 (10.2)                                                 | WOL      | 2.0 (50.8)        | 2.25 (57.2)   | 1.0 (25.4)           |     |
|                             |                             | T-L              | -321 (77)        | 140 (965)                                  | 26 (28)                                                     | 0.086 (2.2)                                                 | WOL      | 2.0 (50.8)        | 2.25 (57.2)   | 1.0 (25.4)           |     |
|                             | C, 3                        | L-T              | -25 (235)        | 61 (421)                                   | 76 (83)                                                     | 3.88 (98.6)                                                 | WOL      | 6.0 (152.5)       | 8.63 (219)    | 3.0 (76.2)           | 104 |
|                             |                             | L-T              | -200 (100)       | 82 (565)                                   | 42 (46)                                                     | 0.656 (16.7)                                                | CT       | 1.0 (25.4)        | 2.0 (50.8)    | 1.0 (25.4)           |     |
|                             |                             | L-T              | -250 (112)       | 98 (676)                                   | 31 (34)                                                     | 0.25 (6.4)                                                  | CT       | 1.0 (25.4)        | 2.0 (50.8)    | 1.0 (25.4)           |     |
|                             |                             | L-T              | -100 (200)       | 60 (414)                                   | 40 (44)                                                     | 1.11 (28.2)                                                 | WOL      | 4.0 (101.6)       | 4.5 (114.3)   | 1.5 (38.1)           | 105 |
|                             | D, 2                        | L-T              | -200 (144)       | 80 (552)                                   | 30 (33)                                                     | 0.35 (8.9)                                                  | WOL      | 2.0 (50.8)        | 2.25 (57.2)   | 0.75 (19.1)          |     |
|                             |                             | L-T              | -321 (77)        | 130 (896)                                  | 27 (30)                                                     | 0.11 (2.7)                                                  | WOL      | 4.0 (101.6)       | 4.5 (114.3)   | 1.5 (38.1)           |     |

## COMPOSITION

|   | C    | Mn   | P     | S     | Si   | Mo   | Ni   | Cr   | Cu    | Al    |
|---|------|------|-------|-------|------|------|------|------|-------|-------|
| A | 0.19 | 1.40 | 0.017 | 0.014 | 0.16 | 0.49 | 0.03 | 0.07 | 0.03  | 0.010 |
| B | 0.21 | 1.34 | 0.015 | 0.010 | 0.27 | 0.50 | 0.04 | -    | -     | -     |
| C | 0.21 | 1.35 | 0.013 | 0.014 | 0.34 | 0.33 | 0.16 | 0.21 | 0.005 | -     |
| D | 0.21 | 1.54 | 0.015 | 0.010 | 0.27 | 0.50 | 0.04 | -    | -     | -     |

## HEAT TREATMENT

- 1650F (1172K), 70 minutes, Air Cool
- Normalize 1650F (1172K), 7 hr, Fan Cool to 200F (367K), Air Cool; Stress Relieve 1200F (922K), 7 hr
- 1650F (1172K), 7 hr; Stress Relieve 1200F (922K), 7 hr; Fan Cool to 800F (700K), Air Cool

STEEL: Low Strength: ASTM A533 (Sheet 1 of 2)

Table 27

| Form                                                       | Composition,<br>Heat Treatment | Test<br>Orientation | Yield<br>Strength<br>KSI (N/m <sup>2</sup> ) | Typical<br>K <sub>IC</sub><br>(KSI√in) (MN/m <sup>3/2</sup> ) | 2.5( $\frac{K_{IC}}{\sigma_{ys}}$ ) <sup>2</sup><br>in (mm) | Specimen |                      |                  |                            |
|------------------------------------------------------------|--------------------------------|---------------------|----------------------------------------------|---------------------------------------------------------------|-------------------------------------------------------------|----------|----------------------|------------------|----------------------------|
|                                                            |                                |                     |                                              |                                                               |                                                             | Type     | Thickness<br>in (mm) | Width<br>in (mm) | Crack<br>Length<br>in (mm) |
| ASTM A533, Grade B, Class 1<br>Plate: 12 in (305 mm) Thick | A,1                            | L-T                 | 70(483)                                      | *140(153)                                                     | 10 (254)                                                    | CT       | 12 (305)             | 24 (610)         | 12 (305)                   |
|                                                            |                                | L-T                 | 73(503)                                      | *105(115)                                                     | 5.17 (1.31)                                                 | CT       | 10 (254)             | 20 (508)         | 10 (254)                   |
|                                                            |                                | L-T                 | 75(517)                                      | * 75( 83)                                                     | 2.5 (63.5)                                                  | CT       | 6 (152)              | 12 (305)         | 6 (152)                    |
|                                                            |                                | L-T                 | 77(531)                                      | * 57( 62)                                                     | 1.37 (34.8)                                                 | CT       | 4 (102)              | 8 (203)          | 4 (102)                    |
|                                                            |                                | L-T                 | 79(545)                                      | * 48( 53)                                                     | 0.92 (23.3)                                                 | CT       | 4 (102)              | 8 (203)          | 4 (102)                    |
|                                                            |                                | L-T                 | 86(593)                                      | * 40( 44)                                                     | 0.54 (13.7)                                                 | CT       | 4 (102)              | 8 (203)          | 4 (102)                    |
|                                                            |                                | L-T                 | 95(655)                                      | * 38( 42)                                                     | 0.40 (10.2)                                                 | CT       | 4 (102)              | 8 (203)          | 4 (102)                    |
|                                                            |                                | L-T                 | 111(765)                                     | * 37( 41)                                                     | 0.38 (9.7)                                                  | WOL      | 1 (25.4)             | 1.25(31.8)       | 0.5(13.5)                  |
|                                                            |                                | L-T                 | 85(586)                                      | 33( 36)                                                       | 0.38 (9.7)                                                  | WOL      | 1 (25.4)             | 1.25(31.8)       | 0.5(12.7)                  |
|                                                            |                                | L-T                 | 93(641)                                      | 29( 32)                                                       | 0.24 (6.1)                                                  | WOL      | 1 (25.4)             | 1.25(31.8)       | 0.5(12.7)                  |
| Plate: 11.75 in (298 mm) Thick                             | C,3                            | L-T                 | 124(855)                                     | 26( 28)                                                       | 0.11 (2.8)                                                  | WOL      | 1 (25.4)             | 1.25(31.1)       | 0.5(12.7)                  |
|                                                            |                                | L-T                 | 77(531)                                      | 86( 95)                                                       | 3.12 (79.2)                                                 | CT       | 4 (102)              | 8 (203)          | 4 (102)                    |
|                                                            |                                | L-T                 | 82(565)                                      | 75( 82)                                                       | 2.09 (53.1)                                                 | CT       | 4 (102)              | 8 (203)          | 4 (102)                    |
|                                                            |                                | L-T                 | 85(586)                                      | 55( 60)                                                       | 1.05 (26.7)                                                 | CT       | 3 (76.2)             | 6 (152)          | 3 (76.2)                   |
|                                                            |                                | L-T                 | 95(655)                                      | 45( 49)                                                       | 0.56 (14.2)                                                 | CT       | 2 (50.8)             | 4 (102)          | 2 (50.8)                   |
|                                                            |                                | L-T                 | 143(986)                                     | 38( 42)                                                       | 0.18 (4.6)                                                  | CT       | 1 (25.4)             | 2 (50.8)         | 1 (25.4)                   |
|                                                            |                                | L-T                 | 71(490)                                      | 38( 42)                                                       | 0.716(18.2)                                                 | WOL      | 1 (25.4)             | 1.25(31.8)       | 0.5(12.7)                  |
|                                                            |                                | L-T                 | 102(702)                                     | 33( 36)                                                       | 0.262(6.6)                                                  | WOL      | 1 (25.4)             | 1.25(31.8)       | 0.5(12.7)                  |
|                                                            |                                | L-T                 | 129(889)                                     | 34( 37)                                                       | 0.174(4.4)                                                  | WOL      | 1 (25.4)             | 1.25(31.8)       | 0.5(12.7)                  |
|                                                            |                                | L-T                 |                                              |                                                               |                                                             |          |                      |                  |                            |
| Plate: 6 in (152 mm) Thick                                 | B,2                            | L-T                 |                                              |                                                               |                                                             |          |                      |                  |                            |
|                                                            |                                | L-T                 |                                              |                                                               |                                                             |          |                      |                  |                            |

\*Mild-Thickness Values

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(Table 27 (Cont.))

| Form                                                                                                                                                                                                                                 | C    | Mn   | P     | S     | Si   | Ni   | Mo   | Cr   | Cu   | Al    | Yield Strength<br>KSI (MN/m <sup>2</sup> ) | Typical<br>K <sub>IC</sub><br>KSI√in (MN/m <sup>3/2</sup> ) | 2.5( $\frac{K_{IC}}{\sigma_{ys}}$ ) <sup>2</sup><br>in (mm) | Specimen                                    |                          |                  | Ref |
|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|------|------|-------|-------|------|------|------|------|------|-------|--------------------------------------------|-------------------------------------------------------------|-------------------------------------------------------------|---------------------------------------------|--------------------------|------------------|-----|
|                                                                                                                                                                                                                                      |      |      |       |       |      |      |      |      |      |       |                                            |                                                             |                                                             | Compo-<br>sition,<br>Heat<br>Treat-<br>ment | Test<br>Orienta-<br>tion | Temp.<br>°F (°K) |     |
| COMPOSITION                                                                                                                                                                                                                          |      |      |       |       |      |      |      |      |      |       |                                            |                                                             |                                                             |                                             |                          |                  |     |
| A                                                                                                                                                                                                                                    | 0.24 | 1.42 | 0.010 | 0.017 | 0.22 | 0.70 | 0.50 | -    | -    | -     | -                                          | -                                                           | -                                                           | -                                           | -                        | -                | -   |
| B                                                                                                                                                                                                                                    | 0.18 | 1.25 | 0.024 | 0.025 | 0.24 | 0.52 | 0.51 | 0.13 | 0.29 | 0.025 | -                                          | -                                                           | -                                                           | -                                           | -                        | -                | -   |
| C                                                                                                                                                                                                                                    | 0.23 | 1.35 | 0.012 | 0.025 | 0.26 | 0.50 | 0.48 | -    | -    | -     | -                                          | -                                                           | -                                                           | -                                           | -                        | -                | -   |
| HEAT TREATMENT                                                                                                                                                                                                                       |      |      |       |       |      |      |      |      |      |       |                                            |                                                             |                                                             |                                             |                          |                  |     |
| 1. Normalize 1675 ±25F (1186 ±14K); Austenitize 1600 ±500F (1144 ±28K), 4 Hr, Water Quench;<br>Temper 1225 ±25F (936 ±14K), 4 Hr, Furnace Cool; Stress Relieve 1150 ±25F (894 ±14K),<br>40 Hr, Air Cool                              |      |      |       |       |      |      |      |      |      |       |                                            |                                                             |                                                             |                                             |                          |                  |     |
| 2. Austenitize 1650F (1172K), 1 Hr; Temper 1200F (922K), 8 Hr; Stress Relieve 1100F<br>(894K), 24 Hr.                                                                                                                                |      |      |       |       |      |      |      |      |      |       |                                            |                                                             |                                                             |                                             |                          |                  |     |
| 3. Normalize 1675 ±25F (1186 ±14K); Austenitize 1600 ±50F (1144 ±28K), 4 Hr, Water Quench;<br>Temper 1225 ±25F (936 ±14K), 4 Hr, Air Cool; Stress Relieve 1135 ±25F (886 ±14K),<br>Hold 25 Hr, Furnace Cool to 600F (589K), Air Cool |      |      |       |       |      |      |      |      |      |       |                                            |                                                             |                                                             |                                             |                          |                  |     |

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Table 28

STEEL: Low Strength: ASTM A542 and ASTM A543

| Form                                    | Composition | Heat Treatment | $\sigma_F$ (ksi) | Yield strength (ksi) | Typical $K_{IC}$ (ksi $\sqrt{in}$ ) | $2 \sqrt{\frac{a_{IC}}{b_{IC}}}$ (in) | Specimen       |             |                   |
|-----------------------------------------|-------------|----------------|------------------|----------------------|-------------------------------------|---------------------------------------|----------------|-------------|-------------------|
|                                         |             |                |                  |                      |                                     |                                       | Thickness (in) | Width (in)  | Crack Length (in) |
| ASTM A542<br>Plate: 6 in (152 mm) Thick | A, 1        | L-T            | -250 (144)       | 118 (814)            | 41 (35)                             | 0.302 (7.7)                           | 1 (25.4)       | 1.25 (31.8) | 0.53 (13.5)       |
|                                         |             |                | -250 (112)       | 132 (916)            | 55 (38)                             | 0.176 (4.5)                           | 1 (25.4)       | 1.25 (31.8) | 0.53 (13.5)       |
|                                         |             |                | -320 (76)        | 157 (1083)           | 29 (52)                             | 0.08 (2.2)                            | 1 (25.4)       | 1.25 (31.8) | 0.53 (13.5)       |
|                                         | A, 1        | L-T            | -250 (144)       | 113 (779)            | 69 (76)                             | 0.932 (23.7)                          | 1 (25.4)       | 1.25 (31.8) | 0.53 (13.5)       |
|                                         |             |                | -250 (112)       | 128 (893)            | 54 (38)                             | 0.176 (4.5)                           | 1 (25.4)       | 1.25 (31.8) | 0.53 (13.5)       |
| ASTM A543<br>Plate: 6 in (152 mm) Thick | B, 2        | L-T            | -320 (78)        | 156 (1076)           | 30 (33)                             | 0.992 (2.3)                           | 1 (25.4)       | 1.25 (31.8) | 0.53 (13.5)       |
|                                         |             |                | -250 (112)       | 116 (800)            | 40 (44)                             | 0.297 (7.5)                           | 1 (25.4)       | 1.25 (31.8) | 0.53 (13.5)       |
|                                         |             |                | -320 (78)        | 141 (972)            | 30 (35)                             | 0.113 (2.9)                           | 1 (25.4)       | 1.25 (31.8) | 0.53 (13.5)       |
|                                         | B, 2        | L-T            | -200 (144)       | 110 (758)            | 75 (82)                             | 1.16 (29.5)                           | 1 (25.4)       | 1.25 (31.8) | 0.53 (13.5)       |
|                                         |             |                | -250 (112)       | 119 (821)            | 50 (55)                             | 0.441 (11.2)                          | 1 (25.4)       | 1.25 (31.8) | 0.53 (13.5)       |
| Plate: 12 in (305 mm) Thick             | B, 2        | L-T            | -320 (78)        | 140 (965)            | 35 (39)                             | 0.156 (4.0)                           | 1 (25.4)       | 1.25 (31.8) | 0.53 (13.5)       |
|                                         |             |                | -250 (112)       | 119 (821)            | 50 (55)                             | 0.441 (11.2)                          | 1 (25.4)       | 1.25 (31.8) | 0.53 (13.5)       |
|                                         |             |                | -320 (78)        | 140 (965)            | 35 (39)                             | 0.156 (4.0)                           | 1 (25.4)       | 1.25 (31.8) | 0.53 (13.5)       |
|                                         | B, 2        | L-T            | -200 (144)       | 110 (758)            | 75 (82)                             | 1.16 (29.5)                           | 1 (25.4)       | 1.25 (31.8) | 0.53 (13.5)       |
|                                         |             |                | -250 (112)       | 119 (821)            | 50 (55)                             | 0.441 (11.2)                          | 1 (25.4)       | 1.25 (31.8) | 0.53 (13.5)       |

## COMPOSITION

|   | C    | Mn   | P     | S     | Si   | Ni   | Cr   | Mo   | Cu   | Al    |
|---|------|------|-------|-------|------|------|------|------|------|-------|
| A | 0.15 | 0.46 | 0.013 | 0.027 | 0.30 | 0.22 | 2.34 | 1.10 | 0.22 | 0.008 |
| B | 0.15 | 0.32 | 0.013 | 0.020 | 0.28 | 3.55 | 1.85 | 0.50 | 0.06 | --    |

## HEAT TREATMENT

1. 1750F (955K), 1 hr; 1200F (649K), 8 hr; 1100F (594K), 24 hr.
2. 1575F (858K), 1 hr; 1200F (649K), 8 hr; 1100F (594K), 24 hr.



STEEL: Intermediate Strength. ASTM A469 and NI-Mo-V Table 30

| Form                                               | Composition, Heat Treatment | Orientation | Temp. °K   | Yield Strength ksi (N/mm <sup>2</sup> ) | Typical K <sub>IC</sub> KSI√in (N/m <sup>3/2</sup> ) | 2.5( $\frac{K_{IC}}{\sigma_{ys}}$ ) <sup>2</sup> in (mm) | Specimen |                   |               |                      | Ref |
|----------------------------------------------------|-----------------------------|-------------|------------|-----------------------------------------|------------------------------------------------------|----------------------------------------------------------|----------|-------------------|---------------|----------------------|-----|
|                                                    |                             |             |            |                                         |                                                      |                                                          | Type     | Thickness in (mm) | Width in (mm) | Crack Length in (mm) |     |
| ASTM A469                                          |                             |             |            |                                         |                                                      |                                                          |          |                   |               |                      |     |
| Forging: 31 in (787 mm) Dia., 15 in (381 mm) Thick | A, 1                        | L-R         | 50 (283)   | 88 (607)                                | 120 (131)                                            | 4.65 (118)                                               | WOL      | 4 (102)           | 10.2 (259)    | 4 (102)              | 108 |
|                                                    |                             | L-R         | 0 (256)    | 90 (621)                                | 70 (77)                                              | 1.51 (38.4)                                              | WOL      | 2 (50.8)          | 5.1 (130)     | 2 (50.8)             |     |
|                                                    |                             | L-R         | -100 (200) | 95 (655)                                | 35 (38)                                              | 0.339 (8.6)                                              | CT       | 1 (25.4)          | 2 (50.8)      | 1 (25.4)             |     |
|                                                    |                             | L-R         | -200 (144) | 105 (724)                               | 27 (30)                                              | 0.165 (4.2)                                              | CT       | 1 (25.4)          | 2 (50.8)      | 1 (25.4)             |     |
|                                                    |                             | L-R         | -320 (78)  | 150 (1034)                              | 25 (27)                                              | 0.069 (1.8)                                              | CT       | 1 (25.4)          | 2 (50.8)      | 1 (25.4)             |     |
| Ni-Mo-V                                            |                             |             |            |                                         |                                                      |                                                          |          |                   |               |                      |     |
| Forging: 38 in (965 mm) Dia.                       | B, 2                        | C-R         | 150 (339)  | 80 (552)                                | 70 (77)                                              | 1.914 (48.6)                                             | WOL      | 4 (102)           | 10.2 (259)    | 3.6 (91.4)           | 105 |
|                                                    |                             | C-R         | 70 (294)   | 90 (621)                                | 50 (50)                                              | 0.772 (19.6)                                             | WOL      | 3 (76.2)          | 7.7 (196)     | 2.7 (68.6)           |     |
|                                                    |                             | C-R         | 0 (756)    | 95 (655)                                | 40 (44)                                              | 0.443 (11.3)                                             | WOL      | 2 (50.8)          | 5.1 (130)     | 1.8 (45.7)           |     |
|                                                    |                             | C-R         | -100 (200) | 100 (690)                               | 30 (33)                                              | 0.225 (5.7)                                              | WOL      | 2 (50.8)          | 5.1 (130)     | 1.8 (45.7)           |     |
|                                                    |                             | C-R         | -200 (144) | 110 (758)                               | 25 (27)                                              | 0.129 (3.3)                                              | WOL      | 1 (25.4)          | 2.6 (66)      | 0.9 (22.9)           |     |
|                                                    | C-R                         | -320 (78)   | 140 (965)  | 23 (25)                                 | 0.067 (1.7)                                          | WOL                                                      | 1 (25.4) | 2.6 (66)          | 0.9 (22.9)    |                      |     |

COMPOSITION

|   | C    | Mn   | P     | S     | Si   | Ni   | Cr   | Mo   | V    |
|---|------|------|-------|-------|------|------|------|------|------|
| A | 0.20 | 0.55 | 0.010 | 0.009 | 0.19 | 2.96 | 0.48 | 0.29 | 0.08 |
| B | 0.23 | 0.50 | 0.005 | 0.010 | 0.21 | 3.4  | 0.48 | 0.30 | 0.07 |

HEAT TREATMENT

1. 1520F (830K), 1180F (640K), 40 Hr.
2. 1475F (808K), 20 Hr, Furnace Cool to 600F (316K), Hold 30 Hr; 1640F (893K), 30 Hr, Air Cool to 530F (277K), Hold 30 Hr; Temper 1130F (611K), 40 Hr, Air Cool to 400F (204K), Air Cool

Table 31

STEEL: Intermediate Strength: ASTM A470 and CR-Mo-V

| STEEL: Intermediate Strength: ASTM A470 and CR-MO-V |                                |                     |                                               |                                                              |                                                             |          |                      |                  |                            |     |
|-----------------------------------------------------|--------------------------------|---------------------|-----------------------------------------------|--------------------------------------------------------------|-------------------------------------------------------------|----------|----------------------|------------------|----------------------------|-----|
| Form                                                | Composition,<br>Heat Treatment | Test<br>Orientation | Yield<br>Strength<br>ksi (N/mm <sup>2</sup> ) | Typical<br>K <sub>IC</sub><br>(ksi√in) (N/m <sup>3/2</sup> ) | 2.5( $\frac{K_{IC}}{\sigma_{ys}}$ ) <sup>2</sup><br>in (mm) | Specimen |                      |                  |                            | Ref |
|                                                     |                                |                     |                                               |                                                              |                                                             | Type     | Thickness<br>in (mm) | Width<br>in (mm) | Crack<br>Length<br>in (mm) |     |
| ASTM A470<br>Forging: 15 in (381 mm) Dia.           | A, 1                           | L-R                 | 150(339)                                      | 84 (92)                                                      | 2.48 (57.9)                                                 | WOL      | 4 (.02)              | 10.2(259)        | 4 (102)                    | 108 |
|                                                     |                                | L-R                 | 75(297)                                       | 50 (55)                                                      | 0.723(18.4)                                                 | WOL      | 4 (102)              | 10.2(259)        | 4 (102)                    |     |
|                                                     |                                | L-R                 | 0(256)                                        | 40 ( )                                                       | 0.443(11.3)                                                 | WOL      | 1 (25.4)             | 2.55(64.8)       | 1 (25.4)                   |     |
|                                                     |                                | L-R                 | -100(200)                                     | 30 (33)                                                      | 0.204(5.2)                                                  | WOL      | 1 (25.4)             | 2.55(64.8)       | 1 (25.4)                   |     |
|                                                     |                                | L-R                 | -200(144)                                     | 25 (27)                                                      | 0.109(2.8)                                                  | WOL      | 1 (25.4)             | 2.55(64.8)       | 1 (25.4)                   |     |
|                                                     |                                | L-R                 | -320( 78)                                     | 23 (25)                                                      | 0.052(1.3)                                                  | WOL      | 1 (25.4)             | 2.55(64.8)       | 1 (25.4)                   |     |
| CR-MO-V<br>Hot Forging                              | B, -<br>C, -                   | L-R                 | 70(294)                                       | 69 (76)                                                      | 1.738(44.1)                                                 | Bend     | 4 (102)              | 4 (102)          | 1 (25.4)                   | 109 |
|                                                     |                                | L-R                 | 70(294)                                       | 65 (71)                                                      | 1.650(41.9)                                                 | Bend     | 6.7(170)             | 6.7(170)         | 1.6(40.6)                  |     |

## COMPOSITION

|   | C    | Mn   | P     | S     | Si   | Ni   | Cr   | Mo   | V    |
|---|------|------|-------|-------|------|------|------|------|------|
| A | 0.31 | 0.78 | 0.009 | 0.010 | 0.28 | 0.07 | 1.10 | 1.15 | 6.26 |
| B | 0.3  | -    | -     | -     | -    | 0.7  | 1.0  | 0.7  | 0.32 |
| C | 0.3  | -    | -     | -     | -    | 0.6  | 1.2  | 1.1  | 0.37 |

## HEAT TREATMENT

1. 175F (1242K), 1240F (944K), 40 Hr.

STEEL: Intermediate Strength: ASTM A471 and Ni-Cr-Mo-V

Table 32

| Form                                       | Compo-<br>sition,<br>Heat<br>Treat-<br>ment | Test<br>Orienta-<br>tion | $\sigma_L$ (ksi) | Yield<br>Strength<br>ksi (N/mm <sup>2</sup> ) | Typical<br>K <sub>IC</sub><br>ksi√in (MN/m <sup>3/2</sup> ) | 2.5( $\frac{K_{IC}}{\sigma_{YS}}$ ) <sup>2</sup><br>in (mm) | Specimen |                      |                  | Ref        |                            |
|--------------------------------------------|---------------------------------------------|--------------------------|------------------|-----------------------------------------------|-------------------------------------------------------------|-------------------------------------------------------------|----------|----------------------|------------------|------------|----------------------------|
|                                            |                                             |                          |                  |                                               |                                                             |                                                             | Type     | Thickness<br>in (mm) | Width<br>in (mm) |            | Crack<br>length<br>in (mm) |
| ASTM A471<br>Forging: 60 in (1524 mm) Dia. |                                             |                          |                  |                                               |                                                             |                                                             |          |                      |                  |            |                            |
|                                            | A, 1                                        | L-L                      | (256)            | 115 (795)                                     | 155 (170)                                                   | 1.54 (115)                                                  | KOL      | 4 (102)              | 10.2 (259)       | 4 (102)    | 108                        |
|                                            |                                             | L-R                      | -100 (200)       | 125 (862)                                     | 100 (110)                                                   | 1.6 (40.6)                                                  | KOL      | 5 (76.2)             | 7.7 (196)        | 5 (76.2)   |                            |
|                                            |                                             | L-R                      | -200 (144)       | 140 (965)                                     | 60 (66)                                                     | 0.459 (11.7)                                                | KOL      | 3 (76.2)             | 7.7 (196)        | 3 (76.2)   |                            |
|                                            |                                             | L-R                      | -320 (78)        | 180 (1241)                                    | 35 (38)                                                     | 0.095 (2.4)                                                 | KOL      | 3 (76.2)             | 7.7 (196)        | 3 (76.2)   |                            |
| Forging: 65 in (16' x 27 in Thick          | B, 1                                        | L-R                      | 200 (367)        | 140 (965)                                     | 150 (164)                                                   | 2.86 (72.6)                                                 | CT       | 4 (102)              | 8 (203)          | 4 (102)    |                            |
|                                            |                                             | L-R                      | 70 (294)         | 155 (1060)                                    | 90 (99)                                                     | 0.842 (21.4)                                                | CT       | 2 (50.8)             | 4 (102)          | 2 (50.8)   |                            |
|                                            |                                             | L-R                      | 0 (256)          | 165 (1138)                                    | 65 (71)                                                     | 0.388 (9.9)                                                 | CT       | 2 (50.8)             | 4 (102)          | 2 (50.8)   |                            |
|                                            |                                             | L-R                      | -100 (200)       | 170 (1172)                                    | 58 (64)                                                     | 0.291 (7.4)                                                 | CT       | 2 (50.8)             | 4 (102)          | 2 (50.8)   |                            |
| Ni-Cr-Mo-V<br>Disc Forging                 | C, 1                                        | L-R                      | -200 (144)       | 180 (1241)                                    | 45 (47)                                                     | 0.143 (3.6)                                                 | CT       | 2 (50.8)             | 4 (102)          | 2 (50.8)   |                            |
|                                            |                                             | L-R                      | -320 (78)        | 205 (1413)                                    | 25 (25)                                                     | 0.031 (0.8)                                                 | CT       | 2 (50.8)             | 4 (102)          | 2 (50.8)   |                            |
|                                            |                                             | L-R                      | 70 (294)         | 109 (752)                                     | 90 (99)                                                     | 1.7 (43.2)                                                  | Bend     | 5.66 (144)           | 5.66 (144)       | 1.5 (33)   | 109                        |
|                                            |                                             | L-R                      | -104 (198)       | 117 (807)                                     | 58 (64)                                                     | 0.614 (15.6)                                                | Bend     | 3 (76.2)             | 3 (76.2)         | 0.9 (22.9) |                            |
| D, 1                                       |                                             | L-R                      | -71 (213)        | 117 (807)                                     | 83 (91)                                                     | 1.258 (32)                                                  | Bend     | 5 (127)              | 5 (127)          | 1.1 (27.9) |                            |
|                                            |                                             |                          |                  |                                               |                                                             |                                                             |          |                      |                  |            |                            |
| COMPOSITION                                |                                             |                          |                  |                                               |                                                             |                                                             |          |                      |                  |            |                            |
|                                            | C                                           | Mn                       | P                | S                                             | Si                                                          | Ni                                                          | Cr       | Mo                   | V                |            |                            |
| A                                          | 0.24                                        | 0.28                     | 0.005            | 0.012                                         | 0.04                                                        | 3.51                                                        | 1.64     | 0.39                 | 0.21             |            |                            |
| B                                          | 0.27                                        | 0.33                     | 0.009            | 0.009                                         | 0.04                                                        | 3.48                                                        | 1.57     | 0.40                 | 0.13             |            |                            |
| C                                          | 0.28                                        | -                        | -                | -                                             | -                                                           | 2.4                                                         | 0.8      | 0.5                  | 0.1              |            |                            |
| D                                          | 0.35                                        | -                        | -                | -                                             | -                                                           | 3.3                                                         | 1.6      | 0.6                  | 0.15             |            |                            |
| HEAT TREATMENT                             |                                             |                          |                  |                                               |                                                             |                                                             |          |                      |                  |            |                            |
| 1. 1550F (1117K), 1090F (862K), 40 hr.     |                                             |                          |                  |                                               |                                                             |                                                             |          |                      |                  |            |                            |

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Table 33  
SHELL: Intermediate Strength: ASTM A517-F and HY130

| Form                                            |      | Composition, Heat Treatment | Yield strength, $f_{y1}$ (ksi/mm <sup>2</sup> ) | Typical $K_{IC}$ (ksi√in) (MN/m <sup>3/2</sup> ) | $\Delta S(\frac{K_{IC}}{\sigma})$ in (mm) | Specimen     |                   |               | Ref                  |            |      |       |
|-------------------------------------------------|------|-----------------------------|-------------------------------------------------|--------------------------------------------------|-------------------------------------------|--------------|-------------------|---------------|----------------------|------------|------|-------|
|                                                 |      |                             | $\sigma_f$                                      |                                                  |                                           | type         | thickness in (mm) | width in (mm) | Crack Length in (mm) |            |      |       |
| ASTM A517-F                                     |      |                             |                                                 |                                                  |                                           |              |                   |               |                      |            |      |       |
| Plate: 1 in (25.4 mm) Thick, Open hearth Melted |      |                             |                                                 |                                                  |                                           |              |                   |               |                      |            |      |       |
|                                                 | A, 1 | 1-1                         | -100 (200)                                      | 127 (876)                                        | 75 (82)                                   | 0.872 (22.1) | Bend              | 1 (25.4)      | 3 (76.2)             | 1.6 (40.1) | 10   |       |
|                                                 |      | 1-1                         | -165 (16.2)                                     | 133 (917)                                        | 53 (58)                                   | 0.397 (10.1) | Bend              | 1 (25.4)      | 3 (76.2)             | 1.6 (40.1) |      |       |
|                                                 |      | 1-1                         | -200 (111)                                      | 139 (958)                                        | 47 (51)                                   | 0.286 (7.3)  | Bend              | 1 (25.4)      | 3 (76.2)             | 1.6 (40.1) |      |       |
|                                                 |      | 1-1                         | -320 (78)                                       | 171 (1200)                                       | 35 (38)                                   | 0.101 (2.6)  | Bend              | 1 (25.4)      | 3 (76.2)             | 1.6 (40.1) |      |       |
| HY130                                           |      |                             |                                                 |                                                  |                                           |              |                   |               |                      |            |      |       |
| Plate: 1 in (25.4 mm) Thick, Air Melted         |      |                             |                                                 |                                                  |                                           |              |                   |               |                      |            |      |       |
|                                                 | B, 2 | 1-1                         | -250 (112)                                      | 165 (1138)                                       | 80 (88)                                   | 0.588 (14.9) | Bend              | 1 (25.4)      | 3 (76.2)             | 1.6 (40.1) | 10   |       |
|                                                 |      | 1-1                         | -320 (78)                                       | 190 (1310)                                       | 13 (17)                                   | 0.128 (3.3)  | Bend              | 1 (25.4)      | 3 (76.2)             | 1.6 (40.1) |      |       |
| COMPOSITION                                     |      |                             |                                                 |                                                  |                                           |              |                   |               |                      |            |      |       |
|                                                 | C    | Mn                          | P                                               | S                                                | Si                                        | Ni           | Cr                | Mo            | V                    | B          | Cu   | Al    |
| A                                               | 0.17 | 0.78                        | 0.012                                           | 0.017                                            | 0.23                                      | 0.88         | 0.56              | 0.42          | 0.036                | 0.003      | 0.26 | 0.035 |
| B                                               | 0.11 | 0.85                        | 0.009                                           | 0.007                                            | 0.25                                      | 1.91         | 0.58              | 0.58          | 0.06                 | -          | -    | 0.021 |

HEAT TREATMENT

1. 1660f (1178K), 70 minutes, water quench; 1230f (939K), 97 minutes, water quench.
2. 1500f (1089K), 95 minutes, water quench; 1163f (890K), 93 minutes, water quench.

Table 34

TITANIUM,  $\alpha$  Alloy: SAI-2.5 Sn

| Form                                                | Composition,<br>Heat Treatment | Test Orientation | Temp<br>$\sigma_F$ ( $^{\circ}$ F) | Yield Strength,<br>KSI ( $\text{MN}/\text{m}^2$ ) | Typical<br>$r_{IC}$<br>KSI/ $\sqrt{\text{in}}$ ( $\text{MN}/\text{m}^2$ ) | $2.5 \left( \frac{K_{IC}}{\sigma_{ys}} \right)^2$<br>in (mm) | Specimen |                      |                  | Ref.                    |
|-----------------------------------------------------|--------------------------------|------------------|------------------------------------|---------------------------------------------------|---------------------------------------------------------------------------|--------------------------------------------------------------|----------|----------------------|------------------|-------------------------|
|                                                     |                                |                  |                                    |                                                   |                                                                           |                                                              | Type     | Thickness<br>in (mm) | Width<br>in (mm) | Crack Length<br>in (mm) |
| Plate: 0.5 in (12.7 mm) Thick<br>(ELI)              | A,1                            | L-T              | -320(78)                           | 175(1237)                                         | 65(71)                                                                    | 0.345(8.8)                                                   | Bend     | 0.250(6.4)           | 0.500(12.7)      | ---                     |
|                                                     |                                | T-L              | -320(78)                           | 171(1179)                                         | 50(55)                                                                    | 0.214(5.43)                                                  | Bend     | 0.250(6.4)           | 0.500(12.7)      | ---                     |
|                                                     |                                | L-T              | -423(21)                           | 205(1413)                                         | 55(60)                                                                    | 0.180(4.6)                                                   | Bend     | 0.250(6.4)           | 0.500(12.7)      | ---                     |
|                                                     |                                | T-L              | -423(21)                           | 209(1441)                                         | 52(57)                                                                    | 0.155(3.9)                                                   | Bend     | 0.250(6.4)           | 0.500(12.7)      | ---                     |
|                                                     |                                | L-T              | -320(78)                           | 203(1400)                                         | 26(28)                                                                    | 0.041(1.0)                                                   | Bend     | 0.250(6.4)           | 0.500(12.7)      | ---                     |
| Plate: 0.5 in (12.7 mm) Thick<br>(Commercial Grade) | B,1                            | T-L              | -320(78)                           | 204(1407)                                         | 50(55)                                                                    | 0.150(3.8)                                                   | Bend     | 0.250(6.4)           | 0.500(12.7)      | ---                     |
|                                                     |                                | L-T              | -423(21)                           | 233(1606)                                         | 25(27)                                                                    | 0.029(0.7)                                                   | Bend     | 0.250(6.4)           | 0.500(12.7)      | ---                     |
|                                                     |                                | T-L              | -320(78)                           | 175(1193)                                         | 62(68)                                                                    | 0.321(8.2)                                                   | Bend     | 0.400(10.2)          | 0.75 (19.0)      | 0.375(9.5)              |
| Plate: 0.8 in (20.3 mm) Thick<br>(ELI)              | C,2                            | T-L              | -423(21)                           | 187(1289)                                         | 65(61)                                                                    | 0.302(7.7)                                                   | Bend     | 0.400(10.2)          | 0.75 (19.0)      | 0.375(9.5)              |

## COMPOSITION

|   | Al  | Sn   | Fe   | N     | C     | Mn    | Mg   | U     | O      | N     |
|---|-----|------|------|-------|-------|-------|------|-------|--------|-------|
| A | 5.0 | 2.6  | 0.16 | 0.01  | 0.023 | 0.006 | ---  | 0.001 | 9.086  | 0.010 |
| B | 5.1 | 2.3  | 0.34 | 0.015 | 0.023 | 0.006 | ---  | 0.017 | ---    | 0.015 |
| C | 5.1 | 2.50 | 0.19 | ---   | 0.02  | ---   | 0.01 | 94ppm | 940ppm | 70ppm |

## HEAT TREATMENT

1. 1500F (1089 $^{\circ}$ C) Furnace Cooled
2. 1500F (1117 $^{\circ}$ C), 16 Hr, Furnace Cooled

TITANIUM, Near  $\alpha$  Alloys: IMI 679, IMI 685, 8Al-1Mo-1V, 6Al-2Sn-4Zr-2Ti (Sheet 1 of 2) Table 35

| Form                                                                              | Composition, Treatment | Test Orientation | $\sigma_F$ (°K) | Yield Strength KSI (N/m <sup>2</sup> ) | Typical $K_{IC}$ KSI/in (N/m <sup>3/2</sup> ) | $2.5 \left( \frac{K_{IC}}{\sigma_F} \right)^2$ in (mm) | Specimen |                   |               |                      |     |
|-----------------------------------------------------------------------------------|------------------------|------------------|-----------------|----------------------------------------|-----------------------------------------------|--------------------------------------------------------|----------|-------------------|---------------|----------------------|-----|
|                                                                                   |                        |                  |                 |                                        |                                               |                                                        | Type     | Thickness in (mm) | Width in (mm) | Crack Length in (mm) | Ref |
| IMI 679<br>Forging: 0.625 in (15.9 mm) Thick<br>8 Processed 2100F (1422K)         | A,1                    | (a)              | 70(294)         | 141(979)                               | 31(34)                                        | 0.119(3.0)                                             | Bend     | 0.5(12.7)         | ---           | ---                  | 22  |
| Forging: 0.625 in (15.9 mm) Thick<br>a + b Processed 1675F (1186 K)               | A,1                    | (a)              | 70(294)         | 153(1055)                              | 26(28)                                        | 0.072(1.8)                                             | Bend     | 0.5(12.7)         | ---           | ---                  |     |
| Forging: 1.25 in (31.8 mm) Thick<br>8 Forged 1800F (1255K)                        | E,5                    | (a)              | 70(297)         | 135(931)                               | 57(62)                                        | 0.445(11.3)                                            | Bend     | 0.5(12.7)         | ---           | ---                  | 92  |
| IMI 685<br>Bar: 1.75 in (45 mm) Dia.<br>8 Worked                                  | E,6                    | L-C              | 70(294)         | 137(941)                               | 64(70)                                        | 0.546(13.9)                                            | (b)      | ---               | ---           | ---                  | 121 |
|                                                                                   | E,7                    | L-C              | 70(294)         | 143(884)                               | 55(66)                                        | 0.370(9.4)                                             | (b)      | ---               | ---           | ---                  |     |
| Plate: 0.7 in (18 mm) Thick,<br>a + b Worked                                      | E,8                    | L-T              | 70(294)         | 130(896)                               | 56(61)                                        | 0.464(11.8)                                            | (b)      | ---               | ---           | ---                  |     |
| 6Al-2Sn-4Zr-2Ti<br>Plate: 1.5 in (38.1 mm) Thick<br>1800F (155K)                  | F,2                    | L-T              | 70(294)         | 138(951)                               | 67(74)                                        | 0.589(15.0)                                            | SEN      | 0.87(22.1)        | 5 (127)       | 1.7(43.2)            | 82  |
| Forging: 0.625 in (15.9 mm) Thick<br>8 Processed 2100F (1422K)                    | C,3                    | (a)              | 70(294)         | 126(868)                               | 57(63)                                        | 0.512(13.0)                                            | Bend     | 0.5(12.7)         | ---           | ---                  | 22  |
| Forging: 0.625 in (15.9 mm) Thick<br>a + b Processed 1800F (155K)                 | C,3                    | (a)              | 70(294)         | 145(986)                               | 34(37)                                        | 0.167(4.3)                                             | Bend     | 0.5(12.7)         | ---           | ---                  |     |
| 6Al-2Sn-4Zr-2Ti<br>Forging: 0.625 in (15.9 mm) Thick<br>8 Processed 2100F (1422K) | D,4                    | (a)              | 70(294)         | 146(1006)                              | 52(57)                                        | 0.37(8.1)                                              | Bend     | 0.5(12.7)         | ---           | ---                  | 22  |
| Forging: 0.625 in (15.9 mm) Thick<br>a + b Processed 1750F (1228K)                | D,4                    | (a)              | 70(294)         | 160(1103)                              | 32(35)                                        | 0.100(2.5)                                             | Bend     | 0.5(12.7)         | ---           | ---                  |     |

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TITANIUM, Near  $\alpha$  Alloys: IMI 679, 1% 685, 8Al-1Mo-1V, 6Al-2Sn-4Zr-2Nb (Sheet 2 of 2) Table 35 (Cont.)

| Form                                                                    | Composition, Heat Treatment |      | Test Orientation | Temp, °F | Yield Strength<br>ksi (N/m <sup>2</sup> ) |       |       |       | Typical<br>K <sub>IC</sub><br>ksi√in (MN/m <sup>3/2</sup> ) | 2.5( $\frac{K_{IC}}{\sigma_{ys}}$ ) <sup>2</sup><br>in (mm) | Specimen |   |      |                      | Ref |
|-------------------------------------------------------------------------|-----------------------------|------|------------------|----------|-------------------------------------------|-------|-------|-------|-------------------------------------------------------------|-------------------------------------------------------------|----------|---|------|----------------------|-----|
|                                                                         | Al                          | Mo   |                  |          | V                                         | Sn    | Zr    | Fe    |                                                             |                                                             | Si       | C | Type | Thickness<br>in (mm) |     |
| A                                                                       | 2.3                         | 0.9  | -                | 11.1     | 5.0                                       | 0.06  | 0.21  | 0.023 | -                                                           | -                                                           | -        | - | -    | -                    |     |
| B                                                                       | 7.96                        | 0.92 | 1.0              | 0.15     | -                                         | 0.12  | 0     | 0.049 | 0.07                                                        | 0.013                                                       | 0.006    | - | -    | -                    |     |
| C                                                                       | 7.7                         | 1.1  | 1.0              | -        | -                                         | 0.07  | -     | 0.022 | -                                                           | -                                                           | -        | - | -    | -                    |     |
| D                                                                       | 5.0                         | 2.0  | -                | 2.1      | 3.9                                       | 0.06  | -     | 0.024 | -                                                           | -                                                           | -        | - | -    | -                    |     |
| E                                                                       | 6.06                        | 0.5  | -                | -        | -                                         | -     | 0.18  | -     | 0.15                                                        | -                                                           | 0.005    | - | -    | -                    |     |
| F                                                                       | 2.25N                       | 1.0N | -                | 11.0N    | 5.0N                                      | 0.12M | 0.12N | 0.04M | 0.10N                                                       | -                                                           | -        | - | -    | -                    |     |
| COMPOSITION                                                             |                             |      |                  |          |                                           |       |       |       |                                                             |                                                             |          |   |      |                      |     |
| HEAT TREATMENT                                                          |                             |      |                  |          |                                           |       |       |       |                                                             |                                                             |          |   |      |                      |     |
| 1. 1650F (1172K), Water Quench, 930F (772K), 24 hr, Air Cool            |                             |      |                  |          |                                           |       |       |       |                                                             |                                                             |          |   |      |                      |     |
| 2. 1803F (1255K), 1 hr, Water Quench; 1100F (867K), 2 hr, Air Cool      |                             |      |                  |          |                                           |       |       |       |                                                             |                                                             |          |   |      |                      |     |
| 3. 1850F (1283K), 1 hr, Water Quench; 1100F (867K), 8 hr, Air Cool      |                             |      |                  |          |                                           |       |       |       |                                                             |                                                             |          |   |      |                      |     |
| 4. 1775F (1242K), 1 hr, Water Quench; Aged 1100F (867K), 8 hr, Air Cool |                             |      |                  |          |                                           |       |       |       |                                                             |                                                             |          |   |      |                      |     |
| 5. 1695F (1198K), 1 hr, Air Cool; 930F (772K), 24 hr, Air Cool          |                             |      |                  |          |                                           |       |       |       |                                                             |                                                             |          |   |      |                      |     |
| 6. 1291F (973K), Air Cool                                               |                             |      |                  |          |                                           |       |       |       |                                                             |                                                             |          |   |      |                      |     |
| 7. 1921F (1223K), Oil Quench; 1021F (823K), 24 hr                       |                             |      |                  |          |                                           |       |       |       |                                                             |                                                             |          |   |      |                      |     |
| 8. 1831F (1273K), Air Cool; 931F (773K), 24 hr                          |                             |      |                  |          |                                           |       |       |       |                                                             |                                                             |          |   |      |                      |     |

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TITANIUM: 3-B Alloys: INI 550, INI 551, 6Al-2Mo (Sheet 1 of 2) Table 36

| Form                                                             | Composition, Heat Treatment | Test Orientation | Temperature, °F (°C) | Yield Strength, ksi (N/mm <sup>2</sup> ) | Typical K <sub>IC</sub> , ksi√in (MN/m <sup>3/2</sup> ) | 2.5( $\frac{K_{IC}}{\sigma_{ys}}$ ) <sup>2</sup> , in (mm) | Specimen  |                   |               | Ref        |                      |
|------------------------------------------------------------------|-----------------------------|------------------|----------------------|------------------------------------------|---------------------------------------------------------|------------------------------------------------------------|-----------|-------------------|---------------|------------|----------------------|
|                                                                  |                             |                  |                      |                                          |                                                         |                                                            | Type      | Thickness in (mm) | Width in (mm) |            | Crack Length in (mm) |
| INI 550<br>Plate: 0.63 in (16 mm) Thick                          | A,1                         | T-L              | 70(294)              | 160(1103)                                | 74(81)                                                  | 0.535(13.6)                                                | Bend 4 pt | 0.5(12.7)         | 1.5(38.1)     | ---        | 95                   |
|                                                                  | A,2                         | T-L              | 70(294)              | 177(1220)                                | 49(54)                                                  | 0.192(4.9)                                                 | Bend 4 pt | 0.5(12.7)         | 1.5(38.1)     | ---        | 121                  |
| Plate: 1.25 in (31.8 mm) Thick                                   | B,3                         | L-T              | 70(294)              | 142(978)                                 | 77(85)                                                  | 0.735(18.7)                                                | (a)       | ---               | ---           | ---        |                      |
| Plate: 2.13 in (54 mm) Thick                                     | C,4                         | L-T              | 70(294)              | 170(1174)                                | 59(65)                                                  | 0.301(7.6)                                                 | (a)       | ---               | ---           | ---        |                      |
| Bar: 3.37 x 0.625 in (85.7 x 15.9 mm)                            | D,5                         | L-T              | 70(294)              | 137(946)                                 | 61(67)                                                  | 0.490(12.6)                                                | (a)       | ---               | ---           | ---        | 64                   |
|                                                                  | D,5                         | T-L              | 70(294)              | 135(931)                                 | 60(65)                                                  | 0.494(12.5)                                                | (a)       | ---               | ---           | ---        | 64                   |
|                                                                  | D,6                         | T-L              | 70(294)              | 135(931)                                 | 59(64)                                                  | 0.494(12.5)                                                | (a)       | ---               | ---           | ---        |                      |
| Bar: 2 x 3.5 in (50.8 x 88.9 mm)                                 | E,7                         | L-S              | 70(294)              | 137(945)                                 | 52(57)                                                  | 0.360(9.1)                                                 | (a)       | ---               | ---           | ---        | 65                   |
|                                                                  | T-L                         |                  | 70(294)              | 150(1034)                                | 34(37)                                                  | 0.126(3.3)                                                 | (a)       | ---               | ---           | ---        |                      |
|                                                                  | T-S                         |                  | 70(294)              | 150(1034)                                | 44(49)                                                  | 0.215(5.5)                                                 | (a)       | ---               | ---           | ---        |                      |
|                                                                  | S-L                         |                  | 70(294)              | 121(831)                                 | 49(54)                                                  | 0.410(10.4)                                                | (a)       | ---               | ---           | ---        |                      |
|                                                                  | S-T                         |                  | 70(294)              | 121(834)                                 | 33(36)                                                  | 0.186(4.7)                                                 | (a)       | ---               | ---           | ---        |                      |
| Forging: 5 x 1.48 in (127 x 36 mm) Thick                         | F,8                         | L-T              | 70(294)              | 136(938)                                 | 48(53)                                                  | 0.311(7.9)                                                 | (a)       | ---               | ---           | ---        | 121                  |
| Forging: 5.1 in (130 mm) Square                                  | K,-                         | S,T-L            | 70(294)              | 136(938)                                 | 62(68)                                                  | 0.520(13.2)                                                | Bend      | 0.5(12.7)         | 1 (25.4)      | 0.54(13.8) | 122                  |
|                                                                  | K,-                         | S,T-S,T          | 70(294)              | 136(938)                                 | 48(53)                                                  | 0.311(7.9)                                                 | Bend      | 0.5(12.7)         | 1 (25.4)      | 0.51(13)   |                      |
| Extrusion                                                        | G,7                         | -                | 70(294)              | 137(945)                                 | 53(58)                                                  | 0.374(9.5)                                                 | (a)       | ---               | ---           | ---        |                      |
| INI 551<br>Bar: 1 in (25.4 mm) Square                            | H,7                         | L-T,S            | 70(294)              | 173(1195)                                | 31(34)                                                  | 0.080(2.0)                                                 | (a)       | ---               | ---           | ---        |                      |
| Extrusion                                                        | I,7                         | L-R              | 70(294)              | 166(1143)                                | 40(44)                                                  | 0.145(3.7)                                                 | (a)       | ---               | ---           | ---        |                      |
|                                                                  | I,9                         | L-R              | 70(294)              | 158(1086)                                | 51(56)                                                  | 0.260(6.6)                                                 | (a)       | ---               | ---           | ---        |                      |
| 6AL-2Mo<br>Plate: 3 in (76.1 mm) Thick<br>8 Forged 2050F (1394K) | J,10                        | T-L              | 70(294)              | 113(779)                                 | 100(110)                                                | 1.958(49.7)                                                | Bend      | 3 (76.1)          | 6 (152)       | 3 (76.1)   | 81                   |

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Specimen in Accordance with ASTM Recommendations

(a) Specimen in Accordance with ASTM Recommendations

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TITANIUM:  $\alpha$ - $\beta$  Alloys: IMI 550, IMI 551, 6Al-2V (Sheet 2 of 2) Table 36 (Cont.)

| Form           | Composition, Heat Treatment, means                                                             |      |      |      |      | Test Orientation | $\sigma_T$ (ksi) | Yield Strength<br>ksi (N/mm <sup>2</sup> ) | Typical<br>$K_{IC}$<br>$KSI\sqrt{in}$ (MN/m <sup>3/2</sup> ) | $2.5\left(\frac{K_{IC}}{\sigma_{ys}}\right)^2$<br>in (mm) | Specimen |   |   | Ref |   |      |                      |                  |                            |
|----------------|------------------------------------------------------------------------------------------------|------|------|------|------|------------------|------------------|--------------------------------------------|--------------------------------------------------------------|-----------------------------------------------------------|----------|---|---|-----|---|------|----------------------|------------------|----------------------------|
|                | Al                                                                                             | Mo   | Sn   | Fe   | Si   |                  |                  |                                            |                                                              |                                                           | C        | H | O |     | N | Type | Thickness<br>in (mm) | Width<br>in (mm) | Crack<br>Length<br>in (mm) |
|                |                                                                                                |      |      |      |      |                  |                  |                                            |                                                              |                                                           |          |   |   |     |   |      |                      |                  |                            |
| COMPOSITION    |                                                                                                |      |      |      |      |                  |                  |                                            |                                                              |                                                           |          |   |   |     |   |      |                      |                  |                            |
| A              | 4.0                                                                                            | 4.3  | 2.1  | 0.09 | 0.50 | -                | 0.005            | -                                          | -                                                            | -                                                         | -        | - | - | -   | - | -    |                      |                  |                            |
| B              | 4.125                                                                                          | 4.08 | 2.04 | -    | 0.47 | -                | 0.002            | 0.185                                      | -                                                            | -                                                         | -        | - | - | -   | - | -    |                      |                  |                            |
| C              | 4.08                                                                                           | 3.99 | 2.10 | -    | 0.48 | -                | 0.001            | 0.19                                       | -                                                            | -                                                         | -        | - | - | -   | - | -    |                      |                  |                            |
| D              | 4.0                                                                                            | 3.95 | 2.19 | 0.12 | 0.54 | -                | 0.003            | -                                          | -                                                            | -                                                         | -        | - | - | -   | - | -    |                      |                  |                            |
| E              | 4.0                                                                                            | 4.0  | 2.08 | 0.29 | 0.48 | -                | 0.159            | -                                          | -                                                            | -                                                         | -        | - | - | -   | - | -    |                      |                  |                            |
| F              | 4.02                                                                                           | 4.03 | 2.10 | -    | 0.46 | -                | 0.002            | 0.14                                       | -                                                            | -                                                         | -        | - | - | -   | - | -    |                      |                  |                            |
| G              | 4.11                                                                                           | 3.95 | 2.00 | -    | 0.53 | -                | 0.003            | 0.2                                        | -                                                            | -                                                         | -        | - | - | -   | - | -    |                      |                  |                            |
| H              | 3.93                                                                                           | 4.02 | 4.10 | -    | 0.48 | -                | 0.004            | 0.19                                       | -                                                            | -                                                         | -        | - | - | -   | - | -    |                      |                  |                            |
| I              | 4.08                                                                                           | 3.89 | 3.97 | -    | 0.55 | -                | 0.001            | 0.2                                        | -                                                            | -                                                         | -        | - | - | -   | - | -    |                      |                  |                            |
| J              | 6.2                                                                                            | 2.0  | -    | 0.4  | -    | 0.25             | -                | 0.06                                       | -                                                            | 0.006                                                     | -        | - | - | -   | - | -    |                      |                  |                            |
| K              | 4.01                                                                                           | 3.95 | 2.09 | 0.04 | 0.51 | -                | 0.003            | -                                          | -                                                            | -                                                         | -        | - | - | -   | - | -    |                      |                  |                            |
| HEAT TREATMENT |                                                                                                |      |      |      |      |                  |                  |                                            |                                                              |                                                           |          |   |   |     |   |      |                      |                  |                            |
| 1.             | 1650F (1173K), 0.5 hr, Air Cool; 800F (700K), 24 hr, Air Cool; 932F (773K), 24 hr, Air Cool    |      |      |      |      |                  |                  |                                            |                                                              |                                                           |          |   |   |     |   |      |                      |                  |                            |
| 2.             | 1650F (1173K), 0.5 hr, Air Cool; Cold Rolled 20% Reduction; 932F (773K), 24 hr, Air Cool       |      |      |      |      |                  |                  |                                            |                                                              |                                                           |          |   |   |     |   |      |                      |                  |                            |
| 3.             | 1760F (1248K), 1 hr, Water Quench; 1650F (1173K), 4 hr, Air Cool; 931F (773K), 24 hr, Air Cool |      |      |      |      |                  |                  |                                            |                                                              |                                                           |          |   |   |     |   |      |                      |                  |                            |
| 4.             | 1650F (1173K), 2 hr, Air Cool; 931F (773K), 24 hr                                              |      |      |      |      |                  |                  |                                            |                                                              |                                                           |          |   |   |     |   |      |                      |                  |                            |
| 5.             | 1795F (1253K), 1 hr, Air Cool; 1650F (1173K), 1 hr, Air Cool; 931F (773K), 24 hr               |      |      |      |      |                  |                  |                                            |                                                              |                                                           |          |   |   |     |   |      |                      |                  |                            |
| 6.             | 1795F (1253K), 1 hr, Air Cool; 1597F (1143K), 1 hr, Air Cool; 931F (773K), 24 hr               |      |      |      |      |                  |                  |                                            |                                                              |                                                           |          |   |   |     |   |      |                      |                  |                            |
| 7.             | 1650F (1173K), Air Cool; 931F (773K), 24 hr                                                    |      |      |      |      |                  |                  |                                            |                                                              |                                                           |          |   |   |     |   |      |                      |                  |                            |
| 8.             | 1650F (1173K), 6 hr, Air Cool; 931F (773K), 24 hr                                              |      |      |      |      |                  |                  |                                            |                                                              |                                                           |          |   |   |     |   |      |                      |                  |                            |
| 9.             | 1957F (1243K), Air Cool; 1650F (1173K), Air Cool; 931F (773K), 24 hr                           |      |      |      |      |                  |                  |                                            |                                                              |                                                           |          |   |   |     |   |      |                      |                  |                            |
| 10.            | 1750F (1228K), 3 hr, Air Cool; 1100F (867K), 1 hr, Water Quench                                |      |      |      |      |                  |                  |                                            |                                                              |                                                           |          |   |   |     |   |      |                      |                  |                            |

ALUMINUM: 6061 Alloy: IMI 680

Table 37

| Form                                     | Composition, Heat Treatment | Test Orientation | Temp °F (°K) | Yield Strength KSI (MN/m <sup>2</sup> ) | Typical K <sub>IC</sub> KSI√in (MN m <sup>-3/2</sup> ) | 2.5 $\frac{K_{IC}}{\sigma_{ys}}$ in (mm) | Specimen |                   |               |                      | Ref. |
|------------------------------------------|-----------------------------|------------------|--------------|-----------------------------------------|--------------------------------------------------------|------------------------------------------|----------|-------------------|---------------|----------------------|------|
|                                          |                             |                  |              |                                         |                                                        |                                          | Type     | Thickness in (mm) | Width in (mm) | Crack Length in (mm) |      |
| Bar: 2 x 1.3 in (50.8 x 33 mm)           | A,1                         | L-T              | 70(294)      | 179(1234)                               | 29(32)                                                 | 0.066 (1.7)                              | (a)      | ---               | ---           | ---                  | 65   |
|                                          | A,2                         | ---              | 70(294)      | 140(965)                                | 59(65)                                                 | 0.444 (11.3)                             | (a)      | ---               | ---           | ---                  | 56   |
| Forging: 0.75 in (19mm) Thick Disc       | A,3                         | ---              | 70(294)      | 143(984)                                | 50(55)                                                 | 0.306 (7.8)                              | (a)      | ---               | ---           | ---                  |      |
|                                          | A,4                         | ---              | 70(294)      | 159(1093)                               | 40(44)                                                 | 0.158 (4.0)                              | (a)      | ---               | ---           | ---                  |      |
|                                          | A,5                         | ---              | 70(294)      | 163(1123)                               | 32(35)                                                 | 0.96 (2.4)                               | (a)      | ---               | ---           | ---                  |      |
|                                          | A,6                         | ---              | 70(294)      | 171(1200)                               | 19(21)                                                 | 0.29 (0.76)                              | (a)      | ---               | ---           | ---                  |      |
|                                          | A,7                         | ---              | 70(294)      | 192(1321)                               | 15(16.5)                                               | 0.15 (0.39)                              | (a)      | ---               | ---           | ---                  |      |
| Forging: 4 x 6.2 in (102 x 158 mm) Thick | A,8                         | L-T              | 70(294)      | 166(1145)                               | 45(49)                                                 | 0.184(4.7)                               | Bend     | 0.50(12.7)        | 1.5(38.1)     | 0.35(8.9)            | 31   |
|                                          | A,9                         | T-S              | 70(294)      | 138(951)                                | 69(76)                                                 | 0.625(4.7)                               | Bend     | 0.5(12.7)         | 1.0(25.4)     | ---                  | 60   |
|                                          |                             | T-S              | 70(294)      | 150(1034)                               | 54(59)                                                 | 0.333(8.5)                               | Bend     | 0.5(12.7)         | 1.0(25.4)     | ---                  |      |

(a) Specimen in accordance with ASTM Recommendations

#### COMPOSITION

|   | Al    | Mg   | Si    | Fe   | S      | P |
|---|-------|------|-------|------|--------|---|
| A | 2.25N | 4.0N | 11.0N | 0.2N | 0.013N |   |

#### HEAT TREATMENT

1. 1471-1501F (1073-1123K); 931F (773K), 24 hr, Air Cool
2. Forged at 1831F (1273K); 1606F (1148K), Furnace Cool; 967F (793K), 24 hr, Air Cool
3. Forged at 1596F (1198K); 1606F (1148K), Furnace Cool; 967F (793K), 24 hr, Air Cool
4. Forged at 1831F (1273K); 1498F (1088K), Water Quench; 967F (793K), 24 hr, Air Cool
5. Forged at 1696F (1128K); 1498F (1088K), Water Quench; 967F (793K), 24 hr, Air Cool
6. Forged at 1606F (1148K); 1606F (1148K), Water Quench; 967F (793K), 24 hr, Air Cool
7. Forged at 1831F (1273K); 1606F (1148K), Water Quench; 967F (793K), 24 hr, Air Cool
8. 1490F (1083K), 1 hr, Water Quench; 930F (772K), 24 hr, Air Cool

Table 38

TITANIUM:  $\alpha$ -B Alloys: 4Al-3Mo-IV, 7Al-2.5Mo, 7Al-4Mo

| Form                                                           | Composition, Heat Treatment | Test Orientation | $\sigma_{TS}$ , $\sigma_{LS}$ | Yield Strength<br>ksi: ( $10^3$ N/m $^2$ ) | Typical $K_{IC}$<br>( $ksi\sqrt{in}$ ) ( $MPa\sqrt{m}$ ) | $2.5\left(\frac{K_{IC}}{\sigma_{YS}}\right)^2$<br>in (mm) | Specimen          |               |                      | Ref |
|----------------------------------------------------------------|-----------------------------|------------------|-------------------------------|--------------------------------------------|----------------------------------------------------------|-----------------------------------------------------------|-------------------|---------------|----------------------|-----|
|                                                                |                             |                  |                               |                                            |                                                          |                                                           | Thickness in (mm) | Width in (mm) | Crack Length in (mm) |     |
| Ti-4Al-3Mo-IV<br>Plate: 0.5 in (12.7 mm) Thick                 | A, 1                        | L-T              | 70 (294)                      | 155 (1069)                                 | 72 (78)                                                  | 0.539 (13.7)                                              | Bend 0.5 (12.7)   | 1.5 (38.1)    | 0.5 (7.6)            | 34  |
|                                                                | A, 2                        | L-T              | 70 (294)                      | 161 (1110)                                 | 63 (69)                                                  | 0.382 (9.5)                                               | Bend 0.5 (12.7)   | 1.5 (38.1)    | 0.5 (7.6)            |     |
|                                                                | A, 3                        | T-L              | 70 (294)                      | 175 (1207)                                 | 66 (72)                                                  | 0.356 (9)                                                 | Bend 0.5 (12.7)   | 1.5 (38.1)    | 0.5 (7.6)            | 94  |
|                                                                | B, 3                        | (a)              | 70 (294)                      | 146 (1007)                                 | 49 (53)                                                  | 0.282 (7.2)                                               | Bend 0.5 (12.7)   | ---           | ---                  | 22  |
| Ti-7Al-2.5Mo<br>Plate: 0.5 in (12.7 mm) Thick                  | E, 7                        | T-L              | 70 (294)                      | 152 (1048)                                 | 52 (57)                                                  | 0.293 (7.4)                                               | Bend 0.5 (12.7)   | 1.5 (38.1)    | 0.35 (8.9)           | 95  |
|                                                                | E, 8                        | T-L              | 70 (294)                      | 136 (938)                                  | 65 (71)                                                  | 0.571 (14.5)                                              | Bend 0.5 (12.7)   | 1.5 (38.1)    | 0.35 (8.9)           |     |
| Ti-7Al-4Mo<br>Plate: 0.5 in (12.7 mm) Thick                    | D, 6                        | T-L              | 70 (294)                      | 145 (1006)                                 | 33 (36)                                                  | 0.129 (3.3)                                               | Bend 0.5 (12.7)   | 1.5 (38.1)    | 0.5 (7.6)            | 94  |
|                                                                | C, 4                        | (a)              | 70 (294)                      | 155 (1069)                                 | 41 (45)                                                  | 0.175 (4.4)                                               | Bend 0.5 (12.7)   | ---           | ---                  | 22  |
| Forging: 0.625 in (15.9 mm) Thick<br>8 Processed 2100F (1422K) |                             |                  |                               |                                            |                                                          |                                                           |                   |               |                      |     |

(a) Test orientation is not specified, but loading and crack propagation directions are in a plane where maximum grain flow is approximately radially symmetric.

## COMPOSITION

|   | Al  | Mo  | V   | Fe   | C     | H     | O    | N     |
|---|-----|-----|-----|------|-------|-------|------|-------|
| A | 4.5 | 3.3 | 1.0 | 0.10 | 0.03  | 0.006 | 0.11 | 0.009 |
| B | 4.4 | 3.1 | 1.1 | 0.08 | 0.02  | -     | -    | -     |
| C | 6.9 | 4.0 | -   | 0.12 | 0.023 | -     | -    | -     |
| D | 6.9 | 3.7 | -   | 0.15 | 0.02  | 0.005 | 0.15 | 0.007 |
| E | 6.8 | 2.4 | -   | 0.04 | 0.02  | 0.004 | 0.06 | 0.008 |

## HEAT TREATMENT

- 1875F (1297K), 1 hr, Air Cool; 1725F (1214K), 1 hr, Water Quench; 1050F (839K), 8 hr, Air Cool
- 1800F (1255K), 1 hr, Water Quench; Aged 1100F (867K), 8 hr, Air Cooled
- 1725F (1214K), 1 hr, Water Quench; 1050F (839K), 4 hr, Air Cool
- 1750F (1228K), 1 hr, Water Quench; 1050F (839K), 4 hr, Air Cool
- 1875F (1297K), 1 hr, Water Quench; 1100F (867K), 8 hr, Air Cool
- Mill Annealed
- 1800F (1255K), 0.5 hr, Water Quench; 1100F (867K), 8 hr, Air Cool
- Mill Annealed; Hot Rolled 50% Reduction at 1750F (1228K)

Table 39

| Form                                           | Composition, Heat Treatment | Test Orientation | Temp.<br>°F (°K) | Yield Strength<br>KSI (MN/m <sup>2</sup> ) | Typical<br>K <sub>IC</sub><br>KSI/in (MN m <sup>-3/2</sup> ) | 2.5 (K <sub>IC</sub> <sup>2</sup> / σ <sub>ys</sub> )<br>in (mm) | Specimen |                      |                  |                         | Ref. |
|------------------------------------------------|-----------------------------|------------------|------------------|--------------------------------------------|--------------------------------------------------------------|------------------------------------------------------------------|----------|----------------------|------------------|-------------------------|------|
|                                                |                             |                  |                  |                                            |                                                              |                                                                  | Type     | Thickness<br>in (mm) | Width<br>in (mm) | Crack Length<br>in (mm) |      |
| Plate: 0.5 in (12.7 mm) Thick<br>(c Processed) | A,1                         | L-T              | 75(297)          | 148(1020)                                  | 46(50)                                                       | 0.240(6.1)                                                       | Bend     | 1.0 (25.4)           | 1.0 (25.4)       | 0.290(7.4)              | 7    |
|                                                |                             | T-L              | 75(297)          | ---                                        | 42(46)                                                       | ---                                                              | Bend     | 1.0 (25.4)           | 1.0 (25.4)       | 0.3 (7.6)               |      |
|                                                |                             | L-T              | -50(228)         | ---                                        | 46(50)                                                       | ---                                                              | Bend     | 1.0 (25.4)           | 1.0 (25.4)       | 0.3 (7.6)               |      |
|                                                |                             | L-T              | -100(200)        | 185(1276)                                  | 47(51)                                                       | 0.161(4.1)                                                       | Bend     | 1.0 (25.4)           | 1.0 (25.4)       | 0.26 (6.6)              |      |
|                                                |                             | L-T              | 75(297)          | 148(1020)                                  | 48(52)                                                       | 0.263(6.7)                                                       | Bend     | 1.0 (25.4)           | 1.0 (25.4)       | 0.303(7.7)              |      |
| Plate: 0.75 in (19.1 mm) Nominal Thickness     | B,1                         | L-T              | -50(228)         | 177(1220)                                  | 53(58)                                                       | 0.224(5.7)                                                       | Bend     | 1.0 (25.4)           | 1.0 (25.4)       | 0.267(6.8)              |      |
|                                                |                             | L-T              | -100(200)        | 173(1193)                                  | 54(59)                                                       | 0.246(6.2)                                                       | Bend     | 1.0 (25.4)           | 1.0 (25.4)       | 0.208(5.3)              |      |
|                                                |                             | L-T              | 75(297)          | 133(916)                                   | 75(82)                                                       | 0.792(20.1)                                                      | Bend     | 0.781(19.8)          | 1.5 (38.1)       | 0.3 (7.6)               | 20   |
|                                                |                             | T-L              | 75(297)          | 150(1034)                                  | 45(49)                                                       | 0.225(5.7)                                                       | Bend     | 0.9 (22.9)           | 1.8 (45.8)       | 0.45 (11.4)             | 4    |
|                                                |                             | T-L              | -321(78)         | 227(1565)                                  | 36(39)                                                       | 0.063(1.6)                                                       | Bend     | 0.9 (22.9)           | 1.8 (45.8)       | 0.45 (11.4)             |      |
| Plate: 0.5 in (12.7 mm) Thick                  | E,3                         | L-T              | 70(294)          | 148(1034)                                  | 70(77)                                                       | 0.56(14.2)                                                       | Bend     | 0.5 (12.7)           | 1.5 (38.1)       | ---                     | 34   |
|                                                |                             | (b)              | 75(297)          | 146(1007)                                  | 60(65)                                                       | 0.422(10.7)                                                      | Bend     | 0.5 (12.7)           | ---              | ---                     | 22   |
|                                                |                             | (b)              | 75(297)          | 150(1034)                                  | 46(50)                                                       | 0.235(6.0)                                                       | Bend     | 0.5 (12.7)           | ---              | ---                     |      |
|                                                |                             | L-T              | 70(294)          | 150(1034)                                  | 61(66)                                                       | 0.413(10.5)                                                      | Bend     | 0.55 (14)            | 1.02 (26)        | 0.55 (14)               | 23   |
|                                                |                             | T-L              | 70(294)          | 148(1020)                                  | 55(60)                                                       | 0.345(8.8)                                                       | Bend     | 1.0 (25.4)           | 2.0 (50.8)       | 1.0 (25.4)              |      |
| Forging: 1.0 in (25.4 mm) Thick                | J,6                         | T-L              | 150(339)         | 127(875)                                   | 78(86)                                                       | 0.942(23.9)                                                      | WOL      | 2.0 (50.8)           | 6.2 (15.8)       | 1.8 (4.6)               | 11   |
|                                                |                             | L-T              | 75(297)          | 110(966)                                   | 81(89)                                                       | 0.837(21.3)                                                      | WOL      | 2.0 (50.8)           | 2.25(57.2)       | 0.5 (12.7)              |      |
|                                                |                             | L-T              | -75(214)         | 159(1097)                                  | 68(75)                                                       | 0.457(11.6)                                                      | WOL      | 2.0 (50.8)           | 6.2 (15.8)       | 1.8 (4.6)               |      |
|                                                |                             | L-T              | 70(294)          | 128(883)                                   | 71.78                                                        | 0.769(19.5)                                                      | (a)      | ---                  | ---              | ---                     | 63   |
|                                                |                             | L-T              | 70(294)          | 140(968)                                   | 58(53)                                                       | 0.429(10.9)                                                      | (a)      | ---                  | ---              | ---                     |      |
| Bar: 2.26 x 1.2 in (57.5 x 30.5 mm)            | I,8                         | L-S              | 70(294)          | 140(968)                                   | 55(60)                                                       | 0.350(8.9)                                                       | Bend     | 0.5 (12.7)           | 1.0 (25.4)       | ---                     | 60   |
|                                                |                             | T-S              | 70(294)          | 117(1011)                                  | ---                                                          | ---                                                              | ---      | ---                  | ---              | ---                     |      |

Table 39 (Cont.)

| Form                                                                            | Composition, Heat Treatment | Test Orientation | $\sigma_f^{\text{imp}}$ (ksi) | Yield Strength KSI (N/m <sup>2</sup> ) | Typical $K_{IC}$ KSI√in (MN/m <sup>3/2</sup> ) | $2.5 \left( \frac{K_{IC}}{\sigma_{ys}} \right)^2$ in (mm) | Specimen |                   |               |                      |     |
|---------------------------------------------------------------------------------|-----------------------------|------------------|-------------------------------|----------------------------------------|------------------------------------------------|-----------------------------------------------------------|----------|-------------------|---------------|----------------------|-----|
|                                                                                 |                             |                  |                               |                                        |                                                |                                                           | Type     | Thickness in (mm) | Width in (mm) | Crack Length in (mm) |     |
| Plate: 3 in (76.1 mm) Thick                                                     | K,9                         | T-L              | 70 (294)                      | 122 (841)                              | 101 (111)                                      | 1.717 (43.5)                                              | Bend     | 3.0 (76.1)        | 6.0 (152.2)   | 3.0 (76.1)           | 81  |
|                                                                                 | K,10                        | T-L              | 70 (294)                      | 113 (779)                              | 100 (110)                                      | 1.958 (49.7)                                              | Bend     | 3.0 (76.1)        | 6.0 (152.2)   | 3.0 (76.1)           |     |
| Extrusion: 8.75 in (222 mm) OD<br>3 in (76.2) Wall<br>Extruded at 1750F (1228K) | L,11                        | C-R              | 70 (294)                      | 138 (952)                              | 58 (64)                                        | 0.442 (11.2)                                              | CT       | 0.75 (19.1)       | 1.5 (38.1)    | 0.75 (19.1)          | 117 |

(a) Specimen in accordance with ASTM Recommendations  
(b) Test orientation is not specified but loading and crack propagation directions are in a plane where maximum grain flow; approximately radially symmetric.

COMPOSITION

|   | Al   | V    | Fe   | C     | Si   | O    | N     | H     |
|---|------|------|------|-------|------|------|-------|-------|
| A | 6.2  | 4.2  | 0.15 | 0.020 | -    | -    | -     | -     |
| B | 6.3  | 4.3  | 0.15 | 0.026 | -    | -    | -     | -     |
| C | 5.83 | 3.78 | 0.16 | -     | -    | -    | 0.022 | 0.006 |
| D | 6.1  | 4.12 | 0.13 | 0.024 | -    | 0.16 | 0.013 | 0.008 |
| E | 6.4  | 3.9  | 0.17 | 0.03  | -    | 0.15 | 0.018 | 0.003 |
| F | 6.3  | 4.1  | 0.09 | 0.025 | -    | -    | -     | -     |
| G | 6.3  | 4.1  | 0.13 | 0.023 | -    | 0.17 | -     | 0.004 |
| H | 6.18 | 3.91 | 0.07 | -     | -    | -    | -     | 0.001 |
| I | 6.54 | 4.24 | 0.7  | -     | 0.16 | -    | 0.007 | 0.002 |
| J | 6.13 | 4.0  | 0.31 | 0.11  | -    | -    | -     | -     |
| K | 6.0  | 4.1  | 0.5  | 0.023 | -    | 0.07 | 0.008 | -     |
| L | 6.3  | 4.2  | 0.20 | 0.02  | -    | 0.13 | 0.009 | 0.004 |

HEAT TREATMENT

- 1700F (1200K) Air Cool; Age 1000F (811K), 4 Hr
- 1750F (1228K) 1 Hr, Air Cool; Age 1000F (811K), 4 Hr
- 1850F (1283K) 30 Min, Water Quenched, Aged 1250F (950K) 4 Hr
- 1725F (1214K) 1 Hr, Water Quenched; Aged 1050F (839K) 4 Hr, Air Cool
- 1725F (1214K) 1 Hr, Water Quenched; Aged 1000F (811K) 4 Hr, Air Cool
- Solution Treated and Aged
- 1741F (1223K), 1 Hr, Air Cool; 1246F (948K), 1 Hr, Air Cool
- 1291F (973K), Air Cool
- 1750F (1228K), 3 Hr, Water Quenched; Age 1100F (867K), 4 Hr, Air Cool
- 1700F (1200K), 3 Hr, Air Cool; 1100F (867K), 4 Hr, Water Quench
- 1750F (1228K), 3 Hr, Water Quenched; 1000F (811K), 4 Hr, Air Cool

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TITANIUM,  $\alpha$ - $\beta$  Alloy: 6Al-6V-2Sn (Sheet 1 of 2)

Table 40

| Form                                                                                   | Composition, Heat Treatment | Test Orientation | Yield Strength<br>KSI (N/m <sup>2</sup> ) | Typical<br>K <sub>IC</sub><br>KSI√in (MN/m <sup>3/2</sup> ) | 2.5( $\frac{K_{IC}}{\sigma_{ys}}$ ) <sup>2</sup><br>in (mm) | Specimen |                      |                  |                         | Ref |
|----------------------------------------------------------------------------------------|-----------------------------|------------------|-------------------------------------------|-------------------------------------------------------------|-------------------------------------------------------------|----------|----------------------|------------------|-------------------------|-----|
|                                                                                        |                             |                  |                                           |                                                             |                                                             | Type     | Thickness<br>in (mm) | Width<br>in (mm) | Crack Length<br>in (mm) |     |
| Plate: 1.0 in (25.4 mm) Thick                                                          | A,1                         | L-T              | 75(297)                                   | 33(36)                                                      | 0.079( 2.0)                                                 | SEN      | 1.0 (25.4)           | 5.0 (12.7)       | 1.6 (40.6)              | 24  |
|                                                                                        | A,2                         | L-T              | 75(297)                                   | 60(65)                                                      | 0.323( 8.2)                                                 | SEN      | 1.0 (12.7)           | 5.0 (12.7)       | 1.6 (40.6)              |     |
| Plate: 1.0 in (25.4 mm) Thick<br>ELI Grade                                             | B,3                         | L-T              | 75(297)                                   | 30(33)                                                      | 0.070( 1.8)                                                 | Bend     | 0.250(12.7)          | 0.500(12.7)      | 0.200( 5.1)             | 25  |
|                                                                                        | B,4                         | L-T              | 75(297)                                   | 34(37)                                                      | 0.099( 2.5)                                                 | Bend     | 0.250(12.7)          | 0.500(12.7)      | 0.200( 5.1)             |     |
|                                                                                        | B,4                         | L-S              | 75(297)                                   | 38(42)                                                      | ---                                                         | Bend     | 0.250(12.7)          | 0.500(12.7)      | 0.200( 5.1)             |     |
|                                                                                        | B,4                         | L-T              | -321( 77)                                 | 23(25)                                                      | 0.020( 0.5)                                                 | Bend     | 0.250(12.7)          | 0.500(12.7)      | 0.200( 5.1)             |     |
|                                                                                        | B,4                         | L-S              | -321( 77)                                 | 25(27)                                                      | 0.023( 0.6)                                                 | Bend     | 0.250(12.7)          | 0.500(12.7)      | 0.200( 5.1)             |     |
| Bar: 4.5 in (114.3 mm) Dia.<br>Commercial Grade                                        | G,5                         | L-C              | 75(297)                                   | 31(34)                                                      | 0.070( 1.8)                                                 | Bend     | 0.250(12.7)          | 0.500(12.7)      | 0.200( 5.1)             |     |
|                                                                                        | G,5                         | L-C              | -321( 77)                                 | 23(25)                                                      | 0.018( 0.5)                                                 | Bend     | 0.250(12.7)          | 0.500(12.7)      | 0.200( 5.1)             |     |
| Extrusion: 8.75 in (222 mm) OD<br>3 in (76.2 mm) Wall,<br>Extruded at 1675F<br>(1186K) | H,11                        | C-P              | 70(294)                                   | 69(76)                                                      | 0.582(14.8)                                                 | CT       | 0.75 (19.1)          | 1.5 (38.1)       | 0.75 (19.1)             | 117 |
|                                                                                        | I,12                        | C-R              | 70(294)                                   | 32(35)                                                      | 0.071( 1.8)                                                 | CT       | 0.75 (19.1)          | 1.5 (38.1)       | 0.75 (19.1)             |     |
| Forging: 0.625 in (15.8 mm) Thick<br>8 Processed 2100F (1422K)                         | C,3                         | (a)              | 75(297)                                   | 38(41)                                                      | 0.125( 3.2)                                                 | Bend     | 0.500(12.7)          | ---              | ---                     | 22  |
| Forging: 4.5 x 4.5 in (114.3 x<br>114.3 mm) Vacuum Arc<br>Remelt                       | D,5                         | L-T              | 75(297)                                   | 60(65)                                                      | 0.405(10.3)                                                 | HTC      | 0.500(12.7)          | 3.0 (76.2)       | 1.0 (25.4)              | 26  |
| Forging: 4.5 x 4.5 in (114.3 x<br>114.3 mm) Vacuum Arc<br>Remelt                       | D,5                         | L-ST             | -110(194)                                 | 56(61)                                                      | 0.239( 6.1)                                                 | SEN      | 0.250( 6.4)          | 1.0 (25.4)       | 0.500(12.7)             | 16  |
|                                                                                        | D,5                         | ST-L             | -110(194)                                 | 50(55)                                                      | 0.180( 4.6)                                                 | SEN      | 0.250( 6.4)          | 1.0 (25.4)       | 0.500(12.7)             |     |
| Plate: 1.5 in (38.1 mm) Thick                                                          | D,6                         | L-S              | -110(194)                                 | 41(45)                                                      | 0.110( 2.8)                                                 | SEN      | 0.250( 6.4)          | 1.0 (25.4)       | 0.500(12.7)             |     |
|                                                                                        | D,6                         | L-T              | -110(194)                                 | 32(35)                                                      | 0.068( 1.7)                                                 | SEN      | 0.250( 6.4)          | 1.0 (25.4)       | 0.500(12.7)             |     |
|                                                                                        | D,6                         | TS-TS            | -110(194)                                 | 25(27)                                                      | 0.043( 1.1)                                                 | CT       | 0.500(12.7)          | 1.0 (25.4)       | 0.500(12.7)             |     |
| Plate: 0.5 in (12.7 mm) Thick                                                          | D,6                         | L-T              | -110(194)                                 | 33(36)                                                      | 0.063( 1.6)                                                 | SEN      | 0.250( 6.4)          | 1.0 (25.4)       | 0.500(12.7)             |     |
|                                                                                        | D,6                         | L-L              | -110(194)                                 | 30(33)                                                      | 0.053( 1.3)                                                 | SEN      | 0.250( 6.4)          | 1.0 (25.4)       | 0.500(12.7)             |     |

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TITANIUM,  $\alpha$ - $\beta$  Alloy: 6Al-6V-2Sn (Sheet 2 of 2)

Table 40 (Cont.)

| Form                              | Composition, Heat Treatment | Test Orientation | Temp., °F (°C) | Yield Strength, ksi (N/mm <sup>2</sup> ) | Typical K <sub>IC</sub> (ksi√in (N/mm <sup>3/2</sup> )) | 2.5( $\frac{K_{IC}}{\sigma_{ys}}$ ) <sup>2</sup> in (mm) | Specimen |                   |               | Ref        |                      |
|-----------------------------------|-----------------------------|------------------|----------------|------------------------------------------|---------------------------------------------------------|----------------------------------------------------------|----------|-------------------|---------------|------------|----------------------|
|                                   |                             |                  |                |                                          |                                                         |                                                          | Type     | Thickness in (mm) | Width in (mm) |            | Crack Length in (mm) |
| Handforging: 1.0 in (22 mm) Thick | F, 7                        | L-T              | 75 (297)       | 180 (1241)                               | 29 (32)                                                 | 0.065 (1.7)                                              | Bend     | 0.55 (14)         | 1.02 (26)     | 0.55 (14)  | 23                   |
|                                   |                             | T-L              | 75 (297)       | 186 (1282)                               | 26 (28)                                                 | 0.049 (1.2)                                              | Bend     | 1.0 (25.4)        | 2.0 (50.8)    | 1.0 (25.4) |                      |
| 8 Forged: 4.92 in (125 mm) Dia    | E, 8                        | L-C              | 70 (294)       | 139 (958)                                | 60 (65)                                                 | 0.466 (11.8)                                             | (b)      | ---               | ---           | ---        | 53                   |
|                                   | E, 9                        | L-T              | 70 (294)       | 178 (1227)                               | 32 (35)                                                 | 0.08 (2.1)                                               | (a)      | ---               | ---           | ---        |                      |
|                                   | E, 10                       | L-T              | 70 (294)       | 194 (1338)                               | 27 (30)                                                 | 0.056 (1.4)                                              | (a)      | ---               | ---           | ---        |                      |
|                                   | F, -                        | T-S              | 70 (294)       | 163 (1124)                               | 17 (51)                                                 | 0.200 (5.1)                                              | Bend     | 0.5 (12.7)        | 0.5 (12.7)    | 1.0 (25.4) | 60                   |

(a) Test orientation is not specified but the loading and crack propagation directions are in a plane where maximum grain flow is approximately radially symmetric.  
(b) Specimen in accordance with ASTM Recommendations

COMPOSITION

|   | Al   | V    | Sn   | Cu    | Fe   | Cu   | O     | N     | P     | in   |
|---|------|------|------|-------|------|------|-------|-------|-------|------|
| A | 5.5  | 5.5  | 2.0  | 0.024 | 0.69 | 0.73 | 0.08  | 0.010 | 0.003 | -    |
| B | 5.35 | 5.34 | 1.96 | 0.015 | 0.59 | 0.65 | 0.081 | 0.018 | 0.006 | -    |
| C | 5.4  | 5.3  | 2.0  | 0.022 | 0.63 | 0.6  | -     | -     | -     | -    |
| D | 5.5  | 5.4  | 1.9  | 0.025 | 0.65 | 0.64 | 0.12  | 0.012 | 0.005 | -    |
| E | 5.4  | 5.4  | 2.0  | -     | 0.53 | -    | 0.015 | 0.004 | 0.002 | -    |
| F | 5.5  | 5.5  | 2.0  | 0.051 | 0.68 | 0.68 | 0.29  | 0.04  | 0.015 | -    |
| G | 5.64 | 5.32 | 2.26 | 0.021 | 0.59 | 0.56 | 0.172 | 0.007 | 0.016 | -    |
| H | 5.9  | 5.5  | 2.0  | 0.02  | 0.81 | 0.78 | 0.16  | 0.015 | 0.005 | -    |
| I | 6.0  | 5.9  | 2.0  | 0.12  | 0.99 | 0.97 | 0.07  | 0.010 | 0.004 | 0.02 |

HEAT TREATMENT

1. 1550F (1117K), 1 Hr, Water Quenched; Aged 900F (756K), 4 Hr, Air Cool
2. 1625F (1158K), 1 Hr, Water Quenched; Aged 1200F (822K), 2 Hr, Air Cool
3. 1600F (1144K), 1 Hr, Water Quenched; Aged 1050F (839K), 4 Hr, Air Cool
4. 1650F (1172K), 1 Hr, Water Quenched; Aged 1125F (881K), 4 Hr, Air Cool
5. 1650F (1172K), 1 Hr, Water Quenched; Aged 1050F (839K), 1 Hr, Air Cool
6. 1550F (1117K), 1/4 Hr, Water Quenched; Aged 1050F (839K), 4 Hr, Air Cool
7. Solution Annealed and Aged
8. 1400F (1033K), Air Cooled
9. 1561F (1123K), 1 Hr, Water Quench; 967F (793K), 4 Hr, Air Cool
10. 1741F (1223K), 1 Hr, Water Quench; 967F (793K), 4 Hr, Air Cool
11. 1600F (1144K), 3 Hr, Water Quench; 1300F (978K), 6 Hr, Air Cool
12. 1600F (1144K), 3 Hr, Water Quench; 1000F (811K), 1 Hr, Air Cool

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(a) Test orientation is not specified but the loading and crack propagation directions are in a plane where maximum grain flow is approximately radially symmetric.

(b) Specimen in accordance with ASTM recommendations

## COMPOSITION

|   | Al   | V    | Sn   | C     | Fe   | Cu   | O     | N     | H      | Zn   |
|---|------|------|------|-------|------|------|-------|-------|--------|------|
| A | 5.5  | 5.5  | 2.0  | 0.024 | 0.69 | 0.73 | 0.08  | 0.010 | 0.003  | -    |
| B | 5.33 | 5.34 | 1.96 | 0.015 | 0.59 | 0.65 | 0.081 | 0.018 | 0.006  | -    |
| C | 5.4  | 5.3  | 2.0  | 0.022 | 0.63 | 0.6  | -     | -     | -      | -    |
| D | 5.5  | 5.4  | 1.9  | 0.025 | 0.65 | 0.64 | 0.12  | 0.012 | 0.005  | -    |
| E | 5.4  | 5.4  | 2.0  | -     | 0.53 | -    | 0.015 | 0.004 | 0.002  | -    |
| F | 5.5  | 5.5  | 2.0  | 0.051 | 0.68 | 0.68 | 0.281 | 0.041 | 0.0154 | -    |
| G | 5.64 | 5.32 | 2.26 | 0.021 | 0.59 | 0.56 | 0.172 | 0.007 | 0.016  | -    |
| H | 5.9  | 5.5  | 2.0  | 0.02  | 0.84 | 0.78 | 0.16  | 0.015 | 0.005  | -    |
| I | 6.0  | 5.9  | 2.0  | 0.12  | 0.99 | 0.97 | 0.07  | 0.010 | 0.004  | 0.02 |

## HEAT TREATMENT

- 1550F (1117K), 1 hr, Water Quench; Aged 900F (756K), 4 hr, Air Cool
- 1625F (1158K), 1 hr, Water Quench; Aged 1200F (922K), 2 hr, Air Cool
- 1600F (1144K), 1 hr, Water Quench; Aged 1050F (839K), 4 hr, Air Cool
- 1650F (1172K), 1 hr, Water Quench; Aged 1125F (881K), 4 hr, Air Cool
- 1650F (1172K), 1 hr, Water Quench; Aged 1050F (839K), 1 hr, Air Cool
- 1550F (1117K), 1/4 hr, Water Quench; Aged 1050F (839K), 4 hr, Air Cool
- Solution Annealed and Aged
- 1400F (1033K), Air Cooled
- 1561F (1123K), 1 hr, Water Quench; 967F (793K), 4 hr, Air Cool
- 1741F (1223K), 1 hr, Water Quench; 967F (793K), 4 hr, Air Cool
- 1600F (1144K), 3 hr, Water Quench; 1300F (978K), 6 hr, Air Cool
- 1600F (1144K), 3 hr, Water Quench; 1000F (811K), 1 hr, Air Cool

TITANIUM,  $\alpha$ - $\beta$  Alloys: 6Al-6V-4Zr-4Mo, 6Al-25Sn-4Zr-6Mo and 6Al-25Sn-2Zr-2Mo-2Cr (Sheet 1 of 2) Table 41

| Form                                                                                                                    | Composition, Heat Treatment | Test Orientation | $\sigma_L$ (ksi) | Yield Strength ksi (N/mm <sup>2</sup> ) | Typical $K_{IC}$ ksi√in (MN/m <sup>3/2</sup> ) | $2.5 \left( \frac{K_{IC}}{\sigma_{ys}} \right)^2$ in (mm) | Specimen  |                   |               | Ref        |                      |
|-------------------------------------------------------------------------------------------------------------------------|-----------------------------|------------------|------------------|-----------------------------------------|------------------------------------------------|-----------------------------------------------------------|-----------|-------------------|---------------|------------|----------------------|
|                                                                                                                         |                             |                  |                  |                                         |                                                |                                                           | Type      | Thickness in (mm) | Width in (mm) |            | Crack length in (mm) |
| 6Al-6V-4Zr-4Mo<br>Die Forging: 3.5 in (88.9 mm) Thick, $\beta$ Forged 1750F (1228K) $\alpha+\beta$ Forged 1575F (1130K) | A,1                         | C-R              | 70 (294)         | 157 (1082)                              | 40 (44)                                        | 0.162 (4.1)                                               | Bend 4 Pt | 0.5 (12.7)        | 1.5 (38.1)    | 0.35 (8.9) | 96                   |
|                                                                                                                         |                             | C-S              | 70 (294)         | 156 (1075)                              | 46 (50)                                        | 0.217 (5.5)                                               | Bend 4 Pt | 0.5 (12.7)        | 1.5 (38.1)    | 0.35 (8.9) |                      |
|                                                                                                                         | A,1                         | C-R              | 70 (294)         | 170 (1172)                              | 51 (56)                                        | 0.225 (5.7)                                               | Bend 4 Pt | 0.5 (12.7)        | 1.5 (38.1)    | 0.35 (8.9) |                      |
|                                                                                                                         |                             | C-S              | 70 (294)         | 168 (1158)                              | 62 (68)                                        | 0.340 (8.6)                                               | Bend 4 Pt | 0.5 (12.7)        | 1.5 (38.1)    | 0.35 (8.9) |                      |
| Forging: 4.25 x 6 in (108 x 152 mm), $\alpha+\beta$ Forged 1575F (1130K)                                                | A,1                         | L-T              | 70 (294)         | 160 (1103)                              | 49 (54)                                        | 0.234 (5.9)                                               | Bend 4 Pt | 0.5 (12.7)        | 1.5 (38.1)    | 0.35 (8.9) |                      |
|                                                                                                                         |                             | L-S              | 70 (294)         | 153 (1055)                              | 41 (45)                                        | 0.180 (4.6)                                               | Bend 4 Pt | 0.5 (12.7)        | 1.5 (38.1)    | 0.35 (8.9) |                      |
| Forging: 4 x 6.2 in (102 x 158 mm), $\alpha+\beta$ Forged 1540F (1112K)                                                 | P,2                         | L-T              | 70 (294)         | 151 (1041)                              | 45 (49)                                        | 0.222 (5.6)                                               | Bend 4 Pt | 0.5 (12.7)        | 1.5 (38.1)    | 0.35 (8.9) | 31                   |
| 6Al-25Sn-4Zr-6Mo<br>Forging: 1.5 in (38.1 mm) Square $\beta$ Forged 1800F (1255K), Water Quench                         | C,4                         | -                | 70 (294)         | *180 (1241)                             | 46 (50)                                        | ---                                                       | --        | ---               | ---           | ---        | 100                  |
| Forging: 2 in (50.8 mm) Thick $\beta$ Forged 1800F (1255K), Water Quench                                                | C,4                         | -                | 70 (294)         | *168 (1158)                             | 60 (66)                                        | ---                                                       | --        | ---               | ---           | ---        |                      |
| Forging: 3.5 in (88.9 mm) Thick $\beta$ Forged                                                                          | C,2                         | C-R              | 70 (294)         | 169 (1165)                              | 22 (24)                                        | 0.042 (1.1)                                               | Bend 4 Pt | 0.5 (12.7)        | 1.5 (38.1)    | 0.35 (8.9) | 96                   |
| Forging: 4.5 x 6 in (108 x 152 mm) $\alpha+\beta$ Forged, 1650F (1172K) Max                                             | C,3                         | L-T              | - 1)             | 158 (1089)                              | 41 (45)                                        | 0.168 (4.3)                                               | Bend 4 Pt | 0.5 (12.7)        | 1.5 (38.1)    | 0.35 (8.9) | 31                   |
|                                                                                                                         | C,2                         | L-T              | 70 (294)         | 174 (1200)                              | 25 (27)                                        | 0.052 (1.3)                                               | Bend 4 Pt | 0.5 (12.7)        | 1.5 (38.1)    | 0.35 (8.9) |                      |
| 6Al-25Sn-2Zr-2Mo-2Cr<br>Bar: 4 in (101.6 mm) Dia                                                                        | D,5                         | L                | 70 (294)         | 160 (1103)                              | 62 (68)                                        | 0.376 (9.6)                                               | CT        | 1.0 (25.4)        | 2.0 (50.8)    | 1.0 (25.9) | 101                  |
|                                                                                                                         |                             | R-L              | 70 (294)         | 161 (1131)                              | 51 (56)                                        | 0.242 (6.1)                                               | CT        | 1.0 (25.4)        | 2.0 (50.8)    | 1.0 (25.9) |                      |
|                                                                                                                         | D,6                         | L-R              | 70 (294)         | 161 (1110)                              | 58 (64)                                        | 0.324 (8.2)                                               | CT        | 1.0 (25.4)        | 2.0 (50.8)    | 1.0 (25.9) |                      |
|                                                                                                                         |                             | R-L              | 70 (294)         | 169 (1165)                              | 45 (49)                                        | 0.177 (4.5)                                               | CT        | 1.0 (25.4)        | 2.0 (50.8)    | 1.0 (25.9) |                      |
| Forging: 1 in (25.4 mm) Thick, $\alpha+\beta$ Forged                                                                    | D,7                         | -                | 70 (294)         | 158 (1089)                              | 74 (81)                                        | 0.548 (13.9)                                              | CT        | 1.0 (25.4)        | 2.0 (50.8)    | 1.0 (25.9) |                      |
| $\alpha+\beta$ Forged                                                                                                   | D,7                         | -                | 70 (294)         | 160 (1103)                              | 60 (66)                                        | 0.340 (8.6)                                               | CT        | 1.0 (25.4)        | 2.0 (50.8)    | 1.0 (25.9) |                      |

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TITANIUM,  $\alpha$ - $\beta$  ALLOYS: 6Al-6V-4Zr-4Nb, 6Al-25Sn-4Zr-6Nb and 6Al-25Sn-2Zr-2Nb-2Cr (Sheet 2 of 2) Table 41 (Cont.)

| Form                                                               | Composition, Weight Percent |      | Yield strength, ksi (N/mm <sup>2</sup> ) | Typical $K_{IC}$ KSI√in (MS/m) | $2.5\left(\frac{K_{IC}}{\sigma_{ys}}\right)^2$ in (mm) | Specimen          |               |                      | Ref   |       |       |       |       |
|--------------------------------------------------------------------|-----------------------------|------|------------------------------------------|--------------------------------|--------------------------------------------------------|-------------------|---------------|----------------------|-------|-------|-------|-------|-------|
|                                                                    | Al                          | V    |                                          |                                |                                                        | Thickness in (mm) | Width in (mm) | Crack Length in (mm) |       |       |       |       |       |
| COMPOSITION:                                                       |                             |      |                                          |                                |                                                        |                   |               |                      |       |       |       |       |       |
|                                                                    | Al                          | V    | Zr                                       | Nb                             | Sn                                                     | Cr                | C             | Fe                   | Cu    | H     | O     | N     | Si    |
| A                                                                  | 6.18                        | 5.74 | 4.07                                     | 4.20                           | -                                                      | -                 | -             | 0.07                 | 0.012 | 0.014 | 0.12  | 0.012 | -     |
| B                                                                  | 6.0%                        | 6.0% | 4.0%                                     | 4.0%                           | -                                                      | -                 | -             | -                    | -     | -     | -     | -     | -     |
| C                                                                  | 6.0%                        | -    | 4.0%                                     | 6.0%                           | 2.0%                                                   | -                 | 0.04%         | 0.15%                | -     | 0.15% | 0.15% | 0.02% | -     |
| D                                                                  | 6.0%                        | -    | 2.0%                                     | 2.0%                           | 2.0%                                                   | 2.0%              | -             | -                    | -     | -     | -     | -     | 0.25% |
| HEAT TREATMENT                                                     |                             |      |                                          |                                |                                                        |                   |               |                      |       |       |       |       |       |
| 1. 1525F (1103K), 4 Hr, Air Cool; 950F (873K), 8 Hr, Air Cool      |                             |      |                                          |                                |                                                        |                   |               |                      |       |       |       |       |       |
| 2. 1600F (1144K), 1 Hr, Water Quench; 1100F (867K), 8 Hr, Air Cool |                             |      |                                          |                                |                                                        |                   |               |                      |       |       |       |       |       |
| 3. 1600F (1144K), 1 Hr, Air Cool; 1100F (867K), 8 Hr, Air Cool     |                             |      |                                          |                                |                                                        |                   |               |                      |       |       |       |       |       |
| 4. 1675F (1186K), 1 Hr, Air Cool; 1100F (867K), 8 Hr, Air Cool     |                             |      |                                          |                                |                                                        |                   |               |                      |       |       |       |       |       |
| 5. 1745F (1225K), 1 Hr, Water Quench; 1000F (811K), 4 Hr, Air Cool |                             |      |                                          |                                |                                                        |                   |               |                      |       |       |       |       |       |
| 6. 1745F (1225K), 1 Hr, Oil Quench; 1000F (811K), 4 Hr, Air Cool   |                             |      |                                          |                                |                                                        |                   |               |                      |       |       |       |       |       |
| 7. 1745F (1225K), 1 Hr, Air Cool; 1000F (811K), 4 Hr, Air Cool     |                             |      |                                          |                                |                                                        |                   |               |                      |       |       |       |       |       |

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TITANIUM, B Alloys: 13V-11Cr-3Al, 8Mo-6V-2Fe-3Al, 11.5Mo-6Zr-4.5Sn, 3Al-8V-6Cr-4Zr-4Mo (Sheet 1 of 2) Table 4:

| Form                                                                                            | Corporation,<br>Heat<br>Treatment | Yield<br>Strength<br>$F_y$ (ksi/mm <sup>2</sup> ) | Typical<br>$K_{Ic}$<br>$AS\sqrt{a}$ (ksi/in <sup>3/2</sup> ) | $2.5\left(\frac{K_{Ic}}{a}\right)^2$<br>in (mm) | Specimen |                      |                  | Crack<br>Length:<br>$a$ in (mm) | Ref         |     |
|-------------------------------------------------------------------------------------------------|-----------------------------------|---------------------------------------------------|--------------------------------------------------------------|-------------------------------------------------|----------|----------------------|------------------|---------------------------------|-------------|-----|
|                                                                                                 |                                   |                                                   |                                                              |                                                 | Type     | Thickness<br>in (mm) | Width<br>in (mm) |                                 |             |     |
| 13V-11Cr-3Al(B120VCA)<br>Bar: 1 in (25.4 mm) Dia                                                | A, 1                              | 1-SF                                              | 300 (422)                                                    | 159 (1096)                                      | 39 (43)  | NR                   | Do=.505 (12.8)   | Di=.375 (9.5)                   | 28          |     |
|                                                                                                 | A, 1                              | 1-SF                                              | 70 (294)                                                     | 181 (1248)                                      | 32 (35)  | NR                   | Do=.505 (12.8)   | Di=.375 (9.5)                   |             |     |
|                                                                                                 |                                   | 1-SF                                              | 45 (230)                                                     | 200 (1379)                                      | 28 (31)  | NR                   | Do=.505 (12.8)   | Di=.375 (9.5)                   |             |     |
| Forgin 9.625 in (15.9 mm) Thick<br>C-8 Processed: 1675F<br>(1186K)                              | B, 2                              | (a)                                               | 70 (294)                                                     | 178 (1227)                                      | 43 (47)  | Bend                 | 0.500 (12.7)     | ---                             | 22          |     |
| Forging: 0.625 in (15.9 mm) Thick<br>B Processed: 2109F<br>(1422K)                              | B, 2                              | (a)                                               | 70 (294)                                                     | 176 (1213)                                      | 41 (45)  | Bend                 | 0.500 (12.7)     | ---                             |             |     |
| Forging: 4 in (102 mm) Thick                                                                    | A, 3                              | 1-1                                               | 70 (294)                                                     | 166 (1145)                                      | 24 (26)  | Bend                 | 0.500 (12.7)     | 1.5 (38.1)                      | 0.35 (8.9)  | 31  |
| 8Mo-8V-2Fe-3Al<br>Plate: 0.5 in (12.7 mm) Thick<br>Forged at 1950F (1339K)                      | C, 4                              | 1-1                                               | 70 (294)                                                     | 195 (1345)                                      | 45 (49)  | SEN                  | 0.375 (9.5)      | 1.125 (28.6)                    | 0.375 (9.5) | 93  |
| Plate: 2 in (50.8 mm) Thick<br>Forged at 1950F (1339K)                                          | D, 4                              | 1-1                                               | 70 (294)                                                     | 200 (1379)                                      | 49 (54)  | SEN                  | 0.375 (9.5)      | 1.125 (28.6)                    | 0.375 (9.5) |     |
| Closed die Forging: 0.5 in<br>(12.7 mm) Thick                                                   | L, 5                              | 1-1                                               | 70 (294)                                                     | 181 (1248)                                      | 38 (41)  | Bend                 | 0.500 (12.7)     | 1.5 (38.1)                      | 0.300 (7.6) | 29  |
| 2.5 in (63.5 mm) Thick                                                                          |                                   | 1-1                                               | 70 (294)                                                     | 178 (1227)                                      | 41 (45)  | Bend                 | 2.5 (63.5)       | 1.5 (38.1)                      | 0.300 (7.6) |     |
| Forged Bar: 3 in (76.2 mm)<br>Square                                                            | F, 5                              | 1-1                                               | 70 (294)                                                     | 165 (1158)                                      | 52 (57)  | Bend                 | (b)              | ---                             | ---         | 30  |
| Forging: 4 in (102 mm) Thick                                                                    | F, 5                              | 1-1                                               | 70 (294)                                                     | 176 (1213)                                      | 65 (69)  | Bend                 | 0.5 (12.7)       | 1.5 (38.1)                      | 0.35 (8.9)  | 31  |
| Extrusion: Cylinder 8.75 in<br>(222 mm) OD 3 in (76.2<br>mm) Wall, Extruded at<br>1475F (1075K) | G, 6                              | C-R                                               | 70 (294)                                                     | 179 (1234)                                      | 51 (56)  | CF                   | 0.75 (19.1)      | 1.5 (38.1)                      | 0.75 (19.1) | 117 |
| 11.5Mo-6Zr-4.5Sn (4111)<br>Plate: 0.5 in (12.7 mm) Thick                                        | H, 7                              | 1-1                                               | 70 (294)                                                     | 174 (1200)                                      | 61 (67)  | Bend                 | 0.5 (12.7)       | 1.5 (38.1)                      | ---         | 32  |
| Plate: 0.61 in (16.3 mm) Thick                                                                  | I, 8                              | -                                                 | 70 (294)                                                     | 166 (1145)                                      | 51 (56)  | Bend                 | 0.525 (13.3)     | 1.5 (38.1)                      | ---         | 93  |
|                                                                                                 | I, 9                              | -                                                 | 70 (294)                                                     | 150 (1034)                                      | 65 (71)  | Bend                 | 0.525 (13.3)     | 1.5 (38.1)                      | ---         |     |
|                                                                                                 | I, 10                             | -                                                 | 70 (294)                                                     | 148 (1020)                                      | 71 (78)  | Bend                 | 0.525 (13.3)     | 1.5 (38.1)                      | ---         |     |

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TITANIUM, 8 Alloys: 13V-11Cr-3Al, 8Mo-8V-2Fe-3Al, 11.5Mo-6Zr-4.1Sn, 3Al-8V-eCr-4Zr-4Ho (Sheet 2 of 2) Table 42 (Cont.)

| Form                             | Composition, Heat Treatment | Test Orientation | Yield Strength<br>ksi (N/mm <sup>2</sup> ) | Typical<br>K <sub>IC</sub><br>ksi√in (MN/m <sup>3/2</sup> ) | 2.5( $\frac{K_{IC}^2}{\sigma_y}$ )<br>in (mm) | Specimen |                      |                  | Ref         |     |
|----------------------------------|-----------------------------|------------------|--------------------------------------------|-------------------------------------------------------------|-----------------------------------------------|----------|----------------------|------------------|-------------|-----|
|                                  |                             |                  |                                            |                                                             |                                               | Type     | Thickness<br>in (mm) | Width<br>in (mm) |             |     |
| Forging: 4 in (102 mm) Thick     | I, 11                       | L-T              | 182(1255)                                  | 61(67)                                                      | 0.280(7.1)                                    | Bend     | 0.5 (12.7)           | 1.5 (38.1)       | 0.25 (8.9)  | 31  |
| Extrusion: 0.97 in (24.6 mm) Dia | K, 12                       | L-R              | 233(1606)                                  | 25(27)                                                      | 0.027(0.7)                                    | Bend     | 0.394(1)             | 0.394(1)         | ---         | 113 |
| Extrusion: 0.9 in (22.9 mm) Dia  | K, 14                       | L-R              | 186(1282)                                  | 41(45)                                                      | 0.121(3.1)                                    | Bend     | 0.394(1)             | 0.394(1)         | ---         | 118 |
|                                  | K, 15                       | L-R              | 167(1151)                                  | 54(59)                                                      | 0.261(6.6)                                    | Bend     | 0.394(1)             | 0.394(1)         | ---         |     |
| 3Al-8V-6Cr-4Zr-4Mo (8C)          |                             |                  |                                            |                                                             |                                               |          |                      |                  |             |     |
| Forging: 4 in (102 mm) Thick     | J, 13                       | L-T              | 158(1089)                                  | 53(58)                                                      | 0.281(7.1)                                    | Bend     | 0.5 (12.7)           | 1.5 (38.1)       | 0.35 (8.9)  | 31  |
| Billet: 6 in (152 mm) Square     | J, 13                       | L-T, ST          | 167(1151)                                  | 59(65)                                                      | 0.312(7.9)                                    | Bend     | 0.75(19.1)           | 1.5 (38.1)       | 0.78 (19.8) | 119 |

COMPOSITION

| V | Cr   | Al   | Fe   | C     | Mo     | Zr    | Sn   | N     | H       |
|---|------|------|------|-------|--------|-------|------|-------|---------|
| A | 13N  | 11N  | 3N   | -     | 0.05N  | -     | -    | -     | -       |
| b | 13.5 | 10.5 | 3.1  | 0.16  | 0.17   | -     | -    | -     | -       |
| C | 7.08 | -    | 2.97 | 2.16  | -      | -     | -    | 0.019 | 0.112   |
| D | 8.09 | -    | 3.02 | 2.19  | -      | -     | -    | 0.020 | 0.098   |
| E | 7.81 | -    | 2.95 | 2.17  | -      | -     | -    | 0.005 | 0.122   |
| F | 8N   | -    | 3N   | 0.05N | 8N     | -     | -    | 0.088 | 0.146   |
| G | 8.0  | -    | 2.3  | 1.8   | 0.022  | 8.2   | -    | 0.018 | 0.16    |
| H | -    | -    | -    | 0.03  | -      | 10.71 | 4.12 | 4.60  | -       |
| I | -    | -    | -    | -     | -      | 11.5  | 6    | -     | -       |
| J | 8N   | 6N   | 3.1  | -     | -      | 4N    | 4.6  | -     | -       |
| K | -    | -    | -    | 0.11  | 244ppm | 10.95 | 5.86 | 4.48  | 80ppm   |
|   |      |      |      |       |        |       |      |       | 1515ppm |

HEAT TREATMENT

1. 1425F (1047K), 0.25 hr; 900F (756K), 72 hr

2. 1350F (1006K), 2 hr, Air Cool; 1450F (1061K), 0.5 hr, Water Quench; 900F (756K), 20 hr, Air Cool

3. 1335F (997K), 1 hr, Air Cool; 1450F (1061K), 0.5 hr, Air Cool; 900F (756K), 15 hr, Air Cool

4. 1500F (1089K), 10 min, Air Cool; 200F (756K), 16 hr, Air Cool

5. 1475F (1075K), 1 hr, Water Quench; 1000F (531K), 8 hr, Air Cool

6. 1475F (1075K), 1.5 hr, Water Quench; 1000F (531K), 8 hr, Air Cool

7. 1350F (1006K), 15 min, Delay 15 sec, Water Quench; 950F (783K), 8 hr

8. 1600F (1144K), 1 hr, Water Quench; 900F (756K), 8 hr

9. 1500F (1089K), 1 hr, Water Quench; 550F (561K), 0.5 hr, Air Cool

10. 1600F (1144K), 1 hr, Water Quench; 900F (756K), 100 hr, Air Cool

11. 1325F (992K), 1 hr, Water Quench; 950F (783K), 8 hr, Air Cool

12. Extruded at 1800F (1255K), Water Quench; Swaged 5% Reduction in Area; 900F (756K), 8 hr, Air Cool

13. 1500F (1089K), 0.25 hr, Air Cool; 1050F (839K), 12 hr, Air Cool

14. Extruded at 1400F (1033K), Water Quench; Aged 900F (756K), 8 hr, Air Cool

15. Extruded at 1900F (1255K), Air Cool; 1400F (1033K), 0.5 hr, Water Quench; 900F (756K), 8 hr, Air Cool

ALUMINUM, Copper Alloys: 2014, DTD 5020, MID 66, BS L77, BS L93, GB-265 (Sheet 1 of 2) Table 43

| Temper                      | Form                                                      | Compo-<br>sition,<br>Heat<br>Treat-<br>ment   | Test<br>Orienta-<br>tion | Temp<br>°F (°K) | Yield<br>Strength<br>KSI (MN/m <sup>2</sup> ) | Typical<br>K <sub>IC</sub><br>KSI/in (MN m <sup>3/2</sup> ) | 2.5<br>( $\frac{K_{IC}}{\sigma_{YS}}$ )<br>in (mm) | Specimen    |                      |                  |                            |
|-----------------------------|-----------------------------------------------------------|-----------------------------------------------|--------------------------|-----------------|-----------------------------------------------|-------------------------------------------------------------|----------------------------------------------------|-------------|----------------------|------------------|----------------------------|
|                             |                                                           |                                               |                          |                 |                                               |                                                             |                                                    | Type        | Thickness<br>in (mm) | Wid.n<br>in (mm) | Crack<br>Length<br>in (mm) |
| 2014                        |                                                           |                                               |                          |                 |                                               |                                                             |                                                    |             |                      |                  |                            |
| T651                        | Plate: 1.0 in<br>(25.4 mm) Thick                          | A, (a)                                        | L-T                      | 70( 294)        | 67(462)                                       | 24(26)                                                      | 0.321( 8.2)                                        | (b)         | 1.0 (25.4)           | 2.0 ( 50.8)      | 1.0 (25.4)                 |
|                             |                                                           |                                               | T-L                      | 70( 294)        | 66(455)                                       | 21(23)                                                      | 0.253( 6.4)                                        | (b)         | 1.0 (25.4)           | 2.0 ( 50.8)      | 1.0 (25.4)                 |
|                             | Plate: 5.0 in<br>(127 mm) Thick                           | A, (a)                                        | L-T                      | 70( 294)        | 59(407)                                       | 21(23)                                                      | 0.317( 8.1)                                        | (b)         | 1.0 (25.4)           | 2.0 ( 50.8)      | 1.0 (25.4)                 |
|                             |                                                           |                                               | T-L                      | 70( 294)        | 58(400)                                       | 21(23)                                                      | 0.328( 8.3)                                        | (b)         | 1.0 (25.4)           | 2.0 ( 50.8)      | 1.0 (25.4)                 |
|                             |                                                           |                                               | S-L                      | 70( 294)        | -                                             | 19(21)                                                      | -                                                  | -           | -                    | -                | -                          |
| T6510                       | Plate: 1.0 in<br>(25.4 mm) Thick                          | A, (a)                                        | T-L                      | -320( 78)       | -                                             | 26(28)                                                      | -                                                  | (b)         | 1.02 (25.9)          | 2.0 (50.8)       | 1.01(25.6)                 |
|                             |                                                           |                                               | T-S                      | 70( 294)        | 63(435)                                       | 24(26)                                                      | 0.300 (9.2)                                        | (b)         | -                    | -                | -                          |
|                             | Plate: 2.5 in (63.5<br>mm) Thick                          | A, (a)                                        | L-T                      | 70( 294)        | 64(441)                                       | 30(33)                                                      | 0.549(13.9)                                        | SEV         | 0.594(15.1)          | 3.0 (38.1)       | -                          |
|                             |                                                           |                                               | T-L                      | 70( 294)        | 62(427)                                       | 25(27)                                                      | 0.406 (10.3)                                       | SEV         | 0.312( 7.9)          | 1.940(23.9)      | -                          |
|                             | T652                                                      | Forging: 2.0 in x 8.0 in<br>(50.8 x 203.2 mm) | B, 1                     | L-T             | 70( 294)                                      | 67(462)                                                     | 25(27)                                             | 0.338( 8.8) | Bend                 | 0.750(19.1)      | 1.5 (38.1)                 |
| T-L                         |                                                           |                                               |                          | 70( 294)        | 65(448)                                       | 19(21)                                                      | 0.214( 5.4)                                        | Bend        | 0.750(19.1)          | 1.5 (38.1)       | -                          |
| Plate: 3 in (76.2 mm) Thick |                                                           | C, 1                                          | L-T                      | 70( 294)        | 63(434)                                       | 34(37)                                                      | 0.728(18.5)                                        | Bend        | 1.50 (38.1)          | 3.0 (76.2)       | -                          |
|                             |                                                           |                                               | T-L                      | 70( 294)        | 59(403)                                       | 23(25)                                                      | 0.380( 9.7)                                        | Bend        | 1.50 (38.1)          | 3.0 (76.2)       | -                          |
|                             |                                                           | S-L                                           | 70( 294)                 | 57(393)         | 19(21)                                        | 0.278( 7.1)                                                 | Bend                                               | 1.50 (38.1) | 3.0 (76.2)           | -                |                            |
| DTD 5020                    |                                                           |                                               |                          |                 |                                               |                                                             |                                                    |             |                      |                  |                            |
| WP                          | Plate: 3 in (76.2 mm)<br>thick<br>1 in (25.4 mm)<br>Thick | D, 2                                          | L-T                      | 70( 294)        | 64(442)                                       | 26(28)                                                      | 0.403 (10.5)                                       | (b)         | -                    | -                | -                          |
|                             |                                                           |                                               | T-L                      | 70( 294)        | 59(405)                                       | 24(26)                                                      | 0.414 (10.5)                                       | (b)         | -                    | -                | -                          |

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| Temper | Form                             | Condi-<br>tion,<br>Heat<br>Treat-<br>ment | Test<br>Orienta-<br>tion | Temp<br>°F<br>(°K) | Yield<br>Strength<br>KSI (MN/m <sup>2</sup> ) | Typical<br>K <sub>IC</sub><br>KSI/√in (MN m <sup>-1/2</sup> ) | 2.5 (K <sub>IC</sub><br>σ <sub>ys</sub> )<br>in (mm) | Specimen |                      |                  | Ref.     |                            |
|--------|----------------------------------|-------------------------------------------|--------------------------|--------------------|-----------------------------------------------|---------------------------------------------------------------|------------------------------------------------------|----------|----------------------|------------------|----------|----------------------------|
|        |                                  |                                           |                          |                    |                                               |                                                               |                                                      | Type     | Thickness<br>in (mm) | Width<br>in (mm) |          | Crack<br>Length<br>in (mm) |
| HIB 66 |                                  |                                           |                          |                    |                                               |                                                               |                                                      |          |                      |                  |          |                            |
| NP     | Plate: 0.5 in<br>(12.7 mm) Thick | D, 3                                      | L-S                      | 70(294)            | 62(425)                                       | 23(25)                                                        | 0.344 (8.7)                                          | (b)      | ---                  | ---              | ---      | 73                         |
|        |                                  |                                           | T-S                      | 70(294)            | 62(429)                                       | 19(21)                                                        | 0.235 (6.0)                                          | (b)      | ---                  | ---              | ---      |                            |
| RSL-77 |                                  |                                           |                          |                    |                                               |                                                               |                                                      |          |                      |                  |          |                            |
| WP     | Forging:                         | E, 5                                      | T-S                      | 70(214)            | 65(445)                                       | 20(22)                                                        | 0.239 (60.7)                                         | (b)      | ---                  | ---              | ---      | 71                         |
|        |                                  |                                           | S-L                      | 70(294)            | 64(440)                                       | 17.5(19)                                                      | 0.187 (4.7)                                          | (b)      | ---                  | ---              | ---      |                            |
| RSL-93 |                                  |                                           |                          |                    |                                               |                                                               |                                                      |          |                      |                  |          |                            |
| WP     | Plate: 1.5 in<br>(38.1 mm) Thick | E, 2                                      | L-T                      | 70(294)            | 63(437)                                       | 23(25)                                                        | 0.333 (8.5)                                          | (b)      | ---                  | ---              | ---      | 65                         |
|        |                                  |                                           | T-L                      | 70(294)            | 62(428)                                       | 21(23)                                                        | 0.287 (7.5)                                          | (b)      | ---                  | ---              | ---      |                            |
|        |                                  |                                           | S-L                      | 70(294)            | 60(414)                                       | 19(21)                                                        | 0.251 (6.4)                                          | (b)      | ---                  | ---              | ---      |                            |
| GB-265 |                                  |                                           |                          |                    |                                               |                                                               |                                                      |          |                      |                  |          |                            |
| NP     | Plate: 2.5 in<br>(63.5 mm) Thick | F, 6                                      | T-L                      | 70(294)            | 41(283)                                       | 19(21)                                                        | 0.54 (13.6)                                          | DCB      | 1.5 (38.1)           | 10 (254)         | 3.8 (93) | 83                         |

(a) Fabrication and Heat Treatment in accordance with Applicable Military, Federal, ASTM or Aluminum Association Specifications.

(b) Specimen in accordance with ASTM specifications.

COMPOSITION

|   | Cu   | Mg    | Si    | Fe   | Zn   | Mn    | Cr   | Ti    | Ni | Pb |
|---|------|-------|-------|------|------|-------|------|-------|----|----|
| A | 4.5N | 0.5N  | 1.0N  | 1.0N | 1.0N | 0.25N | 0.1N | 0.15N | -  | -  |
| B | 1.58 | 0.69  | 0.94  | 0.22 | 0.72 | 0.08  | 0.01 | 0.04  | -  | -  |
| C | 1.41 | 0.50  | 0.97  | 0.24 | 0.73 | 0.14  | 0.01 | 0.04  | -  | -  |
| D | 1.3N | 0.62N | 0.75N | 1.0N | 0.8N | 0.2N  | -    | 0.2N  | -  | -  |
| E | 1.15 | 0.55  | 0.75  | 0.5N | 0.85 | 0.24  | -    | 0.2N  | -  | -  |
| F | 1.04 | 0.66  | 0.81  | 0.42 | 0.74 | -     | -    | 0.01  | -  | -  |

65K

1. Solution Heat Treated, Cold Worked and Artificially Aged in Accordance with MIL-Specification MIL-H-6088D and Aluminum Standards and Data.

940F (778K), Water Quench; 1.5-2.5%; Age 319-373F (433-463K)

951F (773K), Water Quench; Age 310-364F (429-458K)

4. 911F (778K), Water Quench; Stretch 1.5-3%; Age 340F (444K), 8-12 hr

5. 951F (773K), Water Quench; Age 319-373F (433-463K)

6. 911F (778K), 3 hr, Quench; Age 319F (433K), 10 hr

(a) Fabrication and Heat Treatment in accordance with Applicable Military, Federal, ASIN or Aluminum Association Specifications.

(b) Specimen in accordance with ASIN specifications.

## COMPOSITION

|   | Cu   | Mg    | Si    | Fe   | Zn   | Cr    | Ti   | Ni    | Pb |
|---|------|-------|-------|------|------|-------|------|-------|----|
| A | 4.5N | 0.5N  | 1.0N  | 1.0N | 1.0N | 0.25N | 0.1N | 0.15N | -  |
| B | 1.58 | 0.60  | 0.94  | 0.22 | 0.72 | 0.08  | 0.01 | 0.04  | -  |
| C | 1.41 | 0.50  | 0.97  | 0.24 | 0.73 | 0.14  | 0.01 | 0.04  | -  |
| D | 1.3N | 0.62N | 0.75N | 1.0N | 0.8N | 0.2N  | -    | 0.2N  | -  |
| E | 1.15 | 0.5N  | 0.7N  | 0.5N | 0.8N | 0.2N  | -    | 0.2N  | -  |
| F | 1.04 | 0.66  | 0.81  | 0.42 | 0.74 | -     | -    | 0.01  | -  |

## HEAT TREATMENT

1. Solution Heat Treated, Cold Worked and Artificially Aged in Accordance with MIL Specification MIL-IL-60880 and Aluminum Standards and Data.

940F (778K), Water Quench; 1.5-2.5%; Age 319-373F (433-463K)  
931F (773K), Water Quench; Age 310-364F (420-458K)  
911F (773K), Water Quench; Stretch 1.5-3%; Age 340F (444K), 8-12 Hr  
931H (773K), Water Quench; Age 319-373F (433-463K)  
911H (773K), 3 Hr. Quench; Age 319F (433K), 10 Hr

ALUMINUM, Copper Alloy: 2020

Table 44

| Temper | Form                            | Composition, Heat Treatment | Test Orientation | Temp °F (°K) | Yield Strength KSI (MN/m <sup>2</sup> ) | Typical K <sub>IC</sub> KSI/in (MN m <sup>-3/2</sup> ) | 2.5 ( $\frac{K_{IC}^2}{\sigma_{ys}}$ ) in (mm) | Specimen |                   |               |                      | Ref. |
|--------|---------------------------------|-----------------------------|------------------|--------------|-----------------------------------------|--------------------------------------------------------|------------------------------------------------|----------|-------------------|---------------|----------------------|------|
|        |                                 |                             |                  |              |                                         |                                                        |                                                | Type     | Thickness in (mm) | Width in (mm) | Crack Length in (mm) |      |
| T6S1   | Plate: 1.375 in (34.9 mm) Thick | A <sub>1</sub> (a)          | L-T              | 70(294)      | 76(524)                                 | 22(24)                                                 | 0.209 (5.3)                                    | Bend     | 1.375(34.9)       | 3.0 (76.2)    | ---                  | 38   |
|        |                                 |                             | T-L              | 70(294)      | 77(531)                                 | 18(21)                                                 | 0.152 (3.9)                                    | Bend     | 1.375(34.9)       | 3.0 (76.2)    | ---                  |      |

(a) Heat Treatment in Accordance with Applicable Military, ASTM or Aluminum Association Specifications.

COMPOSITION

|   | Cu   | Mg    | Si   | Fe   | Mn   | Zn    | Cd    | Li   | Tl   |
|---|------|-------|------|------|------|-------|-------|------|------|
| A | 4.5N | 0.03N | 0.4N | 0.4N | 0.5N | 0.25N | 0.23N | 1.3N | 0.1N |

ALUMINUM, Copper Alloy: 2021 and 2219 (Sheet 1 of 2)

Table 45

| Temper      | Form                             | Compo-<br>sition,<br>Heat<br>Treat-<br>ment | Test<br>Orienta-<br>tion | Temp<br>°F (°K) | Yield<br>Strength<br>KSI (MN/m <sup>2</sup> ) | Typical<br>K <sub>IC</sub><br>KSI/√in (MN m <sup>-3/2</sup> ) | 2.5<br>$\left(\frac{K_{IC}}{\sigma_{ys}}\right)^2$<br>in (mm) | Specimen |                      |                  | Ref.        |                            |
|-------------|----------------------------------|---------------------------------------------|--------------------------|-----------------|-----------------------------------------------|---------------------------------------------------------------|---------------------------------------------------------------|----------|----------------------|------------------|-------------|----------------------------|
|             |                                  |                                             |                          |                 |                                               |                                                               |                                                               | Type     | Thickness<br>in (mm) | Width<br>in (mm) |             | Crack<br>Length<br>in (mm) |
| 2021<br>T6  |                                  | A, 1                                        | T-S                      | 70(294)         | 60(414)                                       | 23(25)                                                        | 0.36" (9.3)                                                   | (b)      | ---                  | ---              | ---         | 60                         |
| 2021<br>T81 | Plate: 1.0 in<br>(25.4 mm) thick | C, 1                                        | T-L                      | 70(294)         | 61(421)                                       | 23(25)                                                        | 0.355( 9.0)                                                   | Bend     | 1.0 (25.4)           | -                | -           | 4                          |
|             |                                  |                                             | T-L                      | -100(200)       | 65(448)                                       | 27(29)                                                        | 0.431(10.9)                                                   | Bend     | 1.0 (25.4)           | -                | -           |                            |
|             |                                  | A, (a)                                      | T-L                      | -321( 78)       | 73(503)                                       | 32(35)                                                        | 0.480(12.2)                                                   | Bend     | 1.0 (25.4)           | -                | -           |                            |
|             |                                  | B, 2                                        | L-T                      | -423(27)        | 80(552)                                       | 40(44)                                                        | 0.625(15.9)                                                   | CT       | 1.0 (25.4)           | 2.0 (50.8)       | 1.0 (25.4)  | 5a                         |
|             | Plate: 0.5 in<br>(12.7 mm) thick |                                             | L-T                      | 70(294)         | 65(448)                                       | 27(29)                                                        | 0.431(10.9)                                                   | Bend     | 0.500(12.7)          | 1.0(25.4)        | 0.500(12.7) | 4a                         |
|             |                                  |                                             | T-L                      | 70(294)         | 61(441)                                       | 23(25)                                                        | 0.323( 8.2)                                                   | Bend     | 0.500(12.7)          | 1.0(25.4)        | 0.500(12.7) |                            |
|             | Plate: 1.0 in<br>(25.4 mm) thick | A, (a)                                      | L-T                      | 70(294)         | 66(455)                                       | 36(49)                                                        | 0.745(18.9)                                                   | (b)      | 1.0 (25.4)           | 2.0(50.8)        | 1.0 (25.4)  | 37                         |
|             |                                  |                                             | T-L                      | 70(294)         | 65(448)                                       | 24(26)                                                        | 0.342( 8.7)                                                   | (b)      | 1.0 (25.4)           | 2.0(50.8)        | 1.0 (25.4)  |                            |
|             | Plate: 0.5 in<br>(12.7 mm) thick | A, (a)                                      | L-T                      | 70(294)         | 65(448)                                       | 26(28)                                                        | 0.4 (10.3)                                                    | (b)      | 0.5 (12.7)           | 1.0(25.4)        | 0.5 (12.7)  | 37                         |
|             |                                  |                                             | T-L                      | 70(294)         | 61(441)                                       | 21(23)                                                        | 0.269( 6.8)                                                   | (b)      | 0.5 (12.7)           | 1.0(25.4)        | 0.5 (12.7)  |                            |
| 2219<br>T87 | Plate: 1 in<br>(25.4 mm) Thick   | B, (a)                                      | L-T                      | 70(294)         | 58(409)                                       | 33(36)                                                        | 0.809(20.5)                                                   | SLS      | 1.0 (25.4)           | 5.0 (127.0)      | 1.5 (40.6)  | 40                         |
|             |                                  | B, (a)                                      | T-L                      | 70(294)         | 55(379)                                       | 30(33)                                                        | 0.743(18.9)                                                   | SLS      | 1.0 (25.4)           | 5.0 (127.0)      | 1.6 (40.6)  |                            |
|             | Plate: 2.5 in<br>(63.5 mm) Thick | B, 3                                        | T-S                      | 72(296)         | 55(379)                                       | 37(40)                                                        | 1.131(28.7)                                                   | Bend     | 1.25 (31.8)          | 2.5 ( 63.5)      | 1.25 (31.8) | 36                         |
|             |                                  |                                             |                          | -320( 73)       | 67(462)                                       | 42(44)                                                        | 0.982(24.9)                                                   | Bend     | 1.25 (31.8)          | 2.5 ( 63.5)      | 1.25 (31.8) |                            |
|             |                                  |                                             |                          | -423( 21)       | 73(503)                                       | 47(51)                                                        | 1.036(26.3)                                                   | Bend     | 1.25 (31.8)          | 2.5 ( 63.5)      | 1.25 (31.8) |                            |

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Aluminum, Copper Alloy: 2021 and 2219 (Sheet 2 of 2)

Table 45 (Cont.)

| Aluminum, Copper Alloy: 2021 and 2219 (Sheet 2 of 2) |                                    |                                             |                          |                 |                                               |                                                                         |                                      |          |                      |                  |                            |      |
|------------------------------------------------------|------------------------------------|---------------------------------------------|--------------------------|-----------------|-----------------------------------------------|-------------------------------------------------------------------------|--------------------------------------|----------|----------------------|------------------|----------------------------|------|
| Table 4S (Cont.)                                     |                                    |                                             |                          |                 |                                               |                                                                         |                                      |          |                      |                  |                            |      |
| Temper                                               | Form                               | Compo-<br>sition,<br>Heat<br>Treat-<br>ment | Test<br>Orienta-<br>tion | Temp<br>°F (°K) | Yield<br>Strength<br>KSI (MN/m <sup>2</sup> ) | Typical<br>K <sub>IC</sub><br>KSI/in ( $\frac{1}{\sqrt{\text{MN m}}}$ ) | $\frac{2.5}{\sigma_{ys}}$<br>in (mm) | Specimen |                      |                  |                            | Ref. |
|                                                      |                                    |                                             |                          |                 |                                               |                                                                         |                                      | Type     | Thickness<br>in (mm) | Width<br>in (mm) | Crack<br>Length<br>in (mm) |      |
| 2219                                                 | Plate:                             | B, -                                        | -                        | 70 (294)        | 51 (352)                                      | 33 (36)                                                                 | 1.047 (26.6)                         | Band     | 1.40 (35.6)          | 3.0 ( 76.2)      | 1.5 (38.1)                 | 44   |
| 1851                                                 |                                    | B, (A)                                      | L-T                      | 70 (294)        | 59 (407)                                      | 38 (41)                                                                 | 1.037 (26.4)                         | SEN      | 1.0 (25.4)           | 5.0 (127.0)      | 1.6 (40.6)                 | 40   |
|                                                      | Plate: 1 in<br>(25.4 mm) Thick     |                                             | T-L                      | 70 (294)        | 58 (408)                                      | 37 (40)                                                                 | 1.017 (25.8)                         | SEN      | 1.0 (25.4)           | 5.0 (127.0)      | 1.6 (40.6)                 |      |
|                                                      |                                    | B, (B)                                      | L-T                      | 70 (294)        | 51 (352)                                      | 36 (39)                                                                 | 1.246 (31.6)                         | (b)      | 1.375 (34.9)         | 2.75 ( 70.0)     | 1.375 (34.9)               | 57   |
|                                                      | Plate: 1.375 in<br>(34.9 mm) Thick |                                             | T-L                      | 70 (294)        | 57 (393)                                      | 32 (35)                                                                 | 0.788 (20.0)                         | (b)      | 1.375 (34.9)         | 2.75 ( 70.0)     | 1.375 (34.9)               |      |
|                                                      |                                    | B, (A)                                      | T-L                      | 70 (294)        | 50 (345)                                      | 29 (32)                                                                 | 0.841 (21.4)                         | (b)      | 1.375 (34.9)         | 3.0 (76.2)       | 1.55 (39.4)                | 56   |

(a) Fabrication and Heat Treatment in Accordance with Applicable Military, Federal, or Aluminum Association Specification  
(b) Specimen in accordance with ASTM Recommendations

# COMPOSITION

|   | Cu   | Mg    | Si   | Fe   | Mn   | Zn   | Al    | V    | Cd    | Sn    |
|---|------|-------|------|------|------|------|-------|------|-------|-------|
| A | 6.35 | 0.025 | 0.20 | 0.30 | 0.55 | 0.10 | 0.065 | 0.10 | 0.185 | 0.150 |
| B | 6.35 | 0.020 | 0.20 | 0.30 | 0.55 | 0.10 | 0.065 | 0.10 | 0.185 | -     |
| C | 6.08 | 0.05  | 0.07 | 0.11 | 0.25 | 0.01 | 0.05  | 0.08 | 0.15  | 0.11  |

# HEAT TREATMENT

- 985F (530K), 2 Hr, Oil Quenched, Preaged 300F (422K), 1 Hr; Stretch 1.5% Maximum Age 325F (436K), 24 Hrs.
- 990F (536K), Water Quenched, Preaged 300F (422K), 1 Hr, Stretch 1.0% Maximum, Aged 325F (436K), 16 Hr
- Annealed 1550F (1117K) Argon Atmosphere, 8 Hr, Furnace Cool

ALUMINUM, Copper Alloy: 2024, 2124, DTD 5090 and A-BAG1 (Sheet 1 of 2) Table 46

| Temper       | Form                                       | Compo-<br>sition,<br>Heat<br>Treat-<br>ment | Test<br>Orienta-<br>tion | $\sigma_{UT}$<br>(ksi) | Yield<br>Strength<br>ksi (N/mm <sup>2</sup> ) | Typical<br>K <sub>IC</sub><br>(ksi√in)<br>(MN/m <sup>3/2</sup> ) | $2.5\left(\frac{K_{IC}}{\sigma_{ys}}\right)^2$<br>in (mm) | Specimen |                      |                  |                            | Ref |
|--------------|--------------------------------------------|---------------------------------------------|--------------------------|------------------------|-----------------------------------------------|------------------------------------------------------------------|-----------------------------------------------------------|----------|----------------------|------------------|----------------------------|-----|
|              |                                            |                                             |                          |                        |                                               |                                                                  |                                                           | Type     | Thickness<br>in (mm) | Width<br>in (mm) | Crack<br>Length<br>in (mm) |     |
| 2024<br>T851 | Plate: 1.375 in<br>(34.9 mm) Thick         | A <sub>1</sub> (n)                          | T-L                      | 70 (294)               | 64 (441)                                      | 20 (22)                                                          | 0.244 ( 6.2)                                              | Bend     | 1.375 (34.9)         | 3.0 ( 76.2)      | 1.51 (38.4)                | 39  |
|              |                                            |                                             | T-L                      | -112 (193)             | 69 (476)                                      | 22 (24)                                                          | 0.254 ( 6.5)                                              | Bend     | 1.375 (34.9)         | 3.0 ( 76.2)      | 1.51 (38.4)                |     |
|              |                                            |                                             | F-L                      | -320 ( 78)             | 79 (545)                                      | 22 (24)                                                          | 0.200 ( 5.1)                                              | Bend     | 1.375 (34.9)         | 3.0 ( 76.2)      | 1.51 (38.4)                |     |
|              |                                            |                                             | T                        | 70 (294)               | 66 (455)                                      | 24 (26)                                                          | 0.331 ( 8.4)                                              | Bend     | 1.375 (34.9)         | 3.0 ( 76.2)      | 1.51 (38.4)                |     |
|              |                                            |                                             |                          | 70 (294)               | 66 (455)                                      | 33 (36)                                                          | 0.625 (15.9)                                              | (b)      | ---                  | ---              | ---                        | 37  |
|              | Preformed Plate: 1.5 in<br>(38.1 mm) Thick | A <sub>1</sub> (n)                          | T-L                      | 70 (294)               | 65 (448)                                      | 32 (35)                                                          | 0.606 (15.4)                                              | (b)      | ---                  | ---              | ---                        |     |
|              |                                            |                                             | L-L                      | 70 (294)               | 62 (427)                                      | 32 (35)                                                          | 0.625 (15.9)                                              | (b)      | 0 ( 25.4)            | 2.0 ( 50.8)      | 1.0 (25.4)                 | 37  |
|              |                                            |                                             | T-L                      | 70 (294)               | 61 (420)                                      | 25 (27)                                                          | 0.42 (10.5)                                               | (b)      | 1.0 ( 25.4)          | 2.0 ( 50.8)      | 1.0 (25.4)                 |     |
|              |                                            |                                             | L-T                      | 70 (294)               | 56 (386)                                      | 25 (27)                                                          | 0.498 (12.6)                                              | Bend     | 0.55 (14)            | 1.02 (26)        | 0.55 (14)                  | 27  |
|              |                                            |                                             | T                        | 70 (294)               | 56 (386)                                      | 22 (24)                                                          | 0.386 ( 9.8)                                              | Bend     | 1.0 ( 25.4)          | 2.0 ( 50.8)      | 1.0 (25.4)                 |     |
| 2024<br>T851 | Plate: 2.2 in<br>(55.9 mm) Thick           | A <sub>1</sub> (n)                          | L-T                      | 300 (422)              | 55 (379)                                      | 27 (29)                                                          | 0.602 (15.3)                                              | CT       | 0.75 (19.0)          | 1.5 ( 38.1)      | 0.75 (19.1)                | 116 |
|              |                                            |                                             | T-L                      | 300 (422)              | 54 (372)                                      | 22 (24)                                                          | 0.415 (10.5)                                              | CT       | 0.75 (19.0)          | 1.5 ( 38.1)      | 0.75 (19.1)                |     |
|              |                                            |                                             | L-T                      | 70 (294)               | 63 (434)                                      | 27 (29)                                                          | 0.459 (11.7)                                              | CT       | 0.75 (19.0)          | 1.5 ( 38.1)      | 0.75 (19.1)                |     |
|              |                                            |                                             | F-L                      | 70 (294)               | 64 (441)                                      | 22 (24)                                                          | 0.295 ( 7.5)                                              | CT       | 0.75 (19.0)          | 1.5 ( 38.1)      | 0.75 (19.1)                |     |
|              |                                            |                                             | L-S                      | 70 (294)               | 61 (421)                                      | 31 (34)                                                          | 0.646 (16.4)                                              | CT       | 0.75 (19.0)          | 1.5 ( 38.1)      | 0.75 (19.1)                |     |
|              | Extrusion: 1.45 in<br>(36.8 mm) Thick      | A <sub>1</sub> (n)                          | L-T                      | -65 (219)              | 67 (462)                                      | 26 (28)                                                          | 0.376 ( 9.6)                                              | CT       | 0.75 (19.0)          | 1.5 ( 38.1)      | 0.75 (19.1)                |     |
|              |                                            |                                             | T-L                      | -65 (219)              | 67 (462)                                      | 23 (25)                                                          | 0.295 ( 7.5)                                              | CT       | 0.75 (19.0)          | 1.5 ( 38.1)      | 0.75 (19.1)                |     |
|              |                                            |                                             | L-T                      | 70 (294)               | 69 (476)                                      | 30 (33)                                                          | 0.480 (10.2)                                              | Bend     | 1.01 (25.7)          | 3.0 ( 76.2)      | ---                        | 42  |
|              |                                            |                                             | T-L                      | 70 (294)               | 66 (455)                                      | 18 (20)                                                          | 0.165 ( 4.2)                                              | Bend     | 0.375 ( 9.5)         | 0.937 ( 23.8)    | ---                        |     |
|              |                                            |                                             | L-T                      | 70 (294)               | 65 (448)                                      | 24 (26)                                                          | 0.341 ( 8.7)                                              | Bend     | 0.750 (19.1)         | 1.5 ( 38.1)      | ---                        | 41  |
| 2024<br>T852 | Forging: 2.0 in<br>(50.8 mm) Thick         | B <sub>1</sub> 1                            | T-L                      | 70 (294)               | 64 (441)                                      | 22 (24)                                                          | 0.295 ( 7.5)                                              | Bend     | 0.750 (19.1)         | 1.5 ( 38.1)      | ---                        |     |
|              |                                            | B <sub>1</sub> 1                            | F-L                      | 70 (254)               |                                               |                                                                  |                                                           |          |                      |                  |                            |     |

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ALUMINUM, Copper Alloy: 2024, 2124, DTD 5090 and A-4001 (Sheet 2 of 3) Table 46 (Cont.)

| Temper                           | Form   | Composition, Heat Treatment | Test Method | Yield Strength, $F_{0.2}$ (ksi/mm <sup>2</sup> ) | Typical $K_{IC}$ (ksi√in) (MS/m <sup>3/2</sup> ) | $2.5 \left( \frac{K_{IC}}{\sigma_{ys}} \right)^2$ in (mm) | Specimen |                   |               | Ref        |                      |
|----------------------------------|--------|-----------------------------|-------------|--------------------------------------------------|--------------------------------------------------|-----------------------------------------------------------|----------|-------------------|---------------|------------|----------------------|
|                                  |        |                             |             |                                                  |                                                  |                                                           | Type     | Thickness in (mm) | Width in (mm) |            | Crack Length in (mm) |
| Forging: 6.0 in (152.4 mm) Thick |        |                             |             |                                                  |                                                  |                                                           |          |                   |               |            |                      |
| T4<br>2124<br>T851               | C, 1   | L-T                         | 70 (294)    | 56 (386)                                         | 30 (33)                                          | 0.717 (18.2)                                              | Bend     | 2.0 (50.8)        | 4.0 (101.6)   | ---        | 41                   |
|                                  |        | T-L                         | 70 (294)    | 58 (400)                                         | 17 (19)                                          | 0.215 ( 5.5)                                              | Bend     | 2.0 (50.8)        | 4.0 (101.6)   | ---        |                      |
|                                  |        | S-L                         | 70 (294)    | 54 (372)                                         | 16 (17)                                          | 0.219 ( 5.6)                                              | Bend     | 0.5 (12.7)        | 1.0 ( 25.4)   | ---        |                      |
|                                  |        | T-L                         | 70 (294)    | 48 (331)                                         | 31 (34)                                          | 0.41 (10.4)                                               | SEN      | 1.0 (25.4)        | 5.0 (127)     | 1.6 (40.6) | 40                   |
| T651                             | E, (a) | L-T                         | 74 (297)    | 66 (455)                                         | 24 (26)                                          | 0.331 ( 8.4)                                              | CT       | 0.75 (19.1)       | 2.0 (50.8)    | 1.0 (25.4) | 110                  |
|                                  |        | T-L                         | 74 (297)    | 65 (448)                                         | 23 (25)                                          | 0.313 ( 8.0)                                              | CT       | 0.75 (19.1)       | 2.0 (50.8)    | 1.0 (25.4) |                      |
| T851                             | D, 2   | L-T                         | 70 (294)    | 54 (379)                                         | 41 (45)                                          | 1.441 (36.6)                                              | (b)      | ---               | ---           | ---        | 72                   |
|                                  | D, -   | T-S                         | 70 (294)    | 50 (345)                                         | 24 (27)                                          | 0.576 (14.6)                                              | Bend     | 0.5 (12.7)        | 1.0 (25.4)    | ---        | 60                   |
| T851                             | D, -   | T-S                         | 70 (294)    | 58 (400)                                         | 22 (24)                                          | 0.360 ( 9.1)                                              | Bend     | 0.5 (12.7)        | 1.0 (25.4)    | ---        |                      |
|                                  | D, -   | T-S                         | 70 (294)    | 61 (421)                                         | 24 (27)                                          | 0.387 ( 9.8)                                              | Bend     | 0.5 (12.7)        | 1.0 (25.4)    | ---        |                      |

(a) Fabrication and Heat Treatment in accordance with Military, Federal, ASTM or Aluminum Association Specifications.

(b) Specimen in accordance with ASTM Recommendations.

COMPOSITION

|   | Cu    | Al   | Fe   | Si   | Mn   | Zn    | Ti    | Cr   | Ni   | Pb    |
|---|-------|------|------|------|------|-------|-------|------|------|-------|
| A | 4.3N  | 1.5N | 0.5N | 0.5N | 0.6N | 0.25N | -     | 0.1N | -    | -     |
| B | 4.63  | 1.54 | 0.15 | 0.11 | 0.53 | 0.07  | 0.02  | -    | -    | -     |
| C | 4.56  | 1.69 | 0.14 | 0.12 | 0.65 | 0.08  | 0.03  | -    | -    | -     |
| D | 4.35N | 1.5N | 0.5N | 0.5N | 0.6N | 0.25N | -     | -    | 0.5N | 0.05N |
| E | 4.35N | 1.5N | 0.3N | 0.2N | 0.6N | 0.25N | 0.15N | 0.1N | -    | -     |

HEAT TREATMENT

1. Solution Heat Treated, Cold Worked and Artificially Aged in accordance with Mil Specification MIL-II-6088D or Aluminum Standards and Data, Aluminum Association, April 1968

2. 922F (768K), Water Quench; Stretch 1.5-2.5%

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(a) Fabrication and Heat Treatment in accordance with Military, Federal, ASTM or Aluminum Association Specifications.  
 (b) Specimen in accordance with ASTM Recommendations.

COMPOSITION

|   | Cu    | Mg   | Fe   | Si   | Mn   | Zn    | Ti    | Cr   | Ni   | Pb    |
|---|-------|------|------|------|------|-------|-------|------|------|-------|
| A | 4.3N  | 1.5N | 0.5N | 0.5N | 0.6N | 0.25N | -     | 0.1N | -    | -     |
| B | 4.63  | 1.54 | 0.15 | 0.11 | 0.53 | 0.07  | 0.02  | -    | -    | -     |
| C | 4.56  | 1.69 | 0.14 | 0.12 | 0.65 | 0.08  | 0.03  | -    | -    | -     |
| D | 4.35N | 1.5N | 0.5N | 0.5N | 0.6N | 0.2N  | -     | -    | 0.5N | 0.05N |
| E | 4.35N | 1.5N | 0.3N | 0.2N | 0.6N | 0.25N | 0.15N | 0.1N | -    | -     |

HEAT TREATMENT

- Solution Heat Treated, Cold Worked and Artificially Aged in accordance with Mil Specification MIL-H-6088D or Aluminum Standards and Data, Aluminum Association, April 1968
- 922F (768K), Water Quench; Stretch 1.5-2.5%

ALUMINUM, Copper Alloy: 2618, RR58, UTD 731, CM 0031/4D, A-U2GN

Table 47

| Tempor                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               | Form                          | Compo-<br>sition, Heat<br>Treat-<br>ment | Test<br>Orienta-<br>tion | Temp<br>°F (°K) | Yield<br>Strength<br>KSI (MN/m <sup>2</sup> ) | Typical<br>K <sub>IC</sub><br>$\frac{KSI\sqrt{in}}{(MN\ m^{\frac{3}{2}})}$ | $\frac{2.5}{\sigma_{ys}} \left( \frac{K_{IC}}{\sigma_{ys}} \right)^2$<br>in (mm) | Specimen |                      |                  |                            | Ref. |    |    |    |    |    |    |    |    |    |      |      |       |      |   |   |       |   |       |      |      |      |      |   |   |      |   |      |       |      |       |       |      |      |   |   |       |
|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-------------------------------|------------------------------------------|--------------------------|-----------------|-----------------------------------------------|----------------------------------------------------------------------------|----------------------------------------------------------------------------------|----------|----------------------|------------------|----------------------------|------|----|----|----|----|----|----|----|----|----|------|------|-------|------|---|---|-------|---|-------|------|------|------|------|---|---|------|---|------|-------|------|-------|-------|------|------|---|---|-------|
|                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      |                               |                                          |                          |                 |                                               |                                                                            |                                                                                  | Type     | Thickness<br>in (mm) | Width<br>in (mm) | Crack<br>Length<br>in (mm) |      |    |    |    |    |    |    |    |    |    |      |      |       |      |   |   |       |   |       |      |      |      |      |   |   |      |   |      |       |      |       |       |      |      |   |   |       |
| 2618                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                 |                               |                                          |                          |                 |                                               |                                                                            |                                                                                  |          |                      |                  |                            |      |    |    |    |    |    |    |    |    |    |      |      |       |      |   |   |       |   |       |      |      |      |      |   |   |      |   |      |       |      |       |       |      |      |   |   |       |
| T651                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                 | Plate: 1 in (25.4 mm) Thick   | A, (a)                                   | T-L                      | 70(294)         | 58(400)                                       | 33(37)                                                                     | 0.85 (22.6)                                                                      | Bend     | 1.0 (25.4)           | 2.0 (50.8)       | 1.0 (25.4)                 | 37   |    |    |    |    |    |    |    |    |    |      |      |       |      |   |   |       |   |       |      |      |      |      |   |   |      |   |      |       |      |       |       |      |      |   |   |       |
| RR58                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                 |                               |                                          |                          |                 |                                               |                                                                            |                                                                                  |          |                      |                  |                            |      |    |    |    |    |    |    |    |    |    |      |      |       |      |   |   |       |   |       |      |      |      |      |   |   |      |   |      |       |      |       |       |      |      |   |   |       |
| MP                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   | Plate: 3 in (76.2 mm) Thick   | B, -                                     | L-T                      | 70(294)         | 60(414)                                       | 22(24)                                                                     | 0.336 (8.6)                                                                      | Bend     | 0.75 (19.1)          | 3.0 (76.2)       | 1.0 (25.4)                 | 62   |    |    |    |    |    |    |    |    |    |      |      |       |      |   |   |       |   |       |      |      |      |      |   |   |      |   |      |       |      |       |       |      |      |   |   |       |
|                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      |                               | B, -                                     | T-L                      | 70(294)         | 58(400)                                       | 19(21)                                                                     | 0.268 (6.8)                                                                      | Bend     | 0.75 (19.1)          | 3.0 (76.2)       | 1.0 (25.4)                 |      |    |    |    |    |    |    |    |    |    |      |      |       |      |   |   |       |   |       |      |      |      |      |   |   |      |   |      |       |      |       |       |      |      |   |   |       |
|                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      |                               | B, -                                     | S-L                      | 70(294)         | 55(379)                                       | 20(22)                                                                     | 0.331 (8.4)                                                                      | Bend     | 0.75 (19.1)          | 3.0 (76.2)       | 1.0 (25.4)                 |      |    |    |    |    |    |    |    |    |    |      |      |       |      |   |   |       |   |       |      |      |      |      |   |   |      |   |      |       |      |       |       |      |      |   |   |       |
| MP                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   | Forging                       | B, -                                     | T-L                      | 70(294)         | 61(421)                                       | 24(26)                                                                     | 0.387 (9.8)                                                                      | Bend     | 1.4 (35.6)           | 0.38(9.7)        | 0.49(12.4)                 |      |    |    |    |    |    |    |    |    |    |      |      |       |      |   |   |       |   |       |      |      |      |      |   |   |      |   |      |       |      |       |       |      |      |   |   |       |
| UTD 731                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              |                               |                                          |                          |                 |                                               |                                                                            |                                                                                  |          |                      |                  |                            |      |    |    |    |    |    |    |    |    |    |      |      |       |      |   |   |       |   |       |      |      |      |      |   |   |      |   |      |       |      |       |       |      |      |   |   |       |
| MP                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   | Forging                       | B, -                                     | L-T                      | 70(294)         | 58(400)                                       | 21(23)                                                                     | 0.328 (8.3)                                                                      | Bend     | 0.38 (9.7)           | 1.5 (38.1)       | 0.34 (8.6)                 | 62   |    |    |    |    |    |    |    |    |    |      |      |       |      |   |   |       |   |       |      |      |      |      |   |   |      |   |      |       |      |       |       |      |      |   |   |       |
|                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      |                               |                                          | T-S                      | 70(294)         | 58(400)                                       | 21(23)                                                                     | 0.328 (8.3)                                                                      | Bend     | 0.38 (9.7)           | 1.5 (38.1)       | 0.34 (8.6)                 |      |    |    |    |    |    |    |    |    |    |      |      |       |      |   |   |       |   |       |      |      |      |      |   |   |      |   |      |       |      |       |       |      |      |   |   |       |
|                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      |                               |                                          | S-L                      | 70(294)         | 57(393)                                       | 16(17.6)                                                                   | 0.197 (5.0)                                                                      | Bend     | 0.25 (6.4)           | 0.75(19.1)       | 0.30 (7.6)                 |      |    |    |    |    |    |    |    |    |    |      |      |       |      |   |   |       |   |       |      |      |      |      |   |   |      |   |      |       |      |       |       |      |      |   |   |       |
| CM 003/4D                                                                                                                                                                                                                                                                                                                                                                                                                                                                                            |                               |                                          |                          |                 |                                               |                                                                            |                                                                                  |          |                      |                  |                            |      |    |    |    |    |    |    |    |    |    |      |      |       |      |   |   |       |   |       |      |      |      |      |   |   |      |   |      |       |      |       |       |      |      |   |   |       |
| MP                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   | Plate: 1.5 in (38.1 mm) Thick | C, 1                                     | L-T                      | 70(294)         | 61(423)                                       | 23(25)                                                                     | 0.355 (9.0)                                                                      | (b)      | ---                  | ---              | ---                        | 72   |    |    |    |    |    |    |    |    |    |      |      |       |      |   |   |       |   |       |      |      |      |      |   |   |      |   |      |       |      |       |       |      |      |   |   |       |
|                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      | Plate: 3 in (76.2 mm) Thick   | C, 1                                     | L-T                      | 70(294)         | 60(417)                                       | 20(22)                                                                     | 0.278 (7.1)                                                                      | (b)      | ---                  | ---              | ---                        |      |    |    |    |    |    |    |    |    |    |      |      |       |      |   |   |       |   |       |      |      |      |      |   |   |      |   |      |       |      |       |       |      |      |   |   |       |
|                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      |                               |                                          | L-T                      | 70(294)         | 58(399)                                       | 17(19)                                                                     | 0.215 (5.5)                                                                      | (b)      | ---                  | ---              | ---                        |      |    |    |    |    |    |    |    |    |    |      |      |       |      |   |   |       |   |       |      |      |      |      |   |   |      |   |      |       |      |       |       |      |      |   |   |       |
|                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      |                               |                                          | S-L                      | 70(294)         | 55(376)                                       | 16(18)                                                                     | 0.212 (5.4)                                                                      | (b)      | ---                  | ---              | ---                        |      |    |    |    |    |    |    |    |    |    |      |      |       |      |   |   |       |   |       |      |      |      |      |   |   |      |   |      |       |      |       |       |      |      |   |   |       |
| A-U2 GN                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              |                               |                                          |                          |                 |                                               |                                                                            |                                                                                  |          |                      |                  |                            |      |    |    |    |    |    |    |    |    |    |      |      |       |      |   |   |       |   |       |      |      |      |      |   |   |      |   |      |       |      |       |       |      |      |   |   |       |
| T 651                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                |                               | A, -                                     | T-S                      | 70(294)         | 57(393)                                       | 21(23)                                                                     | 0.339 (8.6)                                                                      | Bend     | 0.5 (12.7)           | 1.0 (25.4)       | ---                        | 62   |    |    |    |    |    |    |    |    |    |      |      |       |      |   |   |       |   |       |      |      |      |      |   |   |      |   |      |       |      |       |       |      |      |   |   |       |
| T 652                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                |                               | A, -                                     | L-T                      | 70(294)         | 58(400)                                       | 24(26)                                                                     | 0.428 (10.9)                                                                     | Bend     | 0.5 (12.7)           | 1.0 (25.4)       | ---                        |      |    |    |    |    |    |    |    |    |    |      |      |       |      |   |   |       |   |       |      |      |      |      |   |   |      |   |      |       |      |       |       |      |      |   |   |       |
| COMPOSITION                                                                                                                                                                                                                                                                                                                                                                                                                                                                                          |                               |                                          |                          |                 |                                               |                                                                            |                                                                                  |          |                      |                  |                            |      |    |    |    |    |    |    |    |    |    |      |      |       |      |   |   |       |   |       |      |      |      |      |   |   |      |   |      |       |      |       |       |      |      |   |   |       |
| <table><tr><td>Cu</td><td>Mg</td><td>Si</td><td>Fe</td><td>Mn</td><td>Zn</td><td>Ti</td><td>Pb</td><td>Ni</td></tr><tr><td>2.3N</td><td>1.5N</td><td>0.25M</td><td>1.1N</td><td>-</td><td>-</td><td>0.07N</td><td>-</td><td>1.05N</td></tr><tr><td>2.5N</td><td>1.5N</td><td>0.2N</td><td>1.0N</td><td>-</td><td>-</td><td>0.1N</td><td>-</td><td>1.2N</td></tr><tr><td>2.25N</td><td>1.5N</td><td>0.25M</td><td>1.15N</td><td>0.2M</td><td>0.1M</td><td>-</td><td>-</td><td>0.05M</td></tr></table> |                               |                                          |                          |                 |                                               |                                                                            |                                                                                  |          |                      |                  |                            |      | Cu | Mg | Si | Fe | Mn | Zn | Ti | Pb | Ni | 2.3N | 1.5N | 0.25M | 1.1N | - | - | 0.07N | - | 1.05N | 2.5N | 1.5N | 0.2N | 1.0N | - | - | 0.1N | - | 1.2N | 2.25N | 1.5N | 0.25M | 1.15N | 0.2M | 0.1M | - | - | 0.05M |
| Cu                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   | Mg                            | Si                                       | Fe                       | Mn              | Zn                                            | Ti                                                                         | Pb                                                                               | Ni       |                      |                  |                            |      |    |    |    |    |    |    |    |    |    |      |      |       |      |   |   |       |   |       |      |      |      |      |   |   |      |   |      |       |      |       |       |      |      |   |   |       |
| 2.3N                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                 | 1.5N                          | 0.25M                                    | 1.1N                     | -               | -                                             | 0.07N                                                                      | -                                                                                | 1.05N    |                      |                  |                            |      |    |    |    |    |    |    |    |    |    |      |      |       |      |   |   |       |   |       |      |      |      |      |   |   |      |   |      |       |      |       |       |      |      |   |   |       |
| 2.5N                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                 | 1.5N                          | 0.2N                                     | 1.0N                     | -               | -                                             | 0.1N                                                                       | -                                                                                | 1.2N     |                      |                  |                            |      |    |    |    |    |    |    |    |    |    |      |      |       |      |   |   |       |   |       |      |      |      |      |   |   |      |   |      |       |      |       |       |      |      |   |   |       |
| 2.25N                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                | 1.5N                          | 0.25M                                    | 1.15N                    | 0.2M            | 0.1M                                          | -                                                                          | -                                                                                | 0.05M    |                      |                  |                            |      |    |    |    |    |    |    |    |    |    |      |      |       |      |   |   |       |   |       |      |      |      |      |   |   |      |   |      |       |      |       |       |      |      |   |   |       |
| (a) Fabrication and Heat Treatment in accordance with Military, Federal, ASTM or Aluminum Association Specifications.                                                                                                                                                                                                                                                                                                                                                                                |                               |                                          |                          |                 |                                               |                                                                            |                                                                                  |          |                      |                  |                            |      |    |    |    |    |    |    |    |    |    |      |      |       |      |   |   |       |   |       |      |      |      |      |   |   |      |   |      |       |      |       |       |      |      |   |   |       |
| (b) Specimen in accordance with ASTM Recommendations.                                                                                                                                                                                                                                                                                                                                                                                                                                                |                               |                                          |                          |                 |                                               |                                                                            |                                                                                  |          |                      |                  |                            |      |    |    |    |    |    |    |    |    |    |      |      |       |      |   |   |       |   |       |      |      |      |      |   |   |      |   |      |       |      |       |       |      |      |   |   |       |
| WAT TRIATHLON                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        |                               |                                          |                          |                 |                                               |                                                                            |                                                                                  |          |                      |                  |                            |      |    |    |    |    |    |    |    |    |    |      |      |       |      |   |   |       |   |       |      |      |      |      |   |   |      |   |      |       |      |       |       |      |      |   |   |       |
| 1. 985F (803K), Water Quenched; Stretch 1.5-2.5%; Aged 373F (463F)                                                                                                                                                                                                                                                                                                                                                                                                                                   |                               |                                          |                          |                 |                                               |                                                                            |                                                                                  |          |                      |                  |                            |      |    |    |    |    |    |    |    |    |    |      |      |       |      |   |   |       |   |       |      |      |      |      |   |   |      |   |      |       |      |       |       |      |      |   |   |       |

## COMPOSITION

|   | Cu    | Mg   | Si    | Fe    | Mn   | Zn   | Tl    | Pb    | Ni    |
|---|-------|------|-------|-------|------|------|-------|-------|-------|
| A | 2.3N  | 1.5N | 0.25M | 1.1N  | -    | -    | 0.07N | -     | 1.05N |
| B | 2.5N  | 1.5N | 0.2M  | 1.0N  | -    | -    | 0.1N  | -     | 1.2N  |
| C | 2.25N | 1.5N | 0.25M | 1.15N | 0.2M | 0.1M | -     | 0.05M | 1.1N  |

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(a) Fabrication and Heat Treatment in accordance with Military, Federal, ASTM or Aluminum Association Specifications.  
 (b) Specimen in accordance with ASTM Recommendations.

HAT FRIATMENT

1. 985F (803K), Water Quenched; Stretch 1.5-2.5%; Aged 373F (463F)

ALUMINUM, Zn-Mg Alloy: 7001, 7049 and 7050 (Sheet 1 of 2)

Table 48

| Temper      | Form                                                                      | Compo-<br>sition,<br>Heat<br>Treat-<br>ment | Test<br>Orienta-<br>tion | Temp,<br>°F (°K) | Yield<br>Strength<br>KSI (N/m <sup>2</sup> ) | Typical<br>K <sub>IC</sub><br>KSI√in (N/m <sup>3/2</sup> ) | 2.5( $\frac{K_{IC}}{\sigma_{ys}}$ ) <sup>2</sup><br>in (mm) | Specimen |                      |                  | Ref        |                            |
|-------------|---------------------------------------------------------------------------|---------------------------------------------|--------------------------|------------------|----------------------------------------------|------------------------------------------------------------|-------------------------------------------------------------|----------|----------------------|------------------|------------|----------------------------|
|             |                                                                           |                                             |                          |                  |                                              |                                                            |                                                             | Type     | Thickness<br>in (mm) | Width<br>in (mm) |            | Crack<br>Length<br>in (mm) |
| 7001<br>T75 | Plate: 1.375 in (34.9 mm)<br>Thick                                        | A, (a)                                      | L-T                      | 70 (294)         | 71 (490)                                     | 24 (26)                                                    | 0.286 ( 7.3)                                                | Bend     | 1.37 (34.8)          | 3.0 (76.2)       | 1.5 (38.1) | 38                         |
|             |                                                                           |                                             | T-L                      | 70 (294)         | 70 (483)                                     | 22 (24)                                                    | 0.247 ( 6.3)                                                | Bend     | 1.37 (34.8)          | 3.0 (76.2)       | 1.5 (38.1) |                            |
|             | Extrusion: 0.2 in (5.1 mm)<br>Thick                                       | B,                                          | L-T                      | 70 (294)         | 77 (531)                                     | 20 (22)                                                    | 0.169 ( 4.3)                                                | SEN      | 0.180 ( 4.6)         | 2.0 (50.8)       | 0.67 (17 ) | 48                         |
|             |                                                                           |                                             | T-L                      | 70 (294)         | 78 (537)                                     | 20 (22)                                                    | 0.164 ( 4.2)                                                | SEN      | 0.180 ( 4.6)         | 2.0 (50.8)       | 0.67 (17 ) |                            |
|             | Forging: 6.0 in (152.4 mm)<br>Thick                                       | B, -                                        | T-L                      | 70 (294)         | 70 (483)                                     | 21 (23)                                                    | 0.255 ( 5.7)                                                | SEN      | 0.250 ( 6.3)         | 2.0 (50.8)       | ---        | 49                         |
|             |                                                                           |                                             | T-L                      | 70 (294)         | 71 (490)                                     | 16 (17)                                                    | 0.126 ( 3.2)                                                | CN       | 0.185 ( 4.7)         | 3.0 (76.3)       | ---        |                            |
|             |                                                                           |                                             | S-T                      | 70 (294)         | ---                                          | 16 (17)                                                    | ---                                                         | NOL      | 1.0 (25.4)           | 0.813 (20.6)     | 0.5 (12.7) |                            |
| 7049<br>T73 | Forging: 5 in (127 mm)<br>Thick                                           | C, (a)                                      | L-                       | 70 (294)         | 64 (441)                                     | 32 (35)                                                    | 0.62 (15.8)                                                 | (b)      | ---                  | ---              | ---        | 84                         |
|             | Extrusion, Integrally<br>Stiffened: 18 x 11 x 3 in<br>(457 x 279 x 76 mm) | D, (a)                                      | L-T                      | 75 (297)         | 75 (517)                                     | 28 (31)                                                    | 0.348 ( 8.9)                                                | CT       | 1.0 (25.4)           | 2.0 (50.8)       | 1.0 (25.4) | 97                         |
|             |                                                                           |                                             | T-L                      | 75 (297)         | 75 (517)                                     | 25 (27)                                                    | 0.278 ( 7.1)                                                | CT       | 1.0 (25.4)           | 2.0 (50.8)       | 1.0 (25.4) |                            |
|             |                                                                           |                                             | S-T                      | 75 (297)         | 68 (469)                                     | 20 (22)                                                    | 0.216 ( 5.5)                                                | CT       | 1.0 (25.4)           | 2.0 (50.8)       | 1.0 (25.4) |                            |
|             |                                                                           |                                             | L-T                      | -65 (219)        | 79 (545)                                     | 25 (27)                                                    | 0.250 ( 6.4)                                                | CT       | 1.0 (25.4)           | 2.0 (50.8)       | 1.0 (25.4) |                            |
|             |                                                                           |                                             | T-L                      | -65 (219)        | 78 (538)                                     | 23 (25)                                                    | 0.217 ( 5.5)                                                | CT       | 1.0 (25.4)           | 2.0 (50.8)       | 1.0 (25.4) |                            |
|             | Extrusion, 20 x 3.3 x 3.5 in<br>(508 x 84 x 89 mm)                        | , (a)                                       | L-T                      | 70 (294)         | 73 (503)                                     | 33 (36)                                                    | 0.511 (13)                                                  | CT       | 1.0 (25.4)           | 2.0 (50.8)       | 1.0 (25.4) |                            |
|             |                                                                           |                                             | T-L                      | 70 (294)         | 68 (469)                                     | 22 (24)                                                    | 0.424 (10.8)                                                | CT       | 1.0 (25.4)           | 2.0 (50.8)       | 1.0 (25.4) |                            |
|             |                                                                           |                                             | L-T                      | -65 (219)        | 77 (531)                                     | 31 (34)                                                    | 0.477 (12.1)                                                | CT       | 1.0 (25.4)           | 2.0 (50.8)       | 1.0 (25.4) |                            |
|             |                                                                           |                                             | T-L                      | -65 (219)        | 70 (483)                                     | 20 (22)                                                    | 0.204 ( 5.2)                                                | CT       | 1.0 (25.4)           | 2.0 (50.8)       | 1.0 (25.4) |                            |
| 7049<br>T76 | Extrusion: 20 x 3.3 x 3.5 in<br>(508 x 84 x 89 mm)                        | D, (a)                                      | L-T                      | 70 (294)         | 76 (524)                                     | 33 (36)                                                    | 0.471 (12)                                                  | CT       | 1.0 (25.4)           | 2.0 (50.8)       | 1.0 (25.4) | 97                         |
|             |                                                                           |                                             | T-L                      | 70 (294)         | 69 (476)                                     | 20 (22)                                                    | 0.210 ( 5.3)                                                | CT       | 1.0 (25.4)           | 2.0 (50.8)       | 1.0 (25.4) |                            |
|             |                                                                           |                                             | L-T                      | -65 (219)        | 80 (552)                                     | 30 (33)                                                    | 0.352 ( 8.9)                                                | CT       | 1.0 (25.4)           | 2.0 (50.8)       | 1.0 (25.4) |                            |
|             |                                                                           |                                             | T-L                      | -65 (219)        | 72 (496)                                     | 29 (29)                                                    | 0.174 ( 4.4)                                                | CT       | 1.0 (25.4)           | 2.0 (50.8)       | 1.0 (25.4) |                            |

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ALUMINUM, Zn-Mg Alloy. 7001, 7049 and 7050 (Sheet 2 of 2)

Table 48 (Cont.)

| Temper | Form                                   | Composition, Heat Treatment | Test Orientation | Temp °F (°K) | Yield Strength KSI (N/mm <sup>2</sup> ) | Typical $K_{IC}$ KSI√in (MN/m <sup>3/2</sup> ) | $2.5\left(\frac{K_{IC}}{\sigma_{ys}}\right)^2$ in (mm) | Specimen   |                   |               |
|--------|----------------------------------------|-----------------------------|------------------|--------------|-----------------------------------------|------------------------------------------------|--------------------------------------------------------|------------|-------------------|---------------|
|        |                                        |                             |                  |              |                                         |                                                |                                                        | Type       | Thickness in (mm) | Width in (mm) |
| 7050   |                                        |                             |                  |              |                                         |                                                |                                                        |            |                   |               |
| T73B51 | Plate: 4 in (102 mm) Thick             | E,                          | L-T              | 70(294)      | 67(462)                                 | 35(38)                                         | 0.682(17.3) CT                                         | 1.25(31.8) | 2.5 (63.5)        | 1.25(38.1)    |
| T7E56  | Hand Forging: 5 x 10 in (127 x 254 mm) | F,-                         | T-L              | 70(294)      | 64(70)                                  | 29(32)                                         | 0.513(13.0) Bend                                       | 0.75(19.1) | 1.5 (38.1)        | 0.75(19.1)    |

(a) Heat Treatment in Accordance with Applicable Military, Federal, ASTM or Aluminum Association Specifications.  
 (b) Specimen in Accordance with ASTM Recommendations.

## COMPOSITION

|   | Cu   | Ni   | Fe    | Si    | Mn   | Zn   | Cr    | Ti   | Zr   |
|---|------|------|-------|-------|------|------|-------|------|------|
| A | 2.1N | 3.0N | 0.4N  | 0.35N | 0.3N | 7.4N | 0.28N | 0.2N | -    |
| B | 2.26 | 3.03 | 0.16  | 0.12  | 0.04 | 7.61 | 0.21  | 0.02 | -    |
| C | 1.42 | 2.45 | 0.13  | 0.07  | 0.01 | 7.5  | 0.16  | -    | -    |
| D | 1.5N | 2.5N | 0.35N | 0.25N | 0.2N | 7.6N | 0.15N | 0.1N | -    |
| E | 2.31 | 2.44 | 0.07  | 0.04  | 0.00 | 6.35 | 0.01  | 0.03 | 0.13 |

ALUMINUM, Zn-Mg Alloy: 7007

Table 49

| Temper         | Form                             | Compo-<br>sition,<br>Heat<br>Treat-<br>ment | Test<br>Orienta-<br>tion | Temp<br>°F (°K) | Yield<br>Strength<br>KSI (MN/m <sup>2</sup> ) | Typical<br>K <sub>IC</sub><br><br>KSI√in (MN m <sup>-3/2</sup> ) | 2.5<br>( $\frac{K_{IC}}{\sigma_{ys}}$ ) <sup>2</sup><br>in (mm) | Specimen |                      |                  |                            | Ref. |
|----------------|----------------------------------|---------------------------------------------|--------------------------|-----------------|-----------------------------------------------|------------------------------------------------------------------|-----------------------------------------------------------------|----------|----------------------|------------------|----------------------------|------|
|                |                                  |                                             |                          |                 |                                               |                                                                  |                                                                 | Type     | Thickness<br>in (mm) | Width<br>in (mm) | Crack<br>Length<br>in (mm) |      |
| 7007<br>T6     | Plate: 1.0 in<br>(25.4 mm) Thick | A, (a)                                      | L-T                      | 70(294)         | 73(503)                                       | 44(48)                                                           | 0.903(23.1)                                                     | (b)      | 1.0 ( 25.4)          | 2.0( 50.8)       | 1.0 ( 25.4)                | 37   |
|                |                                  |                                             | T-L                      | 70(294)         | 69(476)                                       | 37(40)                                                           | 0.719(18.3)                                                     | (b)      | 1.0 ( 25.4)          | 2.0( 50.8)       | 1.0 ( 25.4)                |      |
|                |                                  |                                             | T-L                      | 70(294)         | 65(448)                                       | 32(35)                                                           | 0.606 (15.4)                                                    | CT       | 1.0 (25.4)           | 2.0 (50.8)       | 1.0 (25.4)                 | 58   |
|                |                                  |                                             | T-L                      | -321(77)        | 80(552)                                       | 23(25)                                                           | 0.207 (5.2)                                                     | CT       | 1.0 (25.4)           | 2.0 (50.8)       | 1.0 (25.4)                 |      |
|                |                                  |                                             | T-L                      | -423(22)        | 85(586)                                       | 28(193)                                                          | 0.271 (6.9)                                                     | CT       | 1.0 (25.4)           | 2.0 (50.8)       | 1.0 (25.4)                 |      |
| 7007<br>T6 1/2 | Plate: 1.0 in<br>(25.4 mm) Thick | B, (a)                                      | L-T                      | 70(294)         | 73(503)                                       | 46(50)                                                           | 0.999(25.2)                                                     | Bond     | 1.0 ( 25.4)          | 2.0( 50.8)       | 1.0 ( 25.4)                | 43   |
|                |                                  |                                             | T-L                      | 70(294)         | 69(476)                                       | 37(40)                                                           | 0.685(17.4)                                                     | Bond     | 1.0 ( 25.4)          | 2.0( 50.8)       | 1.0 ( 25.4)                |      |

(a) Fabrication and Heat Treatment in accordance with Aluminum Association Specifications.

(b) Specimen in accordance with ASTM Recommendations.

COMPOSITION

|   | Cu    | Mg   | Si           | Fe   | Mn   | Zn   | Ti    | Cr    | Zr    | Ag |
|---|-------|------|--------------|------|------|------|-------|-------|-------|----|
| A | 0.25% | 1.8% | (0.4% total) | 0.4% | 6.5% | 6.5% | 0.04% | 0.12% | 0.12% | -  |
| B | 0.06  | 1.7% | 0.05         | 0.11 | 6.21 | 6.55 | 0.03  | 0.11  | 0.10  | -  |

HEAT TREATMENT

1. 860F (734K), Controlled Moderate Quench; Stretched 1.5 to 3%; Aged 275F (40K), 16 hr

ALUMINUM, Zn-Mg Alloys: 7075, DTD 5050, DTD 5074, BSL 95, AZ 74, and 7175 (Sheet 1 of 4) Table 50

| Temper  | Form                                | Composition, Heat Treatment | Test Orientation | Temp, °F (°C) | Yield Strength ksi (N/mm <sup>2</sup> ) | Typical K <sub>IC</sub> ksi√in (MN/m <sup>3/2</sup> ) | 2.5( $\frac{K_{IC}}{\sigma_{ys}}$ ) in (mm) | Specimen |                   |               |                      | Ref |
|---------|-------------------------------------|-----------------------------|------------------|---------------|-----------------------------------------|-------------------------------------------------------|---------------------------------------------|----------|-------------------|---------------|----------------------|-----|
|         |                                     |                             |                  |               |                                         |                                                       |                                             | Type     | Thickness in (mm) | Width in (mm) | Crack Length in (mm) |     |
| 7075 T6 | Plate: 3 in (76.2 mm) Thick         | A, 1                        | T-S              | 70 (204)      | 63 (435)                                | 26 (28)                                               | 0.459 (11.7)                                | (b)      | ---               | ---           | ---                  | 76  |
| T651    | Plate: 0.5 in (12.7 mm) Thick       | A, (a)                      | T-L              | 70 (204)      | 73 (503)                                | 25 (27)                                               | 0.290 ( 7.4)                                | (b)      | 0.5 (12.7)        | 1.0 (25.4)    | 0.5 (12.7)           | 37  |
|         | Plate: 1.375 in (44.5 mm) Thick     | A, (a)                      | T-L              | 70 (204)      | 74 (510)                                | 19 (21)                                               | 0.165 ( 4.2)                                | (b)      | 1.75 (44.4)       | 3.0 (76.2)    | 1.75 (44.4)          |     |
|         |                                     | A, (a)                      | S-L              | 70 (204)      | ---                                     | 15 (16)                                               | ---                                         | (b)      | 1.75 (44.4)       | 3.0 (76.2)    | 1.75 (44.4)          |     |
|         | Plate: 1.375 in (34.9 mm) Thick     | A, (a)                      | L-T              | 70 (204)      | 75 (517)                                | 28 (31)                                               | 0.350 ( 8.9)                                | Bend     | 1.375 (34.9)      | 3.0 (76.2)    | 1.5 (38.1)           | 38  |
|         |                                     | A, (a)                      | T-L              | 70 (204)      | 78 (537)                                | 23 (25)                                               | 0.218 ( 5.5)                                | ---      | ---               | ---           | ---                  |     |
|         | Plate: 1.375 in (34.9 mm) Thick     | A, (a)                      | T-L              | 70 (204)      | 78 (537)                                | 21 (23)                                               | 0.180 ( 4.6)                                | Bend     | 1.390 (35.3)      | 3.0 (76.2)    | 1.5 (38.1)           | 39  |
|         |                                     | A, (a)                      | T-L              | -112 (193)    | 83 (572)                                | 23 (25)                                               | 0.193 ( 4.9)                                | Bend     | 1.390 (35.3)      | 3.0 (76.2)    | 1.5 (38.1)           |     |
|         |                                     | A, (a)                      | T-L              | -320 ( 78)    | 92 (633)                                | 25 (27)                                               | 0.185 ( 4.7)                                | Bend     | 1.390 (35.3)      | 3.0 (76.2)    | 1.5 (38.1)           |     |
|         | Plate: 4 in (101.6 mm) Thick        | A, 2                        | T-S              | 70 (204)      | 67 (459)                                | 22 (24)                                               | 0.270 ( 6.8)                                | (b)      | ---               | ---           | ---                  | 76  |
| T6511   | Extrusion: 0.688 in (17.5 mm) Thick | A, (a)                      | L-L              | 70 (204)      | 79 (544)                                | 26 (28)                                               | 0.277 ( 7.0)                                | (b)      | 0.625 (15.9)      | 1.25 (31.8)   | 0.625 (15.9)         | 57  |
|         |                                     | A, (a)                      | T-L              | 70 (204)      | 75 (517)                                | 25 (27)                                               | 0.278 ( 7.1)                                | (b)      | 0.625 (15.9)      | 1.25 (31.8)   | 0.625 (15.9)         |     |
|         | Extrusion: 3.5 in (88.9 mm) Thick   | A, (a)                      | L-T              | 70 (204)      | 75 (517)                                | 31 (34)                                               | 0.427 (10.8)                                | (b)      | 1.5 (30.1)        | 3.0 (76.2)    | 1.5 (38.1)           |     |
|         |                                     | A, (a)                      | T-L              | 70 (204)      | 67 (462)                                | 21 (23)                                               | 0.246 ( 6.3)                                | (b)      | 1.5 (30.1)        | 3.0 (76.2)    | 1.5 (38.1)           |     |
|         |                                     | A, (a)                      | S-L              | 70 (204)      | 61 (421)                                | 19 (21)                                               | 0.245 ( 6.2)                                | CT       | 1.0 (25.4)        | 2.0 (50.8)    | 1.0 (25.4)           | 61  |
| T7351   | Plate: 1.375 in (34.9 mm) Thick     | A, (a)                      | T-L              | 70 (204)      | 57 (393)                                | 28 (31)                                               | 0.603 (15.3)                                | Bend     | 1.375 (34.9)      | 3.0 (76.2)    | 1.5 (38.1)           | 39  |
|         |                                     | A, (a)                      | T-L              | -112 (193)    | 59 (407)                                | 28 (31)                                               | 0.565 (16.6)                                |          | 1.375 (34.9)      | 3.0 (76.2)    | 1.5 (38.1)           |     |
|         |                                     | A, (a)                      | T-L              | -320 ( 78)    | 66 (455)                                | 29 (32)                                               | 0.483 (12.3)                                |          | 1.375 (34.9)      | 3.0 (76.2)    | 1.5 (38.1)           |     |
|         | Plate: 1.0 in (25.4 mm) Thick       | A, (a)                      | L-T              | 70 (204)      | 67 (462)                                | 33 (36)                                               | 0.606 (15.4)                                | SLN      | 1.0 (25.4)        | 5.0 (127.0)   | 1.6 (40.6)           | 40  |
|         |                                     | A, (a)                      | T-L              | 70 (204)      | 65 (448)                                | 27 (29)                                               | 0.431 (10.9)                                |          | 1.0 (25.4)        | 5.0 (127.0)   | 1.6 (40.6)           |     |

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ALUMINUM, Zn-Ni Alloys: 7075, UTD 5050, UTD 5074, BSL 95, A2 74, and 7175 (Sheet 2 of 4) Table 50 (Cont.)

| Temper         | Form                                   | Composition,<br>Heat Treatment | Test Orientation | Yield Strength<br>ksi (N/mm <sup>2</sup> ) | Typical<br>K <sub>IC</sub><br>ksi√in (MN/m <sup>3/2</sup> ) | 2.5( $\frac{K_{IC}}{\sigma_{YS}}$ ) <sup>2</sup><br>in (mm) | Specimen |                      |                  |                         | Ref |
|----------------|----------------------------------------|--------------------------------|------------------|--------------------------------------------|-------------------------------------------------------------|-------------------------------------------------------------|----------|----------------------|------------------|-------------------------|-----|
|                |                                        |                                |                  |                                            |                                                             |                                                             | Type     | Thickness<br>in (mm) | Width<br>in (mm) | Crack Length<br>in (mm) |     |
| 7075<br>T73511 | Plate: 1.0<br>(25.0 mm) Thick          | ---                            | L-T              | 58(400)                                    | 34(37)                                                      | 0.859(21.8)                                                 | Bend     | 0.55 (14)            | 1.02 (26)        | 0.55 (14)               | 27  |
|                |                                        |                                | T-L              | 57(393)                                    | 28(31)                                                      | 0.603(15.3)                                                 |          | 1.0 (25.4)           | 2.0 (50.8)       | 1.0 (25.4)              |     |
|                | Plate: 2 in (50.8 mm)<br>Thick         | A,3                            | T-S              | 66(452)                                    | 27(30)                                                      | 0.418(10.6)                                                 |          | ---                  | ---              | ---                     | 76  |
|                | Plate: 4 in (102 mm)<br>thick          | I, (a)                         | T-T              | 53(365)                                    | 31(34)                                                      | 0.855(21.7)                                                 | CT       | 1.25 (31.8)          | 2.5 (63.5)       | 1.25 (31.8)             | 116 |
|                | Forging: 1.1 in<br>(27.9 mm) Thick     | ---                            | L-L              | 58(400)                                    | 33(36)                                                      | 0.809(20.5)                                                 | Bend     | 1.0 (25.4)           | 2.0 (50.8)       | 1.0 (25.4)              |     |
| 7075           |                                        |                                | L-L              | 58(400)                                    | 22(24)                                                      | 0.359(9.1)                                                  |          | 1.0 (25.4)           | 2.0 (50.8)       | 1.0 (25.4)              |     |
|                |                                        |                                | L-S              | 54(370)                                    | 27(30)                                                      | 0.625(15.9)                                                 | Bend     | 0.5 (12.7)           | 1.0 (25.4)       | ---                     | 60  |
|                | Extrusion: 0.688 in<br>(17.5 mm) thick | A, (a)                         | L-T              | 64(441)                                    | 34(37)                                                      | 0.706(17.9)                                                 | (b)      | 0.625(15.9)          | 1.25 (31.8)      | 0.625(15.9)             | 37  |
|                |                                        | A, (a)                         | F-L              | 62(427)                                    | 30(32)                                                      | 0.585(14.9)                                                 | (b)      | 0.625(15.9)          | 1.25 (31.8)      | 0.625(15.9)             |     |
|                | Extrusion: 3.5 in<br>(88.9 mm) thick   | A, (a)                         | L-T              | 64(441)                                    | 35(38)                                                      | 0.748(19.0)                                                 | (b)      | 1.5 (38.1)           | 3.0 (76.2)       | 1.5 (38.1)              |     |
| 7075           |                                        |                                | F-L              | 58(400)                                    | 24(26)                                                      | 0.428(10.5)                                                 | (b)      | 1.5 (38.1)           | 3.0 (76.2)       | 1.5 (38.1)              |     |
|                |                                        | A, (a)                         | S-L              | 54(372)                                    | 20(22)                                                      | 0.343(8.7)                                                  | CT       | 1.0 (25.4)           | 2.0 (50.8)       | 1.0 (25.4)              | 61  |
|                | Forging: 2.0 in<br>(50.8 mm) thick     | B, 1                           | L-T              | 65(448)                                    | 31(34)                                                      | 0.569(14.4)                                                 | Bend     | 0.75 (19.0)          | 1.5 (38.1)       | ---                     | 41  |
|                |                                        |                                | T-L              | 65(448)                                    | 24(26)                                                      | 0.341(8.7)                                                  |          | 0.75 (19.0)          | 1.5 (38.1)       | ---                     |     |
|                | Forging: 6.0 in<br>(152.1 mm) thick    | C, 1                           | L-T              | 55(379)                                    | 40(44)                                                      | 1.322(33.6)                                                 |          | 2.0 (50.8)           | 4.0 (101.6)      | ---                     |     |
| 7075           |                                        |                                | F-L              | 50(345)                                    | 28(31)                                                      | 0.784(19.9)                                                 |          | 2.0 (50.4)           | 4.0 (101.6)      | ---                     |     |
|                |                                        |                                | S-L              | 49(338)                                    | 26(28)                                                      | 0.703(17.9)                                                 |          | 2.0 (50.4)           | 4.0 (101.6)      | ---                     |     |
|                | Forging: 6.0 in<br>(152.1 mm) thick    | A, (a)                         | S-L              | 56(386)                                    | 22(24)                                                      | 0.386(9.8)                                                  | Bend     | 0.7 (17.8)           | 1.4 (35.6)       | 0.7 (17.8)              | 111 |
|                |                                        |                                | T-T              | 56(386)                                    | 20(22)                                                      | 0.319(8.1)                                                  | Bend     | 0.7 (17.8)           | 1.4 (35.6)       | 0.7 (17.8)              |     |
|                | Forging                                | A, (a)                         | L-S              | 57(393)                                    | 30(32)                                                      | 0.692(17.6)                                                 | Bend     | 0.5 (12.7)           | 1.0 (25.4)       | ---                     | 60  |
| 77651          | Plate: 2 in<br>(50.8 mm) thick         | A, (a)                         | L-T              | 65(448)                                    | 27(29)                                                      | 0.431(11)                                                   | CT       | 0.8 (20.3)           | 2.0 (50.8)       | 1.0 (25.4)              | 119 |

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ALUMINUM, Zn-Mg Alloys: 7178 and 7651 and 7652 (Sheet 1 of 2)

| Temper       | Form                                                | Compo-<br>sition,<br>Heat<br>Treat-<br>ment | Test<br>Orien-<br>tation | Temp<br>$\sigma_F$ ( $^{\circ}$ F) | Yield<br>Strength<br>KSI (N/mm <sup>2</sup> ) | Typical<br>$K_{IC}$<br>KSI $\sqrt{in}$ (MN m <sup>-3/2</sup> ) | 2.5 ( $\frac{K_{IC}}{\sigma_{ys}}$ ) <sup>2</sup><br>in (mm) | Specimen |                      |                  |                            | Ref. |
|--------------|-----------------------------------------------------|---------------------------------------------|--------------------------|------------------------------------|-----------------------------------------------|----------------------------------------------------------------|--------------------------------------------------------------|----------|----------------------|------------------|----------------------------|------|
|              |                                                     |                                             |                          |                                    |                                               |                                                                |                                                              | Type     | Thickness<br>in (mm) | Width<br>in (mm) | Crack<br>Length<br>in (mm) |      |
| 7178<br>T651 | Plate: 1.375 in<br>(34.9 mm) Thick                  | A, (a)                                      | L-T                      | 70(294)                            | 83(572)                                       | 23(25)                                                         | 0.192( 4.9)                                                  | (b)      | 1.0 (25.4)           | 2.0 ( 50.8)      | 1.0 (25.4)                 | 37   |
|              | Plate: 1.0 in<br>(25.4 mm) Thick                    | A, (a)                                      | T-L                      | 70(294)                            | 78(538)                                       | 20(138)                                                        | 0.164( 4.2)                                                  | CT       | 1.0 (25.4)           | 2.0 (50.8)       | 1.0 (25.4)                 | 61   |
|              |                                                     |                                             | L-T                      | 70(294)                            | 81(558)                                       | 26(28)                                                         | 0.257( 6.5)                                                  | (b)      | 1.0 (25.4)           | 2.0 ( 50.8)      | 1.0 (25.4)                 |      |
| T6510        | Extrusion: 0.18 to 2.3 in<br>(4.6 to 55.9 mm) Thick | A, (a)                                      | T-L                      | 70(294)                            | 81(558)                                       | 23(25)                                                         | 0.202( 5.1)                                                  | (b)      | 1/0 (25.4)           | 2.0 ( 50.8)      | 1.0 (25.4)                 | 42   |
|              |                                                     |                                             | L-T                      | 70(294)                            | 86(593)                                       | 21(23)                                                         | 0.150( 3.8)                                                  | SEN      | 0.18 min (4.6)       | 0.9 min (22.8)   | 0.4 min (10.2)             |      |
| 7178<br>T651 | Plate: 1.375 in<br>(34.9 mm) Thick                  | A, (a)                                      | T-L                      | 70(294)                            | 79(545)                                       | 21(23)                                                         | 0.177( 4.5)                                                  | SEN      | 0.18 min (4.6)       | 0.9 min (22.8)   | 0.4 min (16.2)             | 37   |
|              | Plate: 2 in (50.8 mm)<br>Thick                      | A, (a)                                      | L-T                      | 70(294)                            | 73(503)                                       | 26(28)                                                         | 0.317( 8.1)                                                  | (b)      | 1.0 (25.4)           | 2.0 ( 50.8)      | 1.0 (25.4)                 |      |
|              |                                                     |                                             | T-L                      | 70(294)                            | 71(490)                                       | 21(23)                                                         | 0.219( 5.6)                                                  | (b)      | 1.0 (25.4)           | 2.0 ( 50.8)      | 1.0 (25.4)                 |      |
| T6511        | Extrusion: 3.5 in<br>(88.9 mm) Thick                | A, (a)                                      | T-L                      | 70(294)                            | 64(441)                                       | 22(24)                                                         | 0.295( 7.5)                                                  | (b)      | 2.0 (50.8)           | 4.0 (101.6)      | 2.0 (50.8)                 |      |
|              |                                                     |                                             | L-T                      | 70(294)                            | 71(490)                                       | 30(33)                                                         | 0.447(11.3)                                                  | (b)      | 2.0 (50.8)           | 4.0 (101.6)      | 2.0 (50.8)                 |      |
|              |                                                     |                                             | T-L                      | 70(294)                            | 71(490)                                       | 28(30)                                                         | 0.391( 9.9)                                                  | (b)      | 2.0 (50.8)           | 4.0 (101.6)      | 2.0 (50.8)                 |      |
| T6511        | Extrusion: 0.688 in<br>(1.5 mm) Thick               | A, (a)                                      | L-T                      | 70(294)                            | 78(538)                                       | 23(25)                                                         | 0.217( 5.5)                                                  | (b)      | 1.5 (38.1)           | 3.0 ( 76.2)      | 1.5 (38.1)                 |      |
|              |                                                     |                                             | T-L                      | 70(294)                            | 69(476)                                       | 16(17)                                                         | 0.134( 3.4)                                                  | (b)      | 1.5 (38.1)           | 3.0 ( 76.2)      | 1.5 (38.1)                 |      |
|              |                                                     |                                             | S-L                      | 70(294)                            | 62(427)                                       | 14(15)                                                         | 0.127( 3.2)                                                  | CT       | 1.0 (25.4)           | 2.0 (50.8)       | 1.0 (25.4)                 | 61   |
| T76511       | Extrusion: 0.688 in<br>(17.5 mm) Thick              | A, (a)                                      | L-T                      | 70(294)                            | 83(572)                                       | 22(24)                                                         | 0.175( 4.4)                                                  | (b)      | 0.625(15.9)          | 1.25( 31.8)      | 0.625(15.4)                |      |
|              |                                                     |                                             | T-L                      | 70(294)                            | 83(572)                                       | 20(22)                                                         | 0.145( 3.7)                                                  | (b)      | 0.625(15.9)          | 1.25( 31.8)      | 0.625(15.4)                |      |
|              |                                                     |                                             | L-T                      | 70(294)                            | 69(476)                                       | 29(32)                                                         | 0.442(11.2)                                                  | (b)      | 0.625(15.9)          | 1.25( 31.8)      | 0.625(15.9)                |      |
| T62          | Extrusion: 0.4 in<br>(10.2 mm) Thick                | A, (a)                                      | T-L                      | 70(294)                            | 68(470)                                       | 26(28)                                                         | 0.365( 9.3)                                                  | (b)      | 0.625(15.9)          | 1.25( 31.8)      | 0.625(15.9)                |      |
|              |                                                     |                                             | L-T                      | 70(294)                            | 90(620)                                       | 23(25)                                                         | 0.163( 4.1)                                                  | (b)      | 0.404(10.3)          | 1.5 ( 38.1)      | ---                        | 42   |
|              |                                                     |                                             | T-L                      | 70(294)                            | 83(573)                                       | 23(25)                                                         | 0.192( 4.9)                                                  | (b)      | 0.512( 7.9)          | 0.940(23.9)      | ---                        |      |

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(a) Composition, Fabrication and Heat Treatment in accordance with Aluminum Association Specifications (b) Specimen in accordance with ASTM Recommendations

(a) Composition, Fabrication and Heat Treatment in accordance with Aluminum Association Specifications (b) Specimen in accordance with ASTM Recommendations

ALUMINUM, Zn-1/2 Alloys: 7178 and DTD 363 (Sheet 2 of 2)

Table S1 (Cont.)

| Temper      | Form      | Compo-<br>sition,<br>Heat<br>Treat-<br>ment | Test<br>Orienta-<br>tion | Temp<br>°F (°K) | Yield<br>Strength<br>KS (MN/m <sup>2</sup> ) | Typical<br>K <sub>IC</sub><br>KSI√in (MN m <sup>3/2</sup> ) | 2.5 (K <sub>IC</sub><br>σ <sub>ys</sub> ) <sup>2</sup><br>in (mm) | Specimen |                      |                  | Ref.        |                            |
|-------------|-----------|---------------------------------------------|--------------------------|-----------------|----------------------------------------------|-------------------------------------------------------------|-------------------------------------------------------------------|----------|----------------------|------------------|-------------|----------------------------|
|             |           |                                             |                          |                 |                                              |                                                             |                                                                   | Type     | Thickness<br>in (mm) | Width<br>in (mm) |             | Crack<br>Length<br>in (mm) |
| DTD 363     |           |                                             |                          |                 |                                              |                                                             |                                                                   |          |                      |                  |             |                            |
| W7          | Extrusion | B <sub>1</sub>                              | L-T                      | 70 (294)        | 87 (600)                                     | 28 (31)                                                     | 0.259 (6.6)                                                       | Band     | 0.8 (20.3)           | 2.6 (66)         | 0.75 (19.1) | 62                         |
| COMPOSITION |           |                                             |                          |                 |                                              |                                                             |                                                                   |          |                      |                  |             |                            |
|             |           | Cu                                          | Mg                       | Si              | Fe                                           | Mn                                                          | Zn                                                                | Tl       | Cr                   |                  |             |                            |
| A           | 2.0N      | 2.75N                                       | 0.5M                     | 0.7M            | 0.3M                                         | 6.8N                                                        | 6.8N                                                              | 0.2M     | 0.29N                |                  |             |                            |
| B           | 2.0N      | 2.7N                                        | -                        | -               | -                                            | 6.8N                                                        | 6.8N                                                              | -        | 0.3M                 |                  |             |                            |

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Table 52

| Temper        | Form                                | Composition,<br>Heat Treatment | Residual Stress<br>(ksi)                                     | Yield Strength<br>(ksi)                  | Typical $K_{IC}$<br>$\left( \frac{KSI\sqrt{in}}{\sqrt{MN/m^2}} \right) \left( -\frac{3}{2} \right)$ | $2.5 \left( \frac{K_{IC}}{\sigma_{ys}} \right)^2$<br>in (mm) | Specimen |                      |                  |                         | Ref |
|---------------|-------------------------------------|--------------------------------|--------------------------------------------------------------|------------------------------------------|-----------------------------------------------------------------------------------------------------|--------------------------------------------------------------|----------|----------------------|------------------|-------------------------|-----|
|               |                                     |                                |                                                              |                                          |                                                                                                     |                                                              | Type     | Thickness<br>in (mm) | Width<br>in (mm) | Crack Length<br>in (mm) |     |
| 7039<br>T6    | Forging: 4.0 in<br>(101.6 mm) Thick | A, 1                           | T-L 70(294)                                                  | 57(393)                                  | 19(21)                                                                                              | 0.277 ( 7.0)                                                 | WOL      | 4.0 (101.6)          | 10.2 (259 )      | 4 ( 101.6)              | 45  |
|               |                                     |                                | T-L 0(256)                                                   | 59(407)                                  | 17(19)                                                                                              | 0.208 ( 5.3)                                                 | WOL      | 4.0 (101.6)          | 10.2 (259 )      | 4 ( 101.6)              |     |
| 6651          | Plate: 2.0 in<br>(50.8 mm) Thick    | B, 2                           | T-L 75(294)<br>- -100(200)                                   | 49(338)<br>53(365)                       | 29(32)<br>30(33)                                                                                    | 0.877(22.3)<br>0.804(20.4)                                   | Bend     | 1.75( 44.5)          | 3.5 ( 89)        | 1.75( 44.5)             | 4   |
| 7001<br>T6, A | Plate: 3 in<br>(76.2 mm) Thick      | C, (a)                         | T-L -321( - 78)<br>L-T 70(294)<br>T-L 70(294)<br>S-L 70(294) | 58(400)<br>53(365)<br>52(359)<br>48(331) | 31(34)<br>47(51)<br>40(44)<br>38(31)                                                                | 0.715(18.2)<br>1.966(49.9)<br>1.479(37.8)<br>0.851(21.6)     | Bend     | 1.75( 44.5)          | 3.5 ( 89)        | 1.75( 44.5)             | 98  |

(a) Fabrication, and Heat Treatment in accordance with Aluminum Association Specification  
(b) Specimen in Accordance with ASTM Recommendations

### COMPOSITION

|   | Cu   | Mg   | Si    | Fe    | Mn    | Zn   | Cr    | Ti    | Zr    |
|---|------|------|-------|-------|-------|------|-------|-------|-------|
| F | 0.1% | 2.8% | 0.3%  | 0.4%  | 0.25% | 4.0% | 0.2%  | 0.1%  | -     |
| C | 0.01 | 2.5  | 0.31  | 0.4%  | 0.25% | 3.75 | 0.3%  | 0.1%  | -     |
|   | 0.1% | 1.4% | 0.35% | 0.35% | 0.45% | 4.6% | 0.13% | 0.03% | 0.13% |

### HEAT TREATMENT

1. 850F (728C), 4 Hr, Aged 320F (433K), 18 Hr
2. 850F (728K), 2.5 Hr, Water Quench, Age Room Temperature, 8 Hr, Age 320F (433K), 18 Hr

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ALUMINUM, Zn-Mg-Mn Alloy: 7079

Table 53

| Temper | Form                                 | Condition,<br>Heat Treat-<br>ment | Test<br>Orienta-<br>tion | Temp<br>$\sigma_f$ ( $^{\circ}$ C) | Yield<br>Strength<br>KSI ( $\text{MN/m}^2$ ) | Typical<br>$K_{IC}$<br>KSI/in ( $\text{MPa m}^{1/2}$ ) | $2.5 \left( \frac{K_{IC}}{\sigma_f} \right)^2$<br>in (mm) | Specimen |                      |                  |                            | Ref. |
|--------|--------------------------------------|-----------------------------------|--------------------------|------------------------------------|----------------------------------------------|--------------------------------------------------------|-----------------------------------------------------------|----------|----------------------|------------------|----------------------------|------|
|        |                                      |                                   |                          |                                    |                                              |                                                        |                                                           | Type     | Thickness<br>in (mm) | Width<br>in (mm) | Crack<br>Length<br>in (mm) |      |
| T6     | Plate: 1.0 in<br>(25.4 mm) Thick     | A, (a)                            | T-L                      | 70(294)                            | 75(517)                                      | 27(24)                                                 | 0.215( 5.5)                                               | SEN      | 1.0 (25.4)           | 5.0 (127.0)      | 1.6 (40.6)                 | 40   |
|        | Forging: 3.0 in<br>(76.1 mm) Thick   | A, 1                              | L-T                      | 75(297)                            | 91(441)                                      | 32(35)                                                 | 0.625(15.9)                                               | WOL      | 2.0 (50.8)           | 2.25( 57.3)      | 1.0 (25.4)                 | 11   |
|        |                                      |                                   | T-L                      | 75(297)                            | 64(441)                                      | 28(31)                                                 | 0.503(12.7)                                               | WOL      | 2.0 (50.8)           | 2.25( 57.3)      | 1.0 (25.4)                 |      |
|        |                                      |                                   | L-T                      | 75(214)                            | 69(476)                                      | 33(36)                                                 | 0.570(14.5)                                               | WOL      | 2.0 (50.8)           | 2.25( 57.3)      | 1.0 (25.4)                 |      |
| 51     | Plate: 1.375 in<br>(34.9 mm) Thick   | A, (a)                            | L-T                      | 70(294)                            | 78(533)                                      | 21(34)                                                 | 0.395(10.0)                                               | Bend     | 1.375(34.9)          | 3.0 ( 76.2)      | 1.5 (38.1)                 | 38   |
|        |                                      |                                   | T-T                      | 70(294)                            | 75(517)                                      | 25(27)                                                 | 0.277( 7.0)                                               | Bend     | 1.375(34.9)          | 3.0 ( 76.2)      | 1.5 (38.1)                 |      |
|        |                                      |                                   | T-L                      | 77(293)                            | 61(558)                                      | 26(28)                                                 | 0.258( 6.6)                                               | Bend     | 1.380(35.1)          | 3.0 ( 76.2)      | 1.65(41.9)                 | 39   |
|        |                                      |                                   | F-L                      | 77(293)                            | 91(627)                                      | 27(29)                                                 | 0.220( 5.6)                                               | Bend     | 1.380(35.1)          | 3.0 ( 76.2)      | 1.45(36.8)                 |      |
| 6510   | Extrusion: 0.5 in<br>(12.7 mm) Thick | A, (a)                            | L-T                      | 70(294)                            | 74(510)                                      | 31(34)                                                 | 0.439(11.1)                                               | SIN      | 0.5 (12.7)           | 1.5 ( 38.1)      | 0.5 (12.7)                 | 42   |
|        |                                      |                                   | T-L                      | 70(294)                            | 71(490)                                      | 29(32)                                                 | 0.417(10.6)                                               | SIN      | 0.5 (12.7)           | 1.5 ( 38.1)      | 0.5 (12.7)                 |      |
|        |                                      |                                   | L-T                      | 70(294)                            | 71(490)                                      | 28(31)                                                 | 0.389( 9.9)                                               | Bend     | 0.75 (19.1)          | 1.5 ( 38.1)      | ---                        | 41   |
|        |                                      |                                   | F-L                      | 70(294)                            | 65(448)                                      | 25(27)                                                 | 0.370( 9.4)                                               | Bend     | 0.75 (19.1)          | 1.5 ( 38.1)      | ---                        |      |
| T652   | Forging: 2.0 in<br>(50.8 mm) Thick   | C, (b)                            | L-T                      | 70(294)                            | 64(441)                                      | 30(33)                                                 | 0.549(13.9)                                               | Bend     | 2.0 (50.8)           | 4.0 (101.6)      | ---                        |      |
|        |                                      |                                   | T-L                      | 70(294)                            | 58(400)                                      | 24(26)                                                 | 0.428(10.9)                                               | Bend     | 2.0 (50.8)           | 4.0 (101.6)      | ---                        |      |
|        |                                      |                                   | S-L                      | 70(294)                            | 58(400)                                      | 18(20)                                                 | 0.241( 6.1)                                               | Bend     | 0.5 (12.7)           | 1.0 ( 25.4)      | ---                        |      |
|        |                                      |                                   |                          |                                    |                                              |                                                        |                                                           |          |                      |                  |                            |      |

(a) Fabrication, and Heat Treatment in accordance with Military, Federal, ASTM or Aluminum Assoc. Specifications  
 (b) Fabrication and Heat Treatment in accordance with Military, Federal, ASTM or Aluminum Assoc. Specifications

## COMPOSITION

|   | Cu   | Zn   | Mg   | Si   | Fe   | Mn   | Cr    | Ti   |
|---|------|------|------|------|------|------|-------|------|
| A | 0.6N | 4.3N | 3.3N | 0.3N | 0.4N | 0.2N | 0.18N | 0.1N |
| B | 0.76 | 4.57 | 3.48 | 0.11 | 0.18 | 0.18 | 0.14  | 0.03 |
| C | 0.72 | 4.60 | 3.55 | 0.10 | 0.16 | 0.17 | 0.15  | 0.02 |

## HEAT TREATMENT

1. Solution treated 830F (717K); Aged 5 days at Room Temp.; 240F (389K), 48 hr

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ALUMINUM, Zn-Mg-Mn Alloys: DTD 5024 and DTD 5094

Table 5a

| Temper   | Form                                              | Compo-<br>sition,<br>Heat<br>Treat-<br>ment | Test<br>Orienta-<br>tion | Temp<br>°F (°C) | Yield<br>Strength<br>KSI (MPa/m <sup>2</sup> ) | Typical<br>K <sub>IC</sub><br>KSI√in (MN m <sup>-3/2</sup> ) | 2.5 (K <sub>IC</sub> <sup>2</sup> / σ <sub>ys</sub> )<br>in (mm) | Specimen |                      |                  | Ref.          |
|----------|---------------------------------------------------|---------------------------------------------|--------------------------|-----------------|------------------------------------------------|--------------------------------------------------------------|------------------------------------------------------------------|----------|----------------------|------------------|---------------|
|          |                                                   |                                             |                          |                 |                                                |                                                              |                                                                  | Type     | Thickness<br>in (mm) | Width<br>in (mm) |               |
| DTC 5024 |                                                   |                                             |                          |                 |                                                |                                                              |                                                                  |          |                      |                  |               |
| WP       | Forging: 6 x 6<br>x 11 in (152 x<br>152 x 279 mm) | A, 1                                        | T-S                      | 70(294)         | 68(471)                                        | 19(21)                                                       | 0.195 (5.0)                                                      | (a)      | ---                  | ---              | 74            |
|          |                                                   |                                             | S-L                      | 70(294)         | 70(485)                                        | 15(16)                                                       | 0.115 (2.9)                                                      | (a)      | ---                  | ---              |               |
| WP       | Forging: 6 x 6<br>x 4 in (152 x<br>152 x 102 mm)  | A, 1                                        | T-L                      | 70(294)         | 63(435)                                        | 18(20)                                                       | 0.204 (5.2)                                                      | (a)      | ---                  | ---              |               |
| DTD 5094 |                                                   |                                             |                          |                 |                                                |                                                              |                                                                  |          |                      |                  |               |
| WP       | Forging:                                          | B, --                                       | L-                       | 70(294)         | 61(421)                                        | 24(26)                                                       | 0.39 (9.9)                                                       | Bend     | 0.32 (8.0)           | 1.5 (38.1)       | 0.32 (8.1) 62 |
|          |                                                   |                                             | T-                       | 70(294)         | 60(414)                                        | 22(24)                                                       | 0.33 (8.4)                                                       | Bend     | 0.32 (8.0)           | 1.5 (38.1)       | 0.35 (8.9)    |
|          |                                                   |                                             | S-                       | 70(294)         | 50(400)                                        | 14(15)                                                       | 0.15 (3.8)                                                       | Bend     | 0.32 (8.0)           | 1.5 (38.1)       | 0.32 (8.1)    |

(a) Specimen in accordance with ASTM Recommendations.

COMPOSITION

|   | Cu   | Mg   | Si   | Fe   | Mn   | Zn   | Cr   | Ni   | Pb    |
|---|------|------|------|------|------|------|------|------|-------|
| A | 0.5N | 2.7N | 0.5M | 0.5M | 0.5N | 5.7M | -    | 0.1M | 0.05M |
| B | 0.5N | 2.5N | -    | -    | 0.5N | 5.5M | 0.2M | -    | -     |

HEAT TREATMENT

1. 859F (733K), Water Quenched at 211F (373K); Aged 275F (408K)

836



## ALUMINUM: 6061

Table 56

| Temper | Form                             | Composition, Heat Treatment | Test Orientation | Yield Strength<br>KSI (N/m <sup>2</sup> ) | Typical<br>K <sub>IC</sub><br>KSI√in (N/m <sup>3/2</sup> ) | 2.5( $\frac{K_{IC}}{\sigma_{ys}}$ ) <sup>2</sup><br>in (mm) | Specimen |                      |                  |                            | Ref |
|--------|----------------------------------|-----------------------------|------------------|-------------------------------------------|------------------------------------------------------------|-------------------------------------------------------------|----------|----------------------|------------------|----------------------------|-----|
|        |                                  |                             |                  |                                           |                                                            |                                                             | Type     | Thickness<br>in (mm) | Width<br>in (mm) | Crack<br>Length<br>in (mm) |     |
| 1651   | Plate: 1.5 in<br>(38.1 mm) thick | A <sub>1</sub> (a)          | T-L              | 43(296)                                   | 26(28)                                                     | 0.914(23.2)                                                 | Bend     | 1.5 (38.1)           | 3.0 (76.2)       | 1.5 (38.1)                 | 39  |
|        |                                  |                             | T-L              | 45(310)                                   | 30(33)                                                     | 1.111(28.2)                                                 | Bend     | 1.5 (38.1)           | 3.0 (76.2)       | 1.5 (38.1)                 |     |
|        | Plate: 3 in<br>(76.2 mm) Thick   | A <sub>1</sub> (a)          | L-T              | 42(290)                                   | 30(33)                                                     | 1.276(32.4)                                                 | Bend     | 3.0 (76.2)           | 6.0 (152)        | 3.0 (76.2)                 | 98  |
|        |                                  |                             | T-L              | 41(283)                                   | 27(30)                                                     | 1.084(37.5)                                                 | Bend     | 3.0 (76.2)           | 6.0 (152)        | 3.0 (76.2)                 |     |
| 1652   | Forging: 9 in<br>(229 mm) Thick  | A <sub>1</sub> (a)          | S-L              | 40(276)                                   | 21(23)                                                     | 0.689(17.5)                                                 | Bend     | 3.0 (76.2)           | 6.0 (152)        | 3.0 (76.2)                 |     |
|        |                                  |                             | S-T              | 58(262)                                   | 23(25)                                                     | 0.916(23.3)                                                 | Bend     | 1.0 (25.4)           | 2.0 (50.8)       | 1.0 (25.4)                 | 111 |

(a) Fabrication and Heat Treatment in Accordance with Aluminum Association Standards.

## COMPOSITION:

|   | Cu    | Pb   | Si   | Fe   | Mn    | Zn    | Ti    | Cr   |
|---|-------|------|------|------|-------|-------|-------|------|
| A | 0.28N | 1.0N | 0.6N | 0.7N | 0.15N | 0.25N | 0.15N | 0.2N |

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BEKYLJIM: S-200

Table 57

| Form                                                        | Composition,<br>Heat<br>Treat-<br>men | Test<br>Orienta-<br>tion | $\phi_F$<br>Temp<br>(°K) | Yield<br>Strength<br>ksi (N/mm <sup>2</sup> ) | Typical<br>$K_{IC}$<br>ksi√in (MN/m <sup>3/2</sup> ) | $2\sigma_{IC}^2$<br>( $\frac{K_{IC}}{\sigma_{ys}}$ ) <sup>2</sup><br>in (mm) | Specimen |                      |                  |                            | Ref |
|-------------------------------------------------------------|---------------------------------------|--------------------------|--------------------------|-----------------------------------------------|------------------------------------------------------|------------------------------------------------------------------------------|----------|----------------------|------------------|----------------------------|-----|
|                                                             |                                       |                          |                          |                                               |                                                      |                                                                              | Type     | Thickness<br>in (mm) | Width<br>in (mm) | Crack<br>Length<br>in (mm) |     |
| Hot Pressed: 30 in<br>(762 mm) Dia x 32 in<br>(813 mm) long | A,-                                   | ---                      | 70(294)                  | 37(255)                                       | 10(11)                                               | 0.183( 4.6)                                                                  | Bend     | 0.5 (12.7)           | 1.0 (25.4)       | 0.25 ( 6.4)                | 86  |
| Forged: 16 in (406 mm) Dia x<br>1 in (25.4 mm) Thick        | B,-                                   | ---                      | 70(294)                  | 61(421)                                       | 11(12.1)                                             | 0.81 ( 2.1)                                                                  | Bend     | 0.5 (12.7)           | 1.0 (25.4)       | 0.25 ( 6.4)                |     |
| Hot Pressed: 11 x 12 x 13 in<br>(279 x 305 x 330 mm)        | C,-                                   | L-T                      | -320( 78)                | 42(289)                                       | 7.6(8.3)                                             | 0.08 ( 2.1)                                                                  | CT       | 1.0 (25.4)           | 2.0 (50.8)       | 1.0 (25.4)                 | 124 |
|                                                             |                                       | T-L                      | -320( 78)                | 41(283)                                       | 8.3(9.1)                                             | 0.10 ( 2.6)                                                                  | CT       | 1.0 (25.4)           | 2.0 (50.8)       | 1.0 (25.4)                 |     |
|                                                             |                                       | L-T                      | -180(155)                | 40(276)                                       | 8.0(8.7)                                             | 0.10 ( 2.5)                                                                  | CT       | 1.0 (25.4)           | 2.0 (50.8)       | 1.0 (25.4)                 |     |
|                                                             |                                       | L-T                      | -50(228)                 | 38(262)                                       | 3.5(9.3)                                             | 0.13 ( 3.2)                                                                  | CT       | 1.0 (25.4)           | 2.0 (50.8)       | 1.0 (25.4)                 |     |
|                                                             |                                       | L-T                      | 75(297)                  | 36(248)                                       | 9.5(10.4)                                            | 0.21 ( 5.3)                                                                  | CT       | 1.0 (25.4)           | 2.0 (50.8)       | 1.0 (25.4)                 |     |
|                                                             |                                       | T-L                      | 75(297)                  | 35(241)                                       | 11.2(12.3)                                           | 0.31 ( 7.8)                                                                  | CT       | 1.0 (25.4)           | 2.0 (50.8)       | 1.0 (25.4)                 |     |
|                                                             |                                       | L-T                      | 300(422)                 | 20(138)                                       | 9.8(10.7)                                            | 0.6 (15.2)                                                                   | CT       | 2.0 (50.8)           | 4.0 (101.6)      | 2.0 (50.8)                 |     |
|                                                             |                                       | L-T                      | 500(533)                 | ---                                           | 14.6(16.0)                                           | ---                                                                          | CT       | 2.0 (50.8)           | 4.0 (101.6)      | 2.0 (50.8)                 |     |

## COMPOSITION

|   | BcG    | Fe   | C    | Al   | Mg   | Si   | Be       |
|---|--------|------|------|------|------|------|----------|
| A | 16,500 | 1180 | 1000 | 700  | 40   | 300  | Ba1(ppm) |
| B | 17,190 | 1280 | 1300 | 400  | 110  | 260  | Ba1(ppm) |
| C | 1.1    | 0.16 | 0.14 | 0.07 | 0.02 | 0.03 | 98.5     |