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# AZUSA PLANT

STRUCTURAL MATERIALS DIVISION

INVESTIGATION OF STRESS-CORROSION CRACKING  
OF HIGH-STRENGTH ALLOYS

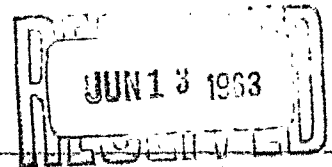
A Report To

FRANKFORD ARSENAL

Contract DA-04-495-ORD-3069

Report No. L0414-01-23/May 1963/Copy No.

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AEROJET-GENERAL CORPORATION

AZUSA, CALIFORNIA

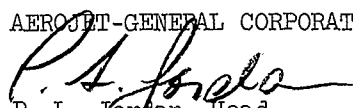
Report No. LO414-01-23

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This is the twenty-third in a series of informal monthly progress reports submitted in partial fulfillment of Contract DA-04-495-ORD-3069. It constitutes the seventh monthly progress report for the one-year continuation of the original two-year program.

This report covers the period 1 April through 30 April 1963. It was written by R. B. Setterlund who was supervised by A. Rubin.

AEROJET-GENERAL CORPORATION



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NOTE: The information contained herein is regarded as preliminary and subject to further checking, verification, and analysis.

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I. OBJECTIVES

The objectives of this program are outlined below:

A. Investigation of the stress-corrosion cracking characteristics of at least three new high-strength alloys of interest for rocket motor case applications. These alloys are 6Al-4V titanium, 18%-nickel maraging steel, and 20%-nickel maraging steel, in addition to limited testing of vacuum-melted 9Ni-4Co steel.

B. Study of the environmental parameters that could affect the rate and extent of stress-corrosion cracking.

C. Determination of the effect of material parameters (composition, strength level, welding, and microstructure) on stress-corrosion susceptibility.

D. Continuation of the evaluation of protective coatings and other techniques for preventing stress-corrosion cracking.

II. SUMMARY

Results obtained to date indicate that the 6Al-4V titanium alloy is immune to stress-corrosion cracking in the annealed, quenched and aged and as-welded conditions.

The 20%-nickel maraging steel is found to be highly susceptible to stress-corrosion cracking in the annealed-and-aged condition. Welding and aging the material causes it to become more susceptible; all failures occur in the heat-affected zone of the weld. When the alloy is cold-worked 50 or 75% before aging, the resistance to stress-corrosion cracking is greatly increased.

The 18%-nickel maraging steel was also found to be susceptible to stress-corrosion cracking. While the 18%-nickel grade was found to have a longer time-to-failure than the annealed-and-aged 20%-nickel steel in the distilled water,

## II Summary (cont.)

salt water, seacoast air, trichloroethylene, and 140°F water-saturated air environments, it showed some failures in tap water, chromate solution and soluble oil solutions where the 20%-nickel grade was not affected. As with the 20%-nickel steel it was found that prior cold-working decreased the stress-corrosion cracking susceptibility.

Fifteen coating systems designed to prevent stress-corrosion cracking are under evaluation over H-11 steel, heat-treated to give high failure susceptibility. The most promising systems are the two inhibited epoxy and one pure vinyl system.

## III. WORK PROGRESS

### A. INTRODUCTION

Since the initiation of the original test program, two years ago, to investigate the stress-corrosion cracking characteristics of high-strength alloys, a number of new high-strength steels have been receiving increased attention for use in constructing rocket motor cases. The third-year test program is directed to the study of three of these new alloys, as well as of one titanium alloy presently being used for the same application.

The test environments, substantially the same as those evaluated in the original two-year investigation, are as follows: (1) distilled water; (2) tap water; (3) salt water; (4) sodium dichromate-inhibited water; (5) soluble oil-inhibited water; (6) air; (7) high humidity atmosphere; (8) trichloroethylene; (9) cosmoline; and (10) solid propellant. These are considered to be environments representative of those to which rocket motor cases would normally be exposed during fabrication, processing, and storage. One additional environment is included in the new program, that of sea-coast atmospheric exposure.

The test methods being used in this investigation employ bent-beam, U-bend, and center-notched specimens. Evaluation of results includes microstructural studies, using both standard metallographic and electron microscopic techniques, to attempt to associate the failure mechanism with specific microstructural characteristics of the materials.

III Work Progress, A (cont.)

An evaluation of protective coatings and surface treatments to prevent stress-corrosion cracking is also being conducted.

B. PROGRAM STATUS

During the period covered by this report, four more groups of bent-beam samples of maraging steels were placed in test. These are: Group I-4 on 9 April, Group I-2 on 15 April, Group H-W on 30 April, and Group I-W on 8 May. (These code numbers refer to Table 1 designations of processing condition,) These bent-beam samples are now in test in all environments except seacoast atmospheric exposure. Seacoast testing on these four groups of specimens will start on 20 May.

Center-notch testing of the maraging steels has been continued during the last monthly period. Also, evaluation of the mechanical properties of one heat of 9Ni-4Co vacuum cast alloy has been made (Code J-1 in Table 1); stress-corrosion testing of this material will start within the next month.

Chemical and mechanical properties of the four materials being evaluated in the program are shown in Tables 2 through 4.

Results of the bent-beam and center-notch tests run to date are shown in Tables 5 through 18. Microexaminations of bent-beam failures of welded-and-aged 20%-nickel maraging steel indicate that all failures occur in the weld heat-affected-zone. A section made of a failed specimen of welded 18%-nickel steel indicates that the failure occurs in the weldment. In both the 18%- and 20%-nickel steels failures of annealed samples are of an intergranular branching pattern as indicated in earlier reports. When either the 18%- or 20%-nickel steels were cold-worked before aging, it was found that its susceptibility to stress-corrosion cracking was reduced and, at the same time, the mode of cracking changed from intergranular to possible cracking along the slip planes. This effect was most clearly shown with the 20%-nickel grade of maraging steel. Photomicrographs of both of these types of failures were included in the last quarterly report.

The results of the coating evaluation program is shown in Table 19. Fifteen different coatings are under test in three environments: aerated 3% N Cl

III Work Progress, B (cont.)

solution, 140°F water-saturated air, and outdoor seacoast exposure. As can be seen in Table 19, no single coating has been able to prevent stress-corrosion cracking in all three environments completely. However, based on data accumulated to date, the best coatings, two inhibited-epoxy systems, 454-1-1 and 463-1-5 and pure vinyl Type 33, have significantly delayed failure of highly susceptible H-11 steel specimens and are considered to be very promising.

IV. FUTURE WORK

Work will continue along the guidelines of the master plan shown in Table 1. Both bent-beam and center-notched specimens will be tested to fulfill as much as possible of this schedule. Only the 9Ni-4Co alloy remains to be tested. This testing will be only exploratory due to the lateness of the delivery of the alloy.

Metallographic sections of selected cracked samples have been photographed and presented in the last quarterly report. In addition, photomicrographs will be made on cracked 18%- and 20%-nickel maraging steel welded samples.

Three samples were studied by means of the electron microscope, utilizing fracture replicas. Selected fractographs were presented in the last quarterly report. For the final report an additional set of fractographs are being prepared using a failed sample of annealed-and-aged 18%-nickel maraging steel.

V. BUDGET

The expenditure rate for the month of April was 272 hours, leaving 207 hours for the final two months of May and June.

| Processing Condition<br>(Titanium Content of<br>Maraging Steel Shown) |                            | Strength Level,<br>0.2% Offset<br>Yield (psi) | Specimen<br>Code | Number of Test Environments |              |                     |                                       |                               |                  |                        |           |                     |                | Sea<br>Coast<br>Atmosphere | Total |
|-----------------------------------------------------------------------|----------------------------|-----------------------------------------------|------------------|-----------------------------|--------------|---------------------|---------------------------------------|-------------------------------|------------------|------------------------|-----------|---------------------|----------------|----------------------------|-------|
|                                                                       |                            |                                               |                  | Distilled<br>Water          | Tap<br>Water | 3% NaCl<br>Solution | 0.2% Sodium<br>Dichromate<br>Solution | 1% Soluble<br>Oil<br>Solution | High<br>Humidity | Trichloro-<br>ethylene | Cosmoline | Solid<br>Propellant | Ambient<br>Air |                            |       |
| 6Al-4V<br>titanium                                                    | Annealed                   | 138,000                                       | G-1              | 3*                          | 3            | 3                   | 3                                     | 3                             | 3                | 3                      | 3         | 3                   | -              | 3                          | 30    |
|                                                                       | Quenched and Aged          | 163,000                                       | G-2              | 3                           | 3            | 3                   | 3                                     | 3                             | 3                | 3                      | 3         | 3                   | -              | 3                          | 30    |
|                                                                       | Welded                     | 135,000                                       | G-W              | 2                           | 2            | 2                   | 2                                     | 2                             | 2                | 2                      | 2         | 2                   | 2              | 2                          | 20    |
|                                                                       | Total                      |                                               |                  | 8                           | 8            | 8                   | 8                                     | 8                             | 8                | 8                      | 6         | 2                   | 2              | 8                          | 80    |
| 20% Nickel<br>Maraging<br>Steel                                       | Annealed and Aged          | 291,000                                       | H-1              | 3                           | 3            | 3                   | 3                                     | 3                             | 3                | 3                      | 3         | 3                   | 3              | 3                          | 33    |
|                                                                       | 50% CW and Aged            | 321,000                                       | H-2              | 3                           | 3            | 3                   | 3                                     | 3                             | 3                | 3                      | 3         | 3                   | 3              | 3                          | 33    |
|                                                                       | 7% CW and Aged             | 298,300                                       | H-3              | 3                           | 3            | 3                   | 3                                     | 3                             | 3                | 3                      | 3         | 3                   | 3              | 3                          | 33    |
|                                                                       | Welded and Aged            | To be tested                                  | H-W              | 2                           | 2            | 2                   | 2                                     | 2                             | 2                | 2                      | 2         | 2                   | 2              | 2                          | 22    |
| Total                                                                 |                            |                                               |                  | 12                          | 12           | 12                  | 12                                    | 12                            | 12               | 12                     | 12        | 12                  | 12             | 12                         | 132   |
| 18% Nickel<br>Maraging<br>Steel                                       | Annealed & Aged (0.62% Ti) | 283,000                                       | I-1              | 3                           | 3            | 3                   | 3                                     | 3                             | 3                | 3                      | 3         | 3                   | 3              | 3                          | 33    |
|                                                                       | 50% CW & Aged (0.50% Ti)   | 302,400                                       | I-2              | 3                           | 3            | 3                   | 3                                     | 3                             | 3                | 3                      | 3         | 3                   | 3              | 3                          | 33    |
|                                                                       | 50% CW & Aged (0.62% Ti)   | 323,000                                       | I-3              | 3                           | 3            | 3                   | 3                                     | 3                             | 3                | 3                      | 3         | 3                   | 3              | 3                          | 33    |
|                                                                       | Annealed & Aged (0.50% Ti) | 249,900                                       | I-4              | 3                           | 3            | 3                   | 3                                     | 3                             | 3                | 3                      | 3         | 3                   | 3              | 3                          | 33    |
|                                                                       | 50% CW & Aged (0.40% Ti)   | 278,000                                       | I-5              | 3                           | 3            | 2                   | 3                                     | 3                             | 3                | 3                      | 3         | 3                   | 3              | 3                          | 33    |
|                                                                       | Annealed & Aged (0.32% Ti) | 255,400                                       | I-6              | 3                           | 3            | 2                   | 3                                     | 3                             | 3                | 3                      | 3         | 3                   | 3              | 3                          | 33    |
|                                                                       | 50% CW & Aged (0.52% Ti)   | 331,000                                       | I-7              | 3                           | 3            | 2                   | 3                                     | 3                             | 3                | 3                      | 3         | 3                   | 3              | 3                          | 33    |
|                                                                       | Annealed & Aged (1.00% Ti) | 323,200                                       | I-8              | 3                           | 3            | 2                   | 3                                     | 3                             | 3                | 3                      | 3         | 3                   | 3              | 3                          | 33    |
|                                                                       | 50% CW & Aged (1.00% Ti)   | 354,400                                       | I-9              | 3                           | 3            | 2                   | 3                                     | 3                             | 3                | 3                      | 3         | 3                   | 3              | 3                          | 33    |
|                                                                       | Welded & Aged (0.50% Ti)   | To be tested                                  | I-W              | 3                           | 3            | 3                   | 3                                     | 3                             | 3                | 3                      | 3         | 3                   | 3              | 3                          | 33    |
| Total                                                                 |                            |                                               | 30               | 15                          | 23           | 15                  | 15                                    | 30                            | 15               | 15                     | 23        | 23                  | 27             | 225                        |       |
| 9 Ni-4 Co<br>Vacuum-<br>Cast Alloy                                    | Aged (0.25-0.50% C)        | To be tested                                  | J-1              | 3                           | 3            | 3                   | 3                                     | 3                             | 3                | 3                      | 3         | 3                   | 3              | 3                          | 33    |
|                                                                       | Aged (0.40-0.45% C)        | To be tested                                  | J-2              | 3                           | 3            | 3                   | 3                                     | 3                             | 3                | 3                      | 3         | 3                   | 3              | 3                          | 33    |
|                                                                       | Total                      |                                               |                  | 6                           | 6            | 6                   | 6                                     | 6                             | 6                | 6                      | 6         | 6                   | 6              | 6                          | 66    |
| Application of Various<br>Protective Coatings                         |                            |                                               |                  |                             |              |                     |                                       |                               |                  |                        |           |                     |                |                            |       |
| H-11 Steel<br>(Coating Tests)                                         |                            |                                               |                  |                             |              |                     |                                       |                               |                  |                        |           |                     |                |                            |       |
|                                                                       | Total                      |                                               |                  | 56                          | 41           | 86                  | 41                                    | 41                            | 29               | 41                     | 41        | 39                  | 43             | 26                         | 92    |
|                                                                       |                            |                                               |                  |                             |              |                     |                                       |                               |                  |                        |           |                     |                |                            |       |
|                                                                       |                            |                                               |                  |                             |              |                     |                                       |                               |                  |                        |           |                     |                |                            |       |
|                                                                       |                            |                                               |                  |                             |              |                     |                                       |                               |                  |                        |           |                     |                |                            |       |
|                                                                       |                            |                                               |                  |                             |              |                     |                                       |                               |                  |                        |           |                     |                |                            |       |
|                                                                       |                            |                                               |                  |                             |              |                     |                                       |                               |                  |                        |           |                     |                |                            |       |
|                                                                       |                            |                                               |                  |                             |              |                     |                                       |                               |                  |                        |           |                     |                |                            |       |
|                                                                       |                            |                                               |                  |                             |              |                     |                                       |                               |                  |                        |           |                     |                |                            |       |
|                                                                       |                            |                                               |                  |                             |              |                     |                                       |                               |                  |                        |           |                     |                |                            |       |
|                                                                       |                            |                                               |                  |                             |              |                     |                                       |                               |                  |                        |           |                     |                |                            |       |
|                                                                       |                            |                                               |                  |                             |              |                     |                                       |                               |                  |                        |           |                     |                |                            |       |
|                                                                       |                            |                                               |                  |                             |              |                     |                                       |                               |                  |                        |           |                     |                |                            |       |
|                                                                       |                            |                                               |                  |                             |              |                     |                                       |                               |                  |                        |           |                     |                |                            |       |
|                                                                       |                            |                                               |                  |                             |              |                     |                                       |                               |                  |                        |           |                     |                |                            |       |
|                                                                       |                            |                                               |                  |                             |              |                     |                                       |                               |                  |                        |           |                     |                |                            |       |
|                                                                       |                            |                                               |                  |                             |              |                     |                                       |                               |                  |                        |           |                     |                |                            |       |
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|                                                                       |                            |                                               |                  |                             |              |                     |                                       |                               |                  |                        |           |                     |                |                            |       |
|                                                                       |                            |                                               |                  |                             |              |                     |                                       |                               |                  |                        |           |                     |                |                            |       |
|                                                                       |                            |                                               |                  |                             |              |                     |                                       |                               |                  |                        |           |                     |                |                            |       |
|                                                                       |                            |                                               |                  |                             |              |                     |                                       |                               |                  |                        |           |                     |                |                            |       |
|                                                                       |                            |                                               |                  |                             |              |                     |                                       |                               |                  |                        |           |                     |                |                            |       |
|                                                                       |                            |                                               |                  |                             |              |                     |                                       |                               |                  |                        |           |                     |                |                            |       |
|                                                                       |                            |                                               |                  |                             |              |                     |                                       |                               |                  |                        |           |                     |                |                            |       |
|                                                                       |                            |                                               |                  |                             |              |                     |                                       |                               |                  |                        |           |                     |                |                            |       |
|                                                                       |                            |                                               |                  |                             |              |                     |                                       |                               |                  |                        |           |                     |                |                            |       |
|                                                                       |                            |                                               |                  |                             |              |                     |                                       |                               |                  |                        |           |                     |                |                            |       |
|                                                                       |                            |                                               |                  |                             |              |                     |                                       |                               |                  |                        |           |                     |                |                            |       |
|                                                                       |                            |                                               |                  |                             |              |                     |                                       |                               |                  |                        |           |                     |                |                            |       |
|                                                                       |                            |                                               |                  |                             |              |                     |                                       |                               |                  |                        |           |                     |                |                            |       |
|                                                                       |                            |                                               |                  |                             |              |                     |                                       |                               |                  |                        |           |                     |                |                            |       |
|                                                                       |                            |                                               |                  |                             |              |                     |                                       |                               |                  |                        |           |                     |                |                            |       |
|                                                                       |                            |                                               |                  |                             |              |                     |                                       |                               |                  |                        |           |                     |                |                            |       |
|                                                                       |                            |                                               |                  |                             |              |                     |                                       |                               |                  |                        |           |                     |                |                            |       |
|                                                                       |                            |                                               |                  |                             |              |                     |                                       |                               |                  |                        |           |                     |                |                            |       |
|                                                                       |                            |                                               |                  |                             |              |                     |                                       |                               |                  |                        |           |                     |                |                            |       |
|                                                                       |                            |                                               |                  |                             |              |                     |                                       |                               |                  |                        |           |                     |                |                            |       |
|                                                                       |                            |                                               |                  |                             |              |                     |                                       |                               |                  |                        |           |                     |                |                            |       |
|                                                                       |                            |                                               |                  |                             |              |                     |                                       |                               |                  |                        |           |                     |                |                            |       |
|                                                                       |                            |                                               |                  |                             |              |                     |                                       |                               |                  |                        |           |                     |                |                            |       |
|                                                                       |                            |                                               |                  |                             |              |                     |                                       |                               |                  |                        |           |                     |                |                            |       |
|                                                                       |                            |                                               |                  |                             |              |                     |                                       |                               |                  |                        |           |                     |                |                            |       |
|                                                                       |                            |                                               |                  |                             |              |                     |                                       |                               |                  |                        |           |                     |                |                            |       |
|                                                                       |                            |                                               |                  |                             |              |                     |                                       |                               |                  |                        |           |                     |                |                            |       |
|                                                                       |                            |                                               |                  |                             |              |                     |                                       |                               |                  |                        |           |                     |                |                            |       |
|                                                                       |                            |                                               |                  |                             |              |                     |                                       |                               |                  |                        |           |                     |                |                            |       |
|                                                                       |                            |                                               |                  |                             |              |                     |                                       |                               |                  |                        |           |                     |                |                            |       |
|                                                                       |                            |                                               |                  |                             |              |                     |                                       |                               |                  |                        |           |                     |                |                            |       |
|                                                                       |                            |                                               |                  |                             |              |                     |                                       |                               |                  |                        |           |                     |                |                            |       |
|                                                                       |                            |                                               |                  |                             |              |                     |                                       |                               |                  |                        |           |                     |                |                            |       |
|                                                                       |                            |                                               |                  |                             |              |                     |                                       |                               |                  |                        |           |                     |                |                            |       |
|                                                                       |                            |                                               |                  |                             |              |                     |                                       |                               |                  |                        |           |                     |                |                            |       |

\* Number of replicate tests conducted.

Table 1

TABLE 2

| Supplier          | Heat No.          | Mill-Certified Analysis, % |                    |       |          |                     |                       |              |            |                                            |      |      | Transverse Mechanical Properties (Aerofjet Tests) |      |         |        |    | R <sub>c</sub> Hardness |
|-------------------|-------------------|----------------------------|--------------------|-------|----------|---------------------|-----------------------|--------------|------------|--------------------------------------------|------|------|---------------------------------------------------|------|---------|--------|----|-------------------------|
|                   |                   | C                          | Mn                 | P     | S        | Si                  | Ni                    | Co           | Mo         | Al                                         | Cr   | Zr   | Th                                                | Ca   | B       |        |    |                         |
| Allegheeny-Indium | W-24254           | 0.009                      | 0.09               | 0.002 | 0.005    | 0.06                | 20.41                 | --           | -          | 0.29                                       | 0.39 | -    | 0.002                                             | 1.40 | 0.004   | 0.003  |    |                         |
|                   | W-24178           | 0.012                      | 0.01               | 0.003 | 0.005    | 0.01                | 18.69                 | 8.90         | 4.92       | 0.029                                      | -    | -    | 0.003                                             | 0.62 | 0.006   | 0.002  |    |                         |
|                   | 477               | 0.018                      | 0.002              | 0.006 | 0.004    | 0.024               | 18.29                 | 9.10         | 4.95       | 0.089                                      | -    | -    | <0.004                                            | 0.40 | <0.0006 | <0.003 |    |                         |
|                   | 448               | 0.029                      | 0.002              | 0.004 | 0.008    | 0.009               | 18.51                 | 8.48         | 4.92       | 0.089                                      | -    | -    | <0.004                                            | 0.52 | <0.0006 | <0.003 |    |                         |
|                   | 476               | 0.020                      | 0.002              | 0.006 | 0.005    | 0.014               | 18.60                 | 9.05         | 4.90       | 0.078                                      | -    | -    | <0.004                                            | 1.00 | <0.0006 | <0.003 |    |                         |
|                   | 3960502           | 0.020                      | 0.08               | 0.007 | 0.006    | 0.15                | 18.48                 | 7.00         | 4.84       | 0.21                                       | -    | 0.10 | 0.055                                             | 0.50 | Added   | 0.0036 |    |                         |
|                   | Allegheeny-Indium | W-24254                    | none               | -     | Table 1  | 0.2% Offset         | Ultimate              | % Elongation | Reduction  | Crack-Growth Energy                        |      |      |                                                   |      |         |        |    |                         |
|                   |                   | W-24178                    | -100°F +850°F 4 hr | H-1   | Code No. | Yield Strength, ksi | Tensile Strength, ksi | in 2 in.     | in Area, % | (G <sub>c</sub> ), in.-lb/in. <sup>2</sup> |      |      |                                                   |      |         |        |    |                         |
|                   |                   | 50% CW                     | none               | -     | -        | 128.5               | 170.7                 | 7.5          | 53         | -                                          |      |      |                                                   |      |         |        | 34 |                         |
|                   |                   | 50% CW                     | none               | -     | -        | 291.3               | 302.2                 | 3            | 17         | 58.3                                       |      |      |                                                   |      |         |        | 54 |                         |
| 75% CW            |                   | 850°F 4 hr                 | H-2                | -     | 184.0    | 201.6               | 5                     | 50           | -          |                                            |      |      |                                                   |      |         | 39     |    |                         |
| 75% CW            |                   | none                       | -                  | -     | 321.0    | 327.1               | 3                     | 25           | 22.7       |                                            |      |      |                                                   |      |         | 55.5   |    |                         |
| Welded            |                   | 850°F 4 hr                 | H-3                | -     | 205.7    | 220.9               | 6                     | 46           | -          |                                            |      |      |                                                   |      |         | 44     |    |                         |
| Welded *          |                   | none                       | -                  | -     | 298.3    | 308.8               | 2.5                   | 13           | 15.7       |                                            |      |      |                                                   |      |         | 55     |    |                         |
| W-24254           |                   | -100°F +850°F 4 hr         | H-W                | -     | 124.4    | 146.7               | 3.5                   | 25           | -          |                                            |      |      |                                                   |      |         | -      |    |                         |
| W-24178           |                   | none                       | -                  | -     | 245.0    | 252.0               | 1.5                   | 5            | -          |                                            |      |      |                                                   |      |         | -      |    |                         |
| Allegheeny-Indium | W-24254           | 900°F 3 hr                 | I-1                | -     | 102.0    | 153.3               | 14.8                  | 62           | -          |                                            |      |      |                                                   |      |         | 30.5   |    |                         |
|                   | 477               | none                       | -                  | -     | 283.0    | 294.0               | 8                     | 38           | 552.0      |                                            |      |      |                                                   |      |         | 53.5   |    |                         |
|                   | 448               | 900°F 3 hr                 | I-3                | -     | 167.7    | 189.0               | 3.5                   | 51           | -          |                                            |      |      |                                                   |      |         | 36.5   |    |                         |
|                   | 477               | none                       | -                  | -     | 323.8    | 328.4               | 1.5                   | 28           | 220.0      |                                            |      |      |                                                   |      |         | 55     |    |                         |
|                   | 477               | none                       | -                  | -     | 169.3    | 196.9               | 6.5                   | 40           | -          |                                            |      |      |                                                   |      |         | 38.5   |    |                         |
|                   | 448               | 900°F 3 hr                 | I-5                | -     | 278.0    | 280.7               | 2                     | 8            | 435.0      |                                            |      |      |                                                   |      |         | 55.0   |    |                         |
|                   | 476               | none                       | -                  | -     | 105.3    | 150.3               | 10                    | 45           | -          |                                            |      |      |                                                   |      |         | 30.5   |    |                         |
|                   | 476               | 900°F 3 hr                 | I-6                | -     | 255.4    | 265.9               | 5                     | 9            | 634.0      |                                            |      |      |                                                   |      |         | 52     |    |                         |
|                   | 476               | none                       | -                  | -     | 175.5    | 199.8               | 4.5                   | 47.5         | -          |                                            |      |      |                                                   |      |         | 38     |    |                         |
|                   | 3960502           | 900°F 3 hr                 | I-7                | -     | 331.0    | 332.5               | 1.5                   | 7            | 525.0      |                                            |      |      |                                                   |      |         | 55     |    |                         |
| Allegheeny-Indium | W-24254           | none                       | -                  | -     | 128.3    | 174.7               | 5.5                   | 48           | -          |                                            |      |      |                                                   |      |         | 36     |    |                         |
|                   | 476               | 900°F 3 hr                 | I-8                | -     | 323.3    | 330.0               | 2.5                   | 27           | 402.0      |                                            |      |      |                                                   |      |         | 56     |    |                         |
|                   | 476               | none                       | -                  | -     | 192.2    | 217.0               | 2.5                   | 40           | -          |                                            |      |      |                                                   |      |         | 41     |    |                         |
|                   | 476               | 900°F 3 hr                 | I-9                | -     | 354.4    | 354.9               | 1                     | 1.5          | 156.5      |                                            |      |      |                                                   |      |         | 58     |    |                         |
|                   | 3960502           | none                       | -                  | -     | 119.5    | 143.5               | 7                     | 55           | -          |                                            |      |      |                                                   |      |         | 29.5   |    |                         |
|                   | 476               | 900°F 3 hr                 | I-4                | -     | 249.9    | 254.7               | 4                     | 37           | 670.0      |                                            |      |      |                                                   |      |         | 50.5   |    |                         |
|                   | 476               | none                       | -                  | -     | 166.2    | 182.9               | 5.5                   | 58.5         | -          |                                            |      |      |                                                   |      |         | 35.5   |    |                         |
|                   | 476               | 900°F 3 hr                 | I-2                | -     | 302.5    | 308.1               | 4                     | 26           | 321.0      |                                            |      |      |                                                   |      |         | 52.5   |    |                         |
|                   | 476               | none                       | -                  | -     | 124.5    | 145.0               | 4.5                   | 47           | -          |                                            |      |      |                                                   |      |         | -      |    |                         |
|                   | 3960502           | 900°F 3 hr                 | I-W                | -     | 236.6    | 242.0               | 2                     | 20           | -          |                                            |      |      |                                                   |      |         | -      |    |                         |

\* Material received in the 50% cold-worked condition and annealed at 1500°F in the laboratory.



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TABLE 3

CHEMICAL ANALYSIS AND MECHANICAL PROPERTIES  
OF 6Al-4V TITANIUM

|                                       | Chemical Analysis, * % |     |     |                |                                        |                             |                      |                                 |       |
|---------------------------------------|------------------------|-----|-----|----------------|----------------------------------------|-----------------------------|----------------------|---------------------------------|-------|
|                                       | C                      | Al  | V   | O <sub>2</sub> | N <sub>2</sub>                         | H <sub>2</sub>              | Ti                   | Fe                              | Other |
| Aerojet analysis                      | 0.3                    | 6.1 | 4.1 | 0.083          | 0.014                                  | 80 ppm                      | Bal                  | 0.16                            | 0.18  |
|                                       |                        |     |     |                | Mechanical Properties (Transverse)     |                             |                      |                                 |       |
|                                       |                        |     |     |                | Yield Strength<br>(0.2% Offset)<br>psi | Ultimate<br>Strength<br>psi | Elon-<br>gation<br>% | R <sub>c</sub><br>Hard-<br>ness |       |
| Annealed                              |                        |     |     |                |                                        |                             |                      |                                 |       |
| Mill report                           |                        |     |     |                | 131,900                                | 141,400                     | 12                   | 33.5                            |       |
| Aerojet test                          |                        |     |     |                | 138,000                                | 143,800                     | 14                   | 34                              |       |
| Notched tensile strength**            |                        |     |     |                | --                                     | 128,500                     | -                    | -                               |       |
| 1675°F 1 hour, W.Q. aged 900°F 8 hour |                        |     |     |                |                                        |                             |                      |                                 |       |
| Aerojet test                          |                        |     |     |                | 162,700                                | 176,800                     | 7                    | 38.5                            |       |
| Notched tensile strength              |                        |     |     |                | --                                     | 132,000                     | -                    | -                               |       |
| Welded                                |                        |     |     |                |                                        |                             |                      |                                 |       |
| Aerojet test                          |                        |     |     |                | 131,500***                             | 135,200                     | 9.5                  | 33.0                            |       |

\*Titanium Metals Corporation HT 4141.

\*\*Using as-fatigue-cracked sample of Figure 3.

\*\*\*Tensile failures in parent metal.

Table 3

TABLE 4CHEMICAL ANALYSIS AND MECHANICAL PROPERTIES OF  
9Ni-4Co VACUUM CAST ALLOYMill Certified Chemical Analysis\*

| <u>C</u> | <u>Mn</u> | <u>P</u> | <u>S</u> | <u>Si</u> | <u>Co</u> | <u>Ni</u> | <u>Cr</u> | <u>Mo</u> | <u>V</u> |
|----------|-----------|----------|----------|-----------|-----------|-----------|-----------|-----------|----------|
| 0.30     | 0.23      | 0.006    | 0.007    | 0.02      | 4.10      | 8.65      | 0.43      | 0.35      | 0.10     |

Mechanical Properties (Transverse) Aerojet Tests

| <u>Condition</u>                                                                                      | <u>Yield Strength</u><br>(0.2% Offset)<br><u>ksi</u> | <u>Ultimate Tensile</u><br>Strength<br><u>ksi</u> | <u>Elongation</u><br><u>%</u> | <u>% Reduction</u><br>of Area | <u>Rc</u><br><u>Hardness</u> |
|-------------------------------------------------------------------------------------------------------|------------------------------------------------------|---------------------------------------------------|-------------------------------|-------------------------------|------------------------------|
| (Austenitized 1550°F<br>in argon - oil<br>quenched 2 hours<br>double temper at<br>temperatures shown) |                                                      |                                                   |                               |                               |                              |
| 400°F                                                                                                 | 190.3                                                | 230.3                                             | 8                             | 52                            | 48                           |
| 600°F                                                                                                 | 184.6                                                | 203.0                                             | 7                             | 54                            | 43                           |
| 800°F                                                                                                 | 172.4                                                | 186.7                                             | 9                             | 59                            | 41                           |
| 1000°F                                                                                                | 176.7                                                | 187.1                                             | 11                            | 60                            | 40.5                         |

\* Republic Heat 3950924

Table 4

TABLE 5

BENT BEAM TESTS, STRESS-CORROSION\* CRACKING IN  
AERATED DISTILLED WATER

| Material              | Variable        | Code<br>No.** | Yield<br>Strength<br>ksi | Failed/ Failure time, hours |      |            |
|-----------------------|-----------------|---------------|--------------------------|-----------------------------|------|------------|
|                       |                 |               |                          | Tested                      | Mean | Range      |
| 6Al-4V Titanium       | Annealed        | G-1           | 138.0                    | 0/3***                      | -    | NF1700     |
| 6Al-4V Titanium       | Quenched & Aged | G-2           | 163.0                    | 0/3                         | -    | NF1700     |
| 6Al-4V Titanium       | As-welded       | G-W           | 135.0                    | 0/2                         | -    | NF750      |
| 20%-Ni Maraging Steel | Annealed & Aged | H-1           | 291.3                    | 3/3                         | 11   | 10.2-18    |
|                       | 50% CW & Aged   | H-2           | 321.0                    | 1/3                         | 330  | 330-NF1600 |
|                       | 75% CW & Aged   | H-3           | 293.3                    | 3/3                         | 2918 | 1284-3450  |
| 20%-Ni Maraging Steel | Welded & Aged   | H-W           | 245.0                    | 3/3                         | 83   | 23-200     |
| 18%-Ni Maraging Steel | Annealed & Aged | I-4           | 249.9                    | 3/3                         | 68   | 60-85      |
|                       |                 | I-6           | 255.4                    | 0/3                         | -    | NF1200     |
|                       |                 | I-1           | 283.0                    | 3/3                         | 34.5 | 20.5-46.5  |
|                       | Annealed & Aged | I-8           | 323.2                    | 3/3                         | 24   | 20-27.5    |
|                       | 50% CW & Aged   | I-5           | 278.0                    | 0/3                         | -    | NF1200     |
| 18%-Ni Maraging Steel |                 | I-2           | 302.5                    | 0/3                         | -    | NF840      |
|                       |                 | I-7           | 331.0                    | 0/3                         | -    | NF1200     |
|                       |                 | I-3           | 323.0                    | 4/4                         | 625  | 440-988    |
|                       | 50% CW & Aged   | I-9           | 354.4                    | 1/3                         | 668  | 668-NF1200 |
| 18%-Ni Maraging Steel | Welded & Aged   | I-W           | 236.6                    | 3/3                         | 343  | 310-360    |

## Notes:

\* All samples stressed to give a maximum outer fiber stress of 75% of the 0.2% offset yield strength.

\*\* Refers to code letter in master schedule, Table 1.

\*\*\* Indicates no failures of three samples exposed.

Table 5

TABLE 6

BENT BEAM TESTS, STRESS-CORROSION CRACKING IN  
AERATED TAP WATER\*

| Material              | Variable        | Code<br>No.** | Yield           | Failed/<br>Tested | Failure Time, hours |             |
|-----------------------|-----------------|---------------|-----------------|-------------------|---------------------|-------------|
|                       |                 |               | Strength<br>ksi |                   | Mean                | Range       |
| 6Al-4V Titanium       | Annealed        | G-1           | 138.0           | 0/3***            | -                   | NF1700      |
| 6Al-4V Titanium       | Quenched & Aged | G-2           | 163.0           | 0/3               | -                   | NF1700      |
| 6Al-4V Titanium       | As-welded       | G-W           | 135.0           | 0/2               | -                   | NF750       |
| 20%-Ni Maraging Steel | Annealed & Aged | H-1           | 291.3           | 0/3               | -                   | NF3100      |
| ↓                     | 50% CW & Aged   | H-2           | 321.0           | 1/3               | 330                 | 330-NF1600  |
|                       | 75% CW & Aged   | H-3           | 298.3           | 2/3               | 2200                | 1284-NF3100 |
|                       |                 |               |                 |                   |                     |             |
| 20%-Ni Maraging Steel | Welded & Aged   | H-W           | 245.0           | 3/3               | 5.2                 | 3.3-6.5     |
| 18%-Ni Maraging Steel | Annealed & Aged | I-4           | 249.9           | 0/3               | -                   | NF980       |
| ↓                     | Annealed & Aged | I-1           | 283.0           | 2/3               | 350                 | 325-NF2000  |
|                       | 50% CW & Aged   | I-2           | 302.5           | 0/3               | -                   | NF840       |
|                       | 50% CW & Aged   | I-3           | 323.0           | 0/3               | -                   | NF2000      |
| 18%-Ni Maraging Steel | Welded & Aged   | I-W           | 236.6           | 0/3               | -                   | NF400       |

## Notes:

\* All samples stressed to give a maximum outer fiber stress of 75% of the 0.2% offset yield strength.

\*\* Refers to code letter in the master schedule, Table 1.

\*\*\* Indicates no failures of three samples exposed.

Table 6

TABLE 7

BENT BEAM TESTS, STRESS-CORROSION CRACKING IN  
AERATED SALT WATER\*

| Material              | Variable        | Code<br>No.** | Yield<br>Strength<br>ksi | Failed/ Failure Time, hours |      |             |
|-----------------------|-----------------|---------------|--------------------------|-----------------------------|------|-------------|
|                       |                 |               |                          | Tested                      | Mean | Range       |
| 6Al-4V Titanium       | Annealed        | G-1           | 138.0                    | 0/3***                      | -    | NF1700      |
| 6Al-4V Titanium       | Quenched & Aged | G-2           | 163.0                    | 0/3                         | -    | NF1700      |
| 6Al-4V Titanium       | As-welded       | G-W           | 135.0                    | 0/2                         | -    | NF750       |
| 20%-Ni Maraging Steel | Annealed & Aged | H-1           | 291.3                    | 3/3                         | 7.3  | 6-8.5       |
|                       | 50% CW & Aged   | H-2           | 321.0                    | 0/3                         | -    | NF1600      |
|                       | 75% CW & Aged   | H-3           | 298.3                    | 0/3                         | -    | NF3100      |
| 20%-Ni Maraging Steel | Welded & Aged   | H-W           | 245.0                    | 3/3                         | 0.8  | 0.75-0.85   |
| 18%-Ni Maraging Steel | Annealed & Aged | I-4           | 249.9                    | 3/3                         | 430  | 140-700     |
|                       |                 | I-6           | 255.4                    | 0/2                         | -    | NF1200      |
|                       |                 | I-1           | 283.0                    | 3/3                         | 51.5 | 19-100      |
|                       | Annealed & Aged | I-8           | 323.2                    | 2/2                         | 6.5  | 6-7         |
|                       | 50% CW & Aged   | I-5           | 278.0                    | 0/2                         | -    | NF1200      |
|                       |                 | I-2           | 302.5                    | 0/3                         | -    | NF840       |
|                       |                 | I-7           | 331.0                    | 0/2                         | -    | NF1200      |
|                       |                 | I-3           | 323.0                    | 2/3                         | 1290 | 1000-NF2000 |
|                       | 50% CW & Aged   | I-9           | 254.4                    | 2/2                         | 20   | 20-20       |
|                       | Welded & Aged   | I-W           | 236.6                    | 4/4                         | 121  | 115-139     |

## Notes:

\* All samples stressed to give a maximum outer fiber stress of 75% of the 0.2% offset yield strength.

\*\* Refers to code letter in master schedule, Table 1.

\*\*\* Indicated no failures of three samples exposed.

Table 7

TABLE 8

BENT BEAM TESTS, STRESS-CORROSION CRACKING IN  
AERATED 0.25% SODIUM DICHROMATE\*

| Material              | Variable        | Code<br>No.** | Yield<br>Strength<br>ksi | Failed/<br>Tested | Failure Time, hours |          |
|-----------------------|-----------------|---------------|--------------------------|-------------------|---------------------|----------|
|                       |                 |               |                          |                   | Mean                | Range    |
| 6Al-4V Titanium       | Annealed        | G-1           | 138.0                    | 0/3***            | -                   | NF1700   |
| 6Al-4V Titanium       | Quenched & Aged | G-2           | 163.0                    | 0/3               | -                   | NF1700   |
| 6Al-4V Titanium       | As-welded       | G-W           | 135.0                    | 0/2               | -                   | NF750    |
| 20%-Ni Maraging Steel | Annealed & Aged | H-1           | 291.3                    | 1/3               | 1.0                 | 1-NF3100 |
|                       | 50% CW & Aged   | H-2           | 321.0                    | 0/3               | -                   | NF1600   |
|                       | 75% CW & Aged   | H-3           | 298.3                    | 0/3               | -                   | NF3100   |
| 20%-Ni Maraging Steel | Welded & Aged   | H-W           | 245.0                    | 0/3               | -                   | NF500    |
| 18%-Ni Maraging Steel | Annealed & Aged | I-4           | 249.9                    | 0/3               | -                   | NF980    |
|                       | Annealed & Aged | I-1           | 283.0                    | 3/3               | 117                 | 100-150  |
|                       | 50% CW & Aged   | I-2           | 302.5                    | 0/3               | -                   | NF840    |
|                       | 50% CW & Aged   | I-3           | 323.0                    | 0/3               | -                   | NF2000   |
| 18%-Ni Maraging Steel | Welded & Aged   | I-W           | 236.6                    | 0/3               | -                   | NF400    |

## Notes:

\* All samples stressed to give a maximum outer fiber stress of 75% of the 0.2% offset yield strength.

\*\* Refers to code letter in master schedule, Table 1.

\*\*\* Indicated no failures of three samples exposed.

TABLE 9

BENT BEAM TESTS, STRESS-CORROSION CRACKING IN  
4% SOLUBLE OIL SOLUTION\*

| Material              | Variable        | Code<br>No.** | Yield<br>Strength<br>ksi | Failed/<br>Tested | Failure Time, hours |         |
|-----------------------|-----------------|---------------|--------------------------|-------------------|---------------------|---------|
|                       |                 |               |                          |                   | Mean                | Range   |
| 6Al-4V Titanium       | Annealed        | G-1           | 138.0                    | 0/3***            | -                   | NF1700  |
| 6Al-4V Titanium       | Quenched & Aged | G-2           | 163.0                    | 0/3               | -                   | NF1700  |
| 6Al-4V Titanium       | As-Welded       | G-W           | 135.0                    | 0/2               | -                   | NF750   |
| 20%-Ni Maraging Steel | Annealed & Aged | H-1           | 291.3                    | 0/2               | -                   | NF2000  |
| 20%-Ni Maraging Steel | 50% CW & Aged   | H-2           | 321.0                    | 0/3               | -                   | NF1600  |
| 20%-Ni Maraging Steel | 75% CW & Aged   | H-3           | 298.8                    | 0/3               | -                   | NF2000  |
| 20%-Ni Maraging Steel | Welded & Aged   | H-W           | 245.0                    | 0/3               | -                   | NF500   |
| 18%-Ni Maraging Steel | Annealed & Aged | I-4           | 249.9                    | 0/3               | -                   | NF980   |
| ↓                     | Annealed & Aged | I-1           | 283.0                    | 3/3               | 417                 | 400-450 |
|                       | 50% CW & Aged   | I-2           | 302.5                    | 0/3               | -                   | NF840   |
|                       | 50% CW & Aged   | I-3           | 323.0                    | 0/3               | -                   | NF2000  |
| 18%-Ni Maraging Steel | Welded & Aged   | I-W           | 236.6                    | 0/3               | -                   | NF400   |

## Notes:

\* All samples stressed to give a maximum outer fiber stress of 75% of the 0.2% offset yield strength.

\*\* Refers to code letter in master schedule, Table 1.

\*\*\* Indicates no failures of three samples exposed.

Table 9

TABLE 10

BENT BEAM TESTS, STRESS-CORROSION CRACKING IN  
140° F MOISTURE-SATURATED AIR\*

| Material              | Variable        | Code<br>No.** | Yield<br>Strength<br>ksi | Failed/<br>Tested | Failure<br>Mean | Time, hours<br>Range |
|-----------------------|-----------------|---------------|--------------------------|-------------------|-----------------|----------------------|
| 6Al-4V Titanium       | Annealed        | G-1           | 138.0                    | 0/3***            | -               | NF1700               |
| 6Al-4V Titanium       | Quenched & Aged | G-2           | 163.0                    | 0/3               | -               | NF1700               |
| 6Al-4V Titanium       | As-welded       | G-W           | 135.0                    | 0/2               | -               | NF750                |
| 20%-Ni Maraging Steel | Annealed & Aged | H-1           | 291.3                    | 3/3               | 100             | 22-174               |
|                       | 50% CW & Aged   | H-2           | 321.0                    | 1/3               | 1410            | 1410-NF1600          |
|                       | 75% CW & Aged   | H-3           | 298.3                    | 3/3               | 1200            | 1080-1860            |
| 20%-Ni Maraging Steel | Welded & Aged   | H-W           | 245.0                    | 3/3               | 10              | 1-14                 |
| 18%-Ni Maraging Steel | Annealed & Aged | I-4           | 249.9                    | 3/3               | 370             | 170-475              |
|                       |                 | I-6           | 255.4                    | 3/3               | 280             | 212-362              |
|                       |                 | I-1           | 283.0                    | 3/3               | 21              | 20.5-21.5            |
|                       | Annealed & Aged | I-8           | 323.2                    | 3/3               | 56.5            | 25.5-72              |
|                       | 50% CW & Aged   | I-5           | 278.0                    | 0/3               | -               | NF1200               |
|                       |                 | I-2           | 302.5                    | 2/3               | 360             | 340-NF840            |
|                       |                 | I-7           | 331.0                    | 0/3               | -               | NF1200               |
|                       |                 | I-3           | 323.0                    | 3/3               | 260             | 245-290              |
|                       | 50% CW & Aged   | I-9           | 354.4                    | 3/3               | 833             | 560-1010             |
| 18%-Ni Maraging Steel | Welded & Aged   | I-W           | 236.6                    | 3/3               | 131             | 115-139              |

## Notes:

\* All samples stressed to give a maximum outer fiber stress of 75% of the 0.2% offset yield strength.

\*\* Refers to code letter in master schedule, Table 1.

\*\*\* Indicates no failures of three samples exposed.

Table 10



TABLE 11BENT BEAM TESTS, STRESS-CORROSION CRACKING IN  
TRICHLOROETHYLENE IMMERSION\*

| Material              | Variable        | Code<br>No. ** | Yield<br>Strength<br>ksi | Failed/<br>Tested | Failure<br>Mean | Time, hours<br>Range |
|-----------------------|-----------------|----------------|--------------------------|-------------------|-----------------|----------------------|
| 6Al-4V Titanium       | Annealed        | G-1            | 138.0                    | 0/3 **            | -               | NF1150               |
| 6Al-4V Titanium       | Quenched & Aged | G-2            | 163.0                    | 0/3               | -               | NF1150               |
| 6Al-4V Titanium       | As-welded       | G-W            | 135.0                    | 0/2               | -               | NF1150               |
| 20%-Ni Maraging Steel | Annealed & Aged | H-1            | 291.3                    | 3/3               | 742             | 550-960              |
|                       | 50% CW & Aged   | H-2            | 321.0                    | 0/3               | -               | NF1150               |
|                       | 75% CW & Aged   | H-3            | 293.3                    | 0/3               | -               | NF1150               |
| 20%-Ni Maraging Steel | Welded & Aged   | H-W            | 245.0                    | 3/3               | 48              | 40-64                |
| 18%-Ni Maraging Steel | Annealed & Aged | I-1            | 283.0                    | 2/3               | 610             | 550-NF1150           |
|                       | 50% CW & Aged   | I-2            | 302.5                    | 0/3               | -               | NF480                |
|                       | 50% CW & Aged   | I-3            | 323.0                    | 0/3               | -               | NF1150               |
| 18%-Ni Maraging Steel | Welded & Aged   | I-W            | 236.6                    | 0/3               | -               | NF400                |

## Notes:

\* All samples stressed to give maximum outer fiber stress of 75% of 0.2% offset yield strength.

\*\* Refers to code letter in master schedule, Table 1.

\*\*\* Indicates no failures of three samples exposed.

Table 11

TABLE 12

BENT BEAM TESTS, STRESS-CORROSION CRACKING IN  
COSMOLINE IMMERSION\*

| Material              | Variable        | Code<br>No.** | Yield<br>Strength<br>ksi | Failed/<br>Tested | Failure Time, hours |        |
|-----------------------|-----------------|---------------|--------------------------|-------------------|---------------------|--------|
|                       |                 |               |                          |                   | Mean                | Range  |
| 6Al-4V Titanium       | Annealed        | G-1           | 138.0                    | 0/3***            | -                   | NF1700 |
| 6Al-4V Titanium       | Quenched & Aged | G-2           | 163.0                    | 0/3               | -                   | NF1700 |
| 6Al-4V Titanium       | As-welded       | G-W           | 135.0                    | 0/2               | -                   | NF750  |
| 20%-Ni Maraging Steel | Annealed & Aged | H-11          | 291.3                    | 0/3               | -                   | NF2000 |
|                       | 50% CW & Aged   | H-2           | 321.0                    | 0/3               | -                   | NF1000 |
|                       | 75% CW & Aged   | H-3           | 293.3                    | 0/3               | -                   | NF2000 |
| 20%-Ni Maraging Steel | Welded & Aged   | H-W           | 245.0                    | 0/0               | -                   | -      |
| 18%-Ni Maraging Steel | Annealed & Aged | I-4           | 249.9                    | 0/3               | -                   | NF980  |
|                       | Annealed & Aged | I-1           | 283.0                    | 0/3               | -                   | NF2000 |
|                       | 50% CW & Aged   | I-3           | 323.0                    | 0/3               | -                   | NF2000 |
| 18%-Ni Maraging Steel | Welded & Aged   | I-W           | 236.6                    | 0/0               | -                   | -      |

## Notes:

\* All samples stressed to give maximum outer fiber stress of 75% of 0.2% offset yield strength.

\*\* Refers to code letter in master schedule, Table 1.

\*\*\* Indicates no failures of three samples exposed.

TABLE 13

BENT BEAM TESTS, STRESS-CORROSION CRACKING IN  
LABORATORY AIR\*

| Material              | Variable        | Code<br>No.** | Yield<br>Strength<br>ksi | Failed/<br>Tested | Failure Time, hours<br>Mean | Range  |
|-----------------------|-----------------|---------------|--------------------------|-------------------|-----------------------------|--------|
| 6Al-4V Titanium       | Annealed        | G-1           | 138.0                    | 0/0               | -                           | -      |
| 6Al-4V Titanium       | Quenched & Aged | G-2           | 163.0                    | 0/0               | -                           | -      |
| 6Al-4V Titanium       | As-welded       | G-W           | 135.0                    | 0/2***            | -                           | NF750  |
| 20%-Ni Maraging Steel | Annealed & Aged | H-1           | 291.3                    | 0/3               | -                           | NF3100 |
|                       | 50% CW & Aged   | H-2           | 321.0                    | 0/2               | -                           | NF1600 |
|                       | 75% CW & Aged   | H-3           | 293.3                    | 0/3               | -                           | NF3100 |
| 20%-Ni Maraging Steel | Welded & Aged   | H-W           | 245.0                    | 0/3               | -                           | NF170  |
| 18%-Ni Maraging Steel | Annealed & Aged | I-4           | 249.9                    | 0/0               | -                           | -      |
|                       |                 | I-6           | 255.4                    | 0/2               | -                           | NF1200 |
|                       |                 | I-1           | 283.0                    | 0/3               | --                          | NF2000 |
|                       | Annealed & Aged | I-8           | 323.2                    | 0/1               | -                           | NF1200 |
|                       | 50% CW & Aged   | I-5           | 278.0                    | 0/1               | -                           | NF1200 |
|                       |                 | I-2           | 302.5                    | 0/0               | -                           | -      |
|                       |                 | I-7           | 331.0                    | 0/2               | ----                        | NF1200 |
|                       |                 | I-3           | 323.0                    | 0/3               | -                           | NF2000 |
|                       | 50% CW & Aged   | I-9           | 354.4                    | 0/2               | -                           | NF1200 |
| 18%-Ni Maraging Steel | Welded & Aged   | I-W           | 336.6                    | 0/3               | -                           | NF400  |

## Notes:

\* All samples stressed to give a maximum outer fiber stress of 75% of the 0.2% offset yield strength.

\*\* Refers to code letter in master schedule, Table 1.

\*\*\* Indicates no failures of two samples exposed.

Table 13

TABLE 14

BENT BEAM TESTS, STRESS-CORROSION CRACKING IN  
SEACOAST ATMOSPHERIC EXPOSURE\*

| Material              | Variable        | Code<br>No. | Yield<br>Strength<br>ksi | Failed/<br>Tested | Failure Time, hours |          |
|-----------------------|-----------------|-------------|--------------------------|-------------------|---------------------|----------|
|                       |                 |             |                          |                   | Mean                | Range    |
| 6Al-4V Titanium       | Annealed        | G-1         | 138.0                    | 0/3***            | -                   | NF1400   |
| 6Al-4V Titanium       | Quenched & Aged | G-2         | 163.0                    | 0/3               | -                   | NF1400   |
| 6Al-4V Titanium       | As-welded       | G-W         | 135.0                    | 0/2               | -                   | NF1400   |
| 20%-Ni Maraging Steel | Annealed & Aged | H-1         | 291.3                    | 3/3               | 140                 | 116-188  |
|                       | 50% CW & Aged   | H-2         | 321.0                    | 3/3               | 1034                | 800-1150 |
|                       | 75% CW & Aged   | H-3         | 293.3                    | 3/3               | 1000                | 860-1150 |
| 20%-Ni Maraging Steel | Welded & Aged   | H-W         | 245.0                    | 0/0               | -                   | -        |
| 18%-Ni Maraging Steel | Annealed & Aged | I-6         | 255.4                    | 0/2               | -                   | NF1400   |
|                       | Annealed & Aged | I-1         | 283.0                    | 6/6               | 380                 | 312-450  |
|                       | Annealed & Aged | I-8         | 323.2                    | 2/2               | 700                 | 350-1050 |
|                       | 50% CW & Aged   | I-5         | 278.0                    | 0/2               | -                   | NF1400   |
|                       |                 | I-2         | 302.5                    | 0/0               | -                   | -        |
|                       |                 | I-7         | 331.0                    | 0/2               | -                   | NF1400   |
|                       |                 | I-3         | 323.0                    | 0/3               | -                   | NF1400   |
|                       | 50% CW & Aged   | I-9         | 354.4                    | 0/2               | -                   | NF1400   |
| 18%-Ni Maraging Steel | Welded & Aged   | I-W         | 236.6                    | 0/0               | -                   | -        |

## Notes:

\* All samples stressed to give a maximum outer fiber stress of 75% of 0.2% offset yield strength.

\*\* Refers to code letter in master schedule, Table 1.

\*\*\* Indicates no failures of three samples exposed.

Table 14

TABLE 15

CENTER NOTCH TESTS, STRESS-CORROSION CRACKING IN  
0.25% SODIUM DICHROMATE

| Material              | Variable        | Code<br>No.* | $K_{IC}$<br>ksi√in | Failed/<br>Tested | Failure Time, hours |       |
|-----------------------|-----------------|--------------|--------------------|-------------------|---------------------|-------|
|                       |                 |              |                    |                   | Mean                | Range |
| 6Al-4V Titanium       | Annealed        | G-1          | 85.0               | 0/2**             | -                   | NF100 |
| 6Al-4V Titanium       | Quenched & Aged | G-2          | 86.2               | 0/2               | -                   | NF100 |
| 20%-Ni Maraging Steel | Annealed & Aged | H-1          | 39.3               | 0/2               | -                   | NF200 |
| 20%-Ni Maraging Steel | 50% CW & Aged   | H-2          | 24.5               | 0/0               | -                   | -     |
| 20%-Ni Maraging Steel | 75% CW & Aged   | H-3          | 20.5               | 0/2               | -                   | NF100 |
| 18%-Ni Maraging Steel | Annealed & Aged | I-4          | 133.0              | 0/1               | -                   | NF100 |
| ↓                     | Annealed & Aged | I-1          | 121.0              | 1/1               | 67.9                | -     |
|                       | Annealed & Aged | I-8          | 103.8              | 1/1               | 37.7                | -     |
|                       | 50% CW & Aged   | I-5          | 107.2              | 0/1               | -                   | NF200 |
|                       | ↓               | I-2          | 92.2               | 0/0               | -                   | -     |
|                       |                 | I-7          | 119.0              | 0/2               | -                   | NF100 |
| 18%-Ni Maraging Steel | 50% CW & Aged   | I-3          | 76.4               | 1/1               | 33.2                | -     |

## Notes:

\* All samples given direct load of 75% of  $K_{IC}$ .

\*\* Refers to code letter in master schedule, Table 1.

\*\*\* Indicates no failures of two samples tested.

Table 15

TABLE 16

CENTER NOTCH TESTS, STRESS-CORROSION CRACKING IN  
3% SODIUM CHLORIDE SOLUTION

| Material              | Variable        | Code<br>No.** | $K_c$<br>ksi $\sqrt{\text{in}}$ | Failed/<br>Tested | Failure Time, hours |           |
|-----------------------|-----------------|---------------|---------------------------------|-------------------|---------------------|-----------|
|                       |                 |               |                                 |                   | Mean                | Range     |
| 6Al-4V Titanium       | Annealed        | G-1           | 85.0                            | 0/2***            | -                   | NF100     |
| 6Al-4V Titanium       | Quenched & Aged | G-2           | 86.2                            | 0/2               | -                   | NF100     |
| 20%-Ni Maraging Steel | Annealed & Aged | H-1           | 39.3****                        | 1/1               | 4.2                 | -         |
|                       |                 | H-1           | 39.3                            | 2/2               | 7.2                 | 6.6-7.8   |
|                       |                 | H-1           | 39.3*****                       | 1/1               | 8.2                 | -         |
|                       | Annealed & Aged | H-1           | 39.3*****                       | 1/1               | 12.7                | -         |
|                       | 50% CW & Aged   | H-2           | 24.5                            | 2/2               | 14.0                | 8.20      |
| 20%-Ni Maraging Steel | 75% CW & Aged   | H-3           | 20.5                            | 2/2               | 40.2                | 34.4-46   |
| 18%-Ni Maraging Steel | Annealed & Aged | I-4           | 133.0****                       | 1/1               | 7.8                 | -         |
|                       |                 | I-4           | 133.0                           | 2/2               | 12.3                | 9.5-15.2  |
|                       |                 | I-4           | 133.0*****                      | 1/1               | 64                  | -         |
|                       |                 | I-6           | 129.5                           | 3/3               | 22                  | 10-35     |
|                       |                 | I-1           | 121.0                           | 2/2               | 20.6                | 18-23     |
|                       | Annealed & Aged | I-8           | 103.2                           | 2/2               | 8.8                 | 8.3-9.3   |
|                       | 50% CW & Aged   | I-5           | 107.2                           | 2/2               | 13.4                | 12.5-14.2 |
|                       |                 | I-2           | 92.2                            | 2/2               | 7.2                 | 7.2-7.2   |
|                       |                 | I-7           | 119.0                           | 3/3               | 9.9                 | 4.4-12.9  |
|                       |                 | I-3           | 76.4                            | 2/2               | 5.9                 | 5.0-6.9   |
| 18%-Ni Maraging Steel | 50% CW & Aged   | I-9           | 64.4                            | 2/2               | 4.5                 | 5.0-4.0   |

## Notes:

\* All samples given direct load of 75% of  $K_c$  except as noted.

\*\* Refers to code letter in master schedule, Table 1.

\*\*\* Indicates no failures of two samples tested.

\*\*\*\* Tested at 83% of  $K_c$ .\*\*\*\*\* Tested at 60% of  $K_c$ .\*\*\*\*\* Tested at 27% of  $K_c$ .

Table 16

TABLE 17

CENTER NOTCH TESTS, STRESS-CORROSION CRACKING IN  
DISTILLED WATER\*

| Material              | Variable        | Code<br>No.* | K <sub>c</sub><br>ksi√in | Failed/<br>Tested | Failure Time, hours |           |
|-----------------------|-----------------|--------------|--------------------------|-------------------|---------------------|-----------|
|                       |                 |              |                          |                   | Mean                | Range     |
| 6Al-4V Titanium       | Annealed        | G-1          | 85.0                     | 0/3**             | -                   | NF100     |
| 6Al-4V Titanium       | Quenched & Aged | G-2          | 86.2                     | 0/3               | -                   | NF100     |
| 20%-Ni Maraging Steel | Annealed & Aged | H-1          | 39.3                     | 3/3               | 5.1                 | 4.6-6.6   |
| 20%-Ni Maraging Steel | 50% CW & Aged   | H-2          | 24.5                     | 0/0               | -                   | -         |
| 20%-Ni Maraging Steel | 75% CW & Aged   | H-3          | 20.5                     | 1/3               | 121                 | 121-NF300 |
| 18%-Ni Maraging Steel | Annealed & Aged | I-4          | 133.0                    | 0/0               |                     |           |
|                       | Annealed & Aged | I-6          | 129.5                    | 0/1               | -                   | NF200     |
|                       | Annealed & Aged | I-1          | 121.0                    | 3/3               | 85.3                | 83-87     |
|                       | 50% CW & Aged   | I-5          | 107.2                    | 0/1               | -                   | NF200     |
|                       |                 | I-2          | 92.2                     | 2/2               | 17.1                | 16.6-17.6 |
|                       |                 | I-7          | 119.0                    | 0/0               | -                   | -         |
|                       |                 | I-3          | 76.4                     | 2/2               | 13.2                | 12.6-13.8 |
| 18%-Ni Maraging Steel | 50% CW & Aged   | I-9          | 64.4                     | 0/0               | -                   | -         |

## Notes:

\* All samples given direct load of 75% of K<sub>c</sub>.

\*\* Refers to code letter in master schedule, Table 1.

\*\*\* Indicates no failures of three samples tested.

Table 17

TABLE 18

CENTER NOTCH TESTS, STRESS-CORROSION CRACKING IN  
4% SOLUBLE OIL SOLUTION\*

| Material              | Variable        | Code<br>No.** | $K_c$<br>ksi $\sqrt{\text{in}}$ | Failed/<br>Tested | Failure Time, hours<br>Mean | Range |
|-----------------------|-----------------|---------------|---------------------------------|-------------------|-----------------------------|-------|
| 6Al-4V Titanium       | Annealed        | G-1           | 85.0                            | 0/1***            | -                           | NF100 |
| 6Al-4V Titanium       | Quenched & Aged | G-2           | 86.2                            | 0/1               | -                           | NF100 |
| 20%-Ni Maraging Steel | Annealed & Aged | H-1           | 39.3                            | 0/2               | -                           | NF200 |
| 20%-Ni Maraging Steel | Annealed & Aged | H-2           | 24.5                            | 0/0               | -                           | -     |
| 20%-Ni Maraging Steel | 75% CW & Aged   | H-3           | 20.5                            | 0/1               | -                           | NF100 |
| 18%-Ni Maraging Steel | Annealed & Aged | I-4           | 133.0                           | 0/1               | -                           | NF100 |
|                       | Annealed & Aged | I-1           | 121.0                           | 0/0               | -                           | -     |
|                       | 50% CW & Aged   | I-2           | 92.2                            | 0/0               | -                           | -     |
| 18%-Ni Maraging Steel | 50% CW & Aged   | I-3           | 76.4                            | 0/0               | -                           | -     |

## Notes:

\* All samples given direct load of 75% of  $K_c$ .

\*\* Refers to code letter in master schedule, Table 1.

\*\*\* Indicates no failure of one sample tested.

Table 18



TABLE 19

| Surface Condition<br>Surface ground<br>or sanded | Coating                          | Aerated 3% NaCl Solution |                          |         | 140°F Saturated Air |                          |             | Seacoast Exposure  |                          |            |
|--------------------------------------------------|----------------------------------|--------------------------|--------------------------|---------|---------------------|--------------------------|-------------|--------------------|--------------------------|------------|
|                                                  |                                  | Failure<br>Ratio *       | Failure Time, hr<br>Mean | Range   | Failure<br>Ratio *  | Failure Time, hr<br>Mean | Range       | Failure<br>Ratio * | Failure Time, hr<br>Mean | Range      |
|                                                  |                                  |                          |                          |         |                     |                          |             |                    |                          |            |
| Surface ground<br>or sanded                      | None (control)                   | 4/4                      | 1.6                      | 0.8-2.5 | 2/2                 | 64                       | 48-70       | 2/2                | 116                      | 116-116    |
|                                                  | Polyurethane                     | 3/3**                    | 149                      | 144-168 | 6/6**               | 3500                     | 2830-5500   | 1/2                | 250                      | 250-NF 900 |
|                                                  | Inhibited epoxy 454-1-1          | 0/2                      | -                        | NF 1200 | 3/3**               | 2720                     | 2590-2850   | 0/2                | -                        | NF 900     |
|                                                  | Inhibited epoxy 463-1-5          | 0/3                      | -                        | NF 3100 | 3/3                 | 656                      | 400-976     | 0/2                | -                        | NF 900     |
|                                                  | Inhibited epoxy 463-4-8          | 3/3                      | 550                      | 525-578 | 3/3                 | 845                      | 289-1512    | -                  | -                        | -          |
|                                                  | Epoxy 463-1-5 over 454-1-1       | 0/4**                    | -                        | NF 5860 | 4/4**               | 4000                     | 2590-4950   | -                  | -                        | -          |
|                                                  | Zinc silicate, Type 4            | 2/2                      | 1.2                      | 0.8-1.6 | 2/2                 | 422                      | 147-696     | 1/2                | 116                      | 116-NF 900 |
|                                                  | 80% aluminum epoxy               | 2/2                      | 1.00                     | 100-100 | 2/2                 | 30                       | 16-45       | 2/2                | 660                      | 550-780    |
|                                                  | 70% titanium epoxy               | 2/2                      | 150                      | 140-160 | 2/2                 | 198                      | 136-256     | 1/2                | 720                      | 720-NF 900 |
|                                                  | None (control)                   | 2/2                      | 18.5                     | 14-23   | 1/1                 | 26.5                     | -           | 1/1                | 188                      | -          |
| Sand-blasted                                     | Pure vinyl                       | 0/2                      | -                        | NF 1500 | 1/2                 | 670                      | 670-NF 1500 | 0/2                | -                        | NF 900     |
|                                                  | Zinc silicate, Type 4            | 2/2                      | 14                       | 10-18   | 0/2                 | -                        | NF 1500     | 0/2                | -                        | NF 900     |
|                                                  | Epoxy over zinc silicate, Type 4 | 2/2                      | 77                       | 1.5-153 | 2/2                 | 513                      | 422-504     | 0/1                | -                        | NF 900     |
|                                                  | Inorganic zinc, Type 11          | 2/2                      | 687                      | 674-702 | 2/2                 | 821                      | 723-819     | 0/4                | -                        | NF 900     |
|                                                  | Epoxy 188 over inorganic zinc 11 | 2/2                      | 54                       | 42-56   | 0/2                 | -                        | NF 2160     | -                  | -                        | -          |
|                                                  | Organic zinc XL-4-245            | 2/2                      | 214                      | 27-400  | 2/2                 | 766                      | 742-790     | -                  | -                        | -          |
|                                                  | Modified vinyl system            | 2/2                      | 550                      | 520-583 | 2/2                 | 640                      | 435-850     | 1/2                | 450                      | 450-NF 900 |

\* Ratio of number failed to number exposed.

\*\* Data taken from earlier work; samples not in current testing.