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**STRESS-CORROSION CRACKING OF  
HIGH-STRENGTH STAINLESS STEELS  
IN ATMOSPHERIC ENVIRONMENTS**

**DEFENSE METALS INFORMATION CENTER**  
**Battelle Memorial Institute**  
**Columb 1, Ohio**

DMIC Report 153  
September 15, 1961

**STRESS-CORROSION CRACKING OF  
HIGH-STRENGTH STAINLESS STEELS  
IN ATMOSPHERIC ENVIRONMENTS**

by

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**OFFICE OF THE DIRECTOR OF DEFENSE  
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**DEFENSE METALS INFORMATION CENTER  
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# STRESS-CORROSION CRACKING OF HIGH-STRENGTH STAINLESS STEELS IN ATMOSPHERIC ENVIRONMENTS

## SUMMARY

The application of high-strength steels in the construction of aircraft and missiles has created a further demand for information on the stress-corrosion properties of such steels. Several experimental programs designed to develop such data have been in progress for the last few years. In this report, the available information on the stress-corrosion cracking of the high-strength stainless steels has been assembled and tabulated according to alloy type and to the environments to which they were exposed. The stainless steels, for which some data are available, include the cold-rolled austenitics, the martensitic grades, the martensitic precipitation-hardenable grades, and the semiaustenitic precipitation hardenable grades. Exposures were in the marine atmosphere at Kure Beach, outdoors at several semiindustrial locations, and in several laboratory test environments. Data on the chemical analyses, heat treatments, and mechanical properties of the test materials are included.

All of the data compiled in this report were obtained on bent-beam specimens stressed below the yield point.

Many factors are known to influence the stress-corrosion cracking of metals. These include composition of the alloy, heat treatment, metallurgical structure, preparation of the test specimens, stress levels, and the environmental conditions. Insufficient data have been accumulated to permit quantitative comparisons of the alloys discussed in this report, and much of the information is considered preliminary because the tests are still in progress; however, tentative conclusions can be made about the utilization of these steels. The compiled data also indicate where additional testing and refinements in the procedures are needed to get more reproducible and reliable results.

Cold-worked and stress-relieved austenitic stainless steels such as AISI 301 have shown excellent resistance to stress-corrosion cracking in both marine and laboratory-type exposures. This is true on specimens stressed to over 200,000 psi. The good performance is attributed to the fact that high strength is developed by mechanical working, rather than by heat treatments.

In the 17-7 PH and PH 15-7 Mo tests also, the most resistant specimens were those in the CH 900 condition; that is, the cold-rolled and tempered structure. These alloys in the other conditions were shown to be

susceptible to stress-corrosion cracking in a marine atmosphere when stressed to over 50 per cent of the yield strength. However, susceptibility was not related solely to the strength of the alloy but was also determined by the heat treatment used to develop the properties. In general, the heat treatments that developed the strongest alloys also resulted in greater susceptibility to stress-corrosion cracking. For both alloys, in certain cases, there were large differences in exposure times between those specimens that failed and those that did not fail. No failures were reported on these alloys (17-7 PH and PH 15-7 Mo) exposed to semi-industrial atmospheres.

The data for AM 350 and AM 355 are not very extensive. The CRT and SCCRT conditions developed very high strengths, and immunity from cracking at Kure Beach was obtained only on specimens stressed to less than 50 per cent of their yield strength. In the salt-spray exposure, specimens cut transverse to the rolling direction were strongly susceptible, whereas those cut longitudinally did not crack. More work is needed on this point. The SCT 850 condition was shown to be more susceptible to cracking than was the CRT 850 condition in the atmospheric exposure tests. Differences were also noted in results on different heats in the CRT 850 condition. Perhaps, the two CRT 850 conditions did not have equal amounts of cold reduction.

New data are given for 17-4 PH in sheet form exposed for almost a year at Kure Beach. No failures occurred on specimens in the H 900 condition (yield strength 180,000 psi) stressed up to 90 per cent of the yield strength. Welded specimens in the H 900 condition failed, and a solution heat treatment following the welding did not completely restore the immunity to stress-corrosion cracking. Specimens aged at 1025 F or higher have not failed. The tests are still in progress, and more data should be forthcoming.

Alloys 12 MoV and Stainless W were reported to be quite susceptible to stress-corrosion cracking, with the latter being slightly superior. Higher tempering temperatures for 12 MoV reduced the susceptibility to cracking, at the same time causing a considerable reduction in the strength of the alloy.

## INTRODUCTION

The general features of stress-corrosion cracking were summarized in a recent DMIC report<sup>(1)\*</sup> to provide a background for materials and design engineers and for others involved in the use of high-strength steels. Alloys in many metal systems, both ferrous and nonferrous, are susceptible to stress-corrosion cracking in specific environments. This does not necessarily prevent the use of such metals and alloys but indicates that certain precautions should be taken to avoid failures in service. The successful utilization of any metal is dependent, therefore, on adequate consideration of stress-corrosion properties, as well as of its other properties. This is particularly true for the high-strength steels in aircraft and missile applications.

The factors that influence or contribute to stress-corrosion cracking may arise in any or all of the steps and sequences that the metal encounters in being converted from its original to its final form. Heat treatment, quenching, fabrication, welding and other assembly operations, surface finishing, and other production steps may affect either the metallurgical structure and mechanical properties of the alloy, or result in the development of harmful residual stresses in the finished product. The alloys are exposed to a variety of conditions during these operations, and it is important to consider what their effect will be on the stress-corrosion-cracking properties of the materials. Then there are the conditions prevailing during transportation and storage of the finished aircraft or missiles. Careless handling may result in deformation or surface damage which aggravates stress-corrosion cracking of susceptible materials by introducing additional stresses and providing sites for the start of corrosion. Finally, aircraft and missiles are subjected to a variety of environments in operation. Exposure to cyclic wetting and drying, in humid or salt air locations, and long-time underground storage are examples of possible harmful conditions for susceptible materials.

The increasing use of the high-strength steels in the construction of aircraft and missiles within the past few years resulted in the initiation of several test programs designed to provide data on the stress-corrosion susceptibility of such steels. The steels of interest in the high-strength category may be classified as

- (1) Stainless steels
- (2) Hot-work die steels
- (3) Low-alloy engineering steels.

The first of these may be broken down further to include the martensitic stainless steels, the martensitic and semiaustenitic precipitation hardenable stainless steels, and the cold-rolled austenitic stainless steels. Some data

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\*References listed on page 32.

on stress-corrosion cracking have become available as a result of the test programs mentioned above, but not all of this information has been published in the technical journals. Furthermore, differences in materials and in details of the tests make evaluation of scattered data difficult.

The purpose of this report is to present a compilation of data accumulated on the stress-corrosion cracking of high-strength stainless steels in laboratory and atmospheric environments. Also, information concerning heat treatments, mechanical properties, and test procedures is included. It is not always possible to make unqualified, quantitative comparisons where so many factors may influence test results. The data tabulated in this report, therefore, are intended to help in the selection of materials for use in aircraft and missile applications rather than to predict the performance of the materials under service conditions. The data were assembled from tests conducted by the U. S. Steel Corporation, Armco Steel Corporation, Allegheny Ludlum Steel Corporation, and the North American Aviation Corporation at Los Angeles. Some of these tests are still in progress, and additional data from these and other test programs could be included in supplements to this report to bring the information up to date.

## EXPERIMENTAL DETAILS

### Materials Tested

Twelve stainless steels of four types were investigated:

- (1) Martensitic  
USS 12 MoV
- (2) Martensitic precipitation hardenable  
17-4 PH  
Stainless W
- (3) Semiaustenitic precipitation hardenable  
17-7 PH  
PH 15-7 Mo  
AM 350  
AM 355
- (4) Cold-rolled austenitic  
AISI 301  
AISI 201  
AISI 202  
USS Tencion  
USS 17-5 MnV

### Method of Stressing

All of the results recorded in this report were obtained on bent-beam specimens. U. S. Steel and Armco used a rigid stainless steel bar with slots machined in it, spaced for either a 4- or 7-inch span. Specimens cut to some length greater than the span between the slots can be stressed by placing one end in one of the slots and bending into a simple arc just enough to slide the other end in the opposite slot (see Figure 1a). The exact specimen length needed to produce the desired tensile stress in the outer fibers at the middle of the specimen is determined from a relationship between the strain, the specimen length and thickness, and the span between the slots in the specimen holder.

North American Aviation used the same principle, but the fixture consisted of two slotted blocks of an epoxy-glass laminate held in place by a bolt and nut. The desired stress level was obtained on one specimen of each group by adjusting the distance between the end blocks with the bolt and nut. The strain on the bent specimen was determined from strain-gage measurements. Then the deflection of the specimen was measured, and this value was used to reproduce the same bending and stress levels in other specimens of the group. Protective coatings were applied to the fixtures.

In the Allegheny Ludlum tests, the strip specimens were bent over a center support in the test assembly. The specimens were bent by tightening the bolts and nuts at the ends of the jig until the desired strain, measured by a strain gage, was produced at the center of the specimens. Each specimen was insulated from the jig assembly by Teflon tape and washers. This fixture is illustrated in Figure 1b.

### Preparation of Test Specimens

Many factors are known to affect the reproducibility of stress corrosion test results. One of these is the condition of the specimens at the start of the tests. In all of the programs reported, an effort was made to prepare specimens carefully and reproducibly, with a uniform and clean surface, so as to minimize erratic corrosion results caused by variable surface conditions. There were some differences, however, in the actual steps taken to prepare the test specimens. The procedures used are given below.

#### U. S. Steel

- (1) Specimens sheared from sheet stock to proper width, but longer than used in the tests
- (2) Heat-treated to get the desired properties
- (3) Surfaces ground on 90-grit dry emery belt to remove scale and visible surface defects



a. Fixture used by U. S. Steel, Armco, and,  
in principle, by North American



b. Three-point loading fixture used by  
Allegheny Ludlum

FIGURE 1. TEST FIXTURES

- (4) Ground on 120-grit emery belt
- (5) Cut to length to produce the desired stress after bending
- (6) Degreased in trichlorethylene vapor
- (7) Washed in distilled water
- (8) Rinsed in acetone
- (9) Stored in desiccator until put in test.

#### Alnico

- (1) Specimens cut from sheet stock
- (2) Machined and deburred
- (3) Cleaned in inhibited phosphoric acid
- (4) Rinsed in distilled water
- (5) Heat treated to desired properties
- (6) Descaled by wet grit blast to a surface roughness of 25-30 microns rms.

#### North American Aviation

- (1) Specimens sheared oversize (1-1/2 x 8-1/8 inches)
- (2) Alkaline cleaned and coated with a scale-inhibiting compound prior to heat treatment
- (3) Heat treated
- (4) Machined to 1.000 ± 0.001 x 8.000 ± 0.001 inches
- (5) Liquid honed
- (6) Passivated by immersion in 40 per cent nitric acid for 1 hour at room temperature.

#### Allegheny Ludlum

- (1) Specimens sheared from sheet in the desired condition, to a size suitable for mounting in the jigs
- (2) Machined to eliminate edge shear effects
- (3) Tempering scale removed by pickling in cold dilute nitric-hydrofluoric acid solution.

In the programs where the specimens were bent into the jigs by hand, the specimens were handled with clean canvas gloves to avoid contamination from fingerprints, or other sources. No data are available that permit evaluation of the preparatory systems listed above.

### Test Environments

Salt air, marine-atmosphere exposure in the U. S. Steel, Armco, and Allegheny Ludlum programs were conducted at the 80- and 800-foot lots (distance from ocean) at Kure Beach, North Carolina. The North American Aviation specimens were exposed in a 20 per cent salt fog at  $95 \pm 3$  F according to Federal Test Method Standard 151(a), and in a cyclic humidity test, MIL-E-5272 C, to simulate an extreme tropical climate. The details of the latter exposure are given in the tables of test results later in the report. Allegheny Ludlum also exposed specimens in a 20 per cent neutral salt spray. Some specimens in all four programs were exposed to the outdoor atmospheres existing at the company locations, namely, Monroeville and Brackenridge, Pennsylvania, Los Angeles, California, and Middletown, Ohio. The conditions were described as being mild to semiindustrial.

### RESULTS

The accumulated data for each class of alloys from all of the sources reviewed has been assembled into tabular form to facilitate comparison and discussion. The data include chemical composition of the alloys, their heat treatment and mechanical properties, exposure conditions, and results. A few blank spaces in the tables indicate that the information was not reported in the original sources. Also, since the tests were conducted by four different companies, there were some scattered data reported that did not fall readily under the table headings. These were included as footnotes to the tables.

#### Cold-Rolled Austenitic Stainless Steels

The cold-rolled austenitic stainless steels are austenitic at room temperature, and frequently contain small amounts of delta ferrite. Very high strengths may be developed during cold rolling, by a combination of work hardening and transformation of the austenite to martensite. Usually a stress-relieving treatment is used to develop the best combination of strength and ductility. The chemical composition of the steels tested and the treatment and mechanical properties are given in Tables 1 and 2. The results of the stress-corrosion-cracking experiments are in Table 3. The steels attained very high tensile strengths, ranging from about 185,000 psi for full-hard AISI 301, to a range of 245,000 to 289,000 psi for the extra-hard steels. The data in Table 3 indicate that, in general, this class of steels is very resistant to stress-corrosion cracking. It is true that some of the test specimens were lightly stressed (less than 50 per cent of the ultimate tensile strength), but others were stressed at up to 70 per cent of the tensile

strength. The tests made by U. S. Steel were at 75 per cent of the yield strength. Only one sample in the entire group developed a crack in the marine-atmosphere exposure. This cracked after 347 days at the 80-foot lot at Kure Beach while stressed at 202,000 psi. Two others developed a crack in the laboratory alternate-immersion test in 3-1/2 per cent salt solution after 39 days. Duplicates did not fail in about 400 days, and it was suggested that the two failures after only 39 days may have been abnormal, caused by a superficial nick or particle of rolled-in scale. If so, it emphasizes the need for care in handling and fabricating these high-strength steels. It may also be noted that the three failures all occurred on specimens cut transverse to the direction of rolling. There is no apparent evidence to indicate whether this is significant.

TABLE 1. CHEMICAL COMPOSITION OF THE COLD-ROLLED AUSTENITIC STAINLESS STEELS

| Alloy                   | Source of Data <sup>(a)</sup> | Composition, weight per cent |       |       |       |      |       |      |      |      |      |      |
|-------------------------|-------------------------------|------------------------------|-------|-------|-------|------|-------|------|------|------|------|------|
|                         |                               | C                            | Mn    | P     | S     | Si   | Cr    | Ni   | Mo   | V    | N    | Cu   |
| AISI 304                | USS                           | 0.03                         | 1.24  | 0.006 | 0.018 | 0.50 | 17.36 | 9.33 | --   | --   | --   | --   |
| AISI 304 <sup>(b)</sup> | A.                            | 0.11                         | 0.53  | 0.002 | 0.015 | 0.22 | 17.39 | 9.91 | 0.10 | --   | --   | 0.25 |
| AISI 201                | USS                           | 0.10                         | 7.73  | 0.009 | 0.021 | 0.23 | 15.43 | 4.60 | --   | --   | 0.15 | --   |
| USS Terelec             | USS                           | 0.094                        | 15.10 | 0.002 | 0.004 | 0.50 | 17.35 | 9.43 | --   | --   | 0.45 | --   |
| USS 17-5 304V           | USS                           | 0.11                         | 12.5  | 0.019 | 0.015 | 0.73 | 15.19 | 4.61 | 2.0  | 0.22 | 0.35 | --   |
| AISI 302                | USS                           | 0.12                         | 7.34  | 0.043 | 0.007 | 0.46 | 17.3  | 4.52 | --   | --   | 0.16 | --   |

(a) USS - U.S. Steel Corporation

A. - Allegheny Ludlum Steel Corporation

(b) Average of two heats.

The other alloys in this group were in the U. S. Steel tests and had been treated to produce yield strengths ranging from 215,000 psi to 264,000 psi. When stressed at 75 per cent of their yield strength, no failures occurred during 240 days' exposure at Kure Beach.

#### Semiaustenitic Precipitation-Hardenable Stainless Steels

The semiaustenitic precipitation-hardenable stainless steels apparently have received more attention than the others covered in this report, and more data on stress-corrosion-cracking data are available. The physical metallurgy of these alloys has been well summarized in DMIC Report 111. (2) As discussed in that report, the alloys have achieved popularity, because they can be fabricated easily in the annealed condition, and then hardened to high strength levels by a series of thermal treatments. The hardening mechanism consists of transformation from an austenitic to a martensitic matrix,

TABLE 2. MECHANICAL PROPERTIES OF THE COLD-

| Alloy        | Source<br>of Data <sup>(a)</sup> | Condition                   | Reduction<br>by Cold Rolling,<br>per cent | Stress<br>Temperature,<br>F |
|--------------|----------------------------------|-----------------------------|-------------------------------------------|-----------------------------|
| AISI 301     | USS                              | Extra hard, stress relieved | 60                                        | 960                         |
| AISI 301     | AL                               | Full hard                   | --                                        | --                          |
| AISI 301     | AL                               | Full hard                   | --                                        | --                          |
| AISI 301     | AL                               | Full hard, stress relieved  | --                                        | 830                         |
| AISI 301     | AL                               | Full hard, stress relieved  | --                                        | 870                         |
| AISI 301     | AL                               | Extra hard, stress relieved | --                                        | 750                         |
| AISI 301     | AL                               | Extra hard, stress relieved | --                                        | 750                         |
| AISI 201     | USS                              | Extra hard, stress relieved | 60                                        | 800                         |
| AISI 202     | USS                              | Extra hard, stress relieved | 60                                        | 800                         |
| USS TENELON  | USS                              | Extra hard, stress relieved | 60                                        | 800                         |
| USS 17-5 MnV | USS                              | Extra hard, stress relieved | 60                                        | 800                         |
| USS 17-5 MnV | USS                              | Extra hard, stress relieved | 60                                        | 900                         |
| USS 17-5 MnV | USS                              | Extra hard, stress relieved | 60                                        | 1100                        |
| USS 17-5 MnV | USS                              | Full hard, stress relieved  | 40                                        | 900                         |
| USS 17-5 MnV | USS                              | Full hard, stress relieved  | 40                                        | 1100                        |

(a) USS - U.S. Steel Corporation

AL - Allegheny Ludlum Steel Corporation

(b) Specimen broke outside of gage marks.

## ROLLED AUSTENITIC STAINLESS STEELS

| Relief<br>Time,<br>hours | Yield Strength,<br>1000 psi | Tensile Strength,<br>1000 psi | Elongation<br>in 2 inches,<br>per cent | Direction    |
|--------------------------|-----------------------------|-------------------------------|----------------------------------------|--------------|
| 2                        | 233                         | 249                           | 3.6                                    | Longitudinal |
| --                       | 154                         | 192                           | 19.6                                   | Longitudinal |
| --                       | 141                         | 183                           | 17.5                                   | Transverse   |
| --                       | 157                         | 184                           | 7.9                                    | Longitudinal |
| --                       | 153                         | 187                           | 11.6                                   | Transverse   |
| --                       | 252                         | 269                           | 1.5 <sup>(b)</sup>                     | Longitudinal |
| --                       | 271                         | 279                           | 1.6 <sup>(b)</sup>                     | Transverse   |
| 2                        | 229                         | 253                           | 1.2                                    | Longitudinal |
| 2                        | 215                         | 245                           | 2.5                                    | Longitudinal |
| 2                        | 239                         | 254                           | 3.5                                    | Longitudinal |
| 2                        | 251                         | 269                           | --                                     | Longitudinal |
| 2                        | 260                         | 277                           | 1.8                                    | Longitudinal |
| 2                        | 264                         | 279                           | 4.0                                    | Longitudinal |
| 2                        | 235                         | 256                           | --                                     | Longitudinal |
| 2                        | 236                         | 250                           | 7.0                                    | Longitudinal |

TABLE 3. RESULTS OF STRESS-CORROSION CRACKING TESTS

| Alloy        | Source of Data <sup>(a)</sup> | Condition <sup>(b)</sup>    | Direction    | Applied Stress               |            |
|--------------|-------------------------------|-----------------------------|--------------|------------------------------|------------|
|              |                               |                             |              | Per Cent of Tensile Strength | 1000 PSI   |
| AISI 301     | USS                           | Extra hard, stress relieved | Longitudinal | 75 <sup>(f)</sup>            | 178.5      |
| AISI 301     | AL                            | Full hard                   | Longitudinal | 10 to 70                     | 18.2-127.4 |
| AISI 301     | AL                            | Full hard                   | Transverse   | 10 to 70                     | 18.8-131.3 |
| AISI 301     | AL                            | Full hard, stress relieved  | Longitudinal | 10 to 70                     | 18.4-128.7 |
| AISI 301     | AL                            | Full hard, stress relieved  | Transverse   | 10 to 70                     | 18.7-130.8 |
| AISI 301     | AL                            | Extra hard, stress relieved | Longitudinal | 10 to 70                     | 25.9-181.3 |
| AISI 301     | AL                            | Extra hard, stress relieved | Transverse   | 10 to 70                     | 28.9-202.2 |
| AISI 201     | USS                           | Extra hard, stress relieved | Longitudinal | 75 <sup>(f)</sup>            | 171.8      |
| AISI 202     | USS                           | Extra hard, stress relieved | Longitudinal | 75 <sup>(f)</sup>            | 161.3      |
| USS TENELON  | USS                           | Extra hard, stress relieved | Longitudinal | 75 <sup>(f)</sup>            | 179.3      |
| USS 17-5 MnV | USS                           | Full hard, stress relieved  | Longitudinal | 75 <sup>(f)</sup>            | 177-198    |

(a) USS - U.S. Steel Corporation

AL - Allegheny Ludlum Steel Corporation.

(b) See Table 2 for details.

(c) 20 per cent neutral salt spray.

(d) 3-1/2 per cent NaCl solution; 10-minute immersion, 50-minute air dry cycle.

(e) Only at 70 per cent of tensile strength, two specimens for each condition.

(f) Per cent of yield strength.

(g) One specimen stressed at 50 per cent of tensile strength cracked after 39 days.

(h) One specimen stressed at 70 per cent of tensile strength cracked after 39 days.

(i) One specimen stressed at 70 per cent of tensile strength cracked after 347 days.

## ON COLD-ROLLED AUSTENITIC STAINLESS STEELS

| Number of<br>Specimens | Number of Days Exposure Without Failure |                            |                           |                                       |                                                |
|------------------------|-----------------------------------------|----------------------------|---------------------------|---------------------------------------|------------------------------------------------|
|                        | Kure Beach,<br>80-Foot Lot              | Kure Beach<br>800-Foot Lot | Salt Spray <sup>(c)</sup> | Alternate<br>Immersion <sup>(d)</sup> | Atmosphere<br>Brackenridge, Pa. <sup>(e)</sup> |
| 6                      | 240                                     | --                         | --                        | --                                    | --                                             |
| 8                      | 398                                     | 398                        | 419                       | 405                                   | 350                                            |
| 8                      | 398                                     | 398                        | 415                       | 405 <sup>(g)</sup>                    | 350                                            |
| 8                      | 398                                     | 398                        | 414                       | 388                                   | 350                                            |
| 8                      | 398                                     | 398                        | 417                       | 388 <sup>(h)</sup>                    | 350                                            |
| 8                      | 398                                     | 398                        | 285-391                   | 392                                   | 350                                            |
| 8                      | 398 <sup>(i)</sup>                      | 398                        | 344                       | 392                                   | 350                                            |
| 6                      | 240                                     | --                         | --                        | --                                    | --                                             |
| 6                      | 240                                     | --                         | --                        | --                                    | --                                             |
| 6                      | 240                                     | --                         | --                        | --                                    | --                                             |
| 15                     | 370                                     | --                         | --                        | --                                    | --                                             |

plus some precipitation hardening during aging treatments. Alloys 17-7 PH and PH 15-7 Mo are hardened in the above manner, but AM 350 and AM 355 are said to harden mainly by the austenite-to-martensite transformation followed by a tempering heat treatment.

The chemical composition of the alloys in this group are given in Table 4, and the details of the heat treatments are in Table 5. The hardening sequence is seen to include an austenite-conditioning step, during which chromium carbides are precipitated from the austenite. This results in raising the  $M_s$  temperature sufficiently that transformation to martensite is more readily accomplished in the subsequent operations. The final treatment is the aging step, during which hardening phases are precipitated in the alloy. The temperature and duration of the aging treatment will have some effect on the size and distribution of the precipitate particles. All of these steps combine to develop the mechanical properties of the heat-treated alloy. The mechanisms of hardening are discussed in much greater detail in the report mentioned above. (2)

TABLE 4. CHEMICAL COMPOSITION OF THE SEMIAUSTENITIC PRECIPITATION-HARDENABLE STAINLESS STEELS

| Alloy     | Source of Data <sup>(2)</sup> | Composition, weight per cent |      |       |       |      |       |      |      |    |       |      |      |
|-----------|-------------------------------|------------------------------|------|-------|-------|------|-------|------|------|----|-------|------|------|
|           |                               | C                            | Mn   | P     | S     | Si   | Cr    | Ni   | Mo   | V  | Ti    | N    | Al   |
| 17-7 PH   | USS                           | 0.075                        | 0.65 | --    | 0.009 | 0.35 | 15.33 | 7.17 | --   | -- | 0.077 | --   | 1.22 |
| 17-7 PH   | NAA                           | 0.063                        | 0.59 | --    | --    | 0.27 | 15.37 | 7.25 | --   | -- | --    | --   | 1.16 |
| 17-7 PH   | Amoco <sup>(3)</sup>          | --                           | --   | --    | --    | --   | --    | --   | --   | -- | --    | --   | --   |
| PH 15-7Mo | USS                           | 0.072                        | 0.52 | --    | --    | 0.32 | 14.79 | 6.34 | 2.47 | -- | 0.053 | --   | 1.13 |
| PH 15-7Mo | NAA                           | 0.070                        | 0.56 | --    | --    | 0.24 | 14.33 | 1.27 | 2.34 | -- | --    | --   | 1.23 |
| PH 15-7Mo | Amoco <sup>(3)</sup>          | --                           | --   | --    | --    | --   | --    | --   | --   | -- | --    | --   | --   |
| AM 350    | NAA                           | 0.12                         | 0.97 | --    | --    | 0.35 | 14.77 | 4.24 | 2.75 | -- | --    | 0.09 | --   |
| AM 355    | NAA                           | 0.14                         | 0.72 | --    | --    | 0.29 | 15.41 | 4.51 | 2.71 | -- | --    | 0.11 | --   |
| AM 355    | Al <sup>(c)</sup>             | 0.14                         | 0.54 | 0.023 | 0.012 | 0.35 | 15.23 | 4.57 | 2.75 | -- | --    | 0.11 | --   |

(2) USS - U.S. Steel Corporation

NAA - North American Aviation, Inc.

Al - Allegheny Ludlum Steel Corporation

Amoco - Amoco Steel Corporation

(3) Analysis not reported.

(c) Average of 4 heats.

Cold rolling is also used to produce hardening in the alloys of this group. This causes the austenite to transform to martensite, and the alloy is then aged or tempered to develop the final properties. Alloys in the CH 900 and SCCRT conditions have very high tensile and yield strengths, but it should be noted that their ductility is low. The properties of all of the alloys tested in the group are listed in Table 6.

TABLE 5. HEAT TREATMENT OF THE SEMIAUSTENITIC PRECIPITATION-HARDENABLE STAINLESS STEELS

| Alloy      | Condition | Source of Data(a) | Austenite Conditioning |               | Transformation                                                   | Age or Temper  |             |
|------------|-----------|-------------------|------------------------|---------------|------------------------------------------------------------------|----------------|-------------|
|            |           |                   | Temperature, F         | Time, minutes |                                                                  | Temperature, F | Time, hours |
| 17-7 PH    | TH 1050   | USS               | 1400                   | 90            | Cool to 60 F within 1 hr, hold 30 min                            | 1050           | 1-1/2       |
|            | TH 950    | USS               | 1400                   | 90            | Cool to 60 F within 1 hr, hold 30 min                            | 950            | 1-1/2       |
|            | RH 950    | USS               | 1750                   | 10            | Hold 8 hr at -100 F                                              | 950            | 1           |
|            | TH 1075   | NAA               | 1400                   | 90            | Cool to 32-60 F within 1 hr, hold 30 min                         | 1075           | 1-1/2       |
|            | TH 1050   | Armco             | 1400                   | 90            | Cool to 60 F within 1 hr, hold 30 min                            | 1050           | 1-1/2       |
|            | PH 950    | Armco             | 1750                   | 10            | Hold 8 hr at -100 F                                              | 950            | 1           |
|            | CH 900    | Armco             | --                     | --            | Cold rolled at mill                                              | 900            | 1           |
| PH 15-7 Mo | TH 1050   | USS               | 1400                   | 90            | Cool to 60 F within 1 hr, hold 30 min                            | 1050           | 1-1/2       |
|            | RH 950    | USS               | 1750                   | 10            | Hold 8 hr at -100 F                                              | 950            | 1           |
|            | RH 950    | NAA               | 1750                   | 20            | Hold 5 hr at -110 F                                              | 950            | 1           |
|            | BCHT(b)   | NAA               | 1625                   | 20            | Cool to 1000 F in 45 min, air cool to room temp., 5 hr at -100 F | 900            | 8           |
|            | TH 1050   | Armco             | 1400                   | 90            | Cool to 60 F within 1 hr, hold 30 min                            | 1050           | 1-1/2       |
|            | RH 950    | Armco             | 1750                   | 10            | Hold 8 hr at -100 F                                              | 950            | 1           |
|            | CH 900    | Armco             | --                     | --            | Cold rolled at mill                                              | 900            | 1           |
|            | BCHT(b)   | Armco             | 1675                   | 20            | Cool to 1000 F in 45 min, cool to room temp, 8 hr at -100 F      | 900            | 24          |
| AM 350     | SCT 850   | NAA               | 1710                   | 20            | 3 hr at -110 F                                                   | 850            | 3           |
|            | BCHT(b)   | NAA               | 1675                   | 20            | Cool to 1000 F in 45 min, cool to room temp, 8 hr at -100 F      | 900            | 24          |
| AM 355     | SCT 850   | NAA               | 1710                   | 20            | 3 hr at -110 F                                                   | 850            | 3           |
|            | BCHT(b)   | NAA               | 1675                   | 20            | Cool to 1000 F in 45 min, cool to room temp, 8 hr at -100 F      | 900            | 24          |
|            | CRT 850   | AL                | --                     | --            | Cold rolled                                                      | 850            | --          |
|            | SCCRT 850 | AL                | --                     | --            | Subzero cooled, cold rolled                                      | 850            | --          |

(a) USS - United States Steel Corporation

NAA - North American Aviation, Inc.

Armco - Armco Steel Corporation,

AL - Allegheny Ludlum Steel Corporation

(b) BCHT - braze cycle heat treatment.

TABLE 6. MECHANICAL PROPERTIES OF THE SEMIAUSTENITIC PRECIPITATION-HARDENABLE STAINLESS STEELS

| Alloy      | Source of Data <sup>(a)</sup> | Condition              | Yield Strength, 1000 psi | Tensile Strength, 1000 psi | Elongation, 2 inches, per cent | Direction    |
|------------|-------------------------------|------------------------|--------------------------|----------------------------|--------------------------------|--------------|
| 17-7 PH    | USS                           | TH 1050                | 154                      | 192                        | 3.7                            | Longitudinal |
|            | USS                           | TH 950                 | 201                      | 219                        | 3.5                            | Longitudinal |
|            | USS                           | EH 950                 | 205                      | 225                        | 5.7                            | Longitudinal |
|            | NAA                           | TH 1075                | 159                      | 177                        | 11.0                           | Longitudinal |
|            | Armco                         | TH 1050 <sup>(b)</sup> | 200                      | 214                        | 5.6                            | Transverse   |
|            | Armco                         | TH 1050 <sup>(b)</sup> | 173                      | 191                        | 9.0                            | Transverse   |
|            | Armco                         | EH 950 <sup>(c)</sup>  | 217 <sup>(c)</sup>       | 234                        | 5.0                            | Transverse   |
|            | Armco                         | CH 900 <sup>(c)</sup>  | 270                      | 279                        | 6.2                            | Transverse   |
| PH 15-7 Mo | USS                           | TH 1050                | 165                      | 193                        | 3.5                            | Longitudinal |
|            | USS                           | PH 950                 | 202                      | 225                        | 5.0                            | Longitudinal |
|            | NAA                           | EH 950                 | 223                      | 250                        | 5.0                            | Longitudinal |
|            | NAA                           | BCHT                   | 220                      | 241                        | 7.0                            | Longitudinal |
|            | Armco                         | TH 1050 <sup>(b)</sup> | 207 <sup>(c)</sup>       | 216                        | 6.5                            | Transverse   |
|            | Armco                         | PH 950 <sup>(b)</sup>  | 200 <sup>(c)</sup>       | 245                        | 4.4                            | Transverse   |
|            | Armco                         | CH 900 <sup>(b)</sup>  | 252                      | 252                        | 1.5                            | Transverse   |
|            | Armco                         | TH 1050 <sup>(c)</sup> | 209                      | 218                        | 6.2                            | Transverse   |
|            | Armco                         | EH 950 <sup>(c)</sup>  | 219                      | 242                        | 6.2                            | Transverse   |
|            | Armco                         | EH 1050 <sup>(c)</sup> | 217                      | 225                        | 5.5                            | Transverse   |
|            | Armco                         | BCHT <sup>(d)</sup>    | 255                      | 252                        | 4.9                            | Transverse   |
| AM 350     | NAA                           | SCT-550                | 175                      | 212                        | 10.5                           | Longitudinal |
|            | NAA                           | BCHT                   | 159                      | 205                        | 10                             | Longitudinal |
| AM 355     | NAA                           | SCT 550                | 182                      | 225                        | 9                              | Longitudinal |
|            | NAA                           | BCHT                   | 166                      | 195                        | 7.5                            | Longitudinal |
|            | Al <sup>(e)</sup>             | CRT 550                | 234                      | 254                        | 11.5                           | Longitudinal |
|            | Al <sup>(f)</sup>             | CRT 550                | 156                      | 210                        | 22.5                           | Longitudinal |
|            | AL                            | SOCRT 550              | 304                      | 304                        | 6.5 <sup>(g)</sup>             | Longitudinal |
|            | AL                            | SOCRT 550              | 233                      | 283                        | 11 <sup>(g)</sup>              | Transverse   |

(a) USS - U.S. Steel Corporation

NAA - North American Aviation, Inc.

Armco - Armco Steel Corporation

AL - Allegheny Ludlum Steel Corporation

(b) Data for specimens exposed up to 7 to 15, 1953, at 50 and 75 per cent of yield strength.

(c) Average of two heats.

(d) Data for specimens exposed up to June 15, 1953 to July 6, 1959, at 40 and 60 per cent of yield strength. Average of two or three heats.

(e) Heat 35526.

(f) Heat 35508.

(g) Specimen broke outside of gage marks.

### Stress-Corrosion Results for 17-7 PH

All of the stress-corrosion data that have been reviewed for Alloy 17-7 PH are tabulated in Table 7. Exposures at Kure Beach, in a 20 per cent salt spray, to a cyclic humidity cycle, and to semiindustrial environments at several localities were evaluated. No failures were reported for exposure periods of 350 to 730 days at any of the three semiindustrial locations included in the tests. The applied stresses ranged from 63,000 psi to 243,000 psi. The environments were described as mild to semiindustrial. No failures were reported in a few tests in the 20 per cent salt spray or in a cyclic-humidity environment. The applied stress levels in these tests varied from 63,000 psi to 126,000 psi.

Exposure to a marine atmosphere at Kure Beach, however, did cause some specimens to crack. The four alloy treatments included in the tests were TH 1050, TH 950, RH 950 and CH 900. It is interesting to note that the CH 900 specimens stressed to 143,000 and 214,000 psi did not fail in 746 days' exposure to the marine atmosphere. These were the strongest alloys tested but also the least ductile. The resistance of 17-7 PH to stress-corrosion cracking when in the CH 900 condition is probably related to the fact that transformation of austenite to martensite is induced by cold work rather than by a heat treatment. In the latter case, precipitation of carbides at grain boundaries may result in the development of corrosion-susceptible paths that favor stress-corrosion cracking.

Examination of the data for the alloy shows how difficult it is to make quantitative evaluations of susceptibility to stress-corrosion cracking. In the TH 1050 condition, for example, 7 out of 27 specimens stressed to 116,000 psi (75 per cent of the yield strength) cracked in an average time of 21 days whereas the other 20 did not fail in 320 days' exposure at the 80-foot lot at Kure Beach. In a test at the 800-foot lot, 2 out of 5 specimens stressed to 151,000 psi failed in an average time of 100 days, while the unfailed specimens were exposed for a total time of 746 days. No explanation has been offered for the wide spread in exposure periods between the specimens that cracked and those that did not crack. In a second heat of the Armco steel in the TH 1050 condition, but having a lower yield strength, no failures were reported for 746 days on specimens stressed to 134,000 psi.

In the RH 950 condition most of the specimens stressed at 90, 75, and 50 per cent of the yield strength (183,000 to 102,000 psi) failed on exposure at Kure Beach. The exposure periods to failure ranged from 2 to 116 days, depending on the stress level and conditions of exposure. Here again, the specimens that did not fail withstood exposures of 380 days at the 80-foot lot and 746 days at the 800-foot lot. In the RH 950 condition the alloy is

TABLE 7. RESULTS OF STRESS-CORROSION-CRACKING TESTS ON ALLOY 17-7 PH

| Alloy and Condition                                                           | Source of Data (A)   | Applied Stress           |          | Number of Specimens |        | Average Time to Failure, days | Exposure Time of Unfailed Specimens, days | Direction    |
|-------------------------------------------------------------------------------|----------------------|--------------------------|----------|---------------------|--------|-------------------------------|-------------------------------------------|--------------|
|                                                                               |                      | Per Cent of Yield Stress | 1000 PSI | Exposed             | Failed |                               |                                           |              |
| <u>Exposed at Kure Beach<sup>(B)</sup></u>                                    |                      |                          |          |                     |        |                               |                                           |              |
| 17-7 PH, TH 1054                                                              | USS                  | 75                       | 116      | 27                  | 7      | 21                            | 320                                       | Longitudinal |
|                                                                               | Amoco <sup>(C)</sup> | 75                       | 151      | 5                   | 2      | 100                           | 745                                       | Transverse   |
|                                                                               | Amoco <sup>(C)</sup> | 75                       | 134      | 5                   | 0      | --                            | 745                                       | Transverse   |
|                                                                               | Amoco <sup>(C)</sup> | 50                       | 101      | 5                   | 0      | --                            | 745                                       | Transverse   |
|                                                                               | Amoco <sup>(C)</sup> | 50                       | 89       | 5                   | 0      | --                            | 745                                       | Transverse   |
| 17-7 PH, TH 250                                                               | USS                  | 90                       | 181      | --                  | --     | 1 <sup>(D)</sup>              | --                                        | Longitudinal |
|                                                                               | USS                  | 75                       | 151      | 4                   | 4      | 1                             | --                                        | Longitudinal |
|                                                                               | USS                  | 50                       | 101      | --                  | --     | 5 <sup>(D)</sup>              | --                                        | Longitudinal |
| 17-7 PH, RH 960                                                               | USS                  | 90                       | 143      | --                  | --     | 2 <sup>(D)</sup>              | --                                        | Longitudinal |
|                                                                               | USS                  | 75                       | 152      | 30                  | 21     | 5                             | 320                                       | Longitudinal |
|                                                                               | USS                  | 50                       | 102      | --                  | --     | 16 <sup>(D)</sup>             | --                                        | Longitudinal |
|                                                                               | Amoco <sup>(C)</sup> | 75                       | 163      | 5                   | 5      | 7.4                           | --                                        | Transverse   |
|                                                                               | Amoco <sup>(C)</sup> | 75                       | 165      | 5                   | 5      | 51.6                          | --                                        | Transverse   |
|                                                                               | Amoco <sup>(C)</sup> | 50                       | 112      | 5                   | 5      | 20.2                          | --                                        | Transverse   |
|                                                                               | Amoco <sup>(C)</sup> | 50                       | 110      | 5                   | 1      | 116.                          | 745                                       | Transverse   |
| 17-7 PH, CH 200                                                               | Amoco <sup>(C)</sup> | 75                       | 214      | 5                   | 0      | --                            | 745                                       | Transverse   |
|                                                                               | Amoco <sup>(C)</sup> | 50                       | 142      | 5                   | 0      | --                            | 745                                       | Transverse   |
| <u>Exposed to Salt Spray - 10 Per Cent NaCl at 75 ± 3 F</u>                   |                      |                          |          |                     |        |                               |                                           |              |
| 17-7 PH, TH 1075                                                              | NAA                  | 50                       | 125      | 3                   | 0      | --                            | 42                                        | Longitudinal |
|                                                                               | NAA                  | 40                       | 63       | 3                   | 0      | --                            | 42                                        | Longitudinal |
| <u>Cyclic Humidity Exposure at Relative Humidity of 90 Per Cent or Higher</u> |                      |                          |          |                     |        |                               |                                           |              |
| Heat from 50 - 100 F to 100 F in 1 hour                                       |                      |                          |          |                     |        |                               |                                           |              |
| Hold at 100 F, 6 hours                                                        |                      |                          |          |                     |        |                               |                                           |              |
| Cool to 50 - 100 F in 15 hours                                                |                      |                          |          |                     |        |                               |                                           |              |
| 17-7 PH, TH 1075                                                              | NAA                  | 50                       | 125      | 3                   | 0      | --                            | 51                                        | Longitudinal |
|                                                                               | NAA                  | 60                       | 95       | 3                   | 0      | --                            | 51                                        | Longitudinal |
|                                                                               | NAA                  | 40                       | 63       | 3                   | 0      | --                            | 51                                        | Longitudinal |
| <u>Atmospheric Exposure</u>                                                   |                      |                          |          |                     |        |                               |                                           |              |
| 17-7 PH, TH 1050                                                              | USS <sup>(E)</sup>   | 75                       | 115      | 7                   | 0      | --                            | 50                                        | Longitudinal |
|                                                                               | Amoco <sup>(F)</sup> | 90                       | 180      | --                  | 0      | --                            | 720                                       | Transverse   |
| 17-7 PH TH 1075                                                               | NAA <sup>(G)</sup>   | 50                       | 125      | 3                   | 0      | --                            | 35 <sup>(H)</sup>                         | Longitudinal |
|                                                                               | NAA <sup>(G)</sup>   | 60                       | 95       | 3                   | 0      | --                            | 35 <sup>(H)</sup>                         | Longitudinal |
|                                                                               | NAA <sup>(G)</sup>   | 40                       | 63       | 3                   | 0      | --                            | 35 <sup>(H)</sup>                         | Longitudinal |
| 17-7 PH, RH 960                                                               | USS                  | 75                       | 152      | 7                   | 0      | --                            | 50                                        | Longitudinal |
|                                                                               | Amoco                | 90                       | 196      | --                  | 0      | --                            | 720                                       | Transverse   |
| 17-7 PH, CH 900                                                               | Amoco                | 90                       | 243      | --                  | 0      | --                            | 720                                       | Transverse   |

Footnotes appear on the following page.

Footnotes for Table 7

- (a) USS - U.S. Steel Corporation  
AISC - American Steel Corporation  
NAA - North American Aviation, Inc.
- (b) U. S. Steel tests, 80-foot lot;  
AISC tests, 80-foot lot.
- (c) Specimens exposed in test up to June 15, 1953.
- (d) Average of three specimens or more.
- (e) Atmospheric exposure at Monroeville, Pennsylvania.
- (f) Atmospheric exposure at Middletown, Ohio.
- (g) Atmospheric exposure at Los Angeles, California.
- (h) Specimens still in test.

somewhat stronger and less ductile than in the TH 1050 condition, and consequently it is also more susceptible to stress-corrosion cracking. It should be noted that the data in Table 7 does not permit direct comparison of results in every case because of some spread in the mechanical properties of different heats of the same alloy, and because some specimens were cut in the direction of rolling and others in the transverse direction. Also, the difference in the severity of the environment at the two Kure Beach lots should be considered in comparing the results reported.

A few tests were made with specimens in the TH 1050 condition. Failures occurred within a few days, even on the specimens stressed to 101,000 psi (50 per cent of the yield strength).

Summarizing, 17-7 PH alloy in the highest strength conditions and high applied stresses was shown to be susceptible to stress-corrosion cracking in a marine atmosphere. The susceptibility is not solely related to the strength of the alloy but is also determined by the heat-treatment procedure used to obtain the properties. Some specimens were reported to have been cut parallel to the rolling direction and others transverse, but no direct comparisons of the effect of this variable were made.

#### Stress-Corrosion Results for PH 15-7 Mo

It was noted earlier in the report that the cold-working and heat-treating conditions for PH 15-7 Mo were the same as those for 17-7 PH. These are given in Table 5, and the mechanical properties of the heats tested in corrosion are in Table 6. Table 8 is a tabulation of the accumulated data on stress-corrosion cracking for PH 15-7 Mo treated by the common procedures and by simulated brazing heat-treatment cycles. Specimens were exposed to semiindustrial atmospheres, at the 80- and 800-foot lots at Kure Beach, in a 20 per cent salt spray, and in a cyclic humidity atmosphere. These were essentially duplicates of the tests on 17-7 PH just described. However, some newer work by Armco and North American Aviation is included.

The results show that the alloy in the TH 1050 is quite susceptible to stress-corrosion cracking in the environment of the 80-foot lot at Kure Beach. A large percentage of the specimens stressed to 60 and 75 per cent of their yield strength were reported cracked after relatively short exposure periods. No failures occurred in 466 days on the specimens stressed to only 40 per cent of the yield strength. Just as with 17-7 PH, however, there was a wide spread in exposure times between those specimens that did fail.

TABLE 1. RESULTS OF STRESS-CORROSION-CRACKING TESTS ON ALLOY PH 15-7 Mo

| Alloy and Condition                | Source of Data(a)   | Applied Stress             |          | Number of Specimens |        | Average Time to Failure, days | Exposure Time of Unfailed Specimens, days | Direction    |            |
|------------------------------------|---------------------|----------------------------|----------|---------------------|--------|-------------------------------|-------------------------------------------|--------------|------------|
|                                    |                     | Per Cent of Yield Strength | 1000 PSI | Exposed             | Failed |                               |                                           |              |            |
| Exposed at Kure Beach, 30-Foot Lot |                     |                            |          |                     |        |                               |                                           |              |            |
| 4                                  |                     |                            |          |                     |        |                               |                                           |              |            |
| PH 15-7 Mo, TH 1050                | USS                 | 5                          | 140      | 10                  | 9      | 16                            | 240                                       | Longitudinal |            |
|                                    | Amoco               | 30                         | 127      | 5                   | 3      | 182                           | --                                        | Transverse   |            |
|                                    | Amoco               | 60                         | 125      | 5                   | 4      | 73                            | 466                                       | Transverse   |            |
|                                    | Amoco               | 80                         | 124      | 5                   | 2      | 71                            | 466                                       | Transverse   |            |
|                                    | Amoco               | 40                         | 85       | 5                   | 4      | --                            | 466                                       | Transverse   |            |
|                                    | Amoco               | 40                         | 84       | 5                   | 6      | --                            | 466                                       | Transverse   |            |
| PH 15-7 Mo, RH 950                 | Amoco               | 40                         | 82       | 5                   | 0      | --                            | 466                                       | Transverse   |            |
|                                    | USS                 | 90                         | 182      | --(b)               | --     | 12                            | --                                        | Longitudinal |            |
|                                    | USS                 | 75                         | 152      | 12                  | 12     | 15                            | --                                        | Longitudinal |            |
|                                    | USS                 | 50                         | 101      | --(b)               | 9      | --                            | 175                                       | Longitudinal |            |
|                                    | Amoco               | 60                         | 131      | 5                   | 5      | 23.2                          | --                                        | Transverse   |            |
|                                    | Amoco               | 60                         | 132      | 5                   | 5      | 23.2                          | --                                        | Transverse   |            |
|                                    | Amoco               | 50                         | 131      | 5                   | 5      | 19                            | --                                        | Transverse   |            |
|                                    | Amoco               | 40                         | 87       | 5                   | 4      | 172                           | 466                                       | Transverse   |            |
|                                    | Amoco               | 40                         | 83       | 5                   | 4      | 74                            | 466                                       | Transverse   |            |
| PH 15-7 Mo, RH 1350                | Amoco               | 40                         | 87       | 5                   | 1      | 82                            | 466                                       | Transverse   |            |
|                                    | Amoco               | 60                         | 131      | 5                   | 4      | 140                           | 466                                       | Transverse   |            |
|                                    | Amoco               | 60                         | 129      | 5                   | 4      | 339                           | 466                                       | Transverse   |            |
|                                    | Amoco               | 40                         | 83       | 5                   | 5      | --                            | 466                                       | Transverse   |            |
| PH 15-7 Mo, BCHT(c)                | Amoco               | 40                         | 86       | 5                   | 0      | --                            | 466                                       | Transverse   |            |
|                                    | Amoco               | 60                         | 140      | 5                   | 5      | 24.2                          | --                                        | Transverse   |            |
|                                    | Amoco               | 60                         | 140      | 5                   | 5      | 44.2                          | --                                        | Transverse   |            |
|                                    | Amoco               | 40                         | 93       | 5                   | 5      | 49.6                          | --                                        | Transverse   |            |
| Exposed at Kure Beach, 50-Foot Lot | Amoco               | 40                         | 94       | 5                   | 5      | 61.6                          | --                                        | Transverse   |            |
|                                    | PH 15-7 Mo, TH 1050 | Amoco                      | 75       | 161                 | 5      | 3                             | 164                                       | 746          | Transverse |
|                                    | Amoco               | 75                         | 164      | 5                   | 5      | 39.8                          | --                                        | Transverse   |            |
|                                    | Amoco               | 60                         | 127      | 5                   | 0      | --                            | 466                                       | Transverse   |            |
|                                    | Amoco               | 60                         | 125      | 5                   | 0      | --                            | 466                                       | Transverse   |            |
|                                    | Amoco               | 60                         | 124      | 5                   | 0      | --                            | 466                                       | Transverse   |            |
|                                    | Amoco               | 50                         | 107      | 5                   | 0      | --                            | 746                                       | Transverse   |            |
|                                    | Amoco               | 50                         | 109      | 5                   | 0      | --                            | 746                                       | Transverse   |            |
|                                    | Amoco               | 40                         | 85       | 5                   | 0      | --                            | 466                                       | Transverse   |            |
|                                    | Amoco               | 40                         | 84       | 5                   | 0      | --                            | 466                                       | Transverse   |            |
| PH 15-7 Mo, RH 950                 | Amoco               | 40                         | 82       | 5                   | 0      | --                            | 466                                       | Transverse   |            |
|                                    | Amoco               | 75                         | 174      | 5                   | 5      | 63.8                          | --                                        | Transverse   |            |
|                                    | Amoco               | 75                         | 175      | 5                   | 5      | 14.2                          | --                                        | Transverse   |            |
|                                    | Amoco               | 60                         | 131      | 5                   | 4      | 179                           | 466                                       | Transverse   |            |
|                                    | Amoco               | 60                         | 132      | 5                   | 4      | 126                           | 466                                       | Transverse   |            |
|                                    | Amoco               | 60                         | 131      | 5                   | 4      | 164                           | 466                                       | Transverse   |            |
|                                    | Amoco               | 50                         | 116      | 5                   | 5      | 169.4                         | --                                        | Transverse   |            |
|                                    | Amoco               | 50                         | 117      | 5                   | 5      | 82.8                          | --                                        | Transverse   |            |
|                                    | Amoco               | 40                         | 87       | 5                   | 1      | 346                           | 466                                       | Transverse   |            |
|                                    | Amoco               | 40                         | 83       | 5                   | 0      | --                            | 466                                       | Transverse   |            |
| Amoco                              | 40                  | 87                         | 5        | 0                   | --     | 466                           | Transverse                                |              |            |

TABLE 9. (Continued)

| Alloy and Condition                                                    | Source of Data <sup>(a)</sup> | Applied Stress             |          | Number of Specimens |                  | Average Time to Failure, days | Exposure Time of Unfailed Specimens, days | Direction    |
|------------------------------------------------------------------------|-------------------------------|----------------------------|----------|---------------------|------------------|-------------------------------|-------------------------------------------|--------------|
|                                                                        |                               | Per Cent of Yield Strength | 1000 PSI | Exposed             | Failed           |                               |                                           |              |
| Exposed at Kure Beach, 800-Foot Lot (Continued)                        |                               |                            |          |                     |                  |                               |                                           |              |
| PH 15-7 Mo, RH 1050                                                    | Armco                         | 60                         | 131      | 5                   | 0                | --                            | 466                                       | Transverse   |
|                                                                        | Armco                         | 60                         | 129      | 5                   | 0                | --                            | 466                                       | Transverse   |
|                                                                        | Armco                         | 40                         | 88       | 5                   | 0                | --                            | 466                                       | Transverse   |
| PH 15-7 Mo, BCHT <sup>(c)</sup>                                        | Armco                         | 60                         | 140      | 5                   | 5                | 236.2                         | --                                        | Transverse   |
|                                                                        | Armco                         | 60                         | 140      | 5                   | 5                | 101.4                         | --                                        | Transverse   |
|                                                                        | Armco                         | 40                         | 93       | 5                   | 0                | --                            | 466                                       | Transverse   |
|                                                                        | Armco                         | 40                         | 94       | 5                   | 3                | 333                           | 466                                       | Transverse   |
| PH 15-7 Mo, CH 900                                                     | Armco                         | 75                         | 196      | 5                   | 0                | --                            | 746                                       | Transverse   |
|                                                                        | Armco                         | 50                         | 131      | 5                   | 0                | --                            | 746                                       | Transverse   |
| Exposed to Salt Spray - 20 Per Cent NaCl at 95 ± 3 F                   |                               |                            |          |                     |                  |                               |                                           |              |
| PH 15-7 Mo, RH 950                                                     | NAA                           | 80                         | 178      | 2                   | 0                | --                            | 42                                        | Longitudinal |
|                                                                        | NAA                           | 40                         | 89       | 3                   | 0                | --                            | 42                                        | Longitudinal |
| PH 15-7 Mo BCHT <sup>(d)</sup>                                         | NAA                           | 80                         | 176      | 2                   | 2                | 7                             | --                                        | Longitudinal |
|                                                                        | NAA                           | 40                         | 88       | 3                   | 0                | --                            | 42                                        | Longitudinal |
| PH 15-7 Mo, brazed <sup>(e)</sup>                                      | NAA                           | 40                         | --       | -                   | 0                | --                            | 21                                        | --           |
| PH 15-7 Mo, BCHT <sup>(f)</sup>                                        | NAA                           | 40                         | --       | -                   | 0                | --                            | 21                                        | --           |
| Cyclic Humidity Exposure at Relative Humidity of 95 Per Cent or Higher |                               |                            |          |                     |                  |                               |                                           |              |
| Heat from 80-100 F to 160 F in 2 hours                                 |                               |                            |          |                     |                  |                               |                                           |              |
| Hold at 160 F 6 hours                                                  |                               |                            |          |                     |                  |                               |                                           |              |
| Cool to 80-100 F in 16 hours.                                          |                               |                            |          |                     |                  |                               |                                           |              |
| PH 15-7 Mo, RH 950                                                     | NAA                           | 80                         | 178      | 3                   | 0                | --                            | 51                                        | Longitudinal |
|                                                                        | NAA                           | 60                         | 134      | 3                   | 0                | --                            | 51                                        | Longitudinal |
|                                                                        | NAA                           | 40                         | 89       | 3                   | 0                | --                            | 51                                        | Longitudinal |
| PH 15-7 Mo, BCHT <sup>(d)</sup>                                        | NAA                           | 80                         | 176      | 3                   | 1 <sup>(g)</sup> | 52                            | 52 <sup>(h)</sup>                         | Longitudinal |
|                                                                        | NAA                           | 40                         | 88       | 3                   | 0                | --                            | 51                                        | Longitudinal |
| Atmospheric Exposure                                                   |                               |                            |          |                     |                  |                               |                                           |              |
| PH 15-7 Mo, TH 1050                                                    | Armco <sup>(i)</sup>          | 90                         | 186      | -                   | 0                | --                            | 730                                       | Transverse   |
| PH 15-7 Mo, RH 950                                                     | Armco <sup>(i)</sup>          | 90                         | 198      | -                   | 0                | --                            | 730                                       | Transverse   |
|                                                                        | NAA <sup>(j)</sup>            | 80                         | 178      | 3                   | 0                | --                            | 350 <sup>(k)</sup>                        | Longitudinal |
|                                                                        | NAA <sup>(j)</sup>            | 60                         | 134      | 3                   | 0                | --                            | 350 <sup>(k)</sup>                        | Longitudinal |
|                                                                        | NAA <sup>(j)</sup>            | 40                         | 89       | 3                   | 0                | --                            | 350 <sup>(k)</sup>                        | Longitudinal |
| PH 15-7 Mo CH 900                                                      | Armco <sup>(i)</sup>          | 75                         | 196      | 5                   | 0                | --                            | 746                                       | Transverse   |
|                                                                        | Armco <sup>(i)</sup>          | 50                         | 131      | 5                   | 0                | --                            | 746                                       | Transverse   |
| PH 15-7 Mo, BCHT <sup>(d)</sup>                                        | NAA <sup>(j)</sup>            | 80                         | 176      | 3                   | 1 <sup>(g)</sup> | 100                           | 350 <sup>(k)</sup>                        | Longitudinal |
|                                                                        | NAA <sup>(j)</sup>            | 40                         | 88       | 3                   | 0                | --                            | 350 <sup>(k)</sup>                        | Longitudinal |
| PH 15-7 Mo brazed                                                      | NAA <sup>(j)</sup>            | 40                         | --       | -                   | 0                | --                            | 290 <sup>(k)</sup>                        | Longitudinal |
| PH 15-7 Mo BCHT <sup>(f)</sup>                                         | NAA <sup>(j)</sup>            | 40                         | --       | -                   | 0                | --                            | 290 <sup>(k)</sup>                        | Longitudinal |
| Footnotes appear on the following page                                 |                               |                            |          |                     |                  |                               |                                           |              |

Footnotes appear on the following page.

## Footnotes for Table 6.

- (a) USS - United States Steel Corporation  
 Armco - Armco Steel Corporation  
 NAA - North American Aviation, Inc.
- (b) Average of three specimens or more.
- (c) See Armco DCHT, Table 5.
- (d) See NAA SCHT, Table 5.
- (e) 3/4 x 1-inch patch bonded to center of 1 x 3-inch specimens.  
 Brazing alloys: (1) L7CM (80-20) and (2) T50 alloy.
- (f) Brazing cycle:  
 1750 F - 20 minutes, slow cool to 1040 F (45 minutes), air cool to room temperature  
 -50 ± 15 F - 3 hours  
 1075 F - 1 hour.
- (g) Specimens not properly coated after heat treatment.
- (h) Cracked, but not fractured.
- (i) Atmospheric exposure at Middletown, Ohio.
- (j) Atmospheric exposure at Los Angeles, California.
- (k) Specimens still in test.

and those that did not fail. In the groups that included failed specimens, 20 of 27 specimens failed after exposure periods of 16 to 182 days. Of the unfailed specimens, three were exposed for 240 days and four for 406 days. The data in Table 8 show that different heats treated to the same strength level, and exposed at equal stresses, show a wide variation in average times to failure, 71 to 182 days in one instance. Evidently, the induction period, during which corrosion and crack formation take place, varies considerably between replicate specimens within a heat and also between similar heats.

At the 800-foot lot at Kure Beach, no failures were reported on PH 15-7 Mo specimens exposed for a total of 466 days. This included 15 specimens stressed at 60 per cent of the yield strength (applied stress about 125,000 psi). Duplicates exposed at the 80-foot lot had shown numerous cracking failures, which is a measure of the difference in corrosiveness of the two exposure environments. In an earlier test, 8 of 10 specimens of PH 15-7 Mo, TH 1050 stressed to 75 per cent of the yield strength were cracked after exposure at the 800-foot lot. Here again the average time to failure ranged from 49 to 103 days, and the unfailed specimens withstood 746 days' exposure.

PH 15-7 Mo in the RH 950 condition appears to be quite susceptible to stress-corrosion cracking in the marine environment at the 80-foot lot at Kure Beach. Many of the specimens in this condition failed during the course of the tests, at all stress levels. Average time to failure ranged from 12 days for the most highly stressed group of specimens to 173 days at lower stresses. The most resistant specimens were those tested at 40 per cent of the yield strength (applied stress of about 87,000 psi). Even under these conditions, most of the specimens cracked. On the other hand, the group stressed at 50 per cent of the yield strength (101,000 psi) showed no failures during 175 days' exposure. Perhaps this is an indication of a directional effect since the specimens in this group were taken in the direction of rolling.

Some specimens of PH 15-7 Mo, RH 950 failed at the 800-foot lot at Kure Beach. One specimen stressed at 87,000 psi (40 per cent of yield strength) failed after 346 days' exposure, while at higher stress levels failures occurred in shorter periods. These results indicate that any exposure of this alloy in the RH 950 condition to marine atmospheres should be at relatively low stress levels.

Specimens in the RH 950 condition at stress levels from 89,000 psi to 173,000 psi were also exposed to a 20 per cent salt-spray solution for 42 days and in the cyclic humidity environment for 51 days without failure. As discussed above, large percentages of similarly stressed specimens failed in a sea-coast environment. At similar stress levels, failures at the 80-foot lot occurred generally in shorter periods than the 42 and 51 days listed for the salt-spray and humidity cycles. This might indicate that the Kure Beach environment is more harmful, but perhaps other factors also play a part in the results.

A few tests were made on PH 15-7 Mo in the RH 1050 condition. Specimens in this condition were more resistant than in the RH 950 conditions at both the 80- and 800-foot lots. At the latter site, none of the RH 1050 specimens failed in 466 days' exposure. At the 80-foot lot, the RH 1050 condition showed somewhat better resistance than the TH 1050 condition. This might be expected on the basis that the RH 1050 structure would have fewer carbides precipitated at the grain boundaries, and somewhat reduced tendency to intergranular attack.

A few specimens of PH 15-7 Mo in the CH 900 condition were exposed at Kure Beach. Very high strength is developed during cold rolling rather than by heat treatment, so carbides are not precipitated at the grain boundaries. No failures occurred on exposure for 746 days at stress levels of 131,000 and 196,000 psi.

The final test treatment was designated as BCHT, i.e., braze-cycle heat treatment. This is intended to simulate the conditions that prevail during brazing of the alloy. The cycles used at Armco and North American Aviation are given in Table 5. The austenite conditioning step at 1625 or 1675 F will cause some carbides to precipitate, probably more than at the standard 1750 F temperature and less than at the 1400 F temperature used to form the T condition. Additional carbide precipitation may occur during the cooling to 1000 F in 45 minutes. However, subzero cooling is required in each case to transform the austenite, and further strength is attained by precipitation hardening. According to Table 6, the Armco treatment using the 1675 F conditioning step and a 24-hour aging at 900 F, resulted in a somewhat stronger, but less ductile, condition than the North American treatment. In the latter, the conditioning temperature was 1625 F, and the aging treatment was conducted at 900 F for 8 hours.

A direct comparison of the effect of these treatments on the susceptibility to stress corrosion was not possible, because the specimens were exposed in different environments. Twenty specimens of twenty with the Armco BCHT treatment, at stress levels of from 93,000 to 140,000 psi, failed after relatively short exposure at the 80-foot lot at Kure Beach. At the 800-foot lot, 13 of 20 specimens failed. Failures also occurred in the salt spray on the North American Aviation BCHT specimens in the highly stressed condition but not at lower stresses (88,000 psi). Here again the total exposure time was only 42 days as compared with 466 days on the specimens exposed at Kure Beach. A comparison with North American Aviation specimens in the RH 950 condition, exposed to the salt spray, indicates that the BCHT treatment results in greater stress-corrosion-cracking susceptibility, but this conclusion is based only on very limited testing. Specimens in the North American BCHT condition were also exposed to the cyclic humidity environment for 51 days. One specimen cracked, but this was attributed to improper cleaning following the heat treatment.

Atmospheric exposure at Middletown, Ohio, for periods up to 2 years, has not resulted in any stress-corrosion cracking failures on PH 15-7 Mo in

the TH 1050, RH 950 or CH 900 conditions. Other tests in the Los Angeles atmosphere are still in progress, with no failures reported.

#### Stress-Corrosion Results for AM 350 and AM 355

These alloys are similar to 17-7 PH and PH 15-7 Mo, both in mechanical and thermal treatments and in strength properties. A discussion of the physical metallurgy of the alloys may be found in DMIC Report 111<sup>(2)</sup> and in a paper by Lula<sup>(4)</sup>.

The stress-corrosion-cracking properties of AM 355 in the CRT and SCCRT conditions were examined by Allegheny-Ludlum Corporation. The data tabulated in Table 9 were taken from a preliminary report issued in 1959. A few additional data on AM 350 and AM 355 in the SCT condition and also treated by the braze-cycle treatment (BCHT) from North American Aviation tests are included in Table 9.

The chemical composition, heat treatments, and mechanical properties of the alloys are given in Tables 4, 5, and 6, respectively. It will be noted that strengths up to about 300,000 psi were developed by the SCCRT treatment on AM 355. Two different heats of AM 355, CRT were treated to produce markedly different properties. These should be noted because the results of stress-corrosion cracking also were different. The designation "CRT 850" does not distinguish the difference in the two heats.

In the Allegheny Ludlum tests, specimens were stressed at 10, 35, 50 and 70 per cent of the ultimate tensile strengths. A glance at Table 9, shows that no failures occurred in any exposure at the two lower stress levels. At the 80-foot lot at Kure Beach, specimens from the higher-strength heat of AM 355, CRT 850 (tensile strength 238,000 psi) failed at both 50 and 70 per cent of the tensile strength, whereas those from the lower strength heat (tensile strength 210,300 psi) did not fail in 321 days' exposure at any stress level. At the 850 foot-lot, specimens from both heats failed, when stressed to 70 per cent of the tensile strength. No explanation was given to account for the failure of one specimen at the 800-foot lot, whereas duplicates at the more severe 80-foot lot did not fail. Exposure to salt spray also resulted in cracking of specimens from the higher strength heat whereas the lower strength specimens did not fail. At the 70 per cent stress level, one specimen failed in one day, and its duplicate did not fail in 359 days. It was noted that similar experiences at U. S. Steel were attributed to probability effects. Specimens of both heats of AM 355, CRT 850 stressed to 70 per cent the tensile strength and exposed to the atmosphere at Brackenridge had not failed after 181 and 321 days, respectively.

In the SCCRT 850 condition, failures occurred only at the 80-ft lot at Kure Beach, on specimens stressed at 50 and 70 per cent of their tensile strength. Since the alloy in this condition is very strong, the applied stress

TABLE 9. RESULTS OF STRESS-CORROSION-CRACKING TESTS  
ON ALLOYS AM 350 AND AM 355

| Alloy<br>and<br>Condition                                            | Source<br>of<br>Data <sup>(a)</sup> | Applied Stress                                          |          | Number of<br>Specimens |        | Average Time<br>to Failure,<br>days | Exposure Time<br>of Unfailed<br>Specimens,<br>days | Direction    |
|----------------------------------------------------------------------|-------------------------------------|---------------------------------------------------------|----------|------------------------|--------|-------------------------------------|----------------------------------------------------|--------------|
|                                                                      |                                     | Per Cent of<br>Ultimate<br>Tensile or<br>Yield Strength | 1000 PSI | Exposed                | Failed |                                     |                                                    |              |
|                                                                      |                                     |                                                         |          |                        |        |                                     |                                                    |              |
| <u>Exposed at Kane Beach, 33-Foot Lot</u>                            |                                     |                                                         |          |                        |        |                                     |                                                    |              |
| AM 355, CRT 550 <sup>(b)</sup>                                       | AL                                  | 10                                                      | 23.8     | 2                      | 0      | --                                  | 63                                                 | Longitudinal |
|                                                                      | AL                                  | 35                                                      | 93.4     | 2                      | 0      | --                                  | 321                                                | Longitudinal |
|                                                                      | AL                                  | 50                                                      | 119.1    | 2                      | 2      | 65                                  | --                                                 | Longitudinal |
|                                                                      | AL                                  | 70                                                      | 166.3    | 2                      | 2      | 112                                 | --                                                 | Longitudinal |
| AM 355, CRT 550 <sup>(c)</sup>                                       | AL                                  | 35                                                      | 73.4     | 2                      | 0      | --                                  | 321                                                | Longitudinal |
|                                                                      | AL                                  | 50                                                      | 104.3    | 2                      | 0      | --                                  | 321                                                | Longitudinal |
|                                                                      | AL                                  | 70                                                      | 145.3    | 1                      | 0      | --                                  | 321                                                | Longitudinal |
| AM 355, SCERT 550                                                    | AL                                  | 10                                                      | 30.4     | 2                      | 0      | --                                  | 63                                                 | Longitudinal |
|                                                                      | AL                                  | 35                                                      | 106.4    | 2                      | 0      | --                                  | 451                                                | Longitudinal |
|                                                                      | AL                                  | 50                                                      | 152.0    | 2                      | 1      | 319                                 | 451                                                | Longitudinal |
|                                                                      | AL                                  | 70                                                      | 212.3    | 2                      | 2      | 21                                  | --                                                 | Longitudinal |
| <u>Exposed at Kane Beach, 350-Foot Lot</u>                           |                                     |                                                         |          |                        |        |                                     |                                                    |              |
| AM 355, CRT 550 <sup>(b)</sup>                                       | AL                                  | 10                                                      | 23.8     | 2                      | 0      | --                                  | 63                                                 | Longitudinal |
|                                                                      | AL                                  | 35                                                      | 93.4     | 2                      | 0      | --                                  | 321                                                | Longitudinal |
|                                                                      | AL                                  | 50                                                      | 119.1    | 2                      | 0      | --                                  | 321                                                | Longitudinal |
|                                                                      | AL                                  | 70                                                      | 166.3    | 2                      | 2      | 152                                 | --                                                 | Longitudinal |
| AM 355, CRT 550 <sup>(c)</sup>                                       | AL                                  | 35                                                      | 73.4     | 2                      | 0      | --                                  | 321                                                | Longitudinal |
|                                                                      | AL                                  | 50                                                      | 104.3    | 2                      | 0      | --                                  | 321                                                | Longitudinal |
|                                                                      | AL                                  | 70                                                      | 145.3    | 2                      | 1      | 177                                 | 321                                                | Longitudinal |
| AM 355, SCERT 550                                                    | AL                                  | 10                                                      | 30.4     | 2                      | 0      | --                                  | 63                                                 | Longitudinal |
|                                                                      | AL                                  | 35                                                      | 106.4    | 2                      | 2      | --                                  | 451                                                | Longitudinal |
|                                                                      | AL                                  | 50                                                      | 152.0    | 2                      | 0      | --                                  | 451                                                | Longitudinal |
|                                                                      | AL                                  | 70                                                      | 212.3    | 2                      | 0      | --                                  | 451                                                | Longitudinal |
| <u>Exposed to Salt Spray - 20 Per Cent NaCl Solution at 95 ± 3 F</u> |                                     |                                                         |          |                        |        |                                     |                                                    |              |
| AM 355, CRT 550 <sup>(b)</sup>                                       | AL                                  | 10                                                      | 23.8     | 2                      | 0      | --                                  | 359                                                | Longitudinal |
|                                                                      | AL                                  | 35                                                      | 93.4     | 2                      | 0      | --                                  | 356                                                | Longitudinal |
|                                                                      | AL                                  | 50                                                      | 119.1    | 2                      | 2      | 171                                 | --                                                 | Longitudinal |
|                                                                      | AL                                  | 70                                                      | 166.3    | 2                      | 1      | 1                                   | 359                                                | Longitudinal |
| AM 355, CRT 550 <sup>(c)</sup>                                       | AL                                  | 35                                                      | 73.4     | 2                      | 0      | --                                  | 344                                                | Longitudinal |
|                                                                      | AL                                  | 50                                                      | 104.3    | 2                      | 0      | --                                  | 344                                                | Longitudinal |
|                                                                      | AL                                  | 70                                                      | 145.3    | 2                      | 0      | --                                  | 344                                                | Longitudinal |
| AM 355, SCERT 550                                                    | AL                                  | 10                                                      | 30.4     | 2                      | 0      | --                                  | 351                                                | Longitudinal |
|                                                                      | AL                                  | 35                                                      | 106.4    | 2                      | 0      | --                                  | 351                                                | Longitudinal |
|                                                                      | AL                                  | 50                                                      | 152.0    | 2                      | 0      | --                                  | 351                                                | Longitudinal |
|                                                                      | AL                                  | 70                                                      | 212.3    | 2                      | 0      | --                                  | 351                                                | Longitudinal |
|                                                                      | AL                                  | 10                                                      | 29.3     | 2                      | 1      | 172                                 | 215                                                | Transverse   |
|                                                                      | AL                                  | 35                                                      | 102.7    | 2                      | 2      | 2                                   | --                                                 | Transverse   |
|                                                                      | AL                                  | 50                                                      | 141.1    | 2                      | 2      | 1                                   | --                                                 | Transverse   |
|                                                                      | AL                                  | 70                                                      | 205.3    | 2                      | 2      | 2.5                                 | --                                                 | Transverse   |

TABLE 9. (Continued)

| Alloy<br>and<br>Condition                                                                                   | Source<br>of<br>Data <sup>(2)</sup> | Applied Stress                                                         |          | Number of<br>Specimens |   | Average Time<br>to Failure,<br>days | Exposure Time<br>of Unfailed<br>Specimens,<br>days | Direction    |
|-------------------------------------------------------------------------------------------------------------|-------------------------------------|------------------------------------------------------------------------|----------|------------------------|---|-------------------------------------|----------------------------------------------------|--------------|
|                                                                                                             |                                     | Per Cent of<br>Ultimate<br>Tensile or<br>Yield <sup>(3)</sup> Strength | 1000 PSI |                        |   |                                     |                                                    |              |
|                                                                                                             |                                     | Exposed                                                                | Failed   |                        |   |                                     |                                                    |              |
| <u>Exposed to Se + Spray - 1.0 Per Cent NaCl Solution at 95 ± 3 F (Continued)</u>                           |                                     |                                                                        |          |                        |   |                                     |                                                    |              |
| AM 355, SGT 850                                                                                             | NAA                                 | 40°                                                                    | 75       | 3                      | 3 | 1.5                                 | --                                                 | Longitudinal |
| AM 355, B-HT                                                                                                | NAA                                 | 50°                                                                    | 130      | 3                      | 3 | 1.5                                 | --                                                 | Longitudinal |
|                                                                                                             | NAA                                 | 40°                                                                    | 66       | 3                      | 3 | 12.0                                | --                                                 | Longitudinal |
| AM 350, SGT 500                                                                                             | NAA                                 | 40°                                                                    | 70       | 3                      | 3 | 3.5                                 | --                                                 | Longitudinal |
| AM 350, B-HT                                                                                                | NAA                                 | 50°                                                                    | 130      | 3                      | 3 | 0.5                                 | --                                                 | Longitudinal |
|                                                                                                             | NAA                                 | 40°                                                                    | 66       | 3                      | 3 | 5                                   | --                                                 | Longitudinal |
| <u>Alternate Immersion in 3-1.7 Per Cent NaCl Solution</u><br>Cycle: 10-minute immersion, 50-minute air dry |                                     |                                                                        |          |                        |   |                                     |                                                    |              |
| AM 355, CRT 550 <sup>(2)</sup>                                                                              | AL                                  | 10                                                                     | 22.5     | 0                      | 0 | --                                  | 345                                                | Longitudinal |
|                                                                                                             | AL                                  | 25                                                                     | 33.4     | 0                      | 0 | --                                  | 345                                                | Longitudinal |
|                                                                                                             | AL                                  | 50                                                                     | 19.1     | 0                      | 0 | --                                  | 345                                                | Longitudinal |
|                                                                                                             | AL                                  | 70                                                                     | 156.5    | 0                      | 0 | --                                  | 345                                                | Longitudinal |
| AM 355, CRT 550 <sup>(2)</sup>                                                                              | AL                                  | 70                                                                     | 146.5    | 0                      | 0 | --                                  | 345                                                | Longitudinal |
| AM 355, SCRT 550                                                                                            | AL                                  | 10                                                                     | 30.4     | 0                      | 0 | --                                  | 345                                                | Longitudinal |
|                                                                                                             | AL                                  | 25                                                                     | 100.0    | 0                      | 0 | --                                  | 345                                                | Longitudinal |
|                                                                                                             | AL                                  | 50                                                                     | 150.0    | 0                      | 0 | --                                  | 345                                                | Longitudinal |
|                                                                                                             | AL                                  | 70                                                                     | 211.7    | 0                      | 0 | --                                  | 345                                                | Longitudinal |
| <u>Thermocyclic Exposure</u>                                                                                |                                     |                                                                        |          |                        |   |                                     |                                                    |              |
| AM 355, CRT 550 <sup>(2)</sup>                                                                              | AL                                  | 70                                                                     | 146.5    | 0                      | 0 | --                                  | 151                                                | Longitudinal |
|                                                                                                             | AL                                  | 70                                                                     | 146.5    | 0                      | 0 | --                                  | 221                                                | Longitudinal |
| AM 355 SCRT 550 <sup>(2)</sup>                                                                              | AL                                  | 70                                                                     | 212.5    | 0                      | 0 | --                                  | 412                                                | Longitudinal |
|                                                                                                             | AL                                  | 70                                                                     | 265.3    | 0                      | 1 | 12                                  | 151                                                | Transverse   |
| AM 355, SGT 550 <sup>(2)</sup>                                                                              | NAA                                 | 50°                                                                    | 110      | 3                      | 3 | 110                                 | --                                                 | Longitudinal |
|                                                                                                             | NAA                                 | 50°                                                                    | 113      | 3                      | 3 | 124                                 | --                                                 | Longitudinal |
|                                                                                                             | NAA                                 | 40°                                                                    | 75       | 3                      | 3 | 133                                 | --                                                 | Longitudinal |
| AM 355, B-HT <sup>(2)</sup>                                                                                 | NAA                                 | 50°                                                                    | 130      | 3                      | 0 | 273                                 | --                                                 | Longitudinal |
|                                                                                                             | NAA                                 | 40°                                                                    | 66       | 3                      | 1 | 316                                 | 24 <sup>(4)</sup>                                  | Longitudinal |
| AM 350, SGT 550 <sup>(2)</sup>                                                                              | NAA                                 | 50°                                                                    | 140      | 3                      | 3 | 110                                 | --                                                 | Longitudinal |
|                                                                                                             | NAA                                 | 50°                                                                    | 165      | 3                      | 3 | 123                                 | --                                                 | Longitudinal |
|                                                                                                             | NAA                                 | 40°                                                                    | 70       | 3                      | 3 | 155                                 | --                                                 | Longitudinal |
| AM 350, B-HT <sup>(2)</sup>                                                                                 | NAA                                 | 50°                                                                    | 135      | 3                      | 3 | 30-64                               | --                                                 | Longitudinal |
|                                                                                                             | NAA                                 | 40°                                                                    | 68       | 3                      | 3 | 151                                 | --                                                 | Longitudinal |

TABLE 9. (Continued)

| Alloy<br>and<br>Condition                                                  | Source<br>of<br>Data <sup>(a)</sup> | Applied Stress                                           |          | Number of<br>Specimens |                  | Average Time<br>to Failure,<br>days | Exposure Time<br>of Unfailed<br>Specimens,<br>days | Direction    |
|----------------------------------------------------------------------------|-------------------------------------|----------------------------------------------------------|----------|------------------------|------------------|-------------------------------------|----------------------------------------------------|--------------|
|                                                                            |                                     | Per Cent of<br>Ultimate<br>Tensile or<br>Yield* Strength | 1000 PSI |                        |                  |                                     |                                                    |              |
|                                                                            |                                     | Exposed                                                  | Failed   |                        |                  |                                     |                                                    |              |
| <u>Cyclic Humidity Exposure at Relative Humidity 95 Per Cent or Higher</u> |                                     |                                                          |          |                        |                  |                                     |                                                    |              |
| Heat from 80-100 F to 160 F in 2 hours                                     |                                     |                                                          |          |                        |                  |                                     |                                                    |              |
| Hold at 160 F 6 hours                                                      |                                     |                                                          |          |                        |                  |                                     |                                                    |              |
| Cool to 80-100 F in 16 hours                                               |                                     |                                                          |          |                        |                  |                                     |                                                    |              |
| AM 355, SCT 850                                                            | NAA                                 | 60°                                                      | 150      | 3                      | 3                | 12                                  | --                                                 | Longitudinal |
|                                                                            | NAA                                 | 60°                                                      | 113      | 3                      | 1                | 13                                  | 52 <sup>(g,h)</sup>                                | Longitudinal |
|                                                                            | NAA                                 | 40°                                                      | 75       | 3                      | 2                | 26 <sup>(g)</sup>                   | 51                                                 | Longitudinal |
| AM 355, BCHT                                                               | NAA                                 | 80°                                                      | 150      | 3                      | 0                | 52 <sup>(h)</sup>                   | --                                                 | Longitudinal |
|                                                                            | NAA                                 | 40°                                                      | 66       | 3                      | 0                | 52 <sup>(h)</sup>                   | --                                                 | Longitudinal |
| AM 350, SCT 850                                                            | NAA                                 | 80°                                                      | 140      | 3                      | 3                | 12                                  | --                                                 | Longitudinal |
|                                                                            | NAA                                 | 60°                                                      | 105      | 3                      | 3                | 13.5                                | --                                                 | Longitudinal |
|                                                                            | NAA                                 | 40°                                                      | 70       | 3                      | 1 <sup>(g)</sup> | 14                                  | 51                                                 | Longitudinal |
| AM 350, BCHT                                                               | NAA                                 | 80°                                                      | 136      | 3                      | 3                | 12                                  | --                                                 | Longitudinal |
|                                                                            | NAA                                 | 40°                                                      | 68       | 3                      | 0                | --                                  | 52 <sup>(h)</sup>                                  | Longitudinal |

\* Indicates percentage of tensile yield strength.

(a) AL - Allegheny Ludlum Steel Corporation

NAA - North American Aviation, Inc.

(b) Heat 35526.

(c) Heat 35808.

(d) Atmospheric exposure at Brackenridge, Pennsylvania.

(e) Atmospheric exposure at Los Angeles, California.

(f) Test still in progress.

(g) Specimens not properly descaled after heat treatment.

(h) Specimens partially fractured.

was over 200,000 psi on some specimens. No failures occurred at the 500-foot lot or in the 20 per cent salt spray. These specimens were all cut longitudinally, i. e., in the direction of rolling. A strong directional effect was revealed in the salt spray. Specimens that were cut transverse to the direction of rolling cracked very quickly, even at an applied stress of about 100,000 psi. This effect was also observed in the atmospheric exposure test.

AM 355 in the SCT 850 condition was evaluated in the North American tests. In this condition, the alloy had a yield strength of about 190,000 psi. The data in Table 9 show that the alloy in this condition is strongly susceptible to stress-corrosion cracking. Failures occurred in all three environments, even at the lower stress levels of 40 per cent of the yield strength (75,000 psi). This is probably related to carbide precipitation during the L-anneal, which conditions the austenite so that complete transformation will occur during subzero cooling. Carbides are precipitated at the grain boundaries, which presumably results in corrosion-susceptible paths. A comparison of the results of atmospheric exposure tests for the CRT 850 and the SCT conditions at comparable stress levels shows that specimens in the SCT condition are susceptible to cracking, whereas those in the CRT 850 condition were not. Exposures were at different locations, but it is probable that transformation by cold rolling (CRT) occurred without the precipitation of carbides at the grain boundaries (as in the SCT condition), and therefore resulted in a structure less susceptible to stress-corrosion cracking.

The braze-cycle heat treatment (BCHT) which includes the slow cooling from 1675 F to 1000 F, resulted in slightly lower properties (yield strength 166,000 psi). The alloy in this condition was also susceptible to cracking. Based on the reported data, the times to failure were slightly longer than for the alloy in the SCT 850 condition. However, they were of the same order of magnitude, and the differences may not be significant.

The North American Aviation program also included tests on AM 350, SCT 850 and AM 350, BCHT. The results were similar to those with AM 355, and the same comments apply.

#### Martensitic and Martensitic Precipitation-Hardenable Stainless Steels

In these two classes of steels, the austenitic structure is transformed to martensite during cooling to room temperature from the annealing temperature. High strength is developed by subsequent tempering or precipitation-hardening treatments. Three steels, one martensitic, 12 MoV, and two martensitic precipitation hardenable, Stainless W and 17-4 PH, have been tested for susceptibility to stress-corrosion cracking. The chemical compositions of the steels tested are given in Table 10, and the details of the heat treatments and mechanical properties are in Table 11.

TABLE 10. CHEMICAL COMPOSITION OF THE MARTENSITIC AND MARTENSITIC PRECIPITATION-HARDENABLE STAINLESS STEELS

| Alloy                  | Source of Data <sup>(a)</sup> | C     | Mn   | P     | S     | Si   | Cr    | Ni   | Mo   | V    | Ti   | N     | Al   | Cu   | Cb   |
|------------------------|-------------------------------|-------|------|-------|-------|------|-------|------|------|------|------|-------|------|------|------|
| 12 MoV                 | USS                           | 0.25  | 0.50 | 0.019 | 0.015 | 0.45 | 12.14 | 0.63 | 0.93 | 0.33 | --   | --    | --   | --   | --   |
| Stainless W            | USS                           | 0.08  | 0.13 | 0.015 | 0.013 | 0.17 | 16.72 | 0.65 | 0.21 | --   | 0.90 | 0.034 | 0.24 | --   | --   |
| 17-4 PH                | Armco                         | 0.044 | 0.27 | 0.022 | 0.014 | 0.48 | 15.91 | 4.37 | --   | --   | --   | --    | --   | 3.19 | 0.22 |
| 17-4 PH <sup>(b)</sup> | Armco                         | 0.033 | 0.27 | 0.021 | 0.011 | 0.42 | 16.81 | 4.88 | --   | --   | --   | --    | --   | 3.46 | 0.19 |

(a) USS - U. S. Steel Corporation.  
Armco - Armco Steel Corporation.

(b) Weld wire.

Stress-corrosion data for the 12 MoV and Stainless W grades were taken from the U. S. Steel report<sup>(3)</sup>, and those for 17-4 PH sheet are preliminary data from incomplete tests being conducted by Armco. The results are tabulated in Table 12.

The data in Table 11 show that the heat treatment selected for 12 MoV alloy resulted in high strength. The yield strength was over 205,000 psi, and corrosion tests at Kure Beach (80-foot lot) were carried out at 50 and 75 per cent of the yield strength. 12 MoV alloy, in the condition tested, is strongly susceptible to stress-corrosion cracking. This was also the conclusion from atmospheric-exposure tests at Monroeville, where 45 of 45 specimens (at 75 per cent of the yield strength) failed after an average exposure period of 5 days. Additional work has shown that the alloy was not susceptible to stress-corrosion cracking when tempered at 1100 or 1200 F. Under these conditions, however, the yield strength was reported to be 133,000 psi, considerably lower than that obtained by tempering at 900 F.

Stainless W, was also hardened to a yield-strength level of about 200,000 psi. The hardening mechanism in this case was by precipitation of compounds of titanium and aluminum within the martensitic structure during the aging treatment. Exposure at Kure Beach at 50 to 90 per cent of the yield strength resulted in failures within relatively short periods. During outdoor exposure at Monroeville, however, no failure occurred over a period of 520 days. Thus, at high strength levels, Stainless W appears to be somewhat more resistant than 12 MoV.

The data shown for alloy 17-4 PH are for the material in thin sheet form which has not been available heretofore. Specimens were cut from 0.050-inch sheet. The high strength in this alloy is developed during the aging step, which causes precipitation of compounds within the martensite. Aging at 900 F resulted in tensile strengths of slightly over 200,000 psi with

TABLE 11. HEAT TREATMENT AND MECHANICAL PROPERTIES OF THE MARTENSITIC AND MARTENSITIC  
PRECIPITATION-HARDENABLE STAINLESS STEELS

| Alloy                                        | Source<br>of<br>Data <sup>(a)</sup> | Heat Treatment    |                  |                    |                | Yield<br>Strength,<br>1000 psi | Tensile<br>Strength,<br>1000 psi | Elongation<br>in 2 Inches,<br>per cent |
|----------------------------------------------|-------------------------------------|-------------------|------------------|--------------------|----------------|--------------------------------|----------------------------------|----------------------------------------|
|                                              |                                     | Austenitize<br>or |                  | Tempered or Aged   |                |                                |                                  |                                        |
|                                              |                                     | Solution Treat    |                  | Temperature, Time, |                |                                |                                  |                                        |
|                                              |                                     | Temperature,<br>F | Time,<br>minutes | Temperature,<br>F  | Time,<br>hours |                                |                                  |                                        |
| 12 MoV                                       | USS                                 | 1850              | 15               | 900                | 4              | 205                            | 256                              | 10.5                                   |
| Stainless W                                  | USS                                 | 1900              | 15               | 1000               | 0.5            | 201                            | 202                              | 7.2                                    |
| 17-4 PH                                      | Armco                               | 1900              | 10               | 900                | 1              | 181.0                          | 202.2                            | 9                                      |
|                                              | Armco                               | 1900              | 10               | 1025               | 1              | 155.4                          | 166.8                            | 10                                     |
|                                              | Armco                               | 1900              | 10               | 1075               | 1              | 150.8                          | 162.2                            | 9                                      |
|                                              | Armco                               | 1900              | 10               | 1150               | 1              | 113.2                          | 139.4                            | 14                                     |
| 17-4 PH,<br>solution treat,<br>weld, and age | Armco                               | 1900              | 10               | 900                | 1              | 183.0                          | 203.5                            | 4                                      |
|                                              | Armco                               | 1900              | 10               | 1025               | 1              | 160.8                          | 175.9                            | 6                                      |
|                                              | Armco                               | 1900              | 10               | 1075               | 1              | 150.0                          | 161.2                            | 6.5                                    |
|                                              | Armco                               | 1900              | 10               | 1150               | 1              | 115.4                          | 115.4                            | 12                                     |
| 17-4 PH, weld,<br>solution treat,<br>and age | Armco                               | 1900              | 10               | 900                | 1              | 182.6                          | 206.1                            | 6.5                                    |
|                                              | Armco                               | 1900              | 10               | 1025               | 1              | 159.6                          | 166.3                            | 6                                      |
|                                              | Armco                               | 1900              | 10               | 1075               | 1              | 153.8                          | 161.1                            | 7                                      |
|                                              | Armco                               | 1900              | 10               | 1150               | 1              | 130.4                          | 147.0                            | 7.5                                    |

(a) USS - U. S. Steel Corporation  
Armco - Armco Steel Corporation.

TABLE 12. RESULTS OF STRESS-CORROSION-CRACKING TESTS ON THE MARTENSITIC AND MARTENSITIC PRECIPITATION HARDENABLE STAINLESS STEELS

| Alloy and Condition                           | Source of Data <sup>(2)</sup> | Applied Stress             |          | Number of Specimens |        | Average Time to Failure, days | Exposure Time of Unfailed specimens, days |
|-----------------------------------------------|-------------------------------|----------------------------|----------|---------------------|--------|-------------------------------|-------------------------------------------|
|                                               |                               | Per Cent of Yield Strength | 1000 PSI | Exposed             | Failed |                               |                                           |
| <u>Exposed at Kure Beach, 60-Foot Lot</u>     |                               |                            |          |                     |        |                               |                                           |
| 12 MoV                                        | USS                           | 75                         | 153.6    | 40                  | 40     | 1                             | --                                        |
|                                               | USS                           | 50                         | 102.5    | --                  | --     | 1.4 <sup>(b)</sup>            | --                                        |
| Stainless W                                   | USS                           | 90                         | 156.9    | --                  | --     | 22 <sup>(b)</sup>             | --                                        |
|                                               | USS                           | 75                         | 150.3    | 11                  | 12     | 47                            | --                                        |
|                                               | USS                           | 50                         | 106.5    | --                  | --     | 63 <sup>(b)</sup>             | --                                        |
| <u>Not Welded</u>                             |                               |                            |          |                     |        |                               |                                           |
| 17-4 PH, H 900                                | Armco                         | 90                         | 162.9    | 5                   | 0      | --                            | 322                                       |
|                                               | Armco                         | 75                         | 135.8    | 5                   | 0      | --                            | 322                                       |
| 17-4 PH, H 1025                               | Armco                         | 90                         | 133.2    | 5                   | 0      | --                            | 322                                       |
|                                               | Armco                         | 75                         | 115.6    | 5                   | 0      | --                            | 322                                       |
| 17-4 PH, H 1075                               | Armco                         | 90                         | 146.7    | 5                   | 0      | --                            | 322                                       |
|                                               | Armco                         | 75                         | 113.1    | 5                   | 0      | --                            | 322                                       |
| 17-4 PH, H 1150                               | Armco                         | 90                         | 161.3    | 5                   | 0      | --                            | 322                                       |
|                                               | Armco                         | 75                         | 94.9     | 5                   | 0      | --                            | 322                                       |
| 17-4 PH, H 900                                | Armco                         | 90                         | --       | 5                   | 3      | 322                           | 550                                       |
| 17-4 PH, H 1150                               | Armco                         | 90                         | --       | 5                   | 0      | --                            | 550                                       |
| <u>Welded, Then Solution Treated and Aged</u> |                               |                            |          |                     |        |                               |                                           |
| 17-4 PH, H 500                                | Armco                         | 90                         | 164.3    | 5                   | 5      | 82                            | --                                        |
|                                               | Armco                         | 75                         | 137.0    | 5                   | 4      | 114                           | 322                                       |
| 17-4 PH, H 1025                               | Armco                         | 90                         | 143.6    | 5                   | 0      | --                            | 322                                       |
|                                               | Armco                         | 75                         | 119.7    | 5                   | 0      | --                            | 322                                       |
| 17-4 PH, H 1075                               | Armco                         | 90                         | 123.4    | 5                   | 0      | --                            | 322                                       |
|                                               | Armco                         | 75                         | 115.4    | 5                   | 0      | --                            | 322                                       |
| 17-4 PH, H 1150                               | Armco                         | 90                         | 117.4    | 5                   | 0      | --                            | 322                                       |
|                                               | Armco                         | 75                         | 97.2     | 5                   | 0      | --                            | 322                                       |
| <u>Solution Treated, Welded, and Aged</u>     |                               |                            |          |                     |        |                               |                                           |
| 17-4 PH, H 500                                | Armco                         | 90                         | 164.3    | 5                   | 5      | 26                            | --                                        |
|                                               | Armco                         | 75                         | 137.3    | 5                   | 5      | 51                            | --                                        |
| 17-4 PH, H 1025                               | Armco                         | 90                         | 144.7    | 5                   | 0      | --                            | 322                                       |
|                                               | Armco                         | 75                         | 120.5    | 5                   | 0      | --                            | 322                                       |
| 17-4 PH, H 1075                               | Armco                         | 90                         | 125.0    | 5                   | 0      | --                            | 322                                       |
|                                               | Armco                         | 75                         | 112.5    | 5                   | 0      | --                            | 322                                       |

TABLE 12. (Continued)

| Alloy<br>and<br>Condition                             | Source<br>of<br>Data <sup>(a)</sup> | Applied Stress                |          | Number of<br>Specimens |        | Average Time<br>to Failure,<br>days | Exposure Time<br>of Unfailed<br>Specimens,<br>days |
|-------------------------------------------------------|-------------------------------------|-------------------------------|----------|------------------------|--------|-------------------------------------|----------------------------------------------------|
|                                                       |                                     | Per Cent of<br>Yield Strength | 1000 PSI | Exposed                | Failed |                                     |                                                    |
| <u>Exposed at Kure Beach, 80-Foot Lot (Continued)</u> |                                     |                               |          |                        |        |                                     |                                                    |
| <u>Solution Treated, Welded, and Aged (Continued)</u> |                                     |                               |          |                        |        |                                     |                                                    |
| 17-4 PH, H 1150                                       | Armco                               | 90                            | 103.9    | 5                      | 0      | --                                  | 322                                                |
|                                                       | Armco                               | 75                            | 90.0     | 5                      | 0      | --                                  | 322                                                |
| <u>Atmospheric Exposure<sup>(c)</sup></u>             |                                     |                               |          |                        |        |                                     |                                                    |
| 12 MoV                                                | USS                                 | 75                            | 153.8    | 45                     | 45     | 5                                   | --                                                 |
| Stainless W                                           | USS                                 | 75                            | 150.8    | 7                      | 0      | --                                  | 520                                                |

(a) USS - U. S. Steel Corporation

Armco - Armco Steel Corporation.

(b) Average of three specimens, or more.

(c) Atmospheric exposure at Monroeville, Pennsylvania.

Data on 17-4 PH are preliminary results from incompletd tests.

a yield strength of about 180,000 psi. Other aging treatments at higher temperatures, up to 1150 F, resulted in correspondingly lower strengths. Stress-corrosion-cracking tests at Kure Beach (80-foot lot) are being made on both ordinary specimens and welded specimens at 90 and 75 per cent of the yield strength. The composition of the weld wire was the same as that of the test material (see Table 10). After welding, one set of specimens was solution treated before aging, to reduce or eliminate nonuniform strains or precipitation in the adjacent metal. It would be expected that this should result in a more uniform response to the subsequent aging treatment. The other group was solution treated, welded, and aged. Heat-treating scale was removed by grinding or wet blasting with alumina grit and Pangbornite. After exposure for 322 days, no failures had occurred in the unwelded specimens at any stress level. In an earlier test, three out of five specimens cracked in 322 days, when stressed at 90 per cent of the yield strength. The other two, and a group stressed at 75 per cent of the yield strength did not fail in 560 days. The welded specimens in the H 900 condition, and not solution treated after welding, failed within a relatively short time. This is an indication that welding is responsible for some change in structure or strain condition, as mentioned above. Solution treatment after welding was beneficial, but it did not prevent failure of the H 900 specimens after a somewhat longer period of exposure. No failures have occurred in the welded specimens aged at 1025, 1075, and 1150 F.

On the basis of these incomplete tests, 17-4 PH sheet material shows good resistance to stress-corrosion cracking in a marine atmosphere. Welding of the alloy in the highest strength condition (H 900) reduced the resistance to cracking. The standard solution heat treatment, following welding, apparently does not completely restore the resistance to stress-corrosion cracking of material. Therefore, in stress-corrosion environments it would appear to be safer to use material aged at higher temperatures, if the lower strength achieved under these conditions is acceptable.

### DISCUSSION OF RESULTS

Most of the comments about the results have already been made in the discussion of each class of alloys. From a general standpoint, it is apparent that the need for stress-corrosion-cracking data for the high strength stainless steels has been recognized, and experimental work has been started to provide such information. A reliable evaluation of the susceptibility to stress-corrosion-cracking of a material involves the consideration of many variables, and consequently a large amount of time-consuming experimental work. Therefore, it has been emphasized that most of the experimental programs to evaluate the susceptibility of the high strength stainless steels to stress-corrosion cracking are still in progress, and that the data reported here should be considered preliminary in nature. Furthermore, correlation of these experimental results with actual service performance has not been

established as yet. The fact that cracking has occurred under some experimental conditions does not mean that the alloy will crack under all service conditions. It is an indication, however, that such an alloy should be used with due regard to environmental and stress conditions that may exist in the intended service.

Tabulations of the results of tests, such as those included in this report, help to visualize in a general way what has been done, and to point out where additional work may be required.

The results of tests reported to date are given in Tables 3, 7, 8, 9, and 12. These show that the majority of the specimens were exposed to the marine atmosphere at Kure Beach. Laboratory tests included the salt spray, alternate immersion in a salt solution, and a cyclic humidity exposure. Exposure tests in semiindustrial outdoor atmospheres were made at the locations of the companies conducting the tests.

Any number of comparisons of the data could probably be made, but at this stage some of the tests are incomplete, and in other cases there is not enough information available to account for the wide spread observed in times to failure.

It is to be expected that the metallurgical structure developed by thermal treatment or mechanical deformation will affect the results. The CH 900 condition, for example, resulted in the highest strength, but the alloy was immune from stress-corrosion cracking. This may be related to the fact that condition CH 900 does not involve heat treatment in the temperature range at which carbides will precipitate. Therefore, carbides at the grain boundaries would not be expected in alloys in the CH 900 condition.

The results for PH 15-7 Mo are somewhat more consistent than those for 17-7 PH. Here again, the alloy in the CH 900 condition was not susceptible to cracking in the marine exposure. In this alloy also, the PH 950 condition seems to produce a more susceptible structure than TH 1050. Cracking occurred on the RH 950 specimens at applied stresses as low as 87,000 psi, representing only 40 per cent of the yield strength. At similar stresses, the TH 1050 condition did not crack by stress corrosion. It would appear from these results that the extent of stress-corrosion cracking is not determined solely by the presence of carbides at the grain boundaries. Such factors as the quantity of precipitate, its dispersion in the structure, and its composition may be the controlling considerations.

It would be of interest to study the effect of these factors, as well as other microstructural details, such as the amount of retained austenite, the presence of delta ferrite, and perhaps the carbon content of the martensite, on the stress-corrosion-cracking properties of these steels. Of course, other variables that affect results, that is, specimen preparation, stressing, and details of exposure, would have to be controlled and taken into account in such an investigation.

WORK IN PROGRESS

The results of the stress-corrosion-cracking tests on the high-strength stainless steels that have been assembled in this report, represent a good start in the direction of providing such information for design and materials engineers in the aircraft and missile industries. Some useful data have been accumulated. However, some unexplained lack of reproducibility was also evident in several of the tests. While some spread in corrosion test results is expected, enough data must be accumulated to attach proper significance to it. Therefore, some phases of the programs discussed in this report are being continued. Also, several new programs are in their early stages.

It has often been emphasized that many factors may influence stress-corrosion-cracking results. Work is in progress to standardize every phase of the tests required to evaluate semiaustenitic precipitation-hardenable stainless steels. A report has been prepared<sup>(5)</sup> in which every detail of specimen preparation, heat treatment, stressing, exposure to laboratory-type environments, operating conditions, and reporting of results has been specified. A continuation of this work describes the details of ring-type specimens for testing specimens in the short transverse direction.<sup>(6)</sup> The work so far in both of the programs mentioned has been concerned with the establishment of standard procedures. Testing will be conducted by numerous participating aircraft companies and by Allegheny Ludlum and Armco Steel Corporations. Salt-spray and alternate-immersion exposure tests are planned for stressed, strip specimens of 17-7 PH, 17-4 PH, PH 15-7 Mo, AM 350, and AM 355. Ring-type specimens for some of these alloys are included. Also, some specimens of AM 355 and 17-4 PH will be exposed to a marine atmosphere. This is a comprehensive program that should produce a large quantity of valuable data.

The difficulties of translating results of accelerated stress-corrosion-cracking tests into expected service results have also been mentioned before. A comprehensive program, sponsored by Frankford Arsenal, has been in progress for about 1 year at Mellon Institute, Pittsburgh, Pennsylvania, and at Aerojet-General Corporation, Azusa, California. High-strength materials, including AM 355 and PH 15-7 Mo, which are of interest in this report, will be tested for susceptibility to stress-corrosion cracking in many environments. The Aerojet-General tests will be in environments that the alloys encounter during fabrication and storage of missiles. The Mellon Institute tests on the same heats of the alloys, will be made in synthetic and artificial environments. The work on these two programs so far has been concerned with procurement of materials, checking of heat-treatment procedures, determination of the mechanical properties of the alloys, preparation of exposure facilities, and evaluation and development of the stressing procedures. Preliminary stress-corrosion tests have been made to check out the various steps. Actual testing of the selected alloys will probably be conducted within the next 12 months and should result in valuable comparisons of the effect of many synthetic and natural environments on stress-corrosion cracking.

Another comprehensive stress-corrosion-cracking program is being conducted by the National Bureau of Standards for the Bureau of Naval Weapons. The precipitation-hardenable stainless steels in several heat-treated conditions are included in the list of alloys being evaluated. Bent beam specimens stressed at 50, 75, 90, and 100 per cent of the yield strength were exposed to the marine atmosphere at Kure Beach a few months ago.

Additional work has also been done on AM 355 and AM 350, but it has not been reported yet. These data, along with the results of the other programs now in progress, should be of great value in the utilization of high-strength stainless steels at the high stress levels desired in modern aircraft and missiles.

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| 132                   | Design Information on Nickel-Base Alloys for Aircraft and Missiles, July 20, 1960 (PB 151090 \$3.00)                                                                              |
| 133                   | Tantalum and Tantalum Alloys, July 26, 1960 (PB 151091 \$5.00)                                                                                                                    |
| 134                   | Strain Aging of Refractory Metals, August 12, 1960 (PB 151092 \$1.75)                                                                                                             |
| 135                   | Design Information on P11 15-7 Mo Stainless Steel for Aircraft and Missiles, August 22, 1960 (PB 151093 \$1.25)                                                                   |

| DMIC<br>Report Number | Title                                                                                                                                                  |
|-----------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------|
| 138A                  | The Effects of Alloying Elements in Titanium, Volume A. Constitution, September 15, 1960 (PB 151094 \$3.50)                                            |
| 138B                  | The Effects of Alloying Elements in Titanium, Volume B. Physical and Chemical Properties, Deformation and Transformation Characteristics, May 29, 1961 |
| 139                   | Design Information on 17-7 PH Stainless Steels for Aircraft and Missiles, September 23, 1960 (PB 151096 \$1.00)                                        |
| 138                   | Availability and Mechanical Properties of High-Strength Steel Extrusions, October 26, 1960 (PB 151097 \$1.75)                                          |
| 139                   | Melting and Casting of the Refractory Metals Molybdenum, Columbium, Tantalum, and Tungsten, November 18, 1960 (PB 151098 \$1.00)                       |
| 140                   | Physical and Mechanical Properties of Commercial Molybdenum-Base Alloys, November 30, 1960 (PB 151099 \$3.00)                                          |
| 141                   | Titanium-Alloy Forgings, December 19, 1960 (PB 151100 \$2.25)                                                                                          |
| 142                   | Environmental Factors Influencing Metals Applications in Space Vehicles, December 27, 1960 (PB 151101 \$1.25)                                          |
| 143                   | High-Strength-Steel Forgings, January 5, 1961 (PB 151102 \$1.75)                                                                                       |
| 144                   | Stress-Corrosion Cracking - A Nontechnical Introduction to the Problem, January 6, 1961 (PB 151103 \$0.75)                                             |
| 145                   | Design Information on Titanium Alloys for Aircraft and Missiles, January 10, 1961                                                                      |
| 146                   | Manual for Beryllium Prospectors, January 18, 1961 (PB 151105 \$1.00)                                                                                  |
| 147                   | The Factors Influencing the Fracture Characteristics of High-Strength Steel, February 6, 1961 (PB 151106 \$1.25)                                       |
| 148                   | Review of Current Data on the Tensile Properties of Metals at Very Low Temperatures, February 14, 1961 (PB 151107 \$2.00)                              |
| 149                   | Brazing for High Temperature Service, February 21, 1961 (PB 151108 \$1.00)                                                                             |
| 150                   | A Review of Bending Methods for Stainless Steel Tubing, March 2, 1961 (PB 151109 \$1.50)                                                               |
| 151                   | Environmental and Metallurgical Factors of Stress-Corrosion Cracking in High-Strength Steels, April 14, 1961 (PB 151110 \$0.75)                        |
| 152                   | Binary and Ternary Phase Diagrams of Columbium, Molybdenum, Tantalum, and Tungsten, April 23, 1961 (AD 257739 \$3.50)                                  |
| 153                   | Physical Metallurgy of Nickel-Base Superalloys, May 5, 1961 (AD 253041 \$1.25)                                                                         |
| 154                   | Evolution of Ultrahigh-Strength, Hardenable Steels for Solid-Propellant Rocket-Motor Cases, May 25, 1961 (AD 257976 \$1.25)                            |
| 155                   | Oxidation of Tungsten, July 17, 1961                                                                                                                   |
| 156                   | Design Information on AM-350 Stainless Steel for Aircraft and Missiles, July 28, 1961                                                                  |
| 157                   | A Summary of the Theory of Fracture in Metals, August 7, 1961                                                                                          |

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| <p>Battelle Memorial Institute, Defense Metals Information Center, Columbus, Ohio.</p> <p>STRESS-CORROSION CRACKING OF HIGH-STRENGTH STAINLESS STEELS IN ATMOSPHERIC ENVIRONMENTS, by C. J. Slunder.</p> <p>15 September 1961. 38 pp incl. illus., tables, 6 refs. (DMIC Report 158)</p> <p>[AF 33(616)-7747]      Unclassified report</p> <p>Available information on the stress-corrosion cracking of the high-strength stainless steels is tabulated and discussed. Data are included for austenitic, martensitic, martensitic</p> | <p>UNCLASSIFIED</p> <ol style="list-style-type: none"> <li>1. Corrosion - Stress</li> <li>2. Stress corrosion</li> <li>3. Stainless steel</li> <li>I. Slunder, C. J.</li> <li>II. Defense Metals Information Center</li> <li>III. Contract AF 33(616)-7747</li> </ol> | <p>Battelle Memorial Institute, Defense Metals Information Center, Columbus, Ohio.</p> <p>STRESS-CORROSION CRACKING OF HIGH-STRENGTH STAINLESS STEELS IN ATMOSPHERIC ENVIRONMENTS, by C. J. Slunder.</p> <p>15 September 1961. 38 pp incl. illus., tables, 6 refs. (DMIC Report 158)</p> <p>[AF 33(616)-7747]      Unclassified report</p> <p>Available information on the stress-corrosion cracking of the high-strength stainless steels is tabulated and discussed. Data are included for austenitic, martensitic, martensitic</p> | <p>UNCLASSIFIED</p> <ol style="list-style-type: none"> <li>1. Corrosion - Stress</li> <li>2. Stress corrosion</li> <li>3. Stainless steel</li> <li>I. Slunder, C. J.</li> <li>II. Defense Metals Information Center</li> <li>III. Contract AF 33(616)-7747</li> </ol> |
| <p>UNCLASSIFIED</p>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   | <p>UNCLASSIFIED</p>                                                                                                                                                                                                                                                   | <p>UNCLASSIFIED</p>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   | <p>UNCLASSIFIED</p>                                                                                                                                                                                                                                                   |
| <p>precipitation-hardenable, and semiaustenitic precipitation-hardenable grades.</p> <p>Although the tests reported are preliminary and further work is in progress, some tentative guidelines are indicated. Stress-corrosion cracking appears to be strongly influenced by prior thermal history.</p>                                                                                                                                                                                                                               | <p>UNCLASSIFIED</p>                                                                                                                                                                                                                                                   | <p>precipitation-hardenable, and semiaustenitic precipitation-hardenable grades.</p> <p>Although the tests reported are preliminary and further work is in progress, some tentative guidelines are indicated. Stress-corrosion cracking appears to be strongly influenced by prior thermal history.</p>                                                                                                                                                                                                                               | <p>UNCLASSIFIED</p>                                                                                                                                                                                                                                                   |
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