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## EFFECT OF MANUFACTURING PROCESSES ON STRUCTURAL ALLOWABLES—PHASE II

BATTELLE COLUMBUS DIVISION  
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NOVEMBER 1986

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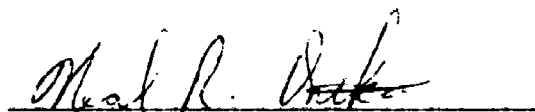
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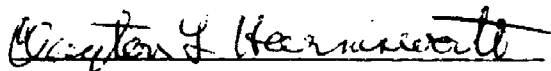
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Please make the following corrections:

| <u>Page<br/>Number</u> | <u>Correction</u>                                                                                                                                                                                                                                                                                                                                                                                                                   |
|------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 46                     | For 0.078 in. thickness, L direction, change shear ultimate strength value of 140.8 to 114.5 ksi and change average from 122.2 to 113.4 ksi. Add footnote indicator (5) to "Shear Ultimate Strength" in column heading.                                                                                                                                                                                                             |
| 47                     | For 0.093 in. thickness, L direction, change both shear ultimate strength values of 153.4 to 120.7 ksi and change average from 140.7 to 118.9 ksi. Add footnote indicator (5) to "Shear Ultimate Strength" in column heading.                                                                                                                                                                                                       |
| 48                     | For 0.125 in. thickness, LT direction, replace shear ultimate strength value of 130.6 with footnote indicator (4). Add footnote (4) to table as follows: "Excessive load inadvertently applied". Add footnote indicator (5) to "Shear Ultimate Strength". Add footnote (5) to table as follows: "Shear ultimate strength values not considered valid due to excessive deformation in test area".                                    |
| 49                     | For 1.98 mm thickness, L direction, change shear ultimate strength value of 970.8 to 781.9 GPa and change average from 842.3 to 779.4 GPa. Add footnote indicator (5) to "Shear Ultimate Strength" in column heading.                                                                                                                                                                                                               |
| 50                     | For 7.36 mm thickness, L direction, change both shear ultimate strength values of 1057.7 to 832.2 GPa and change average from 969.8 to 819.5 GPa. Add footnote indicator (5) to "Shear Ultimate Strength" in column heading.                                                                                                                                                                                                        |
| 51                     | For 3.175 mm thickness, LT direction, replace shear ultimate strength value of 900.3 GPa with footnote indicator (4) and change average to 784.3 GPa. Add footnote (4) to table as follows: "Excessive load inadvertently applied". Add footnote indicator (5) to "Shear Ultimate Strength". Add footnote (5) to table as follows: "Shear ultimate strength values not considered valid due to excessive deformation in test area". |

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| 19. ABSTRACT (Continue on reverse if necessary and identify by block number)<br>This report contains the results of tests to determine the effect of manufacturing processes on the mechanical properties of three aerospace materials: Inconel 718 solution treated and aged bar, Inconel 625 annealed bar, and Inconel 625 annealed sheet. Tensile, compression, shear, bearing, and fatigue (notched and unnotched for three stress ratios) properties were obtained. <i>Keywords: Nickel alloy Inconel</i> |            |                                                    |                                                                                                                                                                   |                                  |
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18. (CONTINUED)

→ strength; bearing ultimate strength; elongation; tensile modulus of elasticity; compressive modulus of elasticity; fatigue properties; Inconel 718 bar, Inconel 625 bar, and Inconel 625 sheet.

→ Inconel bars.  
Inconel sheets.

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## FOREWORD

This project was conducted by Battelle Columbus Division under Contract Number F33615-84-C-5030, Project Number 2865, over the period June 29, 1985, through July 29, 1986. Mr. Neal R. Ontko (MLSE), Engineering and Design Data, Materials Engineering Branch, was the project engineer for the Materials Laboratory, Air Force Wright Aeronautical Laboratories, Air Force Systems Command, Wright-Patterson Air Force Base, Ohio. This final report covering Phase II was submitted by the author, Mr. Paul E. Ruff, in July 1986.

The author wishes to express his appreciation to Mr. Dana Jones for his effort on this project.



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## SUMMARY

To evaluate the effect of newly established manufacturing techniques and processes on the MIL-HDBK-5 design allowable properties of aerospace materials, various mechanical properties, including fatigue, were determined at room temperature for multiple lots of three products. The data which were obtained are suitable for the determination of statistically based design values or can be used to supplement existing data so that design values can be determined. (Statistical analysis of the data to determine design allowables was not performed in this test program.)

Specifically, the following tests were conducted in Phase II:

Inconel 718 (STA Bar). Tensile, compression, shear, and bearing tests in two grain directions were conducted on ten lots of solution treated and aged Inconel 718 bars, which varied in thickness from 2 through 4 inches in diameter. Unnotched and notched,  $K_t = 3$ , axial-stress fatigue tests were performed at three stress ratios,  $R = -0.5$ ,  $R = 0.1$ , and  $R = 0.5$ , using longitudinal specimens from 3/4-inch-diameter bar. S/N curves were constructed.

Inconel 625 (Annealed) Bar. Tensile, compression, shear, and bearing tests in two grain directions were conducted on ten lots of annealed Inconel 625 bars, which varied in thickness from 2 through 4 inches in diameter. Unnotched and notched,  $K_t = 3$ , axial-stress fatigue tests were performed at three stress ratios,  $R = -0.5$ ,  $R = 0.1$ , and  $R = 0.5$ , using longitudinal specimens from 3/4-inch-diameter bar. S/N curves were constructed.

Inconel 625 (Annealed) Sheet. Tensile, compression, shear, and bearing tests in two grain directions were conducted on ten lots of annealed Inconel 625 sheet, which varied in thickness from 0.050 through 0.250 inch. Unnotched and notched,  $K_t = 3$ , axial-stress fatigue tests were performed at three stress ratios,  $R = -0.5$ ,  $R = 0.1$ , and  $R = 0.5$ , using long transverse specimens from 0.093-inch-thick sheet. S/N curves were constructed.

## INTRODUCTION

One of the major problems in the utilization of new manufacturing techniques for metallic materials used in advanced aircraft is the lack of

sufficient comparative mechanical property data to determine the effect of a new manufacturing technique or process on the design properties of the basic material. According to DoD and FAA regulations, a material cannot be used in a structural aircraft design unless the design allowable properties are available in MIL-HDBK-5 or a statistically significant quantity of data are available to provide acceptable documentation to support the values used in the design.

Consequently, test programs were needed to evaluate the effects of new manufacturing techniques or processes on the basic mechanical properties, such as tension, compression, shear, and bearing properties, as well as fatigue characteristics. These data, when suitably obtained, can be used by the MIL-HDBK-5 Program to determine statistically based design values for incorporation into MIL-HDBK-5. The availability of these data will reduce the time lag between the establishment of a new manufacturing process (or alloy) and its use in aerospace vehicles and components.

#### OBJECTIVE

The objective of this program was to evaluate the effect of newly established manufacturing techniques and processes on the MIL-HDBK-5 design allowable properties of structural materials used in aerospace applications.

#### TECHNICAL APPROACH

The technical approach was to fabricate (including heat treatment, when required) test specimens, to perform the mechanical property tests which are required for the development of design allowable properties, and to present the mechanical property data in a format suitable for use by the engineering community. The materials tested were:

Inconel 718 Bar (Solution Treated and Aged)

Inconel 625 Bar (Annealed)

Inconel 625 Sheet (Annealed)

## TEST PROCEDURE

Triplicate specimens, except for fatigue, were conducted for each mechanical property and grain direction. The test specimen location and configurations are described under the individual alloy in the Test Program section. All test specimens were fabricated by Metcut Research Associates, Inc., Cincinnati, Ohio. In general, all mechanical property tests were conducted in accord with ASTM standards. A detailed description of testing procedures is provided in Appendix A. All tests were conducted at room temperature.

## TEST PROGRAM

A description of the test program and the data obtained for each material are presented in this section.

## Inconel 718 Bar (Solution Treated and Aged)

### Background

Because of its many attractive characteristics, Inconel 718 is being used for applications other than for parts exposed to high temperatures. Therefore, data for mechanical properties other than those critical for high temperature performance are needed. Inconel 718 is currently contained in MIL-HDBK-5, but design values for properties other than tensile yield and ultimate strengths are missing. Consequently, a test program was needed to determine the mechanical properties of Inconel 718 bar in the solution treated and aged condition so that design values can be subsequently determined.

### Material

Eleven lots of Inconel 718 bar were procured from Inco Alloys International (formerly Huntington Alloys) in the solution treated condition to AMS 5662. The eleven lots represented nine heats. The chemical compositions, as determined by Inco Alloys International, are shown in Table 1. Bars were obtained in the following sizes: 3/4, 2, 2-1/4, 2-1/2, 2-3/4, 3, 3-1/4, 3-1/2, 3-3/4, and 4 inches in diameter. Two heats of 2-inch-diameter bar were procured. Inconel 718 bar is not produced in rectangular shapes; consequently, round bars with sufficient diameter to accommodate bearing specimens in the longitudinal grain direction at the T/4 location were selected. For economy, 3/4-inch-diameter bar was obtained for fatigue tests.

Bars were supplied in the solution heat treated condition (1775-1825 F). After machining, test specimens were precipitation heat-treated in a vacuum furnace according to AMS 5662, as follows: heat to  $1325\text{ F} \pm 15$  and hold for 8 hours, cool at  $100 \pm 15$  F degrees per hour to  $1150 \pm 15$  F, hold at  $1150 \pm 15$  F for 8 hours, and cool to room temperature. This heat treatment is used primarily for parts requiring maximum resistance to creep and stress rupture. (Tensile properties after heat treatment conformed to AMS 5662.)

### Location of Test Specimens

For mechanical property data to be usable for the determination of MIL-HDBK-5 design values, tensile, compression, shear, and bearing

TABLE 1. CHEMICAL COMPOSITION OF INCONEL 718 BAR

| Heat<br>Number | Element, percent |      |       |       |       |      |       |       |      |      |      |      |       |                |                |
|----------------|------------------|------|-------|-------|-------|------|-------|-------|------|------|------|------|-------|----------------|----------------|
|                | C                | Mn   | Fe    | S     | Si    | Cu   | Ni    | Cr    | Al   | Ti   | Co   | Mo   | Cb+Ta | P <sup>a</sup> | B <sup>a</sup> |
| VT03A1EY       | 0.01             | 0.06 | 18.44 | 0.002 | 0.05  | 0.04 | 53.55 | 17.93 | 0.63 | 0.96 | 0.02 | 3.00 | 5.31  | 0.005          | 0.003          |
| HT2860EY       | 0.03             | 0.10 | 17.35 | 0.001 | 0.012 | 0.13 | 53.86 | 18.48 | 0.52 | 0.95 | 0.21 | 3.01 | 5.22  | 0.012          | 0.003          |
| HT2877EY       | 0.02             | 0.07 | 17.00 | 0.002 | 0.08  | 0.04 | 54.30 | 18.48 | 0.59 | 0.95 | 0.13 | 3.02 | 5.31  | 0.007          | 0.003          |
| HT3111EY       | 0.03             | 0.14 | 17.42 | 0.001 | 0.13  | 0.13 | 53.85 | 18.68 | 0.53 | 0.94 | 0.08 | 2.96 | 5.10  | 0.010          | 0.002          |
| HT36KSEY       | 0.03             | 0.10 | 18.26 | 0.002 | 0.11  | 0.12 | 53.68 | 18.28 | 0.48 | 0.84 | 0.08 | 2.94 | 5.06  | 0.012          | 0.002          |
| HT2859EY       | 0.03             | 0.10 | 17.80 | 0.001 | 0.14  | 0.15 | 53.73 | 18.39 | 0.52 | 0.94 | 0.12 | 2.97 | 5.09  | 0.012          | 0.002          |
| HT3101EY       | 0.03             | 0.14 | 17.45 | 0.001 | 0.10  | 0.13 | 54.18 | 18.35 | 0.53 | 0.90 | 0.07 | 2.99 | 5.12  | 0.010          | 0.002          |
| HT22K9EY       | 0.03             | 0.10 | 17.79 | 0.002 | 0.12  | 0.15 | 54.56 | 17.39 | 0.56 | 0.95 | 0.19 | 3.04 | 5.12  | 0.011          | 0.002          |
| HT31K1EY       | 0.03             | 0.08 | 18.48 | 0.001 | 0.15  | 0.11 | 53.48 | 17.97 | 0.42 | 1.06 | 0.19 | 3.03 | 5.00  | 0.001          | 0.002          |

<sup>a</sup>Included in reported iron.

Note: Composition of all heats conformed to the requirements of AMS 5662.

specimens must be located within the cross section in accord with AMS 2371. Therefore, all specimens, except fatigue, were located with the axis of the specimen at the T/4 location. Since all bars were round, mechanical property tests were conducted on two grain directions, longitudinal and short transverse, except that bearing tests were performed only in the longitudinal direction, since the short transverse dimensions of most bars would not accommodate bearing specimens. Longitudinal fatigue specimens were located at the T/2 location in the 3/4-inch-diameter bar. The location of the test specimens is shown in Figures 1 through 7. Figure 8 shows the code system used to identify test specimens.

### Specimen Configuration

The configurations of test specimens are shown in Appendix B. Subsize tensile specimens were employed for the short transverse grain direction.

### Test Results

Tensile. The results of tensile tests are shown in Tables 2 and 2(a). In addition to tensile yield and ultimate strengths, elongation and modulus of elasticity values are indicated. Typical tensile stress-strain curves for each grain direction are presented in Figure 9. The shape parameter was determined in accord with Section 9.3.2 of MIL-HDBK-5D. The average tensile yield strengths and the average tensile moduli of elasticity determined in this test program were used with the shape parameter to construct typical stress-strain curves.

Compression. The results of compression tests are shown in Tables 2 and 2(a). Compressive modulus of elasticity values are listed in addition to the compressive yield strengths. Typical compressive stress-strain curves are presented in Figure 10 for each grain direction. The shape parameter was determined in accord with Section 9.3.2 of MIL-HDBK-5D. The average compressive yield strengths and average compressive moduli of elasticity determined in this test program were used with the shape parameter to construct typical stress-strain curves.



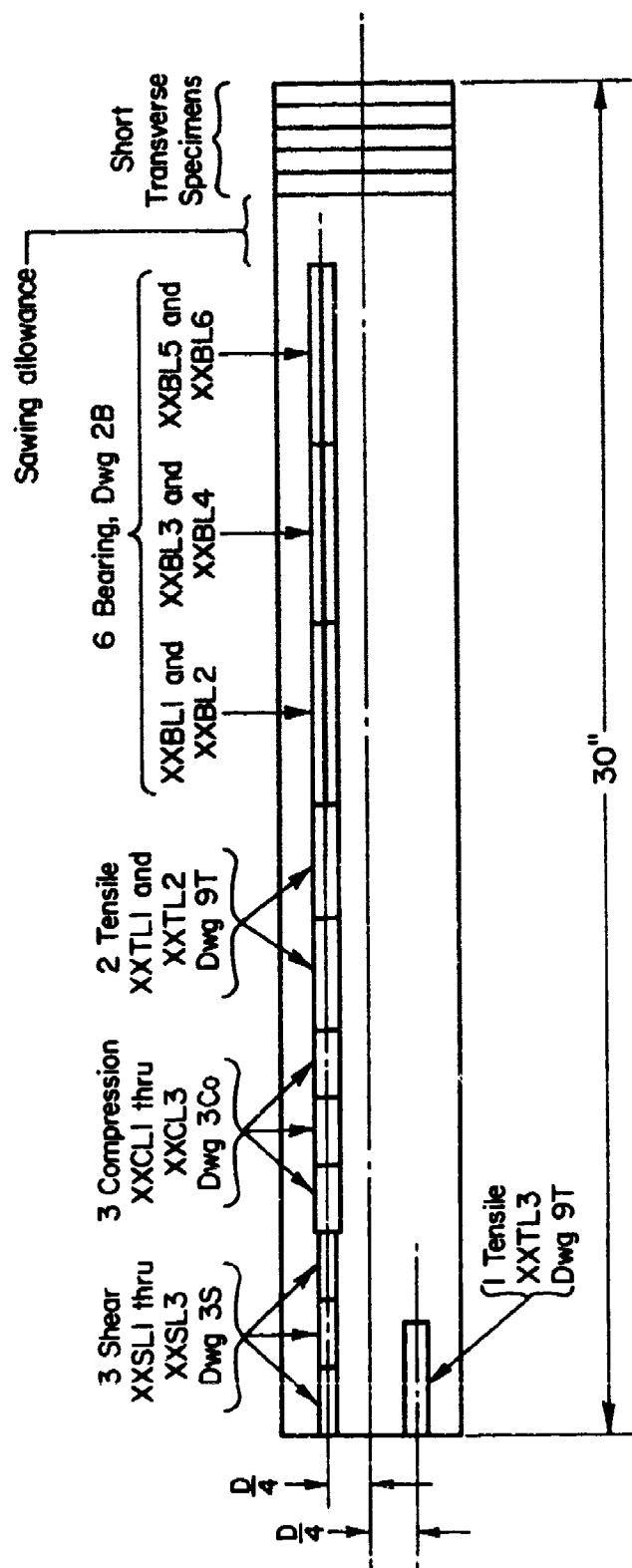


Figure 1. Plan view showing location of specimens for Inconel 625 and Inconel 718 bar.

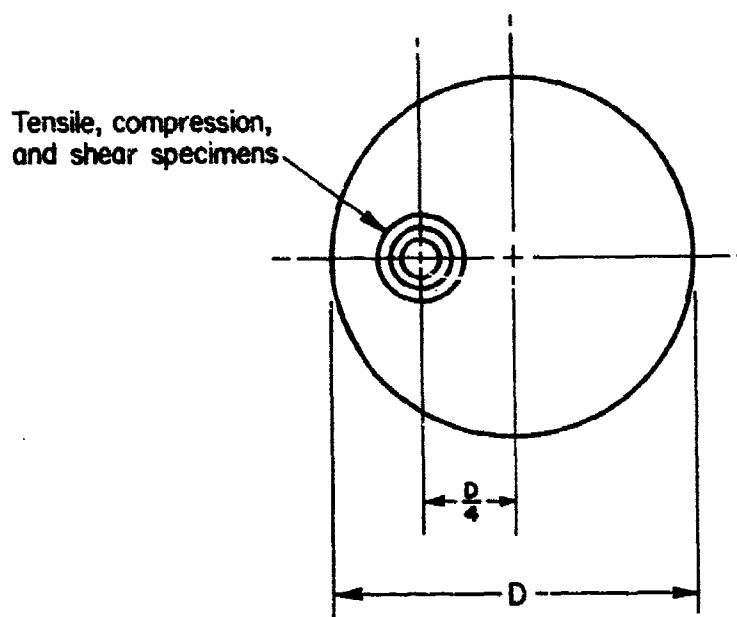


Figure 2. Cross-sectional location of longitudinal tensile, compression, and shear specimens for all diameters of Inconel 625 and Inconel 718 bar.

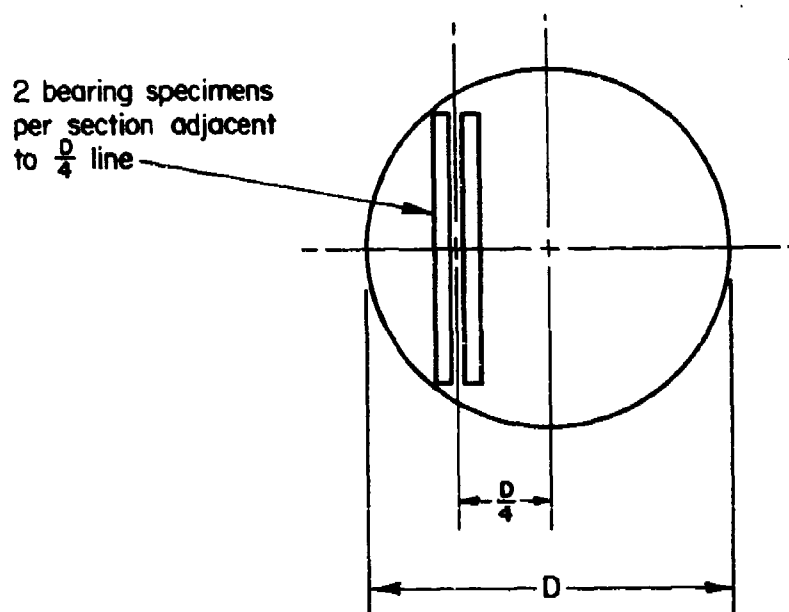


Figure 3. Cross-sectional location of longitudinal bearing specimens for all diameters of Inconel 625 and Inconel 718 bar.

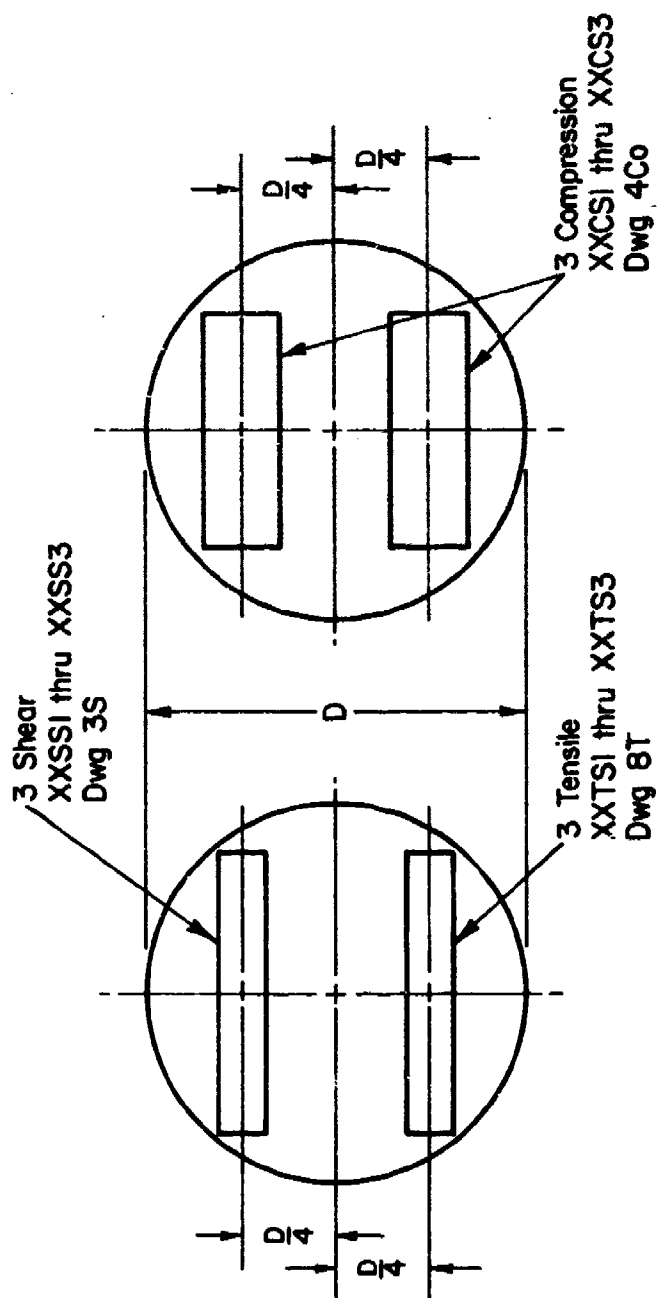


Figure 4. Location of short transverse tensile, compression, and shear specimens for Inconel 625 and Inconel 718 bar--2-inch diameter.

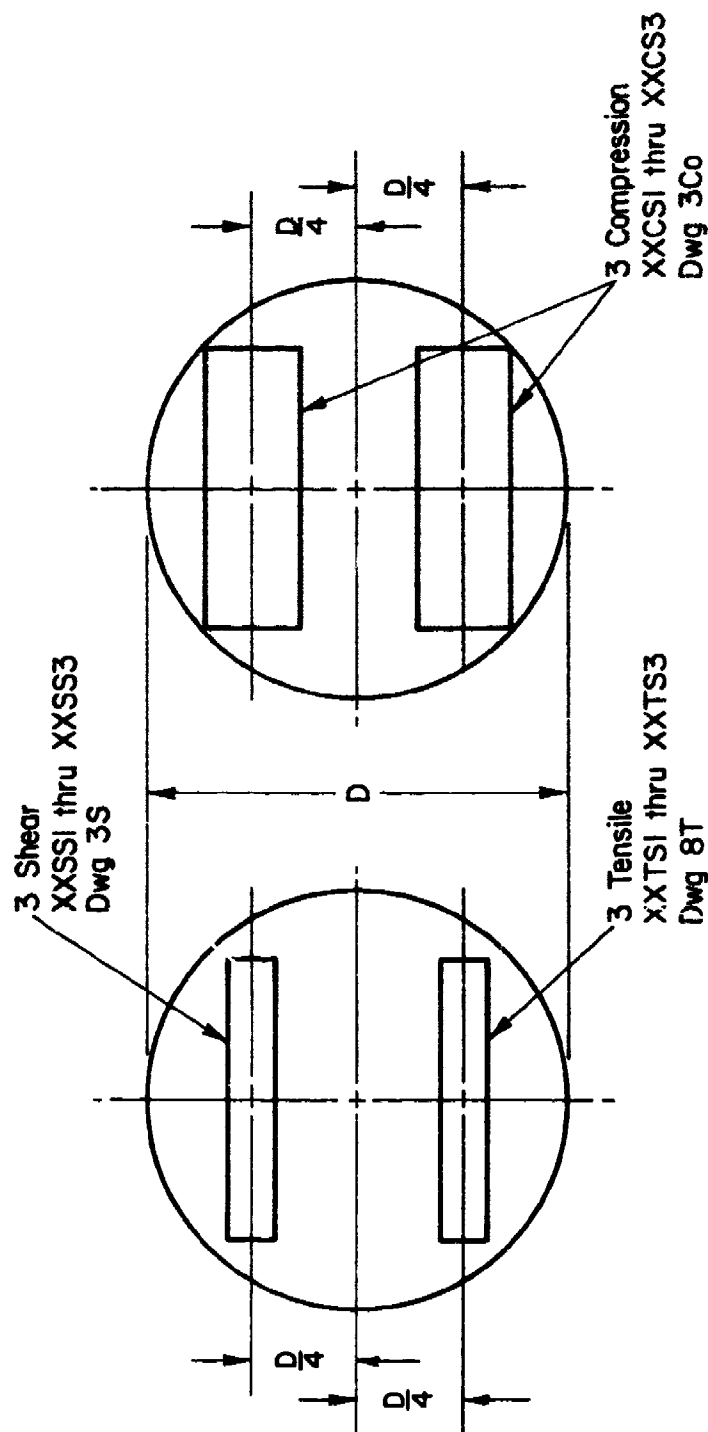


Figure 5. Location of short transverse tensile, compression, and shear specimens for Inconel 625 and Inconel 718 bar--2-1/4-inch diameter.

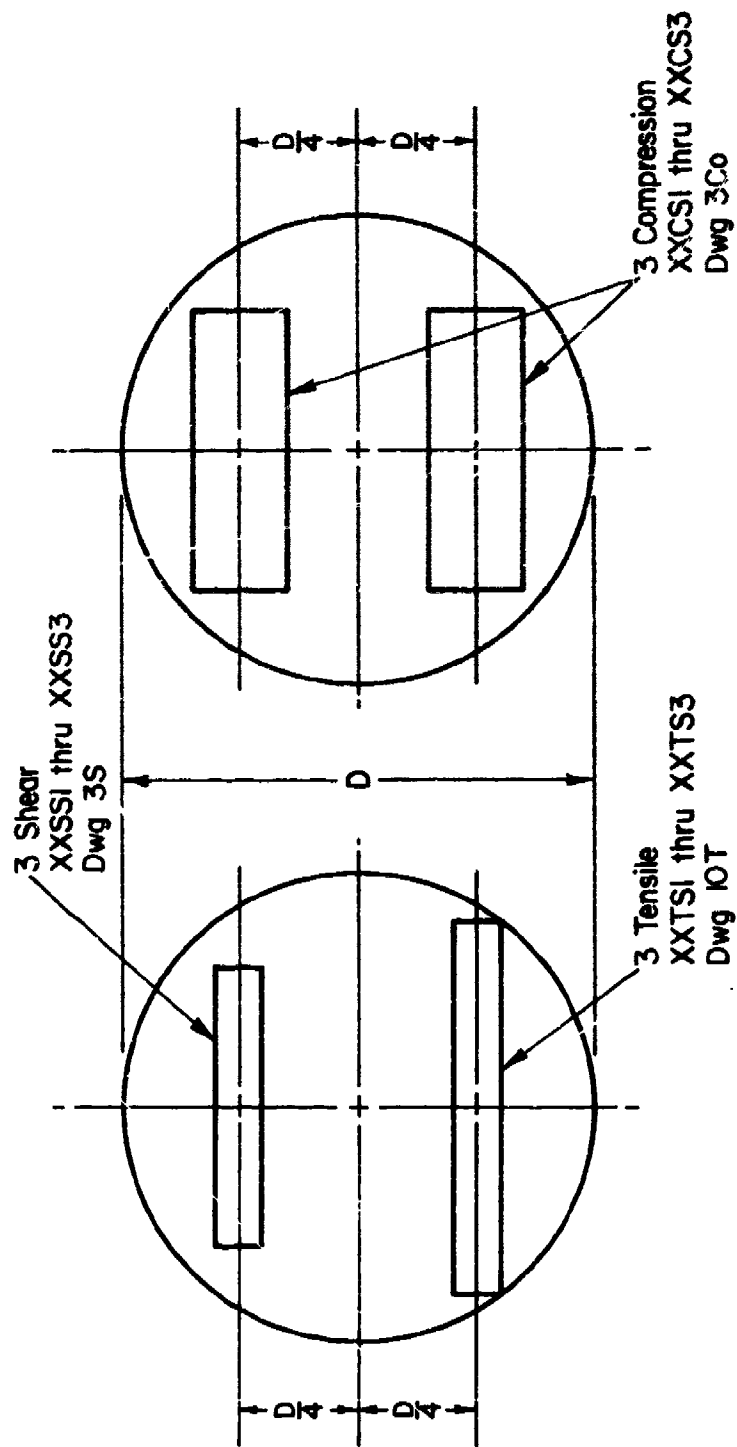


Figure 6. Location of short transverse tensile, compression, and shear specimens for Incone1 625 and Incone1 718 bar--2-1/2-, 2-3/4-, and 3-inch diameter.

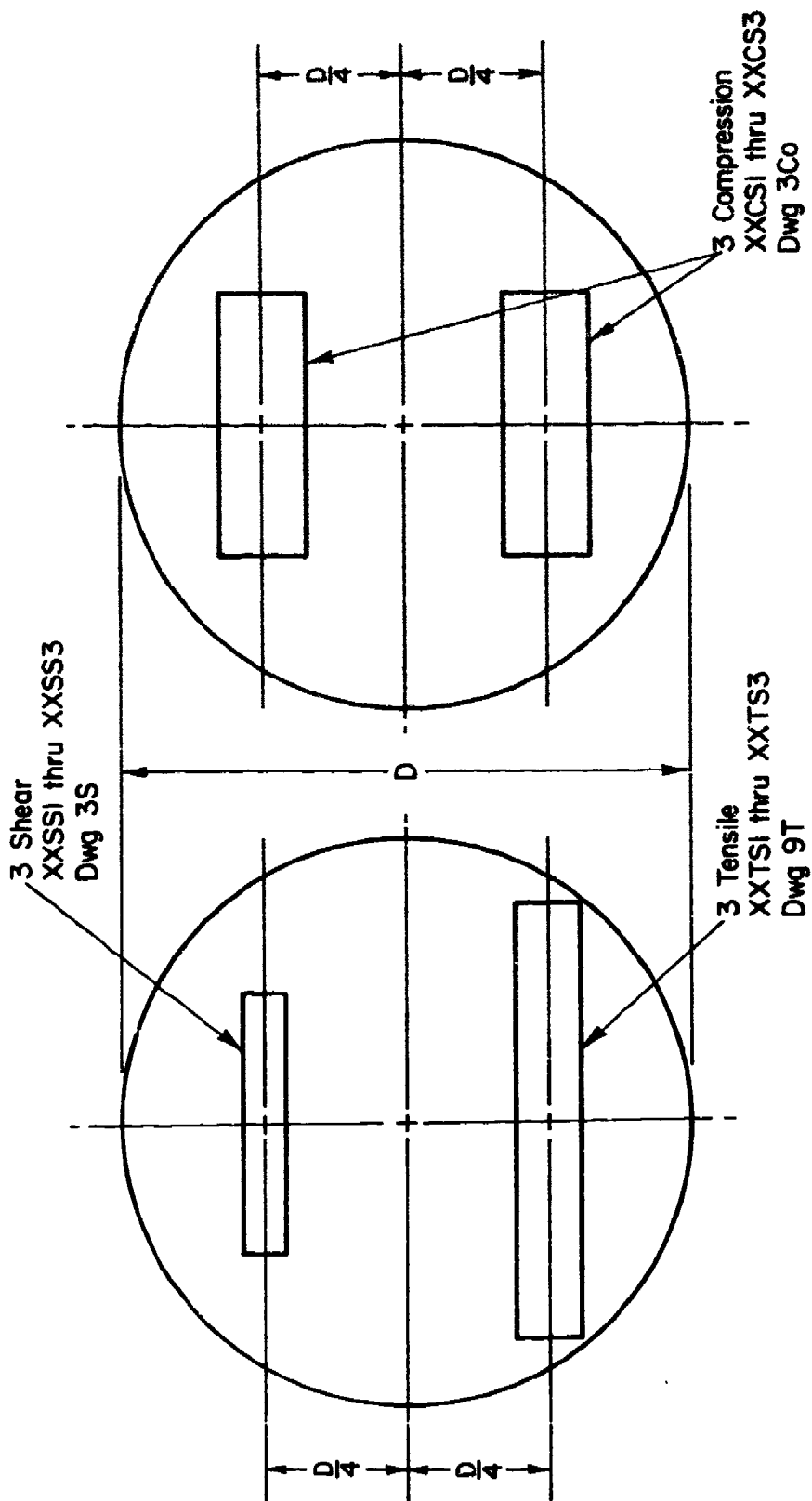


Figure 7. Location of short transverse tensile, compression, and shear specimens for Inconel 625 and Inconel 718 bar--3-1/4-, 3-1/2-, 3-3/4-, and 4-inch diameter.

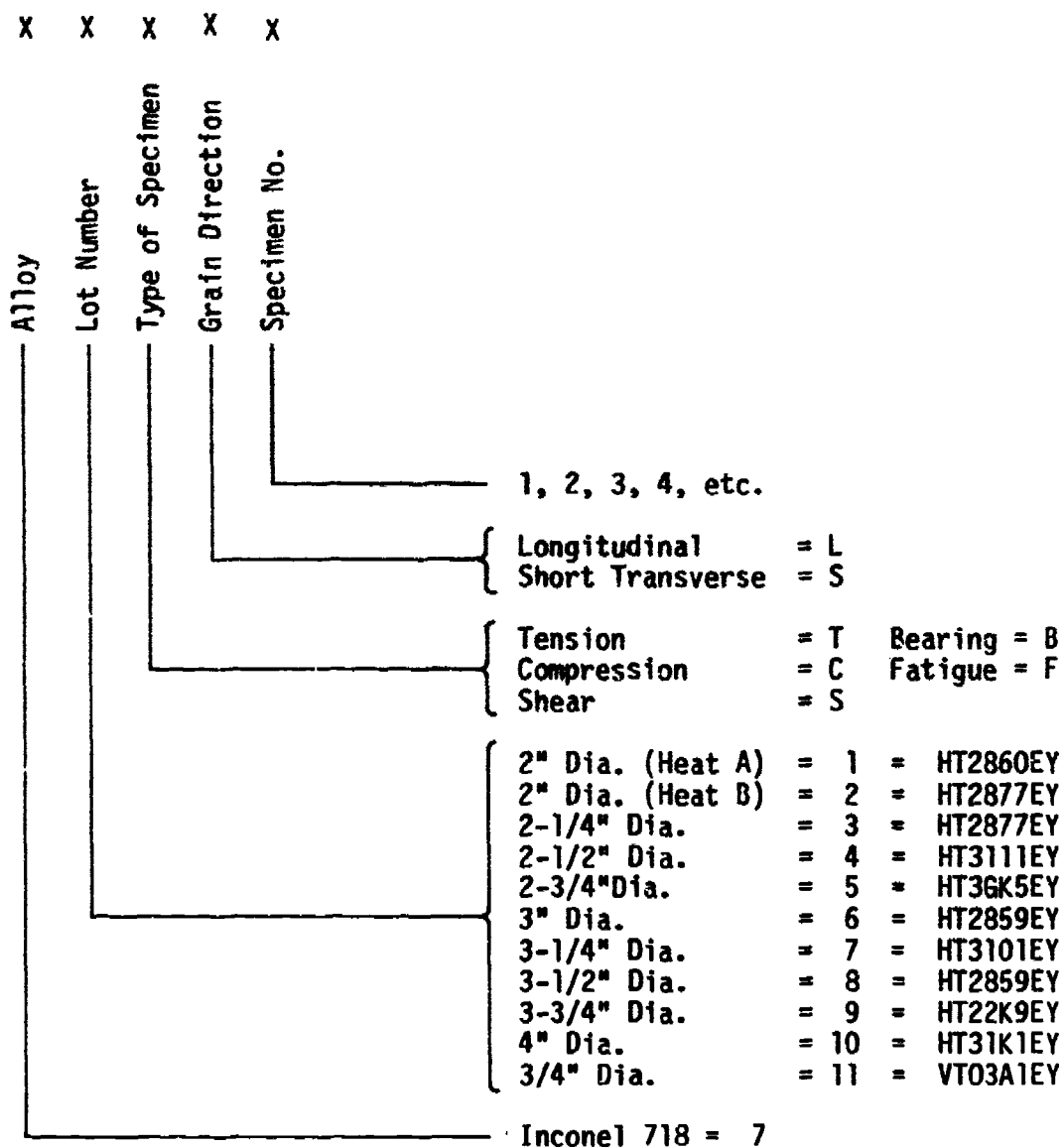


Figure 8. Specification identification code for Inconel 718 bar.

TABLE 2. MECHANICAL PROPERTIES OF INCONEL 718 STA BAR

| Bar Diameter, inches | Grain Direction | Specimen No. | Tensile                |                     |                     |                              | Compressive         |                              | Shear                  | Bearing                |                     |                        |                     |
|----------------------|-----------------|--------------|------------------------|---------------------|---------------------|------------------------------|---------------------|------------------------------|------------------------|------------------------|---------------------|------------------------|---------------------|
|                      |                 |              | Ultimate Strength, ksi | Yield Strength, ksi | Elongation, percent | Modulus, 10 <sup>5</sup> ksi | Yield Strength, ksi | Modulus, 10 <sup>5</sup> ksi | Ultimate Strength, ksi | e/D = 1.5              |                     | e/D = 2.0 (1)          |                     |
|                      |                 |              |                        |                     |                     |                              |                     |                              |                        | Ultimate Strength, ksi | Yield Strength, ksi | Ultimate Strength, ksi | Yield Strength, ksi |
| 2<br>(Heat A)        | L               | 1            | 212.0                  | 182.1               | 22.0                | 27.7                         | 187.3               | 30.1                         | 136.3                  | 350.3                  | 263.5               | 438.2                  | 307.1               |
|                      |                 | 2            | 212.7                  | 181.3               | 22.0                | 34.2                         | 191.0               | 31.0                         | 136.2                  | 346.1                  | 263.3               | 442.2                  | 310.1               |
|                      |                 | 3            | 209.0                  | 181.7               | 22.0                | 31.0                         | 190.0               | 31.1                         | 133.7                  | 350.3                  | 265.3               | 442.5                  | 306.1               |
|                      |                 | Avg.         | 211.2                  | 181.7               | 22.0                | 31.0                         | 189.4               | 30.7                         | 135.4                  | 348.9                  | 264.0               | 441.0                  | 307.7               |
| 2<br>(Heat A)        | ST              | 1            | 203.1                  | 176.0               | 21.5                | 30.5                         | 189.1               | 30.1                         | 136.0                  |                        |                     |                        |                     |
|                      |                 | 2            | 196.7                  | 166.9               | 22.0                | 28.0                         | 188.9               | 29.9                         | 135.8                  |                        |                     |                        |                     |
|                      |                 | 3            | 202.3                  | 175.0               | 22.0                | 28.6                         | 189.1               | 30.7                         | 136.9                  |                        |                     |                        |                     |
|                      |                 | Avg.         | 200.7                  | 172.6               | 21.8                | 29.0                         | 189.0               | 30.2                         | 136.2                  |                        |                     |                        |                     |
| 2<br>(Heat B)        | L               | 1            | 204.6                  | 172.9               | 24.5                | 29.0                         | 180.6               | 31.3                         | 135.4                  | 348.9                  | 258.7               | 440.9                  | 307.1               |
|                      |                 | 2            | 204.7                  | 173.2               | 24.0                | 27.9                         | 178.5               | 31.5                         | 134.7                  | 345.8                  | 256.9               | 444.0                  | 300.9               |
|                      |                 | 3            | 204.1                  | 173.4               | 24.5                | 30.3                         | 177.6               | 31.0                         | 134.3                  | 344.2                  | 258.4               | 450.8                  | 295.5               |
|                      |                 | Avg.         | 204.5                  | 173.2               | 24.3                | 29.1                         | 178.9               | 31.3                         | 134.8                  | 346.3                  | 258.0               | 441.9                  | 301.1               |
| 2<br>(Heat B)        | ST              | 1            | 197.4                  | 169.7               | 24.0                | 30.1                         | 182.4               | 28.9                         | 135.0                  |                        |                     |                        |                     |
|                      |                 | 2            | 199.9                  | 169.5               | 24.0                | 26.6                         | 184.0               | 30.2                         | 134.7                  |                        |                     |                        |                     |
|                      |                 | 3            | 202.0                  | 174.9               | 20.0                | 27.7                         | 182.4               | 30.0                         | 135.4                  |                        |                     |                        |                     |
|                      |                 | Avg.         | 199.8                  | 171.4               | 22.7                | 28.1                         | 182.9               | 29.7                         | 135.0                  |                        |                     |                        |                     |
| 2-1/4                | L               | 1            | 210.8                  | 181.3               | 22.6                | 30.4                         | 187.5               | 31.4                         | 137.1                  | 351.3                  | 262.2               | 451.2                  | 304.3               |
|                      |                 | 2            | 211.0                  | 180.0               | 21.5                | 29.4                         | 190.7               | 31.0                         | 136.4                  | 350.0                  | 266.7               | 444.7                  | 309.2               |
|                      |                 | 3            | 210.4                  | 182.7               | 22.0                | 28.3                         | 189.0               | 30.6                         | 135.6                  | 351.8                  | 260.1               | 445.7                  | 303.9               |
|                      |                 | Avg.         | 210.7                  | 181.3               | 22.0                | 29.4                         | 189.1               | 31.0                         | 136.4                  | 351.0                  | 263.0               | 447.2                  | 305.8               |
| 2-1/4                | ST              | 1            | 204.1                  | 175.5               | 24.0                | 23.1                         | 187.7               | 30.7                         | 135.8                  |                        |                     |                        |                     |
|                      |                 | 2            | 204.5                  | 176.4               | 22.0                | 22.6                         | 186.6               | 31.6                         | 137.3                  |                        |                     |                        |                     |
|                      |                 | 3            | 205.3                  | 177.0               | 24.0                | 23.0                         | 186.7               | 30.7                         | 137.8                  |                        |                     |                        |                     |
|                      |                 | Avg.         | 204.6                  | 176.3               | 23.3                | 22.9                         | 187.0               | 31.0                         | 137.0                  |                        |                     |                        |                     |
| 2-1/2                | L               | 1            | 211.5                  | 176.6               | 22.5                | 28.7                         | 186.7               | 30.2                         | 137.6                  | 351.0                  | 268.5               | 448.1                  | 309.8               |
|                      |                 | 2            | 210.8                  | 175.7               | 22.0                | 27.6                         | 187.2               | 29.3                         | 138.1                  | 348.2                  | 262.8               | 444.2                  | 306.4               |
|                      |                 | 3            | 211.7                  | 179.4               | 21.6                | 30.2                         | 184.2               | 29.7                         | 136.9                  | 352.0                  | 263.1               | 446.5                  | 314.7               |
|                      |                 | Avg.         | 211.3                  | 177.2               | 22.0                | 28.8                         | 186.0               | 29.7                         | 137.5                  | 350.4                  | 264.8               | 446.3                  | 310.3               |



TABLE 2. (Continued)

| Bar Diameter, inches | Grain Direction | Specimen No. | Tensile                |                     |                     |                              | Compressive         |                              | Shear Ultimate Strength, ksi | Bearing                |                     |
|----------------------|-----------------|--------------|------------------------|---------------------|---------------------|------------------------------|---------------------|------------------------------|------------------------------|------------------------|---------------------|
|                      |                 |              | Ultimate Strength, ksi | Yield Strength, ksi | Elongation, percent | Modulus, 10 <sup>3</sup> ksi | Yield Strength, ksi | Modulus, 10 <sup>3</sup> ksi |                              | e/D = 1.5              |                     |
|                      |                 |              |                        |                     |                     |                              |                     |                              |                              | Ultimate Strength, ksi | Yield Strength, ksi |
| 2-1/2                | ST              | 1            | 211.7                  | 180.8               | 22.0                | 27.3                         | 184.7               | 30.8                         | 137.8                        |                        |                     |
|                      |                 | 2            | 211.1                  | 179.6               | 22.0                | 27.8                         | 186.0               | 31.0                         | 137.1                        |                        |                     |
|                      |                 | 3            | 212.4                  | 180.1               | 24.0                | 27.9                         | 185.6               | 31.8                         | 138.6                        |                        |                     |
|                      |                 | Avg.         | 211.7                  | 180.2               | 22.7                | 27.7                         | 185.4               | 31.2                         | 137.8                        |                        |                     |
| 2-3/4                | L               | 1            | 192.8                  | 164.1               | 24.6                | 29.1                         | 180.7               | 30.2                         | 130.4                        | 238.6                  |                     |
|                      |                 | 2            | 191.3                  | 159.6               | 25.5                | 29.2                         | 180.4               | 31.2                         | 130.8                        | 232.4                  | 286.8               |
|                      |                 | 3            | 192.6                  | 163.2               | 25.0                | 29.8                         | 180.6               | 30.7                         | 130.9                        | 239.3                  | 286.2               |
|                      |                 | Avg.         | 192.2                  | 162.3               | 25.0                | 29.4                         | 180.6               | 30.7                         | 130.7                        | 236.8                  | 270.2               |
| 2-3/4                | ST              | 1            | 190.8                  | 161.5               | 26.0                | 27.5                         | 171.3               | 31.4                         | 130.3                        |                        |                     |
|                      |                 | 2            | 191.7                  | 160.1               | 24.0                | 30.8                         | 169.7               | 31.6                         | 131.1                        |                        |                     |
|                      |                 | 3            | 191.6                  | 162.1               | 26.0                | 30.2                         | 171.4               | 31.2                         | 130.2                        |                        |                     |
|                      |                 | Avg.         | 191.4                  | 161.2               | 25.3                | 29.5                         | 170.8               | 31.4                         | 130.5                        |                        |                     |
| 3                    | L               | 1            | 198.4                  | 164.1               | 25.6                | 28.8                         | 174.2               | 30.8                         | 133.6                        | 241.2                  | 284.3               |
|                      |                 | 2            | 197.3                  | 165.6               | 25.0                | 28.2                         | 176.3               | 31.8                         | 133.7                        | 245.5                  | 298.2               |
|                      |                 | 3            | 199.1                  | 166.1               | 24.0                | 28.7                         | 174.9               | 31.4                         | 133.3                        | 248.5                  | 277.4               |
|                      |                 | Avg.         | 198.3                  | 165.3               | 24.9                | 28.6                         | 175.1               | 31.3                         | 133.5                        | 245.1                  | 286.6               |
| 3                    | ST              | 1            | 197.6                  | 168.7               | 26.0                | 26.2                         | 181.3               | 30.9                         | 132.9                        |                        |                     |
|                      |                 | 2            | 197.9                  | 170.6               | 26.0                | 28.2                         | 180.4               | 31.6                         | 131.3                        |                        |                     |
|                      |                 | 3            | 198.0                  | 170.7               | 24.0                | 28.6                         | 178.7               | 31.6                         | 133.8                        |                        |                     |
|                      |                 | Avg.         | 197.8                  | 170.0               | 25.3                | 27.7                         | 180.1               | 31.4                         | 132.7                        |                        |                     |
| 3-1/4                | L               | 1            | 209.3                  | 176.0               | 22.5                | 27.8                         | 183.1               | 30.8                         | 136.0                        | 254.2                  | 297.4               |
|                      |                 | 2            | 208.4                  | 176.1               | 21.5                | 29.5                         | 184.4               | 31.4                         | 135.7                        | 253.4                  | 304.5               |
|                      |                 | 3            | 209.0                  | 176.2               | 22.0                | 31.5                         | 183.6               | 31.9                         | 136.4                        | 258.6                  | 301.6               |
|                      |                 | Avg.         | 208.9                  | 176.1               | 22.0                | 29.6                         | 183.7               | 31.4                         | 136.0                        | 255.4                  | 301.2               |
| 3-1/4                | ST              | 1            | 205.7                  | 173.4               | 20.0                | 28.9                         | 182.4               | 31.1                         | 136.3                        |                        |                     |
|                      |                 | 2            | 206.5                  | 172.4               | 21.0                | 27.9                         | 182.3               | 31.4                         | 136.4                        |                        |                     |
|                      |                 | 3            | 206.5                  | 172.8               | 20.0                | 28.6                         | 182.2               | 31.2                         | 137.6                        |                        |                     |
|                      |                 | Avg.         | 206.2                  | 172.9               | 20.3                | 28.5                         | 182.3               | 31.2                         | 136.8                        |                        |                     |

TABLE 2. (Continued)

| Bar Diameter, inches | Grain Direction | Specimen No. | Tensile                |                     |                     | Compressive                  |                     | Shear                        | Bearing                |                                  |                                     | (1)   |
|----------------------|-----------------|--------------|------------------------|---------------------|---------------------|------------------------------|---------------------|------------------------------|------------------------|----------------------------------|-------------------------------------|-------|
|                      |                 |              | Ultimate Strength, ksi | Yield Strength, ksi | Elongation, percent | Modulus, 10 <sup>3</sup> ksi | Yield Strength, ksi | Modulus, 10 <sup>3</sup> ksi | Ultimate Strength, ksi | e/D = 1.5<br>Yield Strength, ksi | e/D = 2.0<br>Ultimate Strength, ksi |       |
| 3-1/2                | L               | 1            | 199.3                  | 171.9               | 23.6                | 28.8                         | 178.6               | 30.6                         | 133.5                  | 337.3                            | 243.9                               | 296.1 |
|                      |                 | 2            | 198.3                  | 173.0               | 24.5                | 27.7                         | 181.1               | 31.8                         | 134.3                  | 338.2                            | 249.1                               | 302.4 |
|                      |                 | 3            | 198.9                  | 170.6               | 24.5                | 29.3                         | 180.8               | 31.7                         | 133.8                  | 338.4                            | 246.8                               | 288.8 |
|                      |                 | Avg.         | 199.2                  | 171.8               | 24.2                | 28.6                         | 180.2               | 31.4                         | 133.9                  | 338.0                            | 246.6                               | 295.8 |
| 3-1/2                | ST              | 1            | 196.4                  | 168.7               | 21.0                | 29.6                         | 181.1               | 30.7                         | 133.4                  |                                  |                                     |       |
|                      |                 | 2            | 196.0                  | 168.0               | 22.0                | 26.2                         | 180.3               | 30.9                         | 133.5                  |                                  |                                     |       |
|                      |                 | 3            | 196.8                  | 169.3               | 21.5                | 31.0                         | 177.6               | 31.0                         | 133.1                  |                                  |                                     |       |
|                      |                 | Avg.         | 196.4                  | 168.7               | 21.5                | 28.9                         | 179.7               | 30.9                         | 133.3                  |                                  |                                     |       |
| 3-3/4                | L               | 1            | 190.2                  | 161.0               | 26.6                | 30.4                         | 168.5               | 30.9                         | 129.6                  | 328.7                            | 235.9                               | 284.4 |
|                      |                 | 2            | 190.5                  | 162.6               | 25.0                | 31.6                         | 167.4               | 31.3                         | 130.5                  | 329.3                            | 240.6                               | 286.9 |
|                      |                 | 3            | 191.8                  | 163.7               | 26.6                | 29.4                         | 169.4               | 31.5                         | 130.1                  | 329.9                            | 235.1                               | 278.6 |
|                      |                 | Avg.         | 190.8                  | 162.4               | 26.1                | 30.5                         | 168.4               | 31.2                         | 130.1                  | 329.3                            | 237.2                               | 283.3 |
| 3-3/4                | ST              | 1            | 187.3                  | 155.1               | 24.0                | 27.9                         | 169.8               | 31.1                         | 130.4                  |                                  |                                     |       |
|                      |                 | 2            | 187.6                  | 156.4               | 24.0                | 31.0                         | 170.2               | 32.1                         | 129.6                  |                                  |                                     |       |
|                      |                 | 3            | 185.1                  | 156.3               | 25.6                | 29.2                         | 168.4               | 32.0                         | 129.6                  |                                  |                                     |       |
|                      |                 | Avg.         | 186.7                  | 155.9               | 24.5                | 29.4                         | 169.5               | 31.7                         | 129.9                  |                                  |                                     |       |
| 4                    | L               | 1            | 192.6                  | 165.8               | 22.5                | 27.2                         | 173.8               | 30.9                         | 131.1                  | 328.3                            | 237.7                               | 287.2 |
|                      |                 | 2            | 192.2                  | 167.8               | 21.5                | 30.3                         | 174.9               | 31.1                         | 132.7                  | 329.1                            | 236.9                               | 285.7 |
|                      |                 | 3            | 190.9                  | 164.8               | 22.0                | 27.5                         | 173.8               | 31.8                         | 132.8                  | 321.3                            | 226.6                               | 299.0 |
|                      |                 | Avg.         | 191.9                  | 166.1               | 22.0                | 28.3                         | 174.2               | 31.3                         | 132.2                  | 326.3                            | 233.7                               | 290.7 |
| 4                    | ST              | 1            | 190.4                  | 160.4               | 22.0                | 26.9                         | 172.3               | 30.7                         | 132.3                  |                                  |                                     |       |
|                      |                 | 2            | 190.7                  | 164.9               | 22.0                | 29.7                         | 173.3               | 31.4                         | 130.7                  |                                  |                                     |       |
|                      |                 | 3            | 188.6                  | 163.1               | 21.0                | 27.0                         | 174.4               | 31.7                         | 130.2                  |                                  |                                     |       |
|                      |                 | Avg.         | 189.9                  | 162.8               | 21.7                | 27.9                         | 173.3               | 31.3                         | 131.1                  |                                  |                                     |       |
| 3/4                  | L               | 1            | 204.0                  | 177.7               | 24.0                | 28.8                         |                     |                              |                        |                                  |                                     |       |
|                      |                 | 2            | 204.7                  | 177.6               | 24.5                | 28.2                         |                     |                              |                        |                                  |                                     |       |
|                      |                 | 3            | 204.4                  | 177.7               | 24.3                | 28.5                         |                     |                              |                        |                                  |                                     |       |
|                      |                 | Avg.         | 204.4                  | 177.7               | 24.3                | 28.5                         |                     |                              |                        |                                  |                                     |       |

(1) Specimen numbers for e/D = 2.0 were 4 through 6.

TABLE 2(a). MECHANICAL PROPERTIES OF INCONEL 718 STA BAR

| Bar Diameter, mm | Grain Direction | Specimen No. | Tensile                |                     |                     |              | Compressive         |              | Shear | Bearing                |                     |                        |                     |
|------------------|-----------------|--------------|------------------------|---------------------|---------------------|--------------|---------------------|--------------|-------|------------------------|---------------------|------------------------|---------------------|
|                  |                 |              | Ultimate Strength, MPa | Yield Strength, MPa | Elongation, percent | Modulus, GPa | Yield Strength, MPa | Modulus, MPa |       | Ultimate Strength, MPa | Yield Strength, MPa | Ultimate Strength, MPa | Yield Strength, MPa |
| 50.8<br>(Heat A) | L               | 1            | 1461.7                 | 1255.6              | 22.0                | 191.0        | 1291.4              | 207.5        | 939.8 | 2415.2                 | 1817.0              | 3021.6                 | 2117.3              |
|                  |                 | 2            | 1466.8                 | 1250.1              | 22.0                | 235.8        | 1316.9              | 213.7        | 939.1 | 2386.1                 | 1815.4              | 3048.8                 | 2137.9              |
|                  |                 | 3            | 1440.9                 | 1252.8              | 22.0                | 213.7        | 1310.1              | 214.4        | 921.9 | 2415.0                 | 1829.1              | 3050.8                 | 2110.4              |
|                  |                 | Avg.         | 1456.5                 | 1252.8              | 22.0                | 213.5        | 1306.1              | 211.9        | 933.6 | 2405.4                 | 1820.5              | 3040.4                 | 2121.9              |
| 50.8<br>(Heat A) | ST              | 1            | 1400.4                 | 1213.5              | 21.5                | 210.3        | 1303.8              | 207.5        | 937.7 |                        |                     |                        |                     |
|                  |                 | 2            | 1356.2                 | 1150.8              | 22.0                | 193.1        | 1302.5              | 206.2        | 936.3 |                        |                     |                        |                     |
|                  |                 | 3            | 1394.9                 | 1206.6              | 22.0                | 197.2        | 1303.8              | 211.7        | 943.9 |                        |                     |                        |                     |
|                  |                 | Avg.         | 1383.8                 | 1190.3              | 21.8                | 208.2        | 1303.4              | 208.5        | 939.3 |                        |                     |                        |                     |
| 50.8<br>(Heat B) | L               | 1            | 1410.7                 | 1192.1              | 24.5                | 200.0        | 1245.2              | 215.8        | 933.6 | 2405.8                 | 1783.7              | 3040.0                 | 2117.3              |
|                  |                 | 2            | 1411.4                 | 1194.2              | 24.0                | 192.4        | 1230.8              | 217.2        | 928.8 | 2384.4                 | 1771.3              | 3061.4                 | 2074.7              |
|                  |                 | 3            | 1407.3                 | 1195.6              | 24.5                | 208.9        | 1224.6              | 213.7        | 926.0 | 2373.3                 | 1781.5              | 3039.3                 | 2037.2              |
|                  |                 | Avg.         | 1409.8                 | 1194.0              | 24.3                | 200.4        | 1233.5              | 215.6        | 929.4 | 2387.8                 | 1778.8              | 3046.9                 | 2076.4              |
| 50.8<br>(Heat B) | ST              | 1            | 1361.1                 | 1170.1              | 24.0                | 207.5        | 1257.6              | 199.3        | 930.8 |                        |                     |                        |                     |
|                  |                 | 2            | 1378.3                 | 1168.7              | 24.0                | 183.4        | 1268.7              | 208.2        | 928.8 |                        |                     |                        |                     |
|                  |                 | 3            | 1392.8                 | 1205.9              | 20.0                | 191.0        | 1257.6              | 206.9        | 933.6 |                        |                     |                        |                     |
|                  |                 | Avg.         | 1377.4                 | 1181.6              | 22.7                | 194.0        | 1261.3              | 204.8        | 931.1 |                        |                     |                        |                     |
| 57.2             | L               | 1            | 1453.5                 | 1250.1              | 22.6                | 208.6        | 1292.8              | 216.5        | 945.3 | 2422.2                 | 1807.5              | 3110.9                 | 2098.1              |
|                  |                 | 2            | 1454.8                 | 1241.1              | 21.5                | 202.7        | 1314.9              | 213.7        | 940.5 | 2413.1                 | 1838.7              | 3066.0                 | 2131.9              |
|                  |                 | 3            | 1450.7                 | 1259.7              | 22.0                | 195.1        | 1303.2              | 211.0        | 935.0 | 2425.6                 | 1793.3              | 3073.4                 | 2095.2              |
|                  |                 | Avg.         | 1453.0                 | 1250.3              | 22.0                | 202.5        | 1303.6              | 213.7        | 940.2 | 2420.3                 | 1813.2              | 3083.4                 | 2108.4              |
| 57.2             | ST              | 1            | 1407.3                 | 1210.1              | 24.0                | 159.3        | 1294.2              | 211.7        | 936.3 |                        |                     |                        |                     |
|                  |                 | 2            | 1410.0                 | 1216.3              | 22.0                | 155.8        | 1286.6              | 217.9        | 946.7 |                        |                     |                        |                     |
|                  |                 | 3            | 1415.5                 | 1220.4              | 24.0                | 158.6        | 1287.3              | 211.7        | 950.1 |                        |                     |                        |                     |
|                  |                 | Avg.         | 1410.9                 | 1215.6              | 23.3                | 157.9        | 1289.4              | 213.7        | 944.4 |                        |                     |                        |                     |
| 63.5             | L               | 1            | 1458.3                 | 1217.7              | 22.5                | 197.9        | 1287.3              | 208.2        | 948.8 | 2420.4                 | 1851.6              | 3089.5                 | 2136.4              |
|                  |                 | 2            | 1453.5                 | 1211.5              | 22.0                | 190.3        | 1290.7              | 202.0        | 952.2 | 2401.2                 | 1811.7              | 3062.9                 | 2112.5              |
|                  |                 | 3            | 1459.7                 | 1237.0              | 21.6                | 208.2        | 1270.1              | 204.8        | 943.9 | 2427.3                 | 1814.2              | 3078.8                 | 2169.7              |
|                  |                 | Avg.         | 1457.1                 | 1222.0              | 22.0                | 198.8        | 1282.7              | 205.0        | 948.3 | 2416.3                 | 1825.8              | 3077.1                 | 2139.5              |

TABLE 2(a). (Continued)

| Bar Diameter, mm | Grain Direction | Specimen No. | Tensile                |                     |                     |              | Compressive         |              |               | Bearing                |                     |                        |                     |
|------------------|-----------------|--------------|------------------------|---------------------|---------------------|--------------|---------------------|--------------|---------------|------------------------|---------------------|------------------------|---------------------|
|                  |                 |              | Ultimate Strength, MPa | Yield Strength, MPa | Elongation, percent | Modulus, GPa | Yield Strength, MPa | Modulus, MPa | Strength, GPa | e/0 = 1.3              |                     | e/0 = 2.0 (1)          |                     |
|                  |                 |              |                        |                     |                     |              |                     |              |               | Ultimate Strength, MPa | Yield Strength, MPa | Ultimate Strength, MPa | Yield Strength, MPa |
| 63.5             | ST              | 1            | 1459.7                 | 1246.6              | 22.0                | 188.2        | 1273.5              | 212.4        | 950.1         |                        |                     |                        |                     |
|                  |                 | 2            | 1455.5                 | 1239.7              | 22.0                | 191.7        | 1282.5              | 213.7        | 945.3         |                        |                     |                        |                     |
|                  |                 | 3            | 1464.5                 | 1241.8              | 24.0                | 192.4        | 1279.7              | 219.3        | 955.6         |                        |                     |                        |                     |
|                  |                 | Avg.         | 1459.9                 | 1242.7              | 22.7                | 190.8        | 1278.6              | 215.1        | 950.4         |                        |                     |                        |                     |
| 69.8             | L               | 1            | 1329.4                 | 1131.5              | 24.6                | 200.6        | 1245.9              | 208.2        | 899.1         | 2257.4                 | 1646.2              | 2897.5                 | 1977.8              |
|                  |                 | 2            | 1319.0                 | 1100.4              | 25.5                | 201.3        | 1243.9              | 215.1        | 901.9         | 2244.5                 | 1602.6              | 2933.3                 | 1966.4              |
|                  |                 | 3            | 1328.0                 | 1125.3              | 25.0                | 205.5        | 1245.2              | 211.7        | 902.6         | 2280.9                 | 1650.1              | 2911.6                 | 1863.3              |
|                  |                 | Avg.         | 1325.4                 | 1119.1              | 25.0                | 202.5        | 1245.0              | 211.7        | 901.2         | 2260.9                 | 1633.0              | 2914.1                 | 1935.8              |
| 69.8             | ST              | 1            | 1315.6                 | 1113.5              | 26.0                | 189.6        | 1181.1              | 216.5        | 898.4         |                        |                     |                        |                     |
|                  |                 | 2            | 1321.8                 | 1103.9              | 24.0                | 212.4        | 1170.1              | 217.9        | 903.9         |                        |                     |                        |                     |
|                  |                 | 3            | 1321.1                 | 1117.7              | 26.0                | 208.2        | 1181.8              | 215.1        | 897.7         |                        |                     |                        |                     |
|                  |                 | Avg.         | 1319.5                 | 1111.7              | 25.3                | 203.4        | 1177.7              | 216.5        | 900.0         |                        |                     |                        |                     |
| 76.2             | L               | 1            | 1368.0                 | 1131.5              | 25.6                | 198.6        | 1201.1              | 212.4        | 921.2         | 2329.4                 | 1662.9              | 2976.2                 | 1960.2              |
|                  |                 | 2            | 1360.4                 | 1141.8              | 25.0                | 194.4        | 1215.6              | 219.3        | 921.9         | 2331.0                 | 1693.0              | 3028.3                 | 2056.2              |
|                  |                 | 3            | 1372.8                 | 1145.3              | 24.0                | 197.9        | 1205.9              | 216.5        | 919.1         | 2332.9                 | 1713.5              | 2938.0                 | 1912.3              |
|                  |                 | Avg.         | 1367.1                 | 1139.5              | 24.9                | 197.0        | 1207.5              | 216.0        | 920.7         | 2331.1                 | 1689.8              | 2980.8                 | 1976.2              |
| 76.2             | ST              | 1            | 1362.5                 | 1163.2              | 26.0                | 180.6        | 1250.1              | 213.1        | 916.3         |                        |                     |                        |                     |
|                  |                 | 2            | 1364.5                 | 1176.3              | 26.0                | 194.4        | 1243.9              | 217.9        | 905.3         |                        |                     |                        |                     |
|                  |                 | 3            | 1365.2                 | 1177.0              | 24.0                | 197.2        | 1232.1              | 217.9        | 922.6         |                        |                     |                        |                     |
|                  |                 | Avg.         | 1364.1                 | 1172.2              | 25.3                | 190.8        | 1242.0              | 216.3        | 914.7         |                        |                     |                        |                     |
| 82.6             | L               | 1            | 1443.1                 | 1213.5              | 22.5                | 191.7        | 1262.5              | 212.4        | 937.7         | 2399.1                 | 1752.9              | 3080.3                 | 2050.8              |
|                  |                 | 2            | 1436.9                 | 1214.2              | 21.5                | 203.4        | 1271.4              | 216.5        | 935.7         | 2391.3                 | 1747.5              | 3052.0                 | 2099.5              |
|                  |                 | 3            | 1441.1                 | 1214.9              | 22.0                | 217.2        | 1265.9              | 220.0        | 940.5         | 2403.1                 | 1782.9              | 3052.8                 | 2079.5              |
|                  |                 | Avg.         | 1440.4                 | 1214.2              | 22.0                | 204.1        | 1266.6              | 216.3        | 937.9         | 2397.9                 | 1761.1              | 3061.7                 | 2076.6              |
| 82.6             | ST              | 1            | 1418.3                 | 1195.6              | 20.0                | 199.3        | 1257.6              | 214.4        | 939.8         |                        |                     |                        |                     |
|                  |                 | 2            | 1423.8                 | 1188.7              | 21.0                | 192.4        | 1257.0              | 216.5        | 940.5         |                        |                     |                        |                     |
|                  |                 | 3            | 1423.8                 | 1191.5              | 20.0                | 197.2        | 1256.3              | 215.1        | 948.8         |                        |                     |                        |                     |
|                  |                 | Avg.         | 1422.0                 | 1191.9              | 20.3                | 196.3        | 1257.0              | 215.4        | 943.0         |                        |                     |                        |                     |

TABLE 2(a). (Continued)

| Bar Diameter, mm | Grain Direction | Specimen No. | Tensile                |                     |                     |              | Compressive         |              |               | Bearing                |                     |                        |                     |
|------------------|-----------------|--------------|------------------------|---------------------|---------------------|--------------|---------------------|--------------|---------------|------------------------|---------------------|------------------------|---------------------|
|                  |                 |              | Ultimate Strength, MPa | Yield Strength, MPa | Elongation, percent | Modulus, GPa | Yield Strength, MPa | Modulus, MPa | Strength, GPa | Ultimate Strength, MPa | Yield Strength, MPa | Ultimate Strength, MPa | Yield Strength, MPa |
| 88.9             | L               | 1            | 1374.2                 | 1185.3              | 23.6                | 198.6        | 1231.4              | 211.0        | 920.5         | 2325.8                 | 1681.9              | 2910.3                 | 2041.5              |
|                  |                 | 2            | 1374.2                 | 1192.8              | 24.5                | 191.0        | 1248.7              | 219.3        | 926.0         | 2332.1                 | 1717.8              | 3027.2                 | 2085.2              |
|                  |                 | 3            | 1371.4                 | 1176.3              | 24.5                | 202.0        | 1246.6              | 218.6        | 922.6         | 2333.3                 | 1701.6              | 3019.8                 | 1991.3              |
|                  |                 | Avg.         | 1373.3                 | 1164.8              | 24.2                | 197.2        | 1242.2              | 216.3        | 923.0         | 2330.4                 | 1700.4              | 2985.8                 | 2039.3              |
| 88.9             | ST              | 1            | 1354.2                 | 1163.2              | 21.0                | 204.1        | 1248.7              | 211.7        | 919.8         |                        |                     |                        |                     |
|                  |                 | 2            | 1351.4                 | 1158.4              | 22.0                | 180.6        | 1243.2              | 213.1        | 920.5         |                        |                     |                        |                     |
|                  |                 | 3            | 1356.9                 | 1167.3              | 21.5                | 213.7        | 1224.6              | 213.7        | 917.7         |                        |                     |                        |                     |
|                  |                 | Avg.         | 1354.2                 | 1163.0              | 21.5                | 199.5        | 1238.8              | 212.8        | 919.3         |                        |                     |                        |                     |
| 95.2             | L               | 1            | 1311.4                 | 1110.1              | 26.6                | 209.6        | 1161.8              | 213.1        | 893.6         | 2266.3                 | 1626.5              | 2929.4                 | 1960.9              |
|                  |                 | 2            | 1313.5                 | 1121.1              | 25.0                | 217.9        | 1154.2              | 215.8        | 899.8         | 2270.9                 | 1659.0              | 2882.9                 | 1978.1              |
|                  |                 | 3            | 1322.5                 | 1128.7              | 26.6                | 202.7        | 1168.0              | 217.2        | 897.0         | 2274.3                 | 1620.8              | 2939.4                 | 1921.1              |
|                  |                 | Avg.         | 1315.8                 | 1120.0              | 26.1                | 210.1        | 1161.3              | 215.4        | 896.8         | 2270.5                 | 1635.5              | 2917.2                 | 1953.4              |
| 95.2             | ST              | 1            | 1291.4                 | 1069.4              | 24.0                | 192.4        | 1170.8              | 214.4        | 899.1         |                        |                     |                        |                     |
|                  |                 | 2            | 1293.5                 | 1078.4              | 24.0                | 213.7        | 1173.5              | 221.3        | 893.6         |                        |                     |                        |                     |
|                  |                 | 3            | 1276.3                 | 1077.7              | 25.6                | 201.3        | 1161.1              | 220.6        | 893.6         |                        |                     |                        |                     |
|                  |                 | Avg.         | 1287.1                 | 1075.2              | 24.5                | 202.5        | 1168.5              | 218.8        | 895.4         |                        |                     |                        |                     |
| 101.6            | L               | 1            | 1328.0                 | 1143.2              | 22.5                | 187.5        | 1198.4              | 213.1        | 903.9         | 2263.9                 | 1639.1              | 2933.7                 | 1980.3              |
|                  |                 | 2            | 1325.2                 | 1157.0              | 21.5                | 208.9        | 1205.9              | 214.4        | 915.0         | 2269.5                 | 1633.7              | 2905.3                 | 1970.0              |
|                  |                 | 3            | 1316.3                 | 1136.3              | 22.0                | 189.6        | 1198.4              | 219.3        | 915.7         | 2215.5                 | 1562.3              | 2959.0                 | 2061.9              |
|                  |                 | Avg.         | 1323.2                 | 1145.5              | 22.0                | 195.4        | 1200.9              | 215.6        | 911.5         | 2249.6                 | 1611.7              | 2932.6                 | 2004.1              |
| 101.6            | ST              | 1            | 1312.8                 | 1106.0              | 22.0                | 185.5        | 1188.0              | 211.7        | 912.2         |                        |                     |                        |                     |
|                  |                 | 2            | 1314.9                 | 1137.0              | 22.0                | 204.8        | 1194.9              | 216.5        | 901.2         |                        |                     |                        |                     |
|                  |                 | 3            | 1300.4                 | 1124.6              | 21.0                | 186.2        | 1202.5              | 218.6        | 897.7         |                        |                     |                        |                     |
|                  |                 | Avg.         | 1309.4                 | 1122.5              | 21.7                | 192.1        | 1195.1              | 215.6        | 903.7         |                        |                     |                        |                     |
| 19.0             | L               | 1            | 1406.6                 | 1225.2              | 24.0                | 198.6        |                     |              |               |                        |                     |                        |                     |
|                  |                 | 2            | 1411.4                 | 1224.6              | 24.5                | 194.4        |                     |              |               |                        |                     |                        |                     |
|                  |                 |              | -----                  | -----               | -----               | -----        |                     |              |               |                        |                     |                        |                     |
|                  |                 | Avg.         | 1409.0                 | 1224.9              | 24.3                | 196.5        |                     |              |               |                        |                     |                        |                     |

(1) Specimen numbers for  $e/D = 2.0$  were 4 through 6.

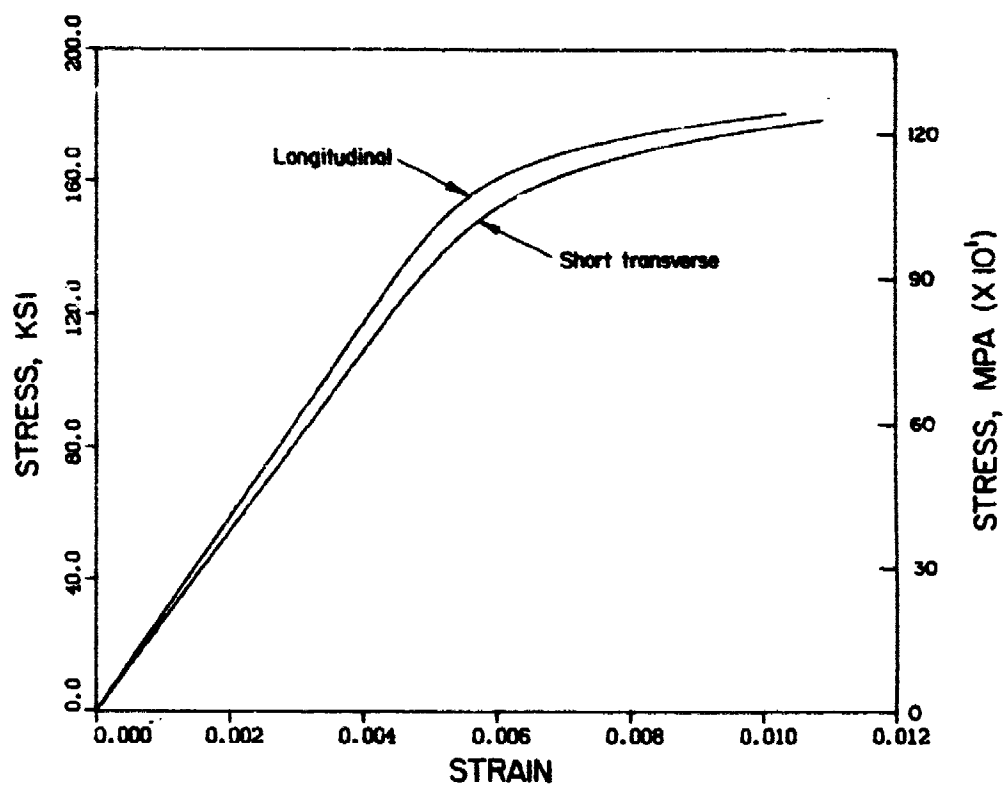


Figure 9. Typical tensile stress-strain curves for Inconel 718 STA bar.

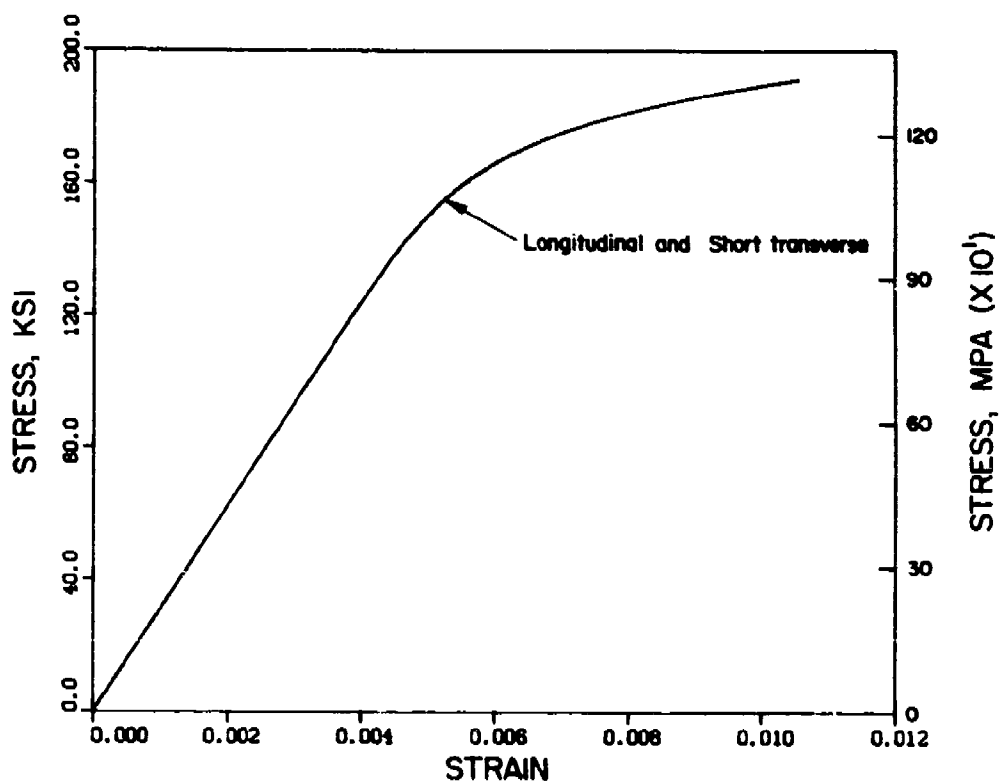


Figure 10. Typical compressive stress-strain curves for Inconel 718 STA bar.

Shear. The results of shear tests are shown in Tables 2 and 2(a). Values for shear ultimate strength are listed.

Bearing. The results of bearing tests are shown in Tables 2 and 2(a). Values for longitudinal bearing yield and ultimate strengths for  $e/D = 1.5$  and  $e/D = 2.0$  are listed. Bearing tests were not conducted in the short transverse direction.

Fatigue. The results of axial-stress fatigue tests are shown in Tables 3 and 4. Fatigue tests were conducted in the longitudinal grain direction utilizing unnotched and notched,  $K_t = 3$ , specimens from the 3/4-inch-diameter bar. Tests were conducted at three stress ratios,  $R = -0.5$ ,  $R = 0.1$ , and  $R = 0.5$ . The fatigue data were analyzed in accord with Section 9.3.4 of MIL-HDBK-5 and S/N curves in Figures 11 and 12 constructed accordingly.

TABLE 3. UNNOTCHED FATIGUE DATA FOR INCONEL 718  
STA BAR--LONGITUDINAL DIRECTION

| Specimen<br>ID | Maximum<br>Stress, |           | R-ratio | Cycles to<br>Failure |
|----------------|--------------------|-----------|---------|----------------------|
|                | ksi                | MPa       |         |                      |
| 7FL7           | 170.0              | (1,172.2) | -0.5    | 14,820               |
| 7FL21          | 160.0              | (1,103.2) | -0.5    | 18,710               |
| 7FL47          | 140.0              | (965.3)   | -0.5    | 46,120               |
| 7FL51          | 130.0              | (896.4)   | -0.5    | 76,500               |
| 7FL35          | 120.0              | (827.4)   | -0.5    | 109,930              |
| 7FL13          | 110.0              | (758.5)   | -0.5    | 241,760              |
| 7FL15          | 100.0              | (689.5)   | -0.5    | 238,970              |
| 7FL3           | 90.0               | (620.6)   | -0.5    | 518,780              |
| 7FL1           | 80.0               | (551.6)   | -0.5    | 4,490,470 (1)        |
| 7FL27          | 77.5               | (534.4)   | -0.5    | DNF                  |
| 7FL19          | 180.0              | (1,241.1) | 0.1     | 36,466               |
| 7FL43          | 170.0              | (1,172.2) | 0.1     | 48,140               |
| 7FL57          | 160.0              | (1,103.2) | 0.1     | 75,240               |
| 7FL5           | 140.0              | (965.3)   | 0.1     | 91,320               |
| 7FL17          | 120.0              | (827.4)   | 0.1     | 199,950              |
| 7FL37          | 100.0              | (689.5)   | 0.1     | 461,620              |
| 7FL39          | 100.0              | (689.5)   | 0.1     | DNF                  |
| 7FL29          | 95.0               | (655.0)   | 0.1     | DNF                  |
| 7FL53          | 90.0               | (620.6)   | 0.1     | DNF                  |
| 7FL59          | 80.0               | (551.6)   | 0.1     | DNF                  |
| 7FL49          | 180.0              | (1,241.1) | 0.5     | 19,950               |
| 7FL33          | 170.0              | (1,172.2) | 0.5     | 260,340              |
| 7FL23          | 170.0              | (1,172.2) | 0.5     | 260,610              |
| 7FL31          | 160.0              | (1,103.2) | 0.5     | 282,140              |
| 7FL45          | 150.0              | (1,034.3) | 0.5     | 307,230              |
| 7FL9           | 140.0              | (965.3)   | 0.5     | 753,940              |
| 7FL55          | 130.0              | (896.4)   | 0.5     | 1,051,710            |
| 7FL11          | 130.0              | (896.4)   | 0.5     | DNF                  |
| 7FL25          | 120.0              | (827.4)   | 0.5     | DNF                  |
| 7FL41          | 100.0              | (689.5)   | 0.5     | DNF                  |

(1) DNF - did not fail; test ran 10,000,000 cycles and stopped.



TABLE 4. NOTCHED,  $K_t = 3$ , FATIGUE DATA FOR INCONEL 718  
STA BAR--LONGITUDINAL DIRECTION

| Specimen ID | Maximum Stress, |         | R-ratio | Cycles to Failure |
|-------------|-----------------|---------|---------|-------------------|
|             | ksi             | MPa     |         |                   |
| 7FL56       | 100.0           | (689.5) | -0.5    | 2,720             |
| 7FL54       | 90.0            | (620.6) | -0.5    | 7,570             |
| 7FL50       | 80.0            | (551.6) | -0.5    | 11,490            |
| 7FL48       | 60.0            | (413.7) | -0.5    | 22,700            |
| 7FL42       | 50.0            | (344.8) | -0.5    | 64,450            |
| 7FL44       | 40.0            | (275.8) | -0.5    | 56,680            |
| 7FL60       | 40.0            | (275.8) | -0.5    | 126,640           |
| 7FL46       | 30.0            | (206.9) | -0.5    | 283,400           |
| 7FL52       | 20.0            | (137.9) | -0.5    | 1,058,530         |
| 7FL58       | 15.0            | (103.4) | -0.5    | DNF (1)           |
| 7FL20       | 120.0           | (827.4) | 0.1     | 10,060            |
| 7FL18       | 110.0           | (758.5) | 0.1     | 11,710            |
| 7FL2        | 100.0           | (689.5) | 0.1     | 20,310            |
| 7FL14       | 90.0            | (620.6) | 0.1     | 21,930            |
| 7FL4        | 80.0            | (551.6) | 0.1     | 30,430            |
| 7FL6        | 70.0            | (482.7) | 0.1     | 94,770            |
| 7FL8        | 65.0            | (448.2) | 0.1     | 84,830            |
| 7FL10       | 55.0            | (379.2) | 0.1     | 297,710           |
| 7FL12       | 50.0            | (344.8) | 0.1     | 160,830           |
| 7FL16       | 45.0            | (310.3) | 0.1     | 302,000           |
| 7FL38       | 35.0            | (241.3) | 0.1     | DNF               |
| 7FL36       | 140.0           | (965.3) | 0.5     | 9,850             |
| 7FL34       | 130.0           | (896.4) | 0.5     | 26,540            |
| 7FL28       | 120.0           | (827.4) | 0.5     | 21,260            |
| 7FL26       | 100.0           | (689.5) | 0.5     | 65,880            |
| 7FL40       | 80.0            | (551.6) | 0.5     | 163,500           |
| 7FL22       | 80.0            | (551.6) | 0.5     | 184,320           |
| 7FL24       | 60.0            | (413.7) | 0.5     | 647,210           |
| 7FL32       | 55.0            | (379.2) | 0.5     | 834,600           |
| 7FL30       | 50.0            | (344.8) | 0.5     | DNF               |

(1) DNF - did not fail; test ran 10,000,000 cycles and stopped.

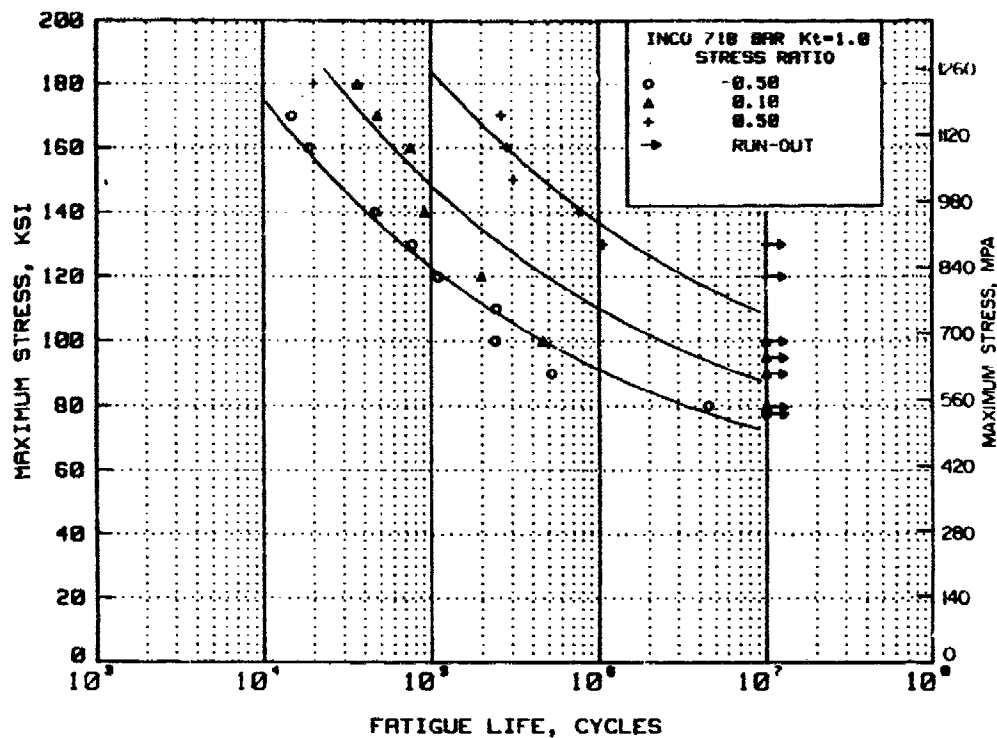


Figure 11. Unnotched axial-stress S/N curves for 3/4-inch-diameter Inconel 718 solution treated and aged bar--longitudinal direction.

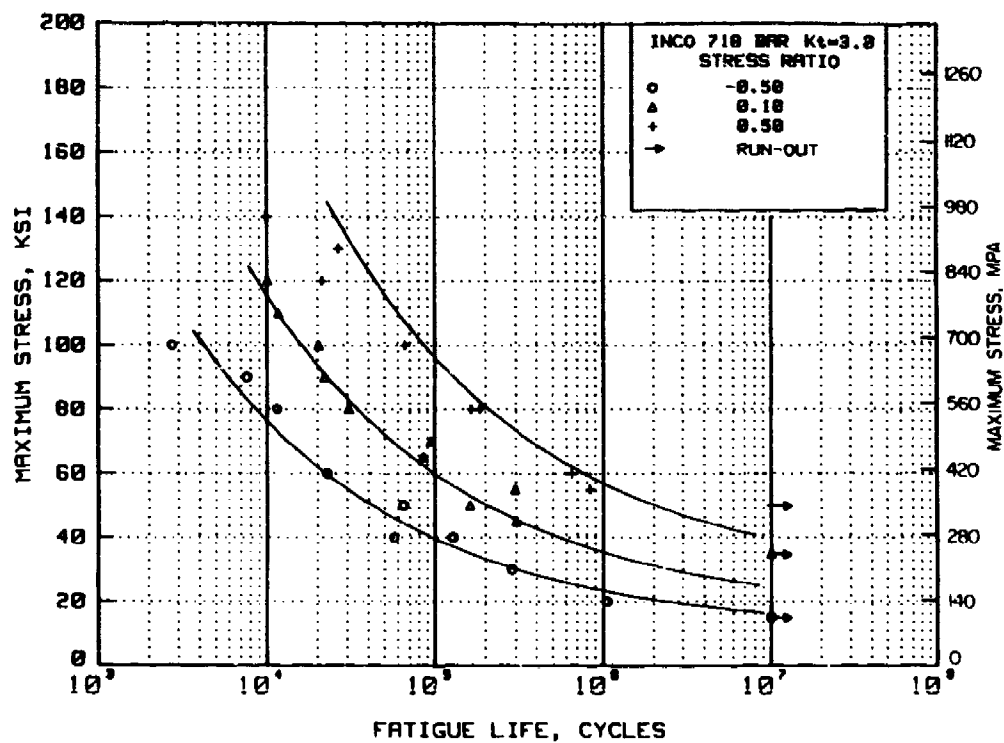


Figure 12. Notched axial-stress S/N curves for 3/4-inch-diameter Inconel 718 solution treated and aged bar--longitudinal direction.

## Inconel 625 Bar (Annealed)

### Background

Inconel 625 has high tensile, creep, and rupture strength, outstanding fatigue and thermal fatigue strength; oxidation and corrosion resistance, and excellent weldability and brazeability. These properties make this alloy attractive for aerospace applications, such as ducting, engine exhaust systems, thrust-reversers, resistance welded honeycomb structures, fuel and hydraulic line tubing, bellows, turbine shroud rings, and heat exchanger tubing. This widely used alloy is currently contained in MIL-HDBK-5, but design values for properties other than tensile yield and ultimate strengths are missing. Consequently, a test program was needed to determine the mechanical properties of Inconel 625 bar in the annealed condition so that design values can be subsequently determined.

### Material

Eleven lots of Inconel 625 bar were procured from Inco Alloys International to AMS 5666. The eleven lots represented eight heats. The chemical compositions, as determined by Inco Alloys International, are shown in Table 5. Bars were obtained in the following sizes: 3/4, 2, 2-1/4, 2-1/2, 2-3/4, 3, 3-1/4, 3-1/2, 3-3/4, and 4 inches in diameter. Two heats of 2-inch-diameter bar were procured. Inconel 625 bar is not produced in rectangular shapes; consequently, round bars with sufficient diameter to accommodate bearing specimens in the longitudinal grain direction at the T/4 location were selected. For economy, 3/4-inch-diameter bar was obtained for fatigue tests. Bars were supplied in the annealed condition and tested "as-received."

### Location of Test Specimens

For mechanical property data to be usable for the determination of MIL-HDBK-5 design values, tensile, compression, shear, and bearing specimens must be located within the cross section in accord with AMS 2371. Therefore, all specimens, except fatigue, were located with the axis of the specimen at the T/4 location. Since all bars were round, mechanical property tests were

TABLE 5. CHEMICAL COMPOSITION OF INCONEL 625 BAR

| Heat<br>Number | Element, percent |      |      |       |      |       |       |      |      |      |       |       |
|----------------|------------------|------|------|-------|------|-------|-------|------|------|------|-------|-------|
|                | C                | Mn   | Fe   | S     | Si   | Ni    | Cr    | Al   | Ti   | Mo   | Cb+Ta | P     |
| NX4474AG       | 0.01             | 0.14 | 4.10 | 0.001 | 0.26 | 61.35 | 21.80 | 0.12 | 0.19 | 8.51 | 3.51  | 0.011 |
| NX4385AV       | 0.03             | 0.13 | 4.21 | 0.001 | 0.29 | 61.07 | 21.64 | 0.31 | 0.21 | 8.57 | 3.53  | 0.012 |
| NX4117AG       | 0.01             | 0.15 | 4.04 | 0.001 | 0.28 | 60.65 | 22.09 | 0.22 | 0.27 | 8.56 | 3.72  | 0.010 |
| NX4154AG       | 0.02             | 0.16 | 4.11 | 0.001 | 0.28 | 60.89 | 21.94 | 0.17 | 0.19 | 8.50 | 3.73  | 0.013 |
| NX4192AG       | 0.01             | 0.19 | 4.15 | 0.001 | 0.28 | 61.37 | 21.58 | 0.15 | 0.22 | 8.50 | 3.54  | 0.013 |
| NX4234AG       | 0.01             | 0.14 | 3.60 | 0.001 | 0.20 | 61.74 | 21.91 | 0.14 | 0.20 | 8.53 | 3.52  | 0.013 |
| NX3648AG       | 0.02             | 0.12 | 4.09 | 0.001 | 0.22 | 61.57 | 21.74 | 0.18 | 0.21 | 8.47 | 3.37  | 0.011 |
| NX4550AV       | 0.02             | 0.14 | 3.77 | 0.001 | 0.26 | 61.92 | 21.50 | 0.12 | 0.18 | 8.54 | 3.47  | 0.009 |

Note: Composition of all heats conformed to the requirements of AMS 5666.

conducted in two grain directions, longitudinal and short transverse, except that bearing tests were performed only in the longitudinal direction, since the short transverse dimensions of most bars would not accommodate bearing specimens. Longitudinal fatigue specimens were located at the T/2 location in the 3/4-inch-diameter bar. The location of the test specimens is shown in Figures 1 through 7. Figure 13 shows the code system used to identify test specimens.

### Specimen Configuration

The configurations of test specimens are shown in Appendix B. Subsize tensile specimens were employed for the short transverse grain direction.

### Test Results

Tensile. The results of tensile tests are shown in Tables 6 and 6(a). In addition to tensile yield and ultimate strengths, elongation and modulus of elasticity values are indicated. The longitudinal tensile yield and ultimate strength of the 4-inch-diameter bar (Heat NX3648A6) did not meet the minimum values specified in AMS 5666. Typical tensile stress-strain curves for each grain direction are presented in Figure 14. Tensile stress-strain curves were constructed in the same manner as those for Inconel 718 bar.

Compression. The results of compression tests are shown in Tables 6 and 6(a). Compressive modulus of elasticity values are listed in addition to the compressive yield strengths. Typical compressive stress-strain curves are presented in Figure 15 for each grain direction. Compressive stress-strain curves were constructed in the same manner as those for Inconel 718 bar.

Shear. The results of shear tests are shown in Tables 6 and 6(a). Values for shear ultimate strength are listed.

Bearing. The results of bearing tests are shown in Tables 6 and 6(a). Values for longitudinal bearing yield and ultimate strengths for  $e/D = 1.5$  and  $e/D = 2.0$  are presented. Bearing tests were not conducted in the short transverse direction.

Fatigue. The results of axial-stress fatigue tests are shown in Tables 7 and 8. Fatigue tests were conducted only in the longitudinal grain direction

X X X X X

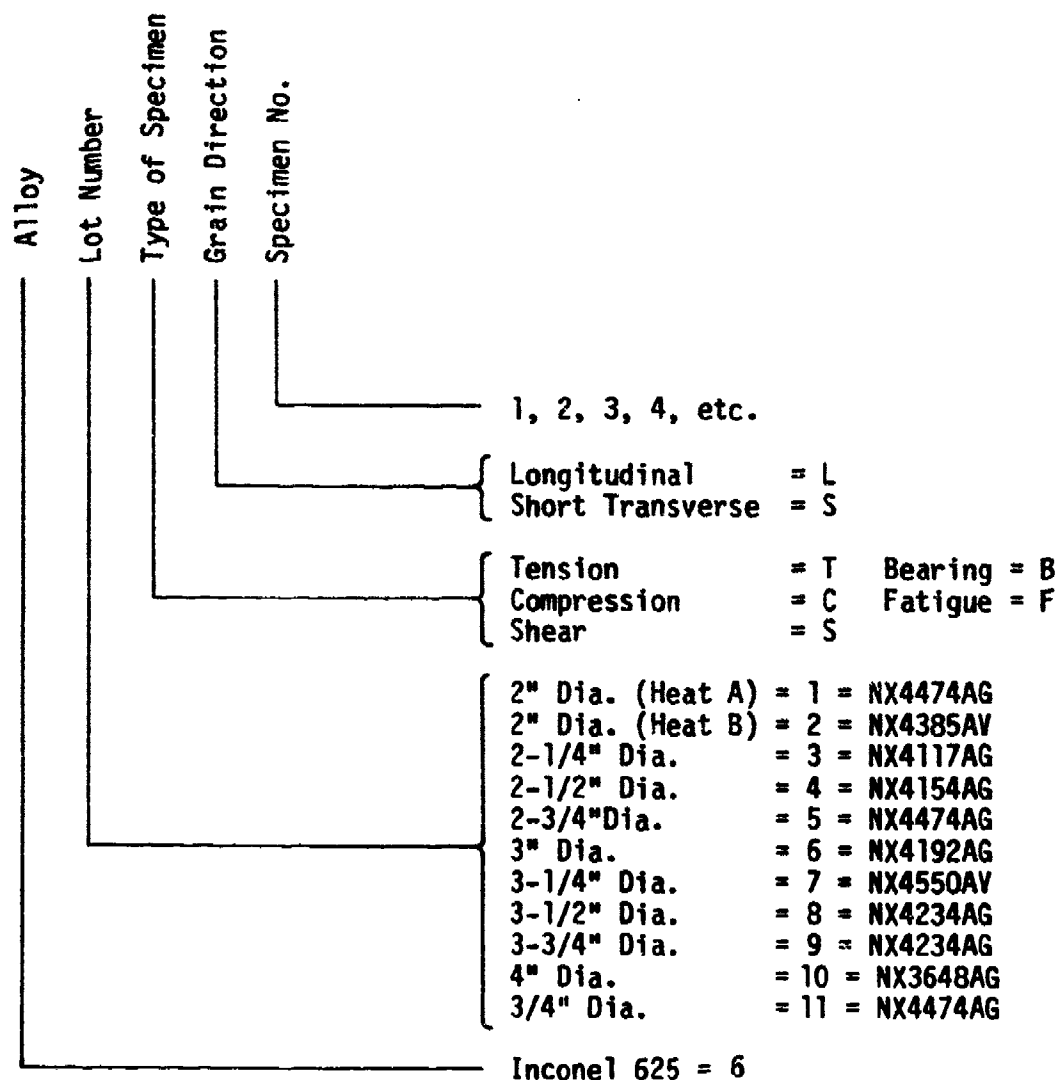


Figure 13. Specimen identification code for Inconel 625 bar.

TABLE 6. MECHANICAL PROPERTIES OF ANNEALED INCONEL 625 BAR

| Bar Diameter, inches | Grain Direction | Specimen No. | Tensile                |                     |                     |                              | Compressive         |                              | Shear Ultimate Strength, ksi | Bearing                |                     |                        |                     |
|----------------------|-----------------|--------------|------------------------|---------------------|---------------------|------------------------------|---------------------|------------------------------|------------------------------|------------------------|---------------------|------------------------|---------------------|
|                      |                 |              | Ultimate Strength, ksi | Yield Strength, ksi | Elongation, percent | Modulus, 10 <sup>3</sup> ksi | Yield Strength, ksi | Modulus, 10 <sup>3</sup> ksi |                              | e/0 = 1.5              |                     | e/0 = 2.0 (1)          |                     |
|                      |                 |              |                        |                     |                     |                              |                     |                              |                              | Ultimate Strength, ksi | Yield Strength, ksi | Ultimate Strength, ksi | Yield Strength, ksi |
| 2<br>(Heat A)        | L               | 1            | 130.0                  | 63.2                | 54.0                | 26.2                         | 63.5                | 26.0                         | 83.7                         | 216.0                  | 97.3                | 269.0                  | 114.4               |
|                      |                 | 2            | 129.5                  | 62.8                | 53.0                | 25.4                         | 64.8                | 27.7                         | 85.1                         | 213.1                  | 94.3                | 275.3                  | 118.0               |
|                      |                 | 3            | 130.1                  | 63.6                | 54.0                | 22.4                         | 65.9                | 24.7                         | 86.7                         | 215.9                  | 99.6                | 272.9                  | 116.5               |
|                      |                 | Avg.         | 129.9                  | 63.2                | 53.7                | 24.7                         | 64.7                | 26.1                         | 85.2                         | 215.0                  | 97.1                | 272.4                  | 116.3               |
| 2<br>(Heat A)        | ST              | 1            | 132.2                  | 64.7                | 52.0                | 28.2                         | 62.4                | 27.3                         | 86.7                         |                        |                     |                        |                     |
|                      |                 | 2            | 131.8                  | 62.6                | 52.0                | 26.3                         | 62.7                | 27.3                         | 86.4                         |                        |                     |                        |                     |
|                      |                 | 3            | 134.4                  | 63.6                | 52.0                | 26.3                         | 64.2                | 27.1                         | 87.7                         |                        |                     |                        |                     |
|                      |                 | Avg.         | 133.5                  | 63.6                | 52.0                | 26.9                         | 63.1                | 27.2                         | 86.9                         |                        |                     |                        |                     |
| 2<br>(Heat B)        | L               | 1            | 130.4                  | 65.0                | 53.0                | 24.8                         | 64.2                | 27.1                         | 87.8                         | 216.4                  | 99.0                | 257.5                  | 113.4               |
|                      |                 | 2            | 130.0                  | 65.0                | 53.0                | 31.3                         | 62.2                | 27.7                         | 86.0                         | 211.3                  | 97.4                | 265.6                  | 124.8               |
|                      |                 | 3            | 130.1                  | 65.3                | 54.0                | 24.0                         | 63.2                | 27.4                         | 86.8                         | 216.4                  | 100.8               | 258.7                  | 119.6               |
|                      |                 | Avg.         | 130.2                  | 65.1                | 53.3                | 26.7                         | 63.2                | 27.4                         | 87.5                         | 214.7                  | 99.1                | 260.6                  | 119.3               |
| 2<br>(Heat B)        | ST              | 1            | 130.8                  | 60.8                | 52.0                | 24.9                         | 62.7                | 26.9                         | 87.5                         |                        |                     |                        |                     |
|                      |                 | 2            | 130.9                  | 62.9                | 52.0                | 28.0                         | 65.0                | 29.2                         | 87.8                         |                        |                     |                        |                     |
|                      |                 | 3            | 129.7                  | 64.1                | 52.0                | 26.8                         | 65.2                | 27.3                         | 87.5                         |                        |                     |                        |                     |
|                      |                 | Avg.         | 130.5                  | 62.6                | 52.0                | 26.6                         | 64.3                | 27.8                         | 87.6                         |                        |                     |                        |                     |
| 2-1/4                | L               | 1            | 137.4                  | 74.7                | 48.0                | 25.7                         | 77.5                | 29.3                         | 91.1                         | 217.2                  | 109.1               | 268.0                  | 129.5               |
|                      |                 | 2            | 139.3                  | 79.1                | 47.0                | 28.9                         | 76.7                | 27.1                         | 90.9                         | 216.5                  | 107.3               | 276.8                  | 120.2               |
|                      |                 | 3            | 138.0                  | 76.3                | 48.0                | 26.2                         | 75.9                | 31.8                         | 90.6                         | 221.4                  | 113.0               | 271.6                  | 130.9               |
|                      |                 | Avg.         | 138.2                  | 76.7                | 47.7                | 26.9                         | 76.7                | 29.4                         | 90.9                         | 218.4                  | 109.8               | 272.1                  | 126.9               |
| 2-1/4                | ST              | 1            | 136.6                  | 75.0                | 36.0                | 26.3                         | 76.8                | 27.9                         | 90.3                         |                        |                     |                        |                     |
|                      |                 | 2            | 137.3                  | 74.6                | 36.0                | 24.0                         | 73.7                | 27.4                         | 90.2                         |                        |                     |                        |                     |
|                      |                 | 3            | 137.5                  | 75.4                | 40.0                | 25.1                         | 73.4                | 28.3                         | 90.5                         |                        |                     |                        |                     |
|                      |                 | Avg.         | 137.2                  | 75.0                | 37.3                | 25.1                         | 74.6                | 27.9                         | 90.3                         |                        |                     |                        |                     |
| 2-1/2                | L               | 1            | 136.5                  | 72.1                | 49.0                | 26.9                         | 72.4                | 27.1                         | 89.9                         | 216.5                  | 105.3               | 261.6                  | 130.0               |
|                      |                 | 2            | 136.7                  | 72.8                | 49.0                | 27.0                         | 74.2                | 27.7                         | 89.5                         | 214.2                  | 103.9               | 266.2                  | 123.1               |
|                      |                 | 3            | 135.7                  | 71.1                | 51.0                | 28.6                         | 74.3                | 27.2                         | 90.0                         | 220.6                  | 96.7                | 258.4                  | 123.0               |
|                      |                 | Avg.         | 136.3                  | 72.0                | 49.7                | 27.5                         | 73.6                | 27.3                         | 89.8                         | 217.1                  | 101.9               | 262.1                  | 125.4               |

TABLE 6. (Continued)

| Bar Diameter, inches | Grain Direction | Specimen No. | Tensile                |                     |                     | Compressive                  |                     | Shear                        | Bearing                |                        |                     |                     |
|----------------------|-----------------|--------------|------------------------|---------------------|---------------------|------------------------------|---------------------|------------------------------|------------------------|------------------------|---------------------|---------------------|
|                      |                 |              | Ultimate Strength, ksi | Yield Strength, ksi | Elongation, percent | Modulus, 10 <sup>6</sup> ksi | Yield Strength, ksi | Modulus, 10 <sup>6</sup> ksi | Ultimate Strength, ksi | Ultimate Strength, ksi | Yield Strength, ksi | Yield Strength, ksi |
| 2-1/2                | ST              | 1            | 133.0                  | 70.5                | 37.3                | 23.8                         | 73.8                | 29.8                         | 89.6                   |                        |                     |                     |
|                      |                 | 2            | 130.6                  | 69.1                | 45.1                | 23.3                         | 75.0                | 26.6                         | 89.6                   |                        |                     |                     |
|                      |                 | 3            | 131.6                  | 67.8                | 43.1                | 24.6                         | 73.0                | 27.4                         | 89.3                   |                        |                     |                     |
|                      |                 | Avg.         | 131.7                  | 69.1                | 41.8                | 23.9                         | 73.9                | 27.9                         | 89.5                   |                        |                     |                     |
| 2-3/4                | L               | 1            | 133.2                  | 68.8                | 51.0                | 27.2                         | 70.8                | 26.0                         | 89.3                   | 217.1                  | 103.8               | 122.2               |
|                      |                 | 2            | 133.8                  | 67.9                | 50.0                | 29.1                         | 69.8                | 26.0                         | 89.2                   | 211.5                  | (2)                 | 124.9               |
|                      |                 | 3            | 134.0                  | 68.6                | 50.0                | 25.9                         | 69.7                | 26.4                         | 89.4                   | 214.0                  | 101.2               | 122.0               |
|                      |                 | Avg.         | 133.7                  | 68.4                | 50.3                | 27.4                         | 70.1                | 26.1                         | 89.3                   | 214.2                  | 102.5               | 123.0               |
| 2-3/4                | ST              | 1            | 133.8                  | 71.8                | 41.1                | 25.2                         | 70.3                | 26.6                         | 89.2                   |                        |                     |                     |
|                      |                 | 2            | 131.6                  | 67.6                | 45.1                | 26.8                         | 68.6                | 27.4                         | 88.4                   |                        |                     |                     |
|                      |                 | 3            | 132.1                  | 67.8                | 47.1                | 26.5                         | 68.8                | 26.8                         | 88.6                   |                        |                     |                     |
|                      |                 | Avg.         | 132.5                  | 69.1                | 44.4                | 26.2                         | 69.2                | 27.7                         | 87.7                   |                        |                     |                     |
| 3                    | L               | 1            | 132.3                  | 68.0                | 59.2                | 29.6                         | 68.6                | 25.8                         | 88.8                   | 213.1                  | 107.0               | 113.7               |
|                      |                 | 2            | 131.1                  | 66.0                | 58.0                | 21.4                         | 69.5                | 24.9                         | 88.4                   | 212.8                  | 98.8                | 108.2               |
|                      |                 | 3            | 131.5                  | 64.8                | 58.0                | 21.8                         | 65.5                | 25.7                         | 88.9                   | 218.6                  | 104.4               | 114.6               |
|                      |                 | Avg.         | 131.6                  | 66.3                | 58.3                | 24.3                         | 67.9                | 25.8                         | 88.7                   | 214.3                  | 103.4               | 112.2               |
| 3                    | ST              | 1            | 131.5                  | 67.3                | 47.1                | 28.8                         | 66.0                | 27.1                         | 87.9                   |                        |                     |                     |
|                      |                 | 2            | 130.5                  | 65.6                | 43.1                | 25.9                         | 70.5                | 26.8                         | 88.3                   |                        |                     |                     |
|                      |                 | 3            | 135.6                  | 72.3                | 41.2                | 29.3                         | 68.9                | 27.1                         | 87.4                   |                        |                     |                     |
|                      |                 | Avg.         | 132.5                  | 68.4                | 43.8                | 28.0                         | 68.5                | 27.0                         | 87.9                   |                        |                     |                     |
| 3-1/4                | L               | 1            | 133.0                  | 74.5                | 50.0                | 25.8                         | 70.6                | 25.4                         | 90.6                   | 217.4                  | 109.7               | 118.2               |
|                      |                 | 2            | 134.3                  | 79.0                | 51.0                | 36.5                         | 69.8                | 23.8                         | 88.8                   | 218.6                  | 109.9               | 129.3               |
|                      |                 | 3            | 133.0                  | 73.2                | 53.0                | 25.0                         | 75.4                | 26.4                         | 88.2                   | 220.2                  | 111.3               | 126.6               |
|                      |                 | Avg.         | 133.4                  | 75.6                | 51.3                | 27.1                         | 71.9                | 25.2                         | 89.2                   | 218.7                  | 110.3               | 124.7               |
| 3-1/4                | ST              | 1            | 132.3                  | 71.0                | 43.0                | 22.1                         | 79.9                | 27.4                         | 91.2                   |                        |                     |                     |
|                      |                 | 2            | 134.5                  | 82.1                | 42.0                | 21.8                         | 73.4                | 27.4                         | 89.0                   |                        |                     |                     |
|                      |                 | 3            | 132.4                  | 73.7                | 43.0                | 23.2                         | 76.2                | 27.4                         | 89.8                   |                        |                     |                     |
|                      |                 | Avg.         | 133.1                  | 75.6                | 42.7                | 22.4                         | 76.5                | 27.4                         | 90.0                   |                        |                     |                     |



TABLE 6. (Continued)

| Bar Diameter, inches | Grain Direction | Specimen No. | Tensile                |                     |                     |                              | Compressive         |                              | Shear | Bearing                |                     |                        |                     |
|----------------------|-----------------|--------------|------------------------|---------------------|---------------------|------------------------------|---------------------|------------------------------|-------|------------------------|---------------------|------------------------|---------------------|
|                      |                 |              | Ultimate Strength, ksi | Yield Strength, ksi | Elongation, percent | Modulus, 10 <sup>3</sup> ksi | Yield Strength, ksi | Modulus, 10 <sup>3</sup> ksi |       | Ultimate Strength, ksi | Yield Strength, ksi | Ultimate Strength, ksi | Yield Strength, ksi |
| 3-1/2                | L               | 1            | 136.2                  | 73.3                | 48.0                | 27.7                         | 60.7                | 24.9                         | 91.0  | 221.0                  | 109.8               | 276.1                  | 128.6               |
|                      |                 | 2            | 138.0                  | 77.4                | 47.0                | 26.1                         | 57.6                | 24.6                         | 89.6  | 216.1                  | 106.0               | 276.0                  | 132.4               |
|                      |                 | 3            | 136.0                  | 72.8                | 49.0                | 31.8                         | 61.0                | 25.3                         | 90.2  | 219.3                  | 111.7               | 268.6                  | 128.3               |
|                      |                 | Avg.         | 136.7                  | 74.5                | 48.0                | 28.5                         | 59.8                | 24.9                         | 90.3  | 218.8                  | 109.1               | 273.5                  | 129.8               |
| 3-1/2                | ST              | 1            | 133.3                  | 68.1                | 36.0                | 23.9                         | 73.9                | 27.2                         | 89.8  |                        |                     |                        |                     |
|                      |                 | 2            | 132.9                  | 65.9                | 37.0                | 23.3                         | 74.8                | 27.4                         | 90.7  |                        |                     |                        |                     |
|                      |                 | 3            | 132.8                  | 69.8                | 34.0                | 27.8                         | 74.9                | 28.0                         | 89.7  |                        |                     |                        |                     |
|                      |                 | Avg.         | 133.0                  | 67.9                | 35.7                | 25.0                         | 74.5                | 27.5                         | 90.1  |                        |                     |                        |                     |
| 3-3/4                | L               | 1            | 136.8                  | 73.6                | 49.0                | 35.3                         | 70.0                | 25.2                         | 91.4  | 222.4                  | {2}                 | 273.4                  | 126.6               |
|                      |                 | 2            | 136.5                  | 73.1                | 48.0                | 31.3                         | 67.5                | 25.2                         | 90.5  | 219.4                  | {2}                 | 282.6                  | 135.0               |
|                      |                 | 3            | 136.6                  | 74.2                | 48.0                | 35.7                         | 65.7                | 25.5                         | 91.5  | 222.2                  | {2}                 | 271.3                  | 125.0               |
|                      |                 | Avg.         | 136.6                  | 73.6                | 48.3                | 34.1                         | 67.7                | 25.3                         | 91.2  | 221.3                  | 114.3               | 275.8                  | 128.9               |
| 3-3/4                | ST              | 1            | 134.2                  | 69.5                | 31.0                | 22.0                         | 77.0                | 27.1                         | 87.7  |                        |                     |                        |                     |
|                      |                 | 2            | 134.9                  | 65.5                | 38.0                | 26.0                         | 76.9                | 27.4                         | 92.0  |                        |                     |                        |                     |
|                      |                 | 3            | 136.1                  | 70.7                | 39.0                | 25.8                         | 76.7                | 27.2                         | 90.8  |                        |                     |                        |                     |
|                      |                 | Avg.         | 135.1                  | 68.6                | 36.0                | 24.9                         | 76.9                | 27.2                         | 90.2  |                        |                     |                        |                     |
| 4                    | L               | 1            | 116.9                  | 56.2                | 45.0                | 33.6                         | 57.5                | 24.5                         | 79.4  | 186.2                  | 84.0                | 218.8                  | 101.0               |
|                      |                 | 2            | 116.1                  | 56.7                | 53.0                | 29.6                         | 56.9                | 24.4                         | 79.0  | 184.4                  | 86.6                | 214.2                  | 104.3               |
|                      |                 | 3            | 116.1                  | 56.6                | 53.0                | 26.9                         | 57.4                | 25.2                         | 78.8  | 180.7                  | 85.4                | 213.1                  | 103.4               |
|                      |                 | Avg.         | 116.4                  | 56.5                | 50.3                | 30.0                         | 57.3                | 24.7                         | 79.1  | 183.7                  | 85.3                | 215.3                  | 102.9               |
| 4                    | ST              | 1            | 115.1                  | 57.0                | 53.0                | 27.3                         | 56.6                | 27.7                         | 76.7  |                        |                     |                        |                     |
|                      |                 | 2            | 114.9                  | 55.8                | 49.0                | 30.6                         | 56.1                | 27.4                         | 76.3  |                        |                     |                        |                     |
|                      |                 | 3            | 114.9                  | 56.2                | 50.0                | 31.1                         | 56.4                | 26.4                         | 78.7  |                        |                     |                        |                     |
|                      |                 | Avg.         | 115.0                  | 56.3                | 50.7                | 29.7                         | 56.4                | 27.2                         | 77.9  |                        |                     |                        |                     |
| 3/4                  | L               | 1            | 132.8                  | 73.4                | 54.8                | 34.9                         |                     |                              |       |                        |                     |                        |                     |
|                      |                 | 2            | 133.6                  | 74.1                | 53.3                | 34.0                         |                     |                              |       |                        |                     |                        |                     |
|                      |                 | Avg.         | 133.2                  | 73.8                | 54.1                | 34.5                         |                     |                              |       |                        |                     |                        |                     |

(1) Specimen numbers for e/D = 2.0 were 4 through 6.

(2) Uncharacteristic load-deformation curve.

TABLE 6(a). MECHANICAL PROPERTIES OF ANNEALED INCONEL 625 BAR

| Bar Diameter, mm | Grain Direction | Specimen No. | Tensile                |                     |                     |              | Compressive         |              | Shear | Bearing                |                     |                        |                     |
|------------------|-----------------|--------------|------------------------|---------------------|---------------------|--------------|---------------------|--------------|-------|------------------------|---------------------|------------------------|---------------------|
|                  |                 |              | Ultimate Strength, MPa | Yield Strength, MPa | Elongation, percent | Modulus, GPa | Yield Strength, MPa | Modulus, MPa |       | $e/D = 1.5$            |                     | $e/D = 2.0 (1)$        |                     |
|                  |                 |              |                        |                     |                     |              |                     |              |       | Ultimate Strength, MPa | Yield Strength, MPa | Ultimate Strength, MPa | Yield Strength, MPa |
| 50.8<br>(Heat A) | L               | 1            | 896.4                  | 435.8               | 54.0                | 180.6        | 437.8               | 179.3        | 577.1 | 1489.2                 | 670.7               | 1855.1                 | 788.8               |
|                  |                 | 2            | 892.9                  | 433.0               | 53.0                | 175.1        | 446.8               | 191.0        | 586.8 | 1469.2                 | 650.5               | 1898.3                 | 813.4               |
|                  |                 | 3            | 897.0                  | 438.5               | 54.0                | 154.4        | 454.4               | 170.3        | 597.8 | 1488.9                 | 687.0               | 1881.3                 | 803.5               |
|                  |                 | Avg.         | 895.4                  | 435.8               | 53.7                | 170.1        | 446.3               | 180.2        | 587.2 | 1482.4                 | 669.4               | 1878.2                 | 801.9               |
| 50.8<br>(Heat A) | ST              | 1            | 911.5                  | 446.1               | 52.0                | 194.4        | 430.2               | 188.2        | 597.8 |                        |                     |                        |                     |
|                  |                 | 2            | 922.6                  | 431.6               | 52.0                | 181.3        | 432.3               | 188.2        | 595.7 |                        |                     |                        |                     |
|                  |                 | 3            | 926.7                  | 438.5               | 52.0                | 181.3        | 442.7               | 186.9        | 604.7 |                        |                     |                        |                     |
|                  |                 | Avg.         | 920.3                  | 438.8               | 52.0                | 185.7        | 435.1               | 187.8        | 599.4 |                        |                     |                        |                     |
| 50.8<br>(Heat B) | L               | 1            | 899.1                  | 448.2               | 53.0                | 171.0        | 442.7               | 186.9        | 605.4 | 1492.0                 | 682.3               | 1775.8                 | 782.0               |
|                  |                 | 2            | 896.4                  | 448.2               | 53.0                | 215.8        | 428.9               | 191.0        | 606.9 | 1456.6                 | 671.6               | 1831.6                 | 860.3               |
|                  |                 | 3            | 897.0                  | 450.2               | 54.0                | 165.5        | 435.8               | 188.9        | 598.5 | 1491.8                 | 695.2               | 1783.9                 | 824.6               |
|                  |                 | Avg.         | 897.5                  | 448.9               | 53.3                | 184.1        | 435.8               | 188.9        | 603.5 | 1480.1                 | 683.0               | 1797.1                 | 822.3               |
| 50.8<br>(Heat B) | ST              | 1            | 901.9                  | 419.2               | 52.0                | 171.7        | 432.3               | 185.5        | 603.3 |                        |                     |                        |                     |
|                  |                 | 2            | 902.6                  | 433.7               | 52.0                | 193.1        | 448.2               | 201.3        | 605.4 |                        |                     |                        |                     |
|                  |                 | 3            | 894.3                  | 442.0               | 52.0                | 184.8        | 449.6               | 188.2        | 603.3 |                        |                     |                        |                     |
|                  |                 | Avg.         | 899.6                  | 431.6               | 52.0                | 183.2        | 443.3               | 191.7        | 604.0 |                        |                     |                        |                     |
| 57.2             | L               | 1            | 947.4                  | 515.1               | 48.0                | 177.2        | 534.4               | 202.0        | 628.1 | 1497.7                 | 752.1               | 1848.1                 | 892.8               |
|                  |                 | 2            | 960.5                  | 545.4               | 47.0                | 195.3        | 528.8               | 186.9        | 626.8 | 1493.1                 | 740.1               | 1908.3                 | 828.5               |
|                  |                 | 3            | 951.5                  | 526.1               | 48.0                | 180.6        | 523.3               | -219.3       | 624.7 | 1526.9                 | 779.0               | 1872.6                 | 902.9               |
|                  |                 | Avg.         | 953.1                  | 528.8               | 47.7                | 185.7        | 528.8               | 202.7        | 626.5 | 1505.9                 | 757.1               | 1876.3                 | 874.7               |
| 57.2             | ST              | 1            | 943.2                  | 517.1               | 36.0                | 181.3        | 529.5               | 192.4        | 622.6 |                        |                     |                        |                     |
|                  |                 | 2            | 946.7                  | 514.4               | 36.0                | 165.5        | 508.2               | 188.9        | 621.9 |                        |                     |                        |                     |
|                  |                 | 3            | 948.1                  | 519.9               | 40.0                | 173.1        | 506.1               | 195.1        | 624.0 |                        |                     |                        |                     |
|                  |                 | Avg.         | 946.0                  | 517.1               | 37.3                | 173.3        | 514.6               | 192.1        | 622.8 |                        |                     |                        |                     |
| 63.5             | L               | 1            | 941.2                  | 497.1               | 49.0                | 185.5        | 499.2               | 186.9        | 619.9 | 1492.5                 | 725.9               | 1803.7                 | 896.7               |
|                  |                 | 2            | 942.5                  | 502.0               | 49.0                | 186.2        | 511.6               | 191.0        | 617.1 | 1476.8                 | 716.1               | 1835.4                 | 848.9               |
|                  |                 | 3            | 935.7                  | 490.2               | 51.0                | 197.2        | 512.3               | 187.5        | 620.6 | 1521.0                 | 666.5               | 1782.0                 | 847.9               |
|                  |                 | Avg.         | 939.8                  | 496.4               | 49.7                | 189.6        | 507.7               | 188.5        | 619.2 | 1496.8                 | 702.9               | 1807.0                 | 864.5               |

TABLE 6(a). (Continued)

| Bar Diameter, mm | Grain Direction | Specimen No. | Tensile                |                     |                     | Compressive  |                     | Shear | Bearing                |                     |                 |                        |
|------------------|-----------------|--------------|------------------------|---------------------|---------------------|--------------|---------------------|-------|------------------------|---------------------|-----------------|------------------------|
|                  |                 |              | Ultimate Strength, MPa | Yield Strength, MPa | Elongation, percent | Modulus, GPa | Yield Strength, MPa |       | $e/D = 1.5$            |                     | $e/D = 2.0$ (1) |                        |
|                  |                 |              |                        |                     |                     |              |                     |       | Ultimate Strength, MPa | Yield Strength, MPa |                 | Ultimate Strength, MPa |
| 63.5             | ST              | 1            | 917.0                  | 486.1               | 37.3                | 164.1        | 508.9               | 617.8 |                        |                     |                 |                        |
|                  |                 | 2            | 900.5                  | 476.4               | 45.1                | 160.7        | 517.1               | 617.8 |                        |                     |                 |                        |
|                  |                 | 3            | 907.4                  | 467.5               | 43.1                | 169.6        | 503.3               | 615.7 |                        |                     |                 |                        |
|                  |                 | Avg.         | 908.5                  | 476.7               | 41.8                | 164.8        | 509.8               | 617.1 |                        |                     |                 |                        |
| 69.8             | L               | 1            | 918.4                  | 474.4               | 51.0                | 187.5        | 488.2               | 615.7 | 1497.1                 | 715.5               | 1843.3          | 842.3                  |
|                  |                 | 2            | 922.6                  | 468.2               | 50.0                | 200.6        | 481.3               | 615.0 | 1458.5                 | (2)                 | 1857.9          | 861.2                  |
|                  |                 | 3            | 923.9                  | 473.0               | 50.0                | 178.6        | 480.6               | 616.4 | 1475.3                 | 698.0               | 1820.4          | 841.3                  |
|                  |                 | Avg.         | 921.6                  | 471.8               | 50.3                | 188.9        | 483.3               | 615.7 | 1477.0                 | 706.7               | 1840.6          | 848.3                  |
| 69.8             | ST              | 1            | 922.6                  | 495.1               | 41.1                | 173.8        | 484.7               | 615.0 |                        |                     |                 |                        |
|                  |                 | 2            | 907.4                  | 466.1               | 45.1                | 184.8        | 473.0               | 609.5 |                        |                     |                 |                        |
|                  |                 | 3            | 910.8                  | 467.5               | 47.1                | 182.7        | 474.4               | 590.2 |                        |                     |                 |                        |
|                  |                 | Avg.         | 913.6                  | 476.2               | 44.4                | 180.4        | 477.4               | 604.9 |                        |                     |                 |                        |
| 76.2             | L               | 1            | 912.2                  | 468.9               | 59.0                | 204.1        | 473.0               | 612.3 | 1469.3                 | 738.0               | 1770.1          | 784.1                  |
|                  |                 | 2            | 903.9                  | 455.1               | 58.0                | 147.6        | 479.2               | 609.5 | 1467.2                 | 681.2               | 1833.3          | 746.4                  |
|                  |                 | 3            | 906.7                  | 446.8               | 58.0                | 150.3        | 451.6               | 613.0 | 1507.1                 | 719.6               | 1803.7          | 789.9                  |
|                  |                 | Avg.         | 907.6                  | 456.9               | 58.3                | 167.3        | 467.9               | 611.6 | 1481.2                 | 712.9               | 1802.4          | 773.5                  |
| 76.2             | ST              | 1            | 906.7                  | 464.0               | 47.1                | 198.6        | 455.1               | 606.1 |                        |                     |                 |                        |
|                  |                 | 2            | 899.8                  | 452.3               | 43.1                | 178.6        | 486.1               | 608.8 |                        |                     |                 |                        |
|                  |                 | 3            | 935.0                  | 498.5               | 41.2                | 202.0        | 475.1               | 602.6 |                        |                     |                 |                        |
|                  |                 | Avg.         | 913.8                  | 471.6               | 43.8                | 193.1        | 472.1               | 605.8 |                        |                     |                 |                        |
| 82.6             | L               | 1            | 917.0                  | 513.7               | 50.0                | 177.9        | 486.8               | 624.7 | 1499.0                 | 756.4               | 1838.4          | 814.7                  |
|                  |                 | 2            | 926.0                  | 544.7               | 51.0                | 210.3        | 481.3               | 612.3 | 1507.0                 | 757.6               | 1912.6          | 891.9                  |
|                  |                 | 3            | 917.0                  | 504.7               | 53.0                | 172.4        | 519.9               | 608.1 | 1518.5                 | 767.1               | 1856.3          | 873.1                  |
|                  |                 | Avg.         | 920.0                  | 521.0               | 51.3                | 186.9        | 496.0               | 615.0 | 1508.2                 | 760.4               | 1869.1          | 859.9                  |
| 82.6             | ST              | 1            | 912.2                  | 489.5               | 43.0                | 152.4        | 550.9               | 628.8 |                        |                     |                 |                        |
|                  |                 | 2            | 927.4                  | 566.1               | 42.0                | 150.3        | 506.1               | 613.7 |                        |                     |                 |                        |
|                  |                 | 3            | 912.9                  | 508.2               | 43.0                | 160.0        | 525.4               | 619.2 |                        |                     |                 |                        |
|                  |                 | Avg.         | 917.5                  | 521.3               | 42.7                | 154.2        | 527.5               | 620.6 |                        |                     |                 |                        |

TABLE 6(a). (Continued)

| Bar Diameter, mm | Grain Direction | Specimen No. | Tensile                |                     |                     | Compressive  |                     | Shear Ultimate Strength, GPa | Bearing                |                     |                        |
|------------------|-----------------|--------------|------------------------|---------------------|---------------------|--------------|---------------------|------------------------------|------------------------|---------------------|------------------------|
|                  |                 |              | Ultimate Strength, MPa | Yield Strength, MPa | Elongation, percent | Modulus, GPa | Yield Strength, MPa | Modulus, MPa                 | $e/D = 1.5$            |                     |                        |
|                  |                 |              |                        |                     |                     |              |                     |                              | Ultimate Strength, MPa | Yield Strength, MPa | Ultimate Strength, MPa |
| 88.5             | L               | 1            | 939.1                  | 505.4               | 48.0                | 191.0        | 418.5               | 171.7                        | 627.4                  | 756.8               | 1903.8                 |
|                  |                 | 2            | 951.5                  | 533.7               | 47.0                | 180.0        | 397.2               | 169.6                        | 617.8                  | 730.6               | 1902.7                 |
|                  |                 | 3            | 937.7                  | 502.0               | 49.0                | 219.3        | 420.6               | 174.4                        | 621.9                  | 770.2               | 1851.7                 |
|                  |                 | Avg.         | 942.8                  | 513.7               | 48.0                | 196.7        | 412.1               | 171.9                        | 622.4                  | 752.5               | 1886.1                 |
| 88.9             | ST              | 1            | 919.1                  | 469.5               | 36.0                | 164.8        | 509.5               | 187.5                        | 619.2                  |                     |                        |
|                  |                 | 2            | 916.3                  | 454.4               | 37.0                | 160.7        | 515.7               | 188.9                        | 625.4                  |                     |                        |
|                  |                 | 3            | 915.7                  | 481.3               | 34.0                | 191.7        | 516.4               | 193.1                        | 618.5                  |                     |                        |
|                  |                 | Avg.         | 917.0                  | 468.4               | 35.7                | 172.4        | 513.9               | 189.8                        | 621.0                  |                     |                        |
| 95.2             | L               | 1            | 943.2                  | 507.5               | 49.0                | 243.4        | 482.7               | 173.8                        | 630.2                  | (2)                 | 1885.2                 |
|                  |                 | 2            | 941.2                  | 504.0               | 48.0                | 215.8        | 465.4               | 173.8                        | 624.2                  | (2)                 | 1948.3                 |
|                  |                 | 3            | 941.9                  | 511.6               | 48.0                | 246.2        | 453.0               | 175.8                        | 631.1                  | 788.4               | 1870.7                 |
|                  |                 | Avg.         | 942.1                  | 507.7               | 48.3                | 235.1        | 467.0               | 174.4                        | 625.5                  | 788.4               | 1901.4                 |
| 95.2             | ST              | 1            | 925.3                  | 479.2               | 31.0                | 157.2        | 530.9               | 186.9                        | 605.0                  |                     |                        |
|                  |                 | 2            | 930.1                  | 451.6               | 38.0                | 179.3        | 530.2               | 188.9                        | 634.5                  |                     |                        |
|                  |                 | 3            | 938.4                  | 487.5               | 39.0                | 177.9        | 528.8               | 187.5                        | 625.9                  |                     |                        |
|                  |                 | Avg.         | 931.3                  | 472.8               | 36.0                | 171.5        | 530.0               | 187.8                        | 621.8                  |                     |                        |
| 101.6            | L               | 1            | 806.0                  | 387.5               | 45.0                | 231.7        | 396.5               | 168.9                        | 547.5                  | 579.2               | 1508.7                 |
|                  |                 | 2            | 800.5                  | 390.9               | 53.0                | 204.1        | 392.3               | 168.2                        | 544.7                  | 596.8               | 1476.7                 |
|                  |                 | 3            | 800.5                  | 390.3               | 53.0                | 185.5        | 395.8               | 173.8                        | 543.5                  | 588.5               | 1469.0                 |
|                  |                 | Avg.         | 802.3                  | 389.6               | 50.3                | 207.1        | 394.9               | 170.3                        | 545.2                  | 588.2               | 1484.8                 |
| 101.6            | ST              | 1            | 793.6                  | 393.0               | 53.0                | 188.2        | 390.3               | 191.0                        | 529.1                  |                     |                        |
|                  |                 | 2            | 792.2                  | 384.7               | 49.0                | 211.0        | 386.8               | 188.9                        | 540.2                  |                     |                        |
|                  |                 | 3            | 792.2                  | 387.5               | 50.0                | 214.4        | 388.9               | 182.0                        | 542.5                  |                     |                        |
|                  |                 | Avg.         | 792.7                  | 388.4               | 50.7                | 204.6        | 388.6               | 187.3                        | 537.2                  |                     |                        |
| 19.0             | L               | 1            | 915.7                  | 506.1               | 54.8                | 240.6        |                     |                              |                        |                     |                        |
|                  |                 | 2            | 921.2                  | 510.9               | 53.3                | 234.4        |                     |                              |                        |                     |                        |
|                  |                 |              |                        |                     |                     |              |                     |                              |                        |                     |                        |
|                  |                 | Avg.         | 918.4                  | 508.5               | 54.1                | 237.5        |                     |                              |                        |                     |                        |

(1) Specimen numbers for  $e/D = 2.0$  were 4 through 6.  
 (2) Uncharacteristic load-deformation curve.

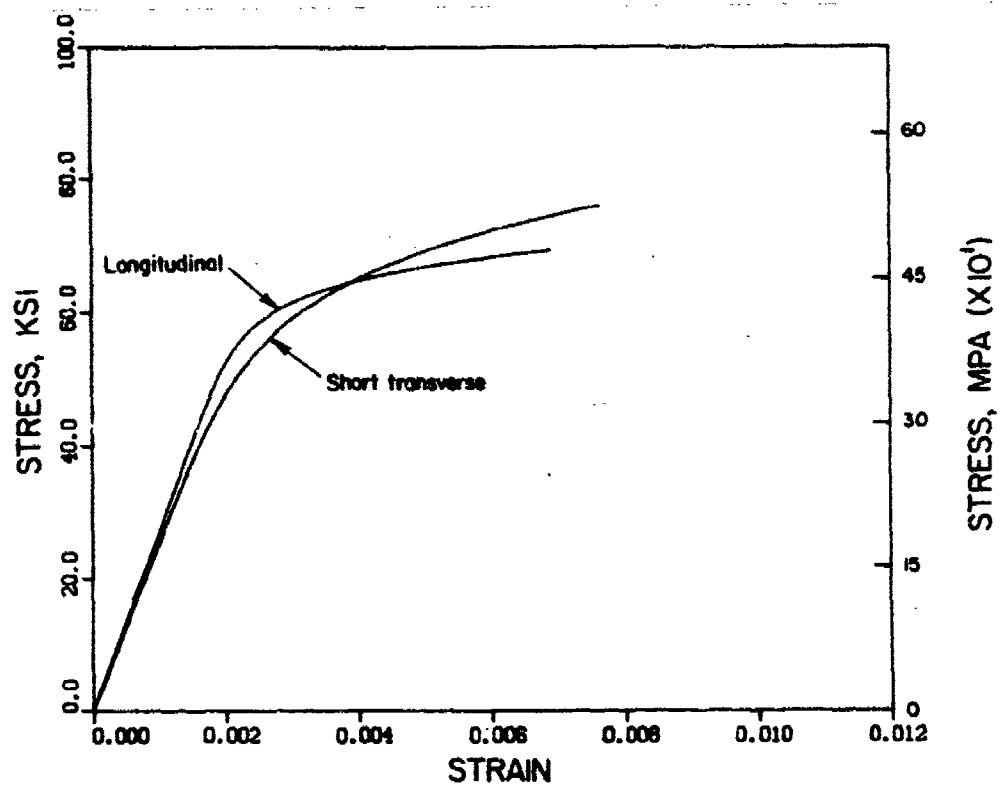


Figure 14. Typical tensile stress-strain curves for annealed Inconel 625 bar.

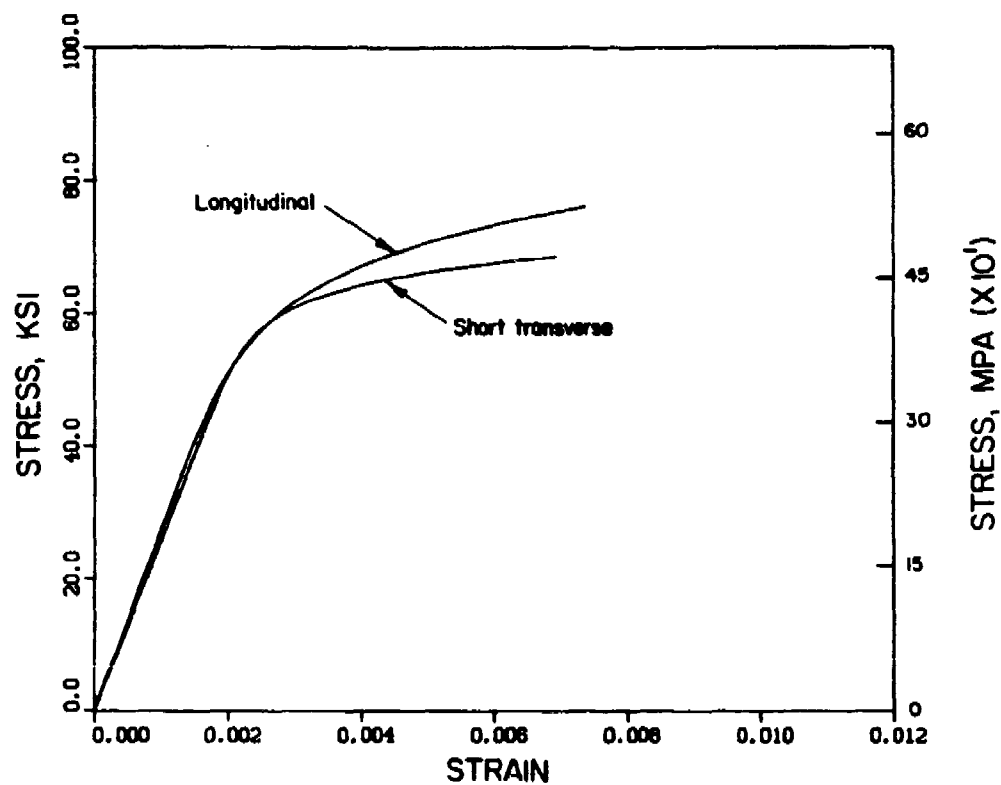


Figure 15. Typical compressive stress-strain curves for annealed Inconel 625 bar.

TABLE 7. UNNOTCHED FATIGUE DATA FOR ANNEALED  
INCONEL 625 BAR--LONGITUDINAL DIRECTION

| Specimen<br>ID | Maximum<br>Stress, |         | R-ratio | Cycles to<br>Failure |
|----------------|--------------------|---------|---------|----------------------|
|                | ksi                | MPa     |         |                      |
| 611FL7         | 120.0              | (827.4) | -0.5    | 110 <sup>(1)</sup>   |
| 611FL15        | 115.0              | (792.9) | -0.5    | 8,000                |
| 611FL19        | 112.5              | (775.7) | -0.5    | 11,370               |
| 611FL9         | 110.0              | (758.5) | -0.5    | 21,310               |
| 611FL3         | 90.0               | (620.6) | -0.5    | 92,760               |
| 611FL5         | 80.0               | (551.6) | -0.5    | 189,960              |
| 611FL11        | 80.0               | (551.6) | -0.5    | 206,730              |
| 611FL13        | 75.0               | (517.1) | -0.5    | 334,810              |
| 611FL17        | 72.5               | (499.9) | -0.5    | 444,460              |
| 611FL1         | 70.0               | (482.7) | -0.5    | DNF <sup>(2)</sup>   |
| 611FL33        | 140.0              | (965.3) | 0.1     | 20 <sup>(1)</sup>    |
| 611FL39        | 125.0              | (861.9) | 0.1     | 47,450               |
| 611FL35        | 120.0              | (827.4) | 0.1     | 60,570               |
| 611FL31        | 110.0              | (758.5) | 0.1     | 128,800              |
| 611FL27        | 100.0              | (689.5) | 0.1     | 167,230              |
| 611FL25        | 90.0               | (620.6) | 0.1     | 359,710              |
| 611FL37        | 80.0               | (551.6) | 0.1     | 642,550              |
| 611FL23        | 80.0               | (551.6) | 0.1     | 863,260              |
| 611FL29        | 70.0               | (482.7) | 0.1     | DNF                  |
| 611FL21        | 70.0               | (482.7) | 0.1     | 7,543,980            |
| 611FL47        | 130.0              | (896.4) | 0.5     | 20 <sup>(1)</sup>    |
| 611FL51        | 127.0              | (875.7) | 0.5     | 222,400              |
| 611FL49        | 125.0              | (861.9) | 0.5     | 125,000              |
| 611FL45        | 120.0              | (827.4) | 0.5     | 370,150              |
| 611FL53        | 115.0              | (792.9) | 0.5     | 626,440              |
| 611FL55        | 112.5              | (775.7) | 0.5     | 800,750              |
| 611FL59        | 110.0              | (758.5) | 0.5     | 622,810              |
| 611FL57        | 110.0              | (758.5) | 0.5     | DNF                  |
| 611FL43        | 100.0              | (689.5) | 0.5     | DNF                  |
| 611FL41        | 70.0               | (482.7) | 0.5     | DNF                  |

(1) Cycle count below  $10^3$ , not plotted.

(2) DNF - did not fail; test ran 10,000,000 cycles and stopped.

TABLE 8. NOTCHED,  $K_t = 3$ , FATIGUE DATA FOR ANNEALED  
INCONEL 625 BAR--LONGITUDINAL DIRECTION

| Specimen<br>ID | Maximum<br>Stress,<br>ksi      MPa |         | R-ratio | Cycles to<br>Failure |
|----------------|------------------------------------|---------|---------|----------------------|
| 611FL46        | 75.0                               | (517.1) | -0.5    | 11,350               |
| 611FL38        | 70.0                               | (482.7) | -0.5    | 14,570               |
| 611FL20        | 65.0                               | (448.2) | -0.5    | 24,890               |
| 611FL12        | 60.0                               | (413.7) | -0.5    | 58,330 (1)           |
| 611FL8         | 55.0                               | (379.2) | -0.5    | 104,190              |
| 611FL6         | 55.0                               | (379.2) | -0.5    | 144,300              |
| 611FL34        | 50.0                               | (344.8) | -0.5    | 263,440              |
| 611FL10        | 50.0                               | (344.8) | -0.5    | 977,110 (2)          |
| 611FL4         | 45.0                               | (310.3) | -0.5    | DNF (3)              |
| 611FL2         | 40.0                               | (275.8) | -0.5    | 146,850              |
| 611FL48        | 100.0                              | (689.5) | 0.1     | 8,120                |
| 611FL50        | 80.0                               | (551.6) | 0.1     | 36,700               |
| 611FL40        | 70.0                               | (482.7) | 0.1     | 67,140               |
| 611FL18        | 65.0                               | (448.2) | 0.1     | 98,450               |
| 611FL14        | 60.0                               | (413.7) | 0.1     | 542,249              |
| 611FL16        | 55.0                               | (379.2) | 0.1     | 936,100 (4)          |
| 611FL28        | 50.0                               | (344.8) | 0.1     | 434,270 (4)          |
| 611FL26        | 50.0                               | (344.8) | 0.1     | 488,750              |
| 611FL32        | 45.0                               | (310.3) | 0.1     | 528,550              |
| 611FL44        | 45.0                               | (310.3) | 0.1     | 4,868,610            |
| 611FL60        | 120.0                              | (827.4) | 0.5     | 21,000               |
| 611FL54        | 110.0                              | (758.5) | 0.5     | 24,740               |
| 611FL56        | 100.0                              | (689.5) | 0.5     | 39,120               |
| 611FL52        | 90.0                               | (620.6) | 0.5     | 90,000               |
| 611FL42        | 75.0                               | (517.1) | 0.5     | 426,090              |
| 611FL30        | 70.0                               | (482.7) | 0.5     | 677,380              |
| 611FL58        | 65.0                               | (448.2) | 0.5     | 845,520              |
| 611FL22        | 65.0                               | (448.2) | 0.5     | 906,420              |
| 611FL36        | 60.0                               | (413.7) | 0.5     | 7,057,900            |
| 611FL24        | 60.0                               | (413.7) | 0.5     | DNF                  |

(1) Inadvertently overloaded.

(2) DNF - did not fail; test ran 10,000,000 cycles and stopped.

(3) Regripped four times due to hydraulic grip malfunction; specimen may have been subjected to bending.

(4) Misaligned.

utilizing unnotched and notched,  $K_t = 3$ , specimens from the 3/4-inch-diameter bar. Tests were conducted at three stress ratios,  $R = -0.5$ ,  $R = 0.1$ , and  $R = 0.5$ . The fatigue data were analyzed in accord with Section 9.3.4 of MIL-HDBK-5 and S/N curves in Figures 16 and 17 constructed accordingly.



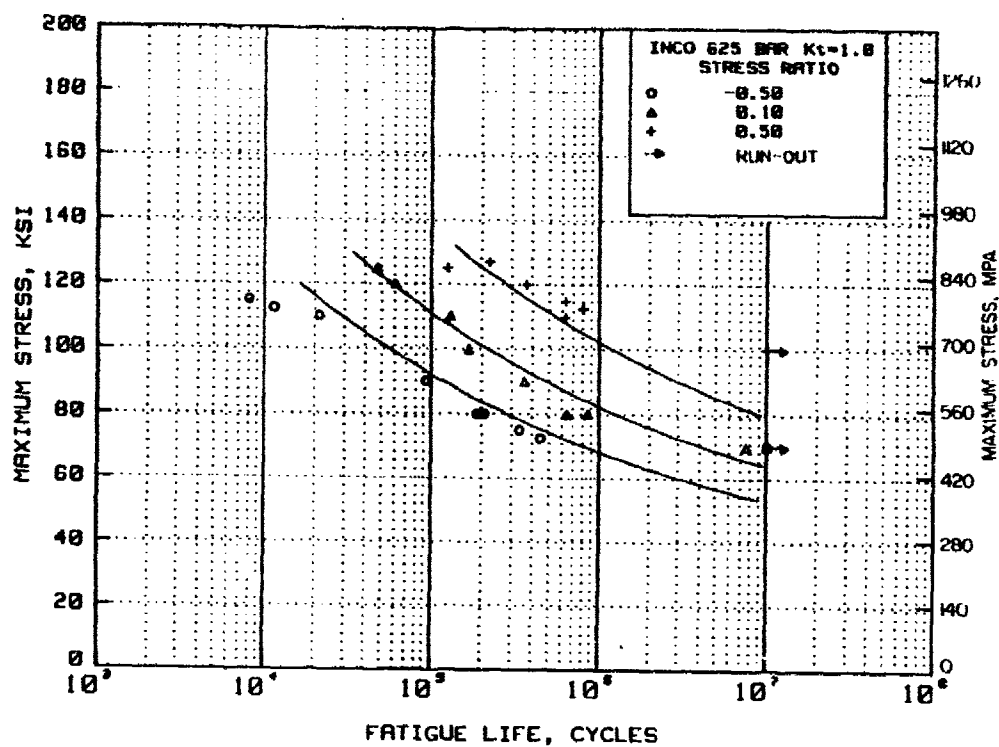


Figure 16. Unnotched axial-stress S/N curves for 3/4-inch-diameter annealed Inconel 625 bar--longitudinal direction.

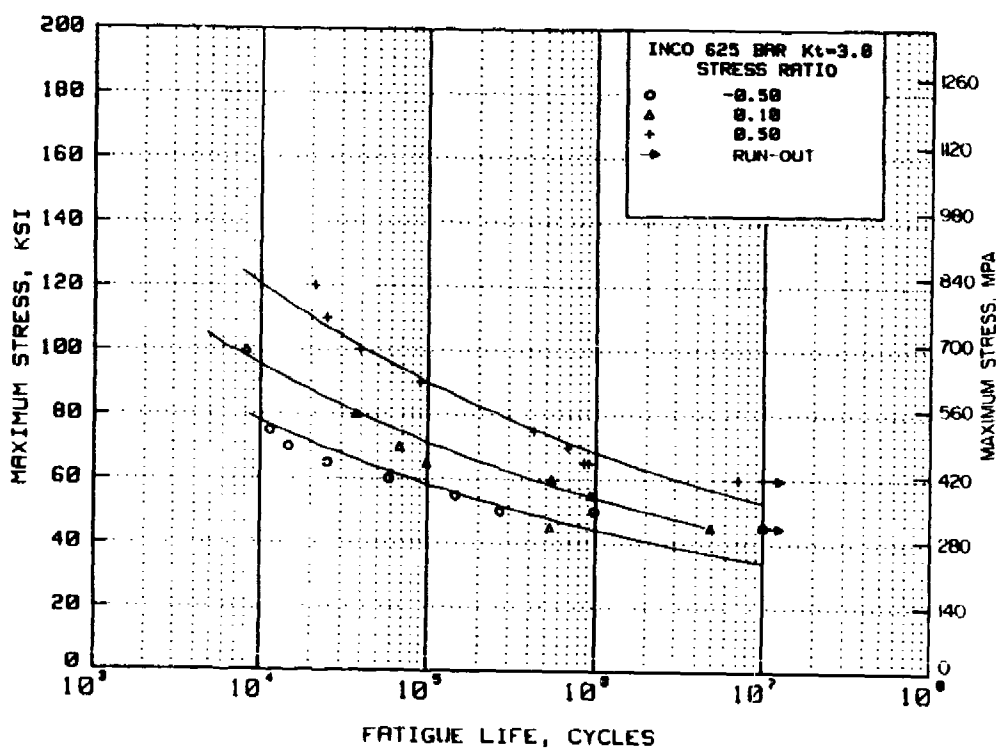


Figure 17. Notched axial-stress S/N curves for 3/4-inch-diameter annealed 625 bar--longitudinal direction.

## Inconel 625 Sheet (Annealed)

### Background

Inconel 625 has high tensile, creep, and rupture strength, outstanding fatigue and thermal fatigue strength; oxidation and corrosion resistance, and excellent weldability and brazeability. These properties make this alloy attractive for aerospace applications, such as ducting, engine exhaust systems, thrust-reversers, resistance welded honeycomb structures, fuel and hydraulic line tubing bellows, turbine shroud rings, and heat exchanger tubing. This widely used alloy is currently contained in MIL-HDBK-5, but design values for properties other than tensile yield and ultimate strengths are missing. Consequently, a test program was needed to determine the mechanical properties of Inconel 625 sheet in the annealed condition so that design values can be subsequently determined.

### Material

Ten heats of Inconel 625 sheet were procured from Inco Alloys International to AMS 5599. The chemical compositions, as determined by Inco Alloys International, are shown in Table 9. Sheets were obtained in the following thicknesses: 0.050, 0.063, 0.078, 0.093, 0.125, and 0.250 inch. Two heats of 0.063-, 0.078-, and 0.125-inch-thick sheet were procured to provide ten heats. The sheets were supplied in the annealed condition and tested "as-received."

### Location of Test Specimens

The location of test specimens is shown in Figures 18 and 19. Figure 20 shows the code system used to identify test specimens.

### Specimen Configuration

The configurations of the test specimens are shown in Appendix B. All specimens were full sheet thickness, except bearing specimens from 0.125-, 0.187-, and 0.250-inch-thick sheets were machined to  $0.100 \pm 0.005$ -inch thickness by removing an equal amount of material from each surface.

TABLE 9. CHEMICAL COMPOSITION OF INCONEL 625 SHEET

| Heat<br>Number | Element, percent |      |      |       |      |       |       |      |      |      |       |       |
|----------------|------------------|------|------|-------|------|-------|-------|------|------|------|-------|-------|
|                | C                | Mn   | Fe   | S     | Si   | Ni    | Cr    | Al   | Ti   | Mo   | Cb+Ta | P     |
| VX0070AK       | 0.03             | 0.09 | 4.07 | 0.001 | 0.15 | 60.80 | 22.36 | 0.22 | 0.24 | 8.66 | 3.37  | 0.006 |
| VX0030AK       | 0.02             | 0.08 | 4.31 | 0.001 | 0.13 | 61.04 | 21.94 | 0.23 | 0.29 | 8.45 | 3.50  | 0.006 |
| NX15E8AK       | 0.01             | 0.08 | 4.39 | 0.001 | 0.11 | 61.22 | 21.90 | 0.20 | 0.21 | 8.43 | 3.44  | 0.006 |
| VX0028AK       | 0.03             | 0.10 | 4.33 | 0.001 | 0.14 | 60.75 | 22.17 | 0.22 | 0.25 | 8.55 | 3.45  | 0.007 |
| VX0055AK       | 0.01             | 0.06 | 4.53 | 0.001 | 0.09 | 60.87 | 21.95 | 0.22 | 0.25 | 8.64 | 3.37  | 0.004 |
| VX0041AK       | 0.02             | 0.06 | 4.48 | 0.001 | 0.07 | 60.76 | 22.12 | 0.24 | 0.22 | 8.53 | 3.49  | 0.004 |
| VX0037AK       | 0.02             | 0.08 | 3.87 | 0.001 | 0.14 | 61.34 | 22.09 | 0.19 | 0.23 | 8.48 | 3.55  | 0.006 |
| VX0056AK       | 0.02             | 0.05 | 4.50 | 0.001 | 0.08 | 60.78 | 22.07 | 0.26 | 0.25 | 8.54 | 3.45  | 0.004 |
| VX0015AK       | 0.02             | 0.07 | 4.32 | 0.001 | 0.14 | 60.87 | 22.04 | 0.20 | 0.24 | 8.56 | 3.53  | 0.006 |
| VX0069AK       | 0.03             | 0.09 | 3.85 | 0.001 | 0.11 | 62.05 | 21.75 | 0.17 | 0.17 | 8.36 | 3.41  | 0.006 |

Note: Composition of all heats conformed to the requirements of AMS 5599.


$$e/D = 1.5$$
 $e/D = 2.0$ 
$$e/D = 2.0$$
$$e/D = 1.5$$

Longitudinal 24"

24

Figure 18. Location of test specimens for annealed Inconel 625 sheet--all thicknesses except 0.093 inch.

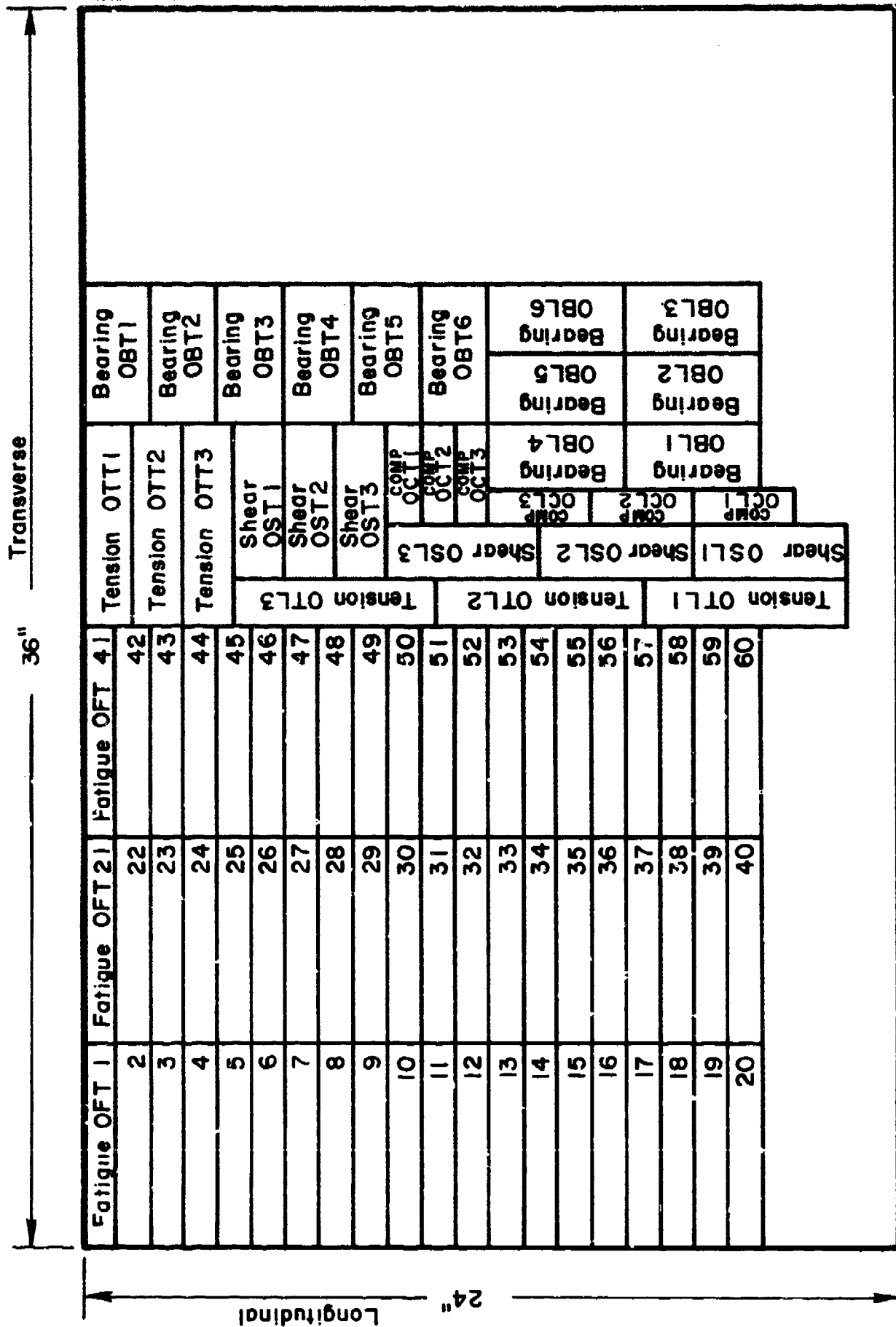


Figure 10. Location of test specimens for annealed Inconel 625 sheet--0.093-inch thick.

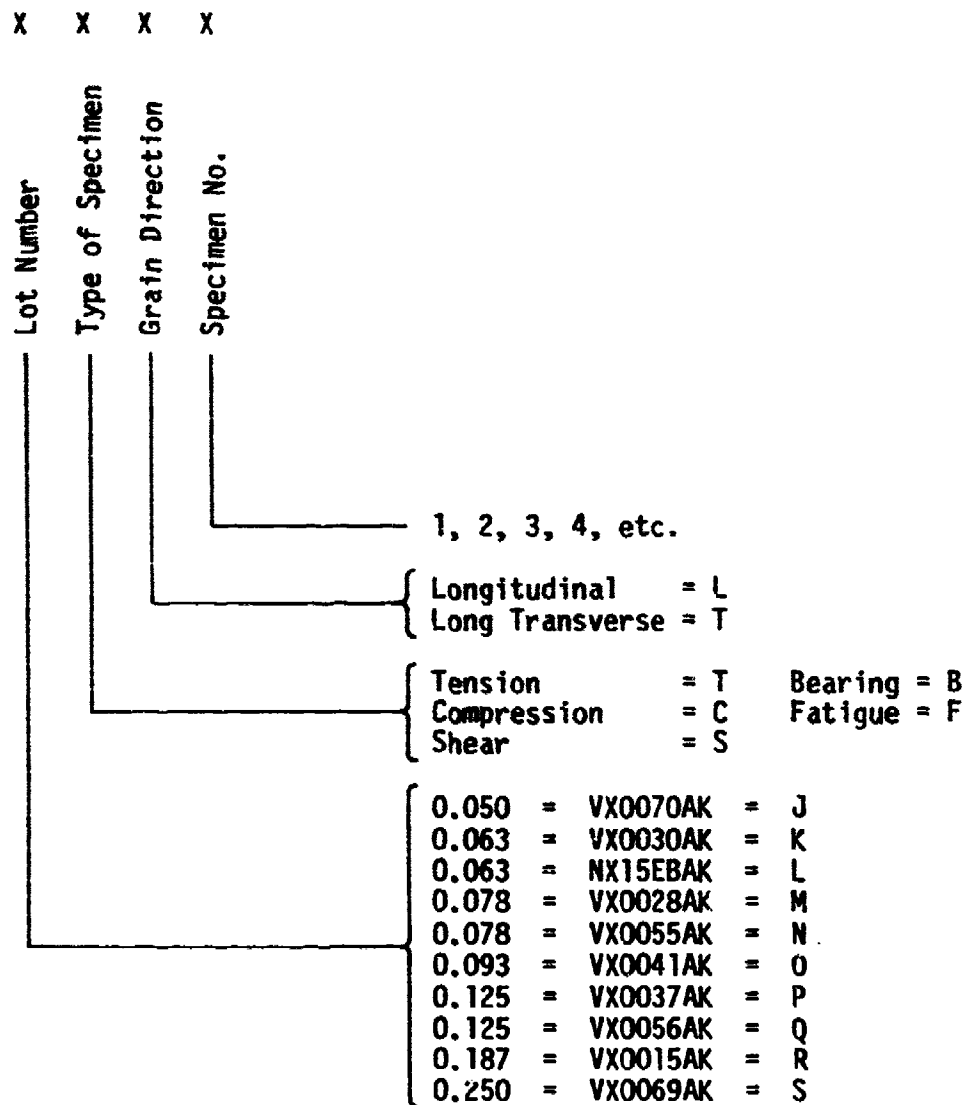


Figure 20. Specimen identification code for Inconel 625 sheet.

## Test Results

Tensile. The results of the tensile tests are shown in Tables 10 and 10(a). In addition to tensile yield and ultimate strengths, elongation and modulus of elasticity values are indicated. The long transverse tensile yield strength of one heat (VX0037AK) of 0.125-inch sheet was marginally below the minimum value of 60 ksi specified in AMS 5599. Typical tensile stress-strain curves for each grain direction are presented in Figure 21. Tensile stress-strain curves were constructed in the same manner as those for Inconel 718 bar.

Compression. The results of compression tests are shown in Tables 10 and 10(a). Compressive modulus of elasticity values are listed in addition to compressive yield strengths. Typical compressive stress-strain curves are presented in Figure 22 for each grain direction. The compressive stress-strain curves were constructed in the same manner as those for Inconel 718 bar.

Shear. The results of tension-shear tests are shown in Tables 10 and 10(a). Values for shear ultimate strength are listed.

Bearing. The results of the bearing tests are shown in Tables 10 and 10(a). Values for bearing yield and ultimate strengths for  $e/D = 1.5$  and  $e/D = 2.0$  are listed.

Fatigue. The results of axial-stress fatigue tests are presented in Tables 11 and 12. All fatigue test specimens were taken from one heat of 0.093-inch-thick sheet. Fatigue tests were conducted only in the long transverse grain direction utilizing unnotched and notched,  $K_t = 3$ , specimens. Tests were conducted at three stress ratios,  $R = -0.5$ ,  $R = 0.1$ , and  $R = 0.5$ .

Initially, the fatigue data were analyzed according to Section 9.3.4 of MIL-HDBK-5, which specifies that runouts not be included. This analytical procedure resulted in extremely conservative fatigue strength estimates in the high cycle region, ( $N_f > 10^6$ ). The data were reanalyzed treating the runouts as failures. Also, runouts significantly below those exhibiting the highest stress were not included in the analyses. These changes in the analytical procedure produced S/N curves which fit the data better, especially in the high cycle region, ( $N_f > 10^6$ ). These S/N curves are presented in Figures 23 and 24.

TABLE 10. MECHANICAL PROPERTIES OF ANNEALED INCONEL 625 SHEET

| Plate Thickness, inches | Grain Direction | Specimen No. | Tensile                |                     |                     | Compressive                  |                     | Shear                        | Bearing                |                     |                        | (1)   |
|-------------------------|-----------------|--------------|------------------------|---------------------|---------------------|------------------------------|---------------------|------------------------------|------------------------|---------------------|------------------------|-------|
|                         |                 |              | Ultimate Strength, ksi | Yield Strength, ksi | Elongation, percent | Modulus, 10 <sup>3</sup> ksi | Yield Strength, ksi | Modulus, 10 <sup>3</sup> ksi | Ultimate Strength, ksi | Yield Strength, ksi | Ultimate Strength, ksi |       |
| 0.050<br>VX0070AK       | L               | 1            | 138.3                  | 74.7                | 44.5                | 28.5                         | 76.5                | 29.9                         | 113.8                  | 233.6               | 119.0                  | 262.4 |
|                         |                 | 2            | 138.8                  | 76.0                | 44.0                | 28.9                         | 77.0                | 30.0                         | 116.8                  | 233.5               | 119.4                  | 295.8 |
|                         |                 | 3            | 136.4                  | 69.4                | 45.5                | 28.5                         | 76.5                | 30.4                         | 114.5                  | 236.1               | 120.3                  | 288.5 |
|                         |                 | Avg.         | 137.8                  | 73.4                | 44.7                | 28.6                         | 76.7                | 30.1                         | 115.0                  | 234.4               | 119.6                  | 282.2 |
| 0.050<br>VX0070AK       | LT              | 1            | 135.9                  | 74.4                | 44.5                | 28.6                         | 78.9                | 31.1                         | 116.5                  | 233.3               | 122.7                  | 274.0 |
|                         |                 | 2            | 135.3                  | 75.0                | 45.0                | 28.1                         | 79.3                | 31.3                         | 112.5                  | 233.0               | 117.0                  | 284.3 |
|                         |                 | 3            | 135.5                  | 74.4                | 46.0                | 28.6                         | 79.5                | 31.3                         | 112.5                  | 219.4               | 115.4                  | 276.1 |
|                         |                 | Avg.         | 135.6                  | 74.6                | 45.2                | 28.4                         | 79.2                | 31.2                         | 113.8                  | 228.6               | 118.4                  | 278.1 |
| 0.063<br>VX0030AK       | L               | 1            | 125.8                  | 67.1                | 48.5                | 26.3                         | 69.7                | 30.6                         | 110.2                  | 220.9               | 113.5                  | 285.1 |
|                         |                 | 2            | 127.0                  | 67.3                | 49.0                | 28.3                         | 69.8                | 30.0                         | 109.7                  | 221.0               | 116.4                  | 291.2 |
|                         |                 | 3            | 127.0                  | 67.3                | 51.0                | 27.5                         | 69.6                | 30.6                         | 109.6                  | 221.2               | 116.4                  | 290.7 |
|                         |                 | Avg.         | 126.6                  | 67.2                | 49.5                | 27.4                         | 69.7                | 30.4                         | 109.8                  | 221.1               | 115.4                  | 289.0 |
| 0.063<br>VX0030AK       | LT              | 1            | 129.7                  | 65.0                | 50.0                | 28.8                         | 71.6                | 30.2                         | 109.3                  | 220.8               | 114.3                  | 288.5 |
|                         |                 | 2            | 126.6                  | 64.6                | 49.5                | 27.1                         | 72.0                | 30.6                         | 108.9                  | 220.5               | 113.7                  | 283.8 |
|                         |                 | 3            | 126.6                  | 64.7                | 50.0                | 28.9                         | 72.0                | 30.4                         | 110.2                  | 220.8               | 115.6                  | 286.8 |
|                         |                 | Avg.         | 127.6                  | 64.8                | 49.8                | 28.3                         | 71.9                | 30.4                         | 109.5                  | 220.7               | 114.5                  | 286.4 |
| 0.063<br>NX15EBAK       | L               | 1            | 133.3                  | 73.1                | 46.0                | 28.2                         | 74.8                | 30.3                         | 111.2                  | 227.5               | 114.5                  | 301.0 |
|                         |                 | 2            | 134.1                  | 72.7                | 46.5                | 28.2                         | 75.1                | 30.1                         | 112.5                  | 228.9               | 115.9                  | 303.3 |
|                         |                 | 3            | 133.7                  | 72.7                | 45.5                | 28.9                         | 74.9                | 30.2                         | 112.6                  | 228.5               | 117.5                  | 308.3 |
|                         |                 | Avg.         | 133.7                  | 72.8                | 46.0                | 28.4                         | 74.9                | 30.2                         | 112.1                  | 228.3               | 115.9                  | 304.2 |
| 0.063<br>NX15EBAK       | LT              | 1            | 134.4                  | 68.2                | 47.5                | 28.5                         | 74.5                | 30.8                         | 111.7                  | 229.2               | 118.6                  | 304.9 |
|                         |                 | 2            | 134.4                  | 70.3                | 47.0                | 27.7                         | 75.0                | 30.7                         | 112.0                  | 229.6               | 118.2                  | 295.9 |
|                         |                 | 3            | 134.1                  | 70.2                | 47.0                | 29.2                         | 75.2                | 31.5                         | 112.0                  | 229.8               | 118.6                  | 299.2 |
|                         |                 | Avg.         | 134.3                  | 69.6                | 47.2                | 28.5                         | 74.9                | 31.0                         | 111.9                  | 229.6               | 118.4                  | 300.0 |
| 0.078<br>VX0028AK       | L               | 1            | 132.9                  | 71.9                | 46.5                | 29.5                         | 75.6                | 30.2                         | 140.8                  | 230.2               | 111.8                  | 299.0 |
|                         |                 | 2            | 132.9                  | 72.2                | 47.0                | 29.9                         | 74.8                | 30.0                         | 112.6                  | 230.3               | 112.9                  | 305.4 |
|                         |                 | 3            | 132.8                  | 71.3                | 47.5                | 30.4                         | 77.0                | 30.4                         | 113.1                  | 229.8               | 112.8                  | 301.4 |
|                         |                 | Avg.         | 132.9                  | 71.8                | 47.0                | 29.9                         | 75.8                | 30.2                         | 122.2                  | 230.1               | 112.5                  | 301.9 |



TABLE 10. (Continued)

| Plate Thickness, inches | Grain Direction | Specimen No. | Tensile                |                     |                     | Compressive                  |                     | Shear                        | Bearing                |                     |                        |
|-------------------------|-----------------|--------------|------------------------|---------------------|---------------------|------------------------------|---------------------|------------------------------|------------------------|---------------------|------------------------|
|                         |                 |              | Ultimate Strength, ksi | Yield Strength, ksi | Elongation, percent | Modulus, 10 <sup>6</sup> ksi | Yield Strength, ksi | Modulus, 10 <sup>6</sup> ksi | Ultimate Strength, ksi | Yield Strength, ksi | Ultimate Strength, ksi |
| 0.078<br>VX0028AK       | LT              | 1            | 136.7                  | 70.9                | 45.5                | 29.4                         | 75.4                | 30.6                         | 113.4                  | (2)                 | 299.7                  |
|                         |                 | 2            | 137.0                  | 73.9                | 45.5                | 30.2                         | 74.3                | 30.8                         | 112.5                  | 115.6               | 305.9                  |
|                         |                 | 3            | 137.0                  | 74.0                | 45.5                | 28.6                         | 75.0                | 31.3                         | 112.5                  | 117.0               | 301.7                  |
|                         |                 | Avg.         | 136.9                  | 72.9                | 45.5                | 29.4                         | 74.9                | 30.9                         | 112.8                  | 116.3               | 302.4                  |
| 0.078<br>VX0055AK       | L               | 1            | 134.5                  | 71.1                | 47.5                | 29.9                         | 74.4                | 30.9                         | 113.2                  | 116.7               | 300.6                  |
|                         |                 | 2            | 133.8                  | 71.2                | 46.5                | 31.3                         | 74.4                | 30.6                         | 113.6                  | 118.3               | 294.9                  |
|                         |                 | 3            | 135.1                  | 70.8                | 46.5                | 31.3                         | 73.9                | 30.2                         | 113.1                  | (2)                 | 301.2                  |
|                         |                 | Avg.         | 134.5                  | 71.0                | 46.8                | 30.8                         | 74.2                | 30.6                         | 113.3                  | 117.5               | 298.9                  |
| 0.078<br>VX0055AK       | LT              | 1            | 134.8                  | 70.6                | 48.5                | 33.6                         | 74.1                | 30.9                         | 113.8                  | 113.5               | 300.0                  |
|                         |                 | 2            | 131.8                  | 70.7                | 47.5                | 29.4                         | 74.3                | 31.1                         | 112.4                  | 114.7               | 299.5                  |
|                         |                 | 3            | 134.2                  | 70.6                | 47.5                | 31.6                         | 74.5                | 31.2                         | 113.1                  | 118.5               | 302.4                  |
|                         |                 | Avg.         | 134.3                  | 70.6                | 47.8                | 31.5                         | 74.3                | 31.1                         | 113.1                  | 115.6               | 300.6                  |
| 0.093<br>VX0041AK       | L               | 1            | 136.4                  | 74.0                | 45.5                | 30.6                         | 72.2                | 29.2                         | 153.4                  | 113.7               | 302.1                  |
|                         |                 | 2            | 137.4                  | 73.0                | 45.5                | 28.2                         | 76.1                | 29.5                         | 153.4                  | 116.2               | 302.4                  |
|                         |                 | 3            | 137.1                  | 73.7                | 45.0                | 29.1                         | 76.2                | 29.9                         | 115.2                  | 97.8                | 304.1                  |
|                         |                 | Avg.         | 137.6                  | 73.6                | 45.3                | 29.6                         | 74.8                | 29.5                         | 140.7                  | 109.2               | 302.9                  |
| 0.093<br>VX0041AK       | LT              | 1            | 136.6                  | 75.0                | 47.5                | 30.8                         | 77.3                | 30.8                         | 113.6                  | 115.6               | 306.7                  |
|                         |                 | 2            | 134.7                  | 74.4                | 46.5                | 29.4                         | 77.8                | 31.2                         | 113.5                  | 111.7               | 306.0                  |
|                         |                 | 3            | 134.9                  | 74.3                | 47.5                | 30.3                         | 77.7                | 31.3                         | 114.8                  | 113.5               | 304.9                  |
|                         |                 | Avg.         | 135.4                  | 74.6                | 47.2                | 30.2                         | 77.6                | 31.1                         | 114.0                  | 113.6               | 305.9                  |
| 0.125<br>VX0037AK       | L               | 1            | 127.6                  | 58.5                | 53.0                | 30.7                         | 61.9                | 30.0                         | 110.1                  | 97.9                | 292.4                  |
|                         |                 | 2            | 126.7                  | 59.7                | 52.0                | 31.4                         | 62.2                | 30.4                         | 113.8                  | 100.4               | 298.0                  |
|                         |                 | 3            | 127.0                  | 60.2                | 51.5                | 29.7                         | 61.8                | 30.6                         | 110.6                  | 96.9                | 290.7                  |
|                         |                 | Avg.         | 127.1                  | 59.5                | 52.2                | 30.6                         | 62.0                | 30.3                         | 111.5                  | 98.4                | 291.0                  |
| 0.125<br>VX0037AK       | LT              | 1            | 126.5                  | 59.6                | 52.0                | 31.0                         | 62.3                | 29.8                         | 110.8                  | 102.9               | 290.2                  |
|                         |                 | 2            | 126.9                  | 59.8                | 51.5                | 30.8                         | 62.5                | 30.0                         | 110.7                  | 105.8               | 292.7                  |
|                         |                 | 3            | 126.4                  | 59.6                | 51.0                | 29.4                         | 62.4                | 30.1                         | 111.2                  | 95.5                | 287.6                  |
|                         |                 | Avg.         | 126.6                  | 59.7                | 51.5                | 30.4                         | 62.4                | 30.0                         | 110.9                  | 101.4               | 290.2                  |

TABLE 10. (Continued)

| Plate Thickness, inches | Grain Direction | Specimen No. | Tensile                |                     |                     |                              | Compressive         |                              | Shear | Bearing                |                     |                        |                     |
|-------------------------|-----------------|--------------|------------------------|---------------------|---------------------|------------------------------|---------------------|------------------------------|-------|------------------------|---------------------|------------------------|---------------------|
|                         |                 |              | Ultimate Strength, ksi | Yield Strength, ksi | Elongation, percent | Modulus, 10 <sup>3</sup> ksi | Yield Strength, ksi | Modulus, 10 <sup>3</sup> ksi |       | e/D = 1.5              |                     | e/D = 2.0 (1)          |                     |
|                         |                 |              |                        |                     |                     |                              |                     |                              |       | Ultimate Strength, ksi | Yield Strength, ksi | Ultimate Strength, ksi | Yield Strength, ksi |
| 0.125<br>VX0056AK       | L               | 1            | 135.7                  | 71.3                | 47.0                | 29.0                         | 73.4                | 30.6                         | 115.0 | 227.8                  | 101.0               | 304.8                  | 125.5               |
|                         |                 | 2            | 135.4                  | 72.2                | 47.0                | 30.1                         | 73.4                | 29.8                         | 114.6 | 221.3                  | 106.5               | 305.5                  | 128.3               |
|                         |                 | 3            | 135.2                  | 71.1                | 47.0                | 30.8                         | 73.5                | 30.1                         | 115.1 | 222.2                  | 94.1                | 304.7                  | 124.2               |
|                         |                 | Avg.         | 135.4                  | 71.5                | 47.0                | 30.0                         | 73.4                | 30.2                         | 114.9 | 223.8                  | 100.5               | 305.0                  | 126.0               |
| 0.125<br>VX0056AK       | LT              | 1            | 134.3                  | 71.4                | 47.5                | 31.5                         | 74.5                | 30.2                         | 113.6 | 231.0                  | 104.3               | 308.5                  | 131.3               |
|                         |                 | 2            | 134.1                  | 71.0                | 47.0                | 29.9                         | 74.6                | 30.5                         | 113.9 | 230.0                  | 108.2               | 307.6                  | 131.9               |
|                         |                 | 3            | 134.1                  | 71.7                | 48.0                | 30.9                         | 74.7                | 31.0                         | 130.6 | 226.9                  | 103.1               | 309.0                  | 137.9               |
|                         |                 | Avg.         | 134.2                  | 71.4                | 47.5                | 30.8                         | 74.6                | 30.6                         | 113.8 | 229.3                  | 105.2               | 308.4                  | 133.7               |
| 0.187<br>VX0015AK       | L               | 1            | 128.4                  | 62.6                | 51.5                | 31.3                         | 68.0                | 29.9                         | 110.2 | 222.2                  | 109.2               | 297.9                  | 133.3               |
|                         |                 | 2            | 129.7                  | 65.7                | 51.5                | 27.1                         | 67.7                | 29.5                         | 109.4 | 223.1                  | 109.1               | 294.8                  | 128.2               |
|                         |                 | 3            | 129.4                  | 65.8                | 52.0                | 29.0                         | 67.5                | 29.4                         | 110.7 | 223.9                  | 109.4               | 296.2                  | 126.6               |
|                         |                 | Avg.         | 129.2                  | 64.7                | 51.7                | 29.1                         | 67.7                | 29.6                         | 110.1 | 223.1                  | 109.3               | 295.6                  | 129.4               |
| 0.187<br>VX0015AK       | LT              | 1            | 129.7                  | 63.8                | 51.5                | 28.2                         | 69.0                | 29.7                         | 109.9 | 221.1                  | 106.5               | 294.7                  | 130.2               |
|                         |                 | 2            | 129.6                  | 64.1                | 50.0                | 30.1                         | 69.4                | 29.6                         | 109.6 | 215.9                  | 105.5               | 290.0                  | 125.4               |
|                         |                 | 3            | 129.7                  | 63.7                | 50.5                | 27.8                         | 68.7                | 29.8                         | 111.9 | 210.3                  | 101.3               | 294.8                  | 131.7               |
|                         |                 | Avg.         | 129.7                  | 63.9                | 50.7                | 28.7                         | 69.0                | 29.7                         | 110.4 | 215.7                  | 104.4               | 293.1                  | 129.1               |
| 0.250<br>VX0059AK       | L               | 1            | 128.9                  | 62.5                | 53.5                | 28.6                         | 66.2                | 29.4                         | 109.8 | 226.3                  | 98.4                | 297.0                  | 131.7               |
|                         |                 | 2            | 128.0                  | 62.6                | 53.0                | 29.3                         | 66.3                | 29.0                         | 109.7 | 221.2                  | 97.8                | 297.5                  | 134.5               |
|                         |                 | 3            | 128.1                  | 63.3                | 53.0                | 27.4                         | 65.9                | 28.5                         | 108.8 | 222.7                  | 102.1               | 296.9                  | 131.7               |
|                         |                 | Avg.         | 128.3                  | 62.8                | 53.2                | 28.4                         | 66.1                | 29.0                         | 109.4 | 223.4                  | 99.4                | 297.1                  | 132.6               |
| 0.250<br>VX0059AK       | LT              | 1            | 128.6                  | 63.8                | 52.5                | 28.7                         | 67.5                | 29.5                         | 110.2 | 221.2                  | 105.0               | 295.1                  | 137.3               |
|                         |                 | 2            | 129.0                  | 62.6                | 52.0                | 27.4                         | 66.2                | 29.5                         | 107.6 | 215.1                  | 103.2               | 294.0                  | 132.7               |
|                         |                 | 3            | 128.2                  | 63.2                | 52.0                | 28.7                         | 68.8                | 29.9                         | 110.1 | 222.6                  | 95.7                | 294.3                  | 131.5               |
|                         |                 | Avg.         | 128.6                  | 63.2                | 52.2                | 28.3                         | 67.5                | 29.6                         | 109.3 | 219.6                  | 101.3               | 294.5                  | 133.8               |

(1) Specimen numbers for  $e/D = 2.0$  were 4 through 6.

(2) Uncharacteristic load-deformation curve.

(3) X-Y plotter problem.

TABLE 10(a). MECHANICAL PROPERTIES OF ANNEALED INCONEL 625 SHEET

| Plate Thickness, mm | Grain Direction | Specimen No. | Tensile                |                     |                     |              | Compressive         |              | Shear | Bearing                |                     |                        |                     |
|---------------------|-----------------|--------------|------------------------|---------------------|---------------------|--------------|---------------------|--------------|-------|------------------------|---------------------|------------------------|---------------------|
|                     |                 |              | Ultimate Strength, MPa | Yield Strength, MPa | Elongation, percent | Modulus, GPa | Yield Strength, MPa | Modulus, MPa |       | e/D = 1.5              |                     | e/D = 2.0 (1)          |                     |
|                     |                 |              |                        |                     |                     |              |                     |              |       | Ultimate Strength, MPa | Yield Strength, MPa | Ultimate Strength, MPa | Yield Strength, MPa |
| 1.27<br>VX0070AK    | L               | 1            | 953.6                  | 515.1               | 44.5                | 196.5        | 527.5               | 206.2        | 784.4 | 1610.4                 | 820.4               | 1808.9                 | 1047.2              |
|                     |                 | 2            | 957.0                  | 524.0               | 44.0                | 199.3        | 530.9               | 206.9        | 805.0 | 1609.7                 | 823.4               | 2039.3                 | 1014.4              |
|                     |                 | 3            | 940.5                  | 478.5               | 45.5                | 196.5        | 527.5               | 209.6        | 789.7 | 1627.6                 | 829.7               | 1986.9                 | (2)                 |
|                     |                 | Avg.         | 950.4                  | 505.9               | 44.7                | 197.4        | 528.6               | 207.5        | 793.0 | 1615.9                 | 824.5               | 1945.7                 | 1030.8              |
| 1.27<br>VX0070AK    | LT              | 1            | 937.0                  | 513.0               | 44.5                | 197.2        | 544.0               | 214.4        | 803.4 | 1608.4                 | 845.9               | 1889.3                 | 1004.2              |
|                     |                 | 2            | 932.9                  | 517.1               | 45.0                | 193.7        | 546.8               | 215.8        | 775.5 | 1606.8                 | 806.9               | 1960.3                 | 1010.4              |
|                     |                 | 3            | 934.3                  | 513.0               | 46.0                | 197.2        | 548.2               | 215.8        | 775.5 | 1512.9                 | 795.8               | 1903.7                 | 971.6               |
|                     |                 | Avg.         | 934.7                  | 514.4               | 45.2                | 196.0        | 546.3               | 215.4        | 784.8 | 1576.1                 | 816.2               | 1917.8                 | 995.4               |
| 1.60<br>VX0030AK    | L               | 1            | 867.4                  | 462.7               | 48.5                | 181.3        | 480.6               | 211.0        | 759.8 | 1523.2                 | 782.5               | 1965.8                 | 942.2               |
|                     |                 | 2            | 875.7                  | 464.0               | 49.0                | 195.1        | 481.3               | 206.9        | 756.5 | 1524.0                 | 802.7               | 2008.1                 | 932.4               |
|                     |                 | 3            | 875.7                  | 464.0               | 51.0                | 189.6        | 479.9               | 211.0        | 755.5 | 1525.2                 | 802.6               | 2004.3                 | (3)                 |
|                     |                 | Avg.         | 872.9                  | 463.6               | 49.5                | 188.7        | 480.6               | 209.6        | 757.3 | 1524.1                 | 795.9               | 1992.7                 | 937.3               |
| 1.60<br>VX0030AK    | LT              | 1            | 894.3                  | 448.2               | 50.0                | 198.6        | 495.1               | 208.2        | 753.7 | 1522.2                 | 788.0               | 1989.3                 | 927.6               |
|                     |                 | 2            | 872.9                  | 445.4               | 49.5                | 186.9        | 496.4               | 211.0        | 751.1 | 1520.2                 | 783.7               | 1956.5                 | 944.8               |
|                     |                 | 3            | 872.9                  | 446.1               | 50.0                | 199.3        | 496.4               | 209.6        | 759.9 | 1522.1                 | 796.8               | 1977.5                 | 903.5               |
|                     |                 | Avg.         | 880.0                  | 446.6               | 49.8                | 194.9        | 496.0               | 209.6        | 754.9 | 1521.5                 | 789.5               | 1974.5                 | 925.3               |
| 1.60<br>WX15EAK     | L               | 1            | 919.1                  | 504.0               | 46.0                | 194.4        | 515.7               | 208.9        | 766.5 | 1568.4                 | 789.2               | 2075.5                 | 993.6               |
|                     |                 | 2            | 924.6                  | 501.3               | 46.5                | 194.4        | 517.8               | 207.5        | 776.0 | 1578.1                 | 798.8               | 2091.5                 | 977.8               |
|                     |                 | 3            | 921.9                  | 501.3               | 45.5                | 199.3        | 516.4               | 208.2        | 776.4 | 1575.4                 | 810.2               | 2125.8                 | 970.4               |
|                     |                 | Avg.         | 921.9                  | 502.2               | 46.0                | 196.0        | 516.7               | 208.2        | 773.0 | 1574.0                 | 799.4               | 2097.6                 | 980.6               |
| 1.60<br>WX15EAK     | LT              | 1            | 926.7                  | 470.2               | 47.5                | 196.5        | 513.7               | 212.4        | 770.2 | 1580.7                 | 817.5               | 2102.0                 | 978.7               |
|                     |                 | 2            | 926.7                  | 484.7               | 47.0                | 191.0        | 517.1               | 211.7        | 772.5 | 1582.9                 | 814.8               | 2040.1                 | 926.8               |
|                     |                 | 3            | 924.6                  | 484.0               | 47.0                | 201.3        | 518.5               | 217.2        | 772.5 | 1584.8                 | 817.8               | 2063.0                 | 949.5               |
|                     |                 | Avg.         | 926.0                  | 479.7               | 47.2                | 196.3        | 516.4               | 213.7        | 771.7 | 1582.8                 | 816.7               | 2068.4                 | 951.7               |
| 1.98<br>VX0028AK    | L               | 1            | 916.3                  | 495.8               | 46.5                | 203.4        | 521.3               | 208.2        | 970.8 | 1587.1                 | 771.0               | 2061.8                 | 938.6               |
|                     |                 | 2            | 916.3                  | 497.8               | 47.0                | 206.2        | 515.7               | 206.9        | 776.4 | 1588.0                 | 778.4               | 2105.6                 | 926.5               |
|                     |                 | 3            | 915.7                  | 491.6               | 47.5                | 209.6        | 530.9               | 209.6        | 779.8 | 1584.5                 | 777.9               | 2077.9                 | 922.3               |
|                     |                 | Avg.         | 916.1                  | 495.1               | 47.0                | 206.4        | 522.6               | 208.2        | 842.3 | 1586.5                 | 775.7               | 2081.7                 | 929.2               |

TABLE 10(a). (Continued)

| Plate Thickness, mm | Grain Direction | Specimen No. | Tensile                |                     |                     |              | Compressive         |              | Shear  | Bearing                |                     |        |        |
|---------------------|-----------------|--------------|------------------------|---------------------|---------------------|--------------|---------------------|--------------|--------|------------------------|---------------------|--------|--------|
|                     |                 |              | Ultimate Strength, MPa | Yield Strength, MPa | Elongation, percent | Modulus, GPa | Yield Strength, MPa | Modulus, MPa |        | $a/D = 1.5$            |                     |        |        |
|                     |                 |              |                        |                     |                     |              |                     |              |        | Ultimate Strength, MPa | Yield Strength, MPa |        |        |
| 1.98<br>VX0028AK    | LT              | 1            | 942.5                  | 488.9               | 45.5                | 202.7        | 519.9               | 211.0        | 782.0  | 1584.4                 | (2)                 | 2066.1 | 967.2  |
|                     |                 | 2            | 944.6                  | 509.5               | 45.5                | 208.2        | 512.3               | 212.4        | 775.8  | 1592.0                 | 796.9               | 2109.3 | 973.9  |
|                     |                 | 3            | 944.6                  | 510.2               | 45.5                | 197.2        | 517.1               | 215.8        | 775.7  | 1588.7                 | 806.4               | 2080.2 | 948.2  |
|                     |                 | Avg.         | 943.9                  | 502.9               | 45.5                | 202.7        | 516.4               | 213.1        | 777.8  | 1588.4                 | 801.6               | 2085.2 | 963.1  |
| 1.98<br>VX0055AK    | L               | 1            | 927.4                  | 490.2               | 47.5                | 205.5        | 513.0               | 213.1        | 780.3  | 1580.2                 | 804.7               | 2072.9 | 954.6  |
|                     |                 | 2            | 922.6                  | 490.9               | 46.5                | 215.8        | 513.0               | 211.0        | 783.3  | 1585.8                 | 815.7               | 2033.6 | 944.6  |
|                     |                 | 3            | 931.5                  | 488.2               | 46.5                | 215.8        | 509.5               | 208.2        | 779.7  | 1586.0                 | (2)                 | 2077.1 | 958.8  |
|                     |                 | Avg.         | 927.1                  | 489.8               | 46.8                | 212.4        | 511.8               | 210.8        | 781.1  | 1584.7                 | 810.2               | 2061.2 | 952.7  |
| 1.98<br>VX0055AK    | LT              | 1            | 929.4                  | 486.8               | 48.5                | 231.7        | 510.9               | 213.1        | 784.7  | 1571.6                 | 782.3               | 2068.3 | 944.7  |
|                     |                 | 2            | 922.6                  | 487.5               | 47.5                | 202.7        | 512.3               | 214.4        | 774.7  | 1568.8                 | 791.0               | 2065.3 | 952.9  |
|                     |                 | 3            | 925.3                  | 486.8               | 47.5                | 217.9        | 513.7               | 215.1        | 780.1  | 1580.7                 | 817.1               | 2085.0 | 933.5  |
|                     |                 | Avg.         | 925.8                  | 487.0               | 47.8                | 217.4        | 512.3               | 214.2        | 779.8  | 1573.7                 | 796.8               | 2072.9 | 943.7  |
| 2.36<br>VX0041AK    | L               | 1            | 954.3                  | 510.2               | 45.5                | 211.0        | 497.8               | 201.3        | 1057.7 | 1596.1                 | 783.8               | 2082.8 | 986.7  |
|                     |                 | 2            | 947.4                  | 503.3               | 45.5                | 201.3        | 524.7               | 203.4        | 1057.7 | 1601.3                 | 891.2               | 2085.3 | 957.6  |
|                     |                 | 3            | 945.3                  | 508.2               | 45.0                | 200.6        | 525.4               | 206.2        | 794.0  | 1553.7                 | 674.6               | 2096.7 | 1027.4 |
|                     |                 | Avg.         | 949.0                  | 507.2               | 45.3                | 204.3        | 516.0               | 203.6        | 969.8  | 1583.7                 | 753.2               | 2088.2 | 990.6  |
| 2.36<br>VX0041AK    | LT              | 1            | 941.9                  | 517.1               | 47.5                | 212.4        | 533.0               | 212.4        | 783.1  | 1595.5                 | 797.3               | 2114.4 | 982.7  |
|                     |                 | 2            | 928.8                  | 513.0               | 46.5                | 202.7        | 536.4               | 215.1        | 782.9  | 1570.3                 | 770.2               | 2110.2 | 968.7  |
|                     |                 | 3            | 930.1                  | 512.3               | 47.5                | 208.9        | 535.7               | 215.8        | 791.3  | 1584.6                 | 782.5               | 2102.0 | 978.1  |
|                     |                 | Avg.         | 933.6                  | 514.1               | 47.2                | 208.0        | 535.1               | 214.4        | 785.7  | 1583.5                 | 783.3               | 2108.8 | 976.5  |
| 3.175<br>VX0037AK   | L               | 1            | 879.8                  | 403.4               | 53.0                | 211.7        | 426.8               | 206.9        | 759.3  | 1443.0                 | 675.0               | 2016.0 | 859.1  |
|                     |                 | 2            | 873.6                  | 411.6               | 52.0                | 216.5        | 428.9               | 209.6        | 784.7  | 1447.8                 | 692.3               | 1999.3 | 846.3  |
|                     |                 | 3            | 875.7                  | 415.1               | 51.5                | 204.8        | 426.1               | 211.0        | 762.7  | 1441.8                 | 667.8               | 2004.2 | 841.6  |
|                     |                 | Avg.         | 876.4                  | 410.0               | 52.2                | 211.0        | 427.3               | 209.1        | 768.9  | 1444.2                 | 678.4               | 2006.5 | 849.0  |
| 3.175<br>VX0037AK   | LT              | 1            | 872.2                  | 410.9               | 52.0                | 213.7        | 429.6               | 205.5        | 764.0  | 1507.8                 | 709.2               | 2001.2 | 862.6  |
|                     |                 | 2            | 875.0                  | 412.3               | 51.5                | 212.4        | 430.9               | 206.9        | 763.2  | 1524.9                 | 729.4               | 2018.0 | 859.7  |
|                     |                 | 3            | 871.5                  | 410.9               | 51.0                | 202.7        | 430.2               | 207.5        | 766.7  | 1445.8                 | 658.7               | 1982.9 | 816.3  |
|                     |                 | Avg.         | 872.9                  | 411.4               | 51.5                | 209.5        | 430.2               | 206.6        | 764.7  | 1492.8                 | 599.1               | 2000.7 | 846.2  |

TABLE 10(a). (Continued)

| plate<br>Thick-<br>ness,<br>mm | Grain<br>Direc-<br>tion | Speci-<br>men<br>No. | Tensile                      |                           |                             |                 | Compressive               |                 |                              | Shear                        |                           | Bearing                      |                           |       |  | (1) |
|--------------------------------|-------------------------|----------------------|------------------------------|---------------------------|-----------------------------|-----------------|---------------------------|-----------------|------------------------------|------------------------------|---------------------------|------------------------------|---------------------------|-------|--|-----|
|                                |                         |                      | Ultimate<br>Strength,<br>MPa | Yield<br>Strength,<br>MPa | Elonga-<br>tion,<br>percent | Modulus,<br>GPa | Yield<br>Strength,<br>MPa | Modulus,<br>MPa | Ultimate<br>Strength,<br>GPa | $e/D = 1.5$                  |                           | $e/D = 2.0$                  |                           |       |  |     |
|                                |                         |                      |                              |                           |                             |                 |                           |                 |                              | Ultimate<br>Strength,<br>MPa | Yield<br>Strength,<br>MPa | Ultimate<br>Strength,<br>MPa | Yield<br>Strength,<br>MPa |       |  |     |
| 3.175<br>VX0056AK              | L                       | 1                    | 935.7                        | 491.6                     | 47.0                        | 200.0           | 506.1                     | 211.0           | 792.9                        | 792.9                        | 1570.5                    | 696.1                        | 2101.9                    | 865.5 |  |     |
|                                |                         | 2                    | 933.6                        | 497.8                     | 47.0                        | 207.5           | 506.1                     | 205.5           | 790.2                        | 790.2                        | 1526.2                    | 734.4                        | 2106.4                    | 884.6 |  |     |
|                                |                         | 3                    | 932.2                        | 490.2                     | 47.0                        | 212.4           | 506.8                     | 207.5           | 793.8                        | 793.8                        | 1532.1                    | 648.6                        | 2101.0                    | 856.2 |  |     |
|                                |                         | Avg.                 | 933.8                        | 493.2                     | 47.0                        | 206.6           | 506.3                     | 208.0           | 792.3                        | 792.3                        | 1542.9                    | 693.0                        | 2103.1                    | 868.8 |  |     |
| 3.175<br>VX0056AK              | LT                      | 1                    | 926.0                        | 492.3                     | 47.5                        | 217.2           | 513.7                     | 208.2           | 783.3                        | 783.3                        | 1592.6                    | 719.3                        | 2127.4                    | 905.6 |  |     |
|                                |                         | 2                    | 924.6                        | 489.5                     | 47.0                        | 206.2           | 514.4                     | 210.3           | 785.3                        | 785.3                        | 1585.8                    | 746.4                        | 2121.1                    | 909.5 |  |     |
|                                |                         | 3                    | 924.6                        | 494.4                     | 48.0                        | 213.1           | 515.1                     | 213.7           | 900.3                        | 900.3                        | 1564.3                    | 710.6                        | 2130.4                    | 951.0 |  |     |
|                                |                         | Avg.                 | 925.1                        | 492.1                     | 47.5                        | 212.1           | 514.4                     | 210.8           | 823.0                        | 823.0                        | 1580.9                    | 725.4                        | 2126.3                    | 922.0 |  |     |
| 4.75<br>VX0015AK               | L                       | 1                    | 885.3                        | 431.6                     | 51.5                        | 215.8           | 468.9                     | 206.2           | 759.8                        | 759.8                        | 1532.2                    | 753.2                        | 2053.7                    | 919.2 |  |     |
|                                |                         | 2                    | 894.3                        | 453.0                     | 51.5                        | 186.9           | 466.8                     | 203.4           | 754.4                        | 754.4                        | 1538.0                    | 752.6                        | 2032.9                    | 884.2 |  |     |
|                                |                         | 3                    | 892.2                        | 453.7                     | 52.0                        | 200.0           | 465.4                     | 202.7           | 763.1                        | 763.1                        | 1544.0                    | 754.6                        | 2028.4                    | 872.7 |  |     |
|                                |                         | Avg.                 | 890.6                        | 446.1                     | 51.7                        | 200.9           | 467.0                     | 204.1           | 759.1                        | 759.1                        | 1538.1                    | 753.5                        | 2038.4                    | 892.0 |  |     |
| 4.75<br>VX0015AK               | LT                      | 1                    | 894.3                        | 439.9                     | 51.5                        | 194.4           | 475.8                     | 204.8           | 757.8                        | 757.8                        | 1524.3                    | 734.0                        | 2031.9                    | 897.4 |  |     |
|                                |                         | 2                    | 893.6                        | 442.1                     | 50.0                        | 207.5           | 478.5                     | 204.1           | 755.3                        | 755.3                        | 1488.4                    | 727.6                        | 1999.3                    | 864.8 |  |     |
|                                |                         | 3                    | 894.3                        | 439.2                     | 50.5                        | 191.7           | 473.7                     | 205.5           | 771.3                        | 771.3                        | 1450.1                    | 698.7                        | 2032.5                    | 907.9 |  |     |
|                                |                         | Avg.                 | 894.1                        | 440.4                     | 50.7                        | 197.9           | 476.0                     | 204.8           | 761.5                        | 761.5                        | 1487.6                    | 720.1                        | 2021.2                    | 890.0 |  |     |
| 6.35<br>VX0069AK               | L                       | 1                    | 888.8                        | 430.9                     | 53.5                        | 197.2           | 456.4                     | 202.7           | 757.0                        | 757.0                        | 1560.4                    | 678.8                        | 2048.1                    | 908.0 |  |     |
|                                |                         | 2                    | 882.6                        | 431.6                     | 53.0                        | 202.0           | 457.1                     | 200.0           | 756.5                        | 756.5                        | 1524.9                    | 674.4                        | 2051.3                    | 927.7 |  |     |
|                                |                         | 3                    | 883.2                        | 436.5                     | 53.0                        | 188.9           | 454.4                     | 196.5           | 750.5                        | 750.5                        | 1535.7                    | 703.9                        | 2046.8                    | 908.2 |  |     |
|                                |                         | Avg.                 | 884.9                        | 433.0                     | 53.2                        | 196.0           | 456.0                     | 199.7           | 754.6                        | 754.6                        | 1540.3                    | 685.7                        | 2048.7                    | 914.6 |  |     |
| 6.35<br>VX0069AK               | LT                      | 1                    | 886.7                        | 439.9                     | 52.5                        | 197.9           | 465.4                     | 203.4           | 759.6                        | 759.6                        | 1524.9                    | 723.9                        | 2034.4                    | 946.5 |  |     |
|                                |                         | 2                    | 889.5                        | 431.6                     | 52.0                        | 188.9           | 456.4                     | 203.4           | 742.0                        | 742.0                        | 1483.0                    | 711.4                        | 2027.1                    | 914.8 |  |     |
|                                |                         | 3                    | 883.9                        | 435.8                     | 52.0                        | 197.9           | 474.4                     | 206.2           | 759.4                        | 759.4                        | 1534.9                    | 659.5                        | 2029.3                    | 906.4 |  |     |
|                                |                         | Avg.                 | 886.7                        | 435.8                     | 52.2                        | 194.9           | 465.4                     | 204.3           | 753.7                        | 753.7                        | 1514.3                    | 698.3                        | 2030.3                    | 922.6 |  |     |

(1) Specimen numbers for  $e/D = 2.0$  were 4 through 6.

(2) Uncharacteristic load-deformation curve.

(3) X-Y plotter problem.

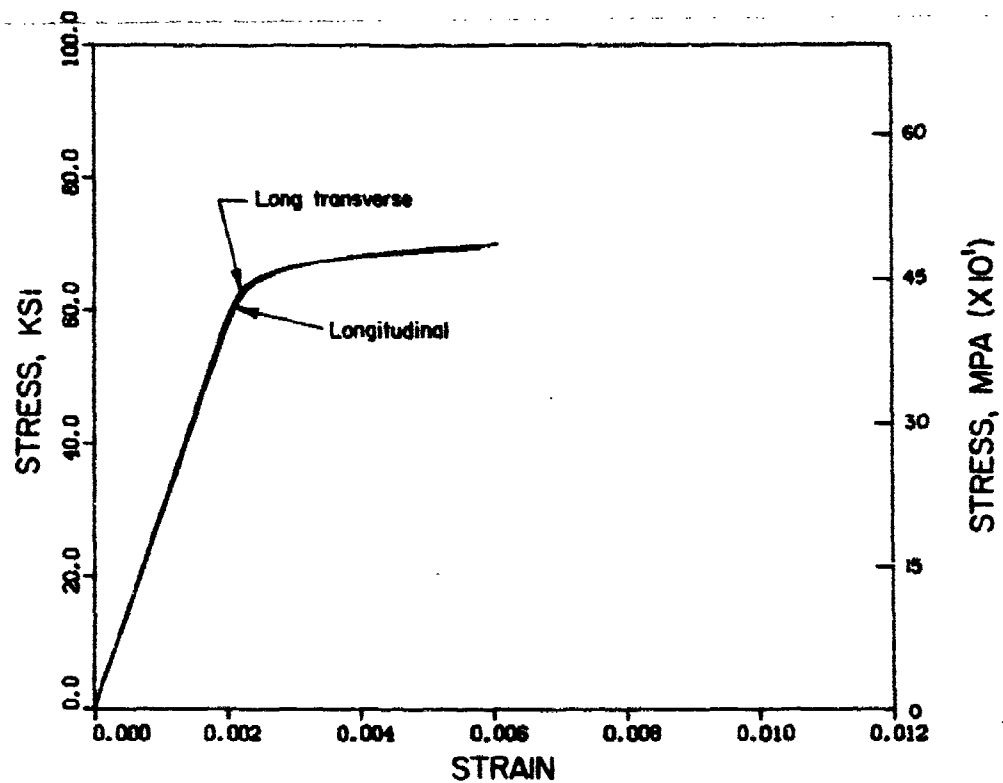


Figure 21. Typical tensile stress-strain curves for annealed Inconel 625 sheet.

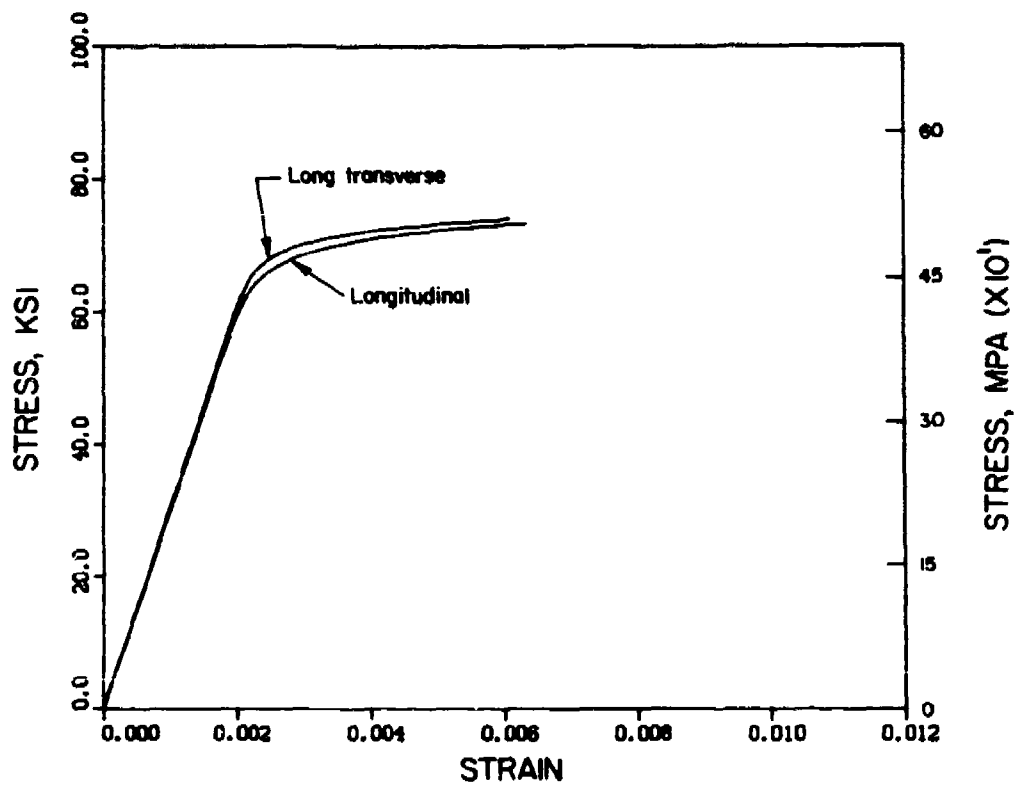


Figure 22. Typical compressive stress-strain curves for annealed Inconel 625 sheet.

TABLE 11. UNNOTCHED FATIGUE DATA FOR ANNEALED INCONEL 625  
SHEET--LONG TRANSVERSE DIRECTION

| Specimen<br>ID | Maximum<br>Stress,<br>ksi      MPa |         | R-ratio | Cycles to<br>Failure |     |
|----------------|------------------------------------|---------|---------|----------------------|-----|
| OFT17          | 120.0                              | (827.4) | -0.5    | ---                  | (1) |
| OFT3           | 120.0                              | (827.4) | -0.5    | 7,170                |     |
| OFT59          | 120.0                              | (827.4) | -0.5    | 8,230                |     |
| OFT11          | 100.0                              | (689.5) | -0.5    | 47,860               |     |
| OFT5           | 90.0                               | (620.6) | -0.5    | 47,590               |     |
| OFT9           | 90.0                               | (620.6) | -0.5    | 87,020               |     |
| OFT19          | 80.0                               | (551.6) | -0.5    | 138,220              |     |
| OFT7           | 80.0                               | (551.6) | -0.5    | 848,150              |     |
| OFT15          | 75.0                               | (517.1) | -0.5    | 3,034,310            | (2) |
| OFT13          | 70.0                               | (482.7) | -0.5    | DNF                  |     |
| OFT1           | 50.0                               | (344.8) | -0.5    | DNF                  |     |
| OFT31          | 140.0                              | (965.3) | 0.1     | 800                  | (3) |
| OFT33          | 130.0                              | (896.4) | 0.1     | 30,430               |     |
| OFT25          | 120.0                              | (827.4) | 0.1     | 47,820               |     |
| OFT27          | 100.0                              | (689.5) | 0.1     | 137,460              |     |
| OFT23          | 90.0                               | (620.6) | 0.1     | 239,350              |     |
| OFT21          | 85.0                               | (586.1) | 0.1     | 455,180              |     |
| OFT35          | 80.0                               | (551.6) | 0.1     | 518,180              |     |
| OFT39          | 70.0                               | (482.7) | 0.1     | DNF                  |     |
| OFT37          | 70.0                               | (482.7) | 0.1     | ---                  |     |
| OFT29          | 50.0                               | (344.8) | 0.1     | DNF                  |     |
| OFT53          | 134.0                              | (923.9) | 0.5     | 123,150              |     |
| OFT51          | 130.0                              | (896.4) | 0.5     | 251,300              |     |
| OFT49          | 130.0                              | (896.4) | 0.5     | 295,760              |     |
| OFT57          | 125.0                              | (861.9) | 0.5     | 278,210              |     |
| OFT47          | 120.0                              | (827.4) | 0.5     | 627,230              |     |
| OFT55          | 118.0                              | (813.6) | 0.5     | DNF                  |     |
| OFT45          | 110.0                              | (758.5) | 0.5     | DNF                  |     |
| OFT43          | 90.0                               | (620.6) | 0.5     | DNF                  |     |
| OFT41          | 50.0                               | (344.8) | 0.5     | DNF                  |     |

(1) Specimen failed on loading.

(2) DNF - did not fail; test ran 10,000,000  
cycles and stopped.

(3) Cycle count below  $10^3$ ; not plotted.

TABLE 12. NOTCHED,  $N_t = 3$ , FATIGUE DATA FOR ANNEALED INCONEL 625 SHEET--LONG TRANSVERSE DIRECTION

| Specimen ID | Maximum Stress, |         | R-ratio | Cycles to Failure |
|-------------|-----------------|---------|---------|-------------------|
|             | ksi             | MPa     |         |                   |
| OFT2        | 80.0            | (551.6) | -0.5    | 3,410             |
| OFT14       | 70.0            | (482.7) | -0.5    | 8,450             |
| OFT4        | 60.0            | (413.7) | -0.5    | 14,960            |
| OFT12       | 50.0            | (344.8) | -0.5    | 28,110 (1)        |
| OFT16       | 40.0            | (275.8) | -0.5    | 74,690            |
| OFT6        | 40.0            | (275.8) | -0.5    | 76,670            |
| OFT10       | 30.0            | (206.9) | -0.5    | 293,490           |
| OFT18       | 30.0            | (206.9) | -0.5    | 1,649,560 (2)     |
| OFT20       | 25.0            | (172.4) | -0.5    | DNF               |
| OFT8        | 20.0            | (137.9) | -0.5    | DNF               |
| OFT32       | 120.0           | (827.4) | 0.1     | 3,290             |
| OFT26       | 100.0           | (689.5) | 0.1     | 6,510             |
| OFT24       | 80.0            | (551.6) | 0.1     | 18,450            |
| OFT40       | 80.0            | (551.6) | 0.1     | 18,890            |
| OFT22       | 60.0            | (413.7) | 0.1     | 82,360            |
| OFT34       | 60.0            | (413.7) | 0.1     | 157,080           |
| OFT28       | 40.0            | (275.8) | 0.1     | 474,770           |
| OFT36       | 40.0            | (275.8) | 0.1     | 759,780           |
| OFT38       | 35.0            | (241.3) | 0.1     | DNF               |
| OFT30       | 30.0            | (206.9) | 0.1     | DNF               |
| OFT54       | 130.0           | (896.4) | 0.5     | 8,090             |
| OFT44       | 120.0           | (827.4) | 0.5     | 15,780            |
| OFT46       | 110.0           | (758.5) | 0.5     | 21,520            |
| OFT42       | 100.0           | (689.5) | 0.5     | --- (3)           |
| OFT48       | 100.0           | (689.5) | 0.5     | 29,940            |
| OFT50       | 90.0            | (620.6) | 0.5     | 40,330            |
| OFT52       | 80.0            | (551.6) | 0.5     | 120,890           |
| OFT56       | 70.0            | (482.7) | 0.5     | 351,660           |
| OFT60       | 60.0            | (413.7) | 0.5     | 1,051,090         |
| OFT58       | 50.0            | (344.8) | 0.5     | DNF               |

(1) Failed in grips.

(2) DNF - did not fail; test ran 10,000,000 cycles and stopped.

(3) Setup error.



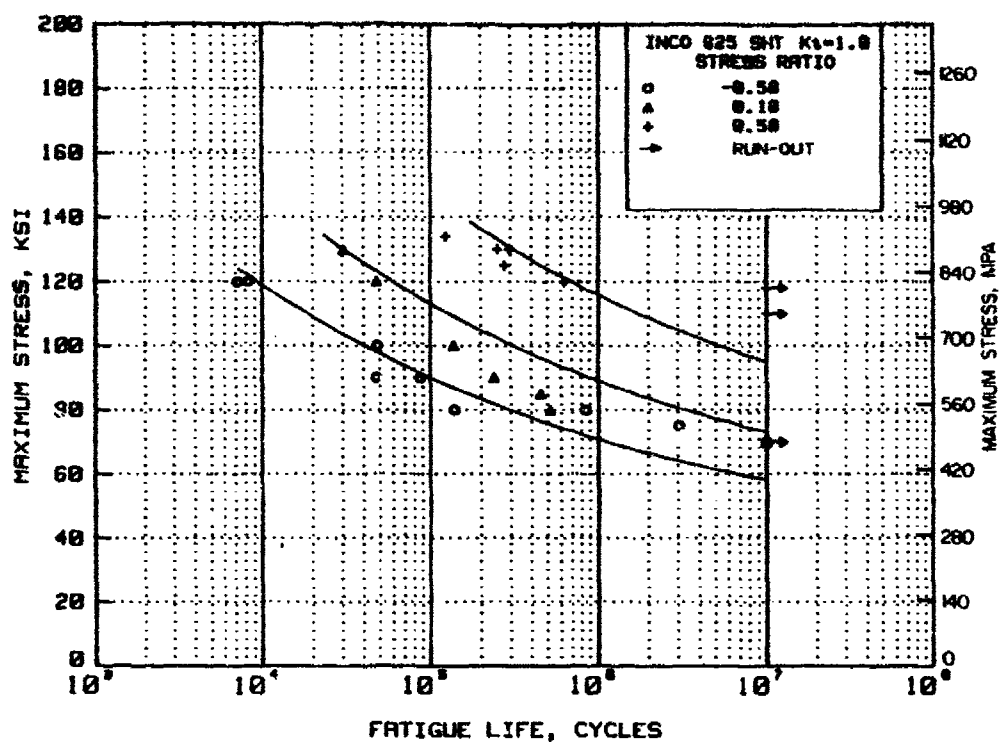


Figure 23. Unnotched axial-stress S/N curves for 0.093-inch-thick, annealed Inconel 625 sheet--long transverse direction.

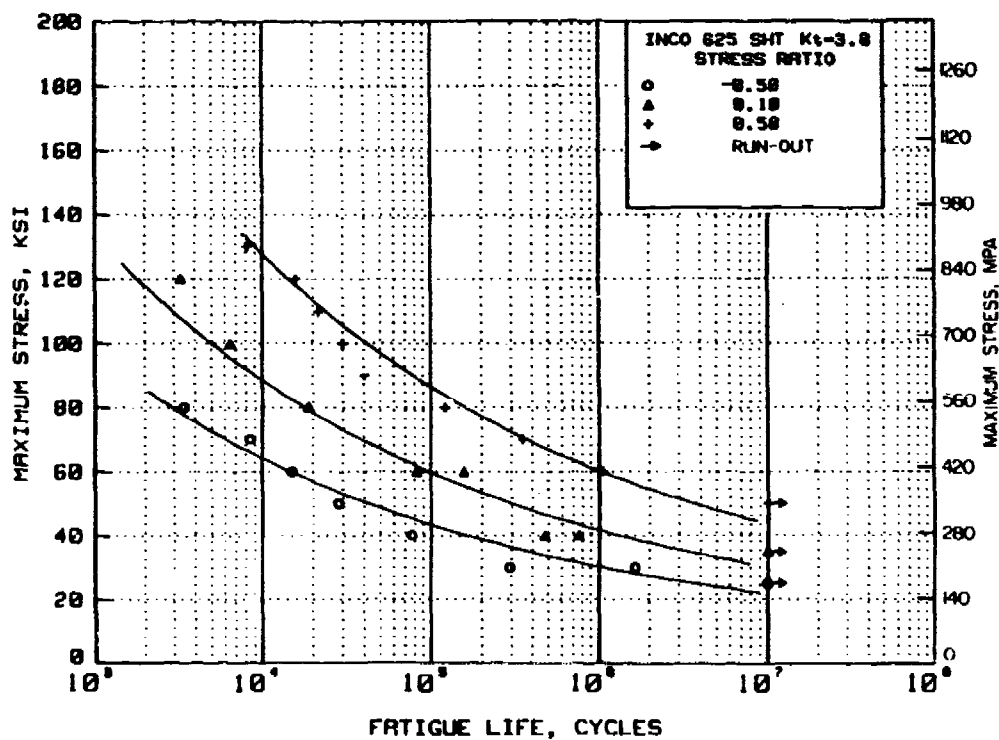


Figure 24. Notched axial-stress S/N curves for 0.093-inch-thick, annealed Inconel 625 sheet--long transverse direction.

## TESTING PROCEDURES

Tension Tests. Tension tests were performed at room temperature in accord with ASTM E8. Flat specimens were utilized for sheet, while round specimens were employed for bar. Subsize round specimens were used, as necessary, when the size of the product would not accommodate full-size specimens. The strain rate was 0.005-inch-per-inch-per-minute, as indicated by a strain pacer, until yield strength was exceeded, after which the rate was increased to 0.1-inch-per-inch-per-minute until failure. The tensile yield strength at 0.2 percent offset, tensile ultimate strength, elongation, and the tensile modulus of elasticity were obtained from this test.

Compression Tests. Compression tests were performed at room temperature in accord with ASTM E9. Cylindrical specimens were used for bar. The ends of the cylindrical specimens were parallel to 0.0002 inch, and fixturing was used to maintain alignment during testing. For sheet, flat specimens were utilized and tested in a "North American-type" compression fixture. This fixture will accommodate sheet specimens 1 by 3 inches and up to about 1/4-inch thick. The ends of the specimens were parallel to within 0.0002 inch. An extensometer, similar to the extension type, was fastened to the specimen at very small notches spanning a 2-inch gage length. The strain signal was generated by a linear differential transformer which was part of the extensometer with readout on an autographic recorder. For all tests, the strain rate was 0.005-inch-per-inch-per-minute until yield strength was exceeded. The compressive yield strength at 0.2-percent offset and the compressive modulus of elasticity were obtained from this test.

Shear Tests. Shear tests were conducted at room temperature. For sheet material, the tension-shear specimen, as specified in Standard Test Procedure ARTC-13-S-1, was used. For bar, a 0.250-inch-diameter, double-shear specimen was used. A rivet-shear type fixture was used to test pin-shear specimens from bar. The ultimate shear strength at room temperature was measured.

Bearing Tests. Bearing tests were conducted at room temperature in accord with ASTM E238. Bearing specimens were full thickness except for products over 0.100-inch thickness, for which the bearing specimens were machined to 0.100-inch thick. All tests were "clean pin" tests as, defined in the above specification. The ultimate bearing strength and bearing yield strength at  $e/D$  ratios of 1.5 and 2.0 were measured. (The ratio of the distance between the centerline of the test hole in the bearing specimen and the edge of the specimen ( $e$ ) to the diameter of the bearing hole ( $D$ ) defines  $e/D$ .)

Fatigue Tests. Fatigue tests were conducted at room temperature in accord with ASTM E466. Axial-stress tests were performed on unnotched and notched specimens to define an S/N curve between  $10^3$  and  $10^7$  cycles. Tests were conducted in the long transverse direction for sheet and longitudinal direction for bar. Tests were conducted on smooth,  $K_t = 1$ , and notched,  $K_t = 3$ , specimens at three stress ratios.

# APPENDIX B

## SPECIMEN CONFIGURATIONS

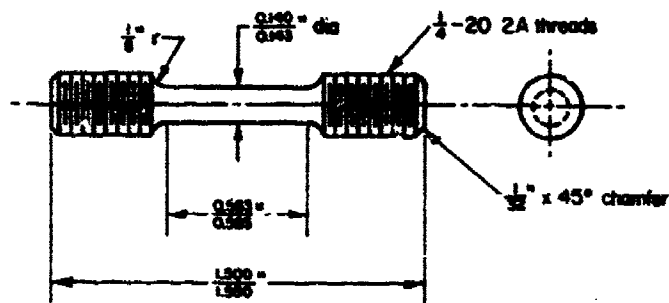


Figure B-1. Tensile specimen (short transverse direction) for 2- and 2-1/4-inch diameter Inconel 718 and Inconel 625 bars. Drawing 8T.

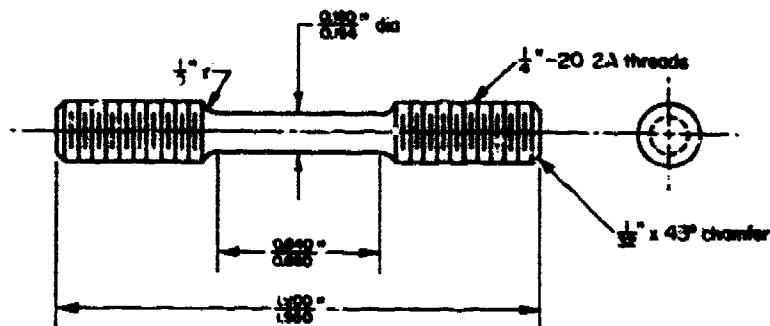


Figure B-2. Tensile specimen (short transverse direction) for 2-1/2-, 2-3/4-, and 3-inch diameter Inconel 718 and Inconel 625 bars. Drawing 10T.

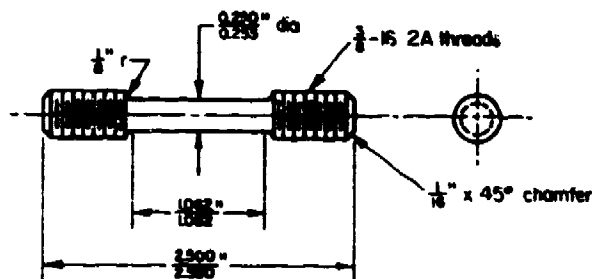


Figure B-3. Tensile specimen (short transverse direction for 3-1/4-, 3-1/2-, 3-3/4-, and 4-inch diameter and longitudinal direction for all diameters) for Inconel 718 and Inconel 625 bars. Drawing 9T.

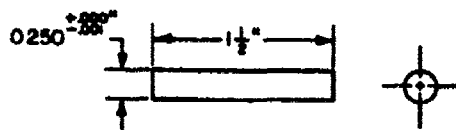


Figure B-4. Shear specimen for Inconel 718 and Inconel 625 bars. Drawing 3S.

Note: Ends of specimen shall be plane and perpendicular to the axis of specimen within 0.25 degrees. Ends shall be parallel within 0.0002°.

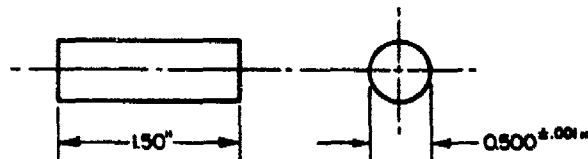


Figure B-5. Compression specimen for Inconel 718 and Inconel 625 bars. Drawing 3Co.

Note: Ends of specimen shall be plane and perpendicular to the axis of specimen within 0.25 degrees. Ends shall be parallel within 0.0002°.

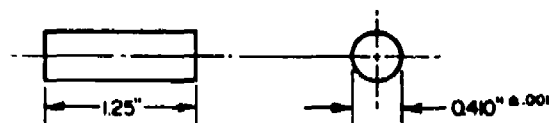


Figure B-6. Subsize compression specimen (short transverse for 2-inch-diameter) for Inconel 718 and Inconel 625 bars. Drawing 4Co.

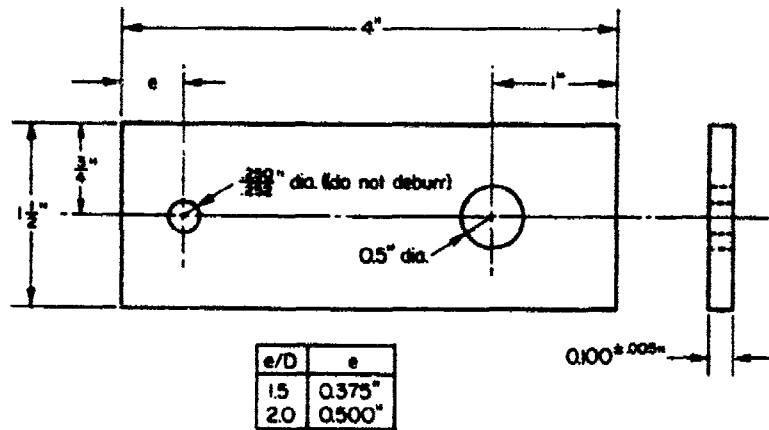


Figure B-7. Bearing specimen for Inconel 718 and Inconel 625 bars.

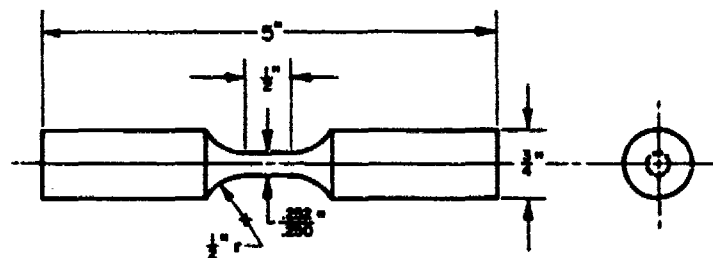


Figure B-8. Unnotched fatigue specimen for Inconel 718 and Inconel 625 bars.

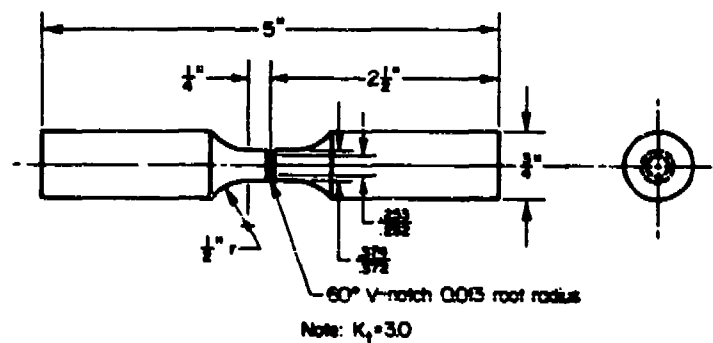
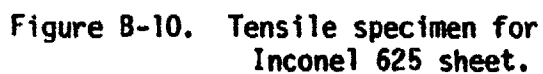


Figure B-9. Notched,  $K_t = 3$ , fatigue specimen for Inconel 718 and Inconel 625 bars.



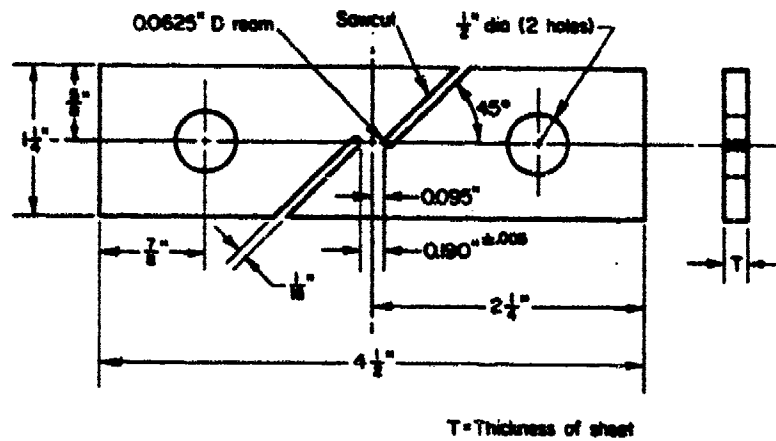


Figure B-12. Tension-shear specimen for Inconel 625 sheet.

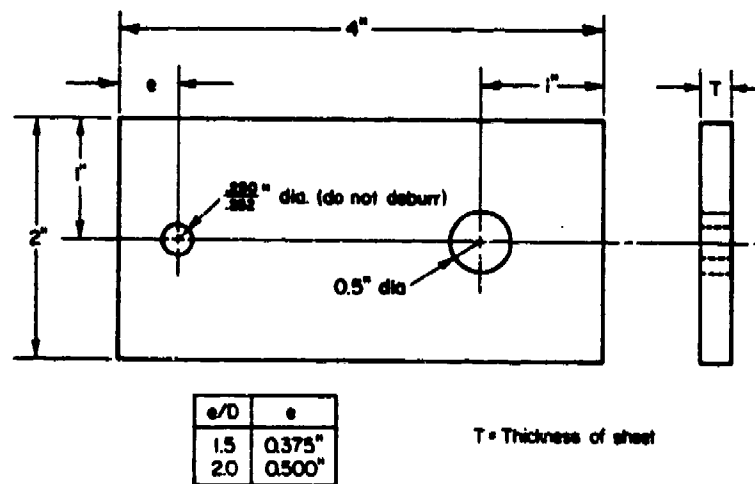


Figure B-13. Bearing specimen for Inconel 625 sheet.



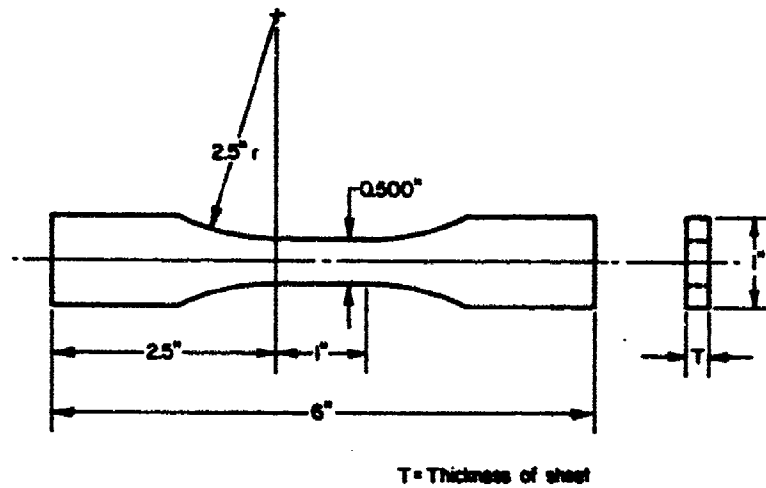


Figure B-14. Unnotched fatigue specimen  
for Inconel 625 sheet.

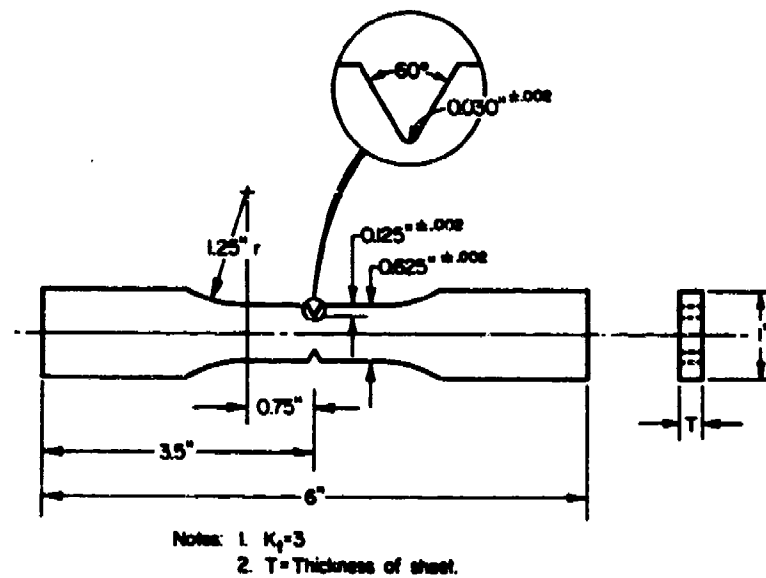


Figure B-15. Notched fatigue specimen  
for Inconel 625 sheet.