UNCLASSIFIED

AD NUMBER

AD281712

NEW LIMITATION CHANGE

TO

Approved for public release, distribution unlimited

FROM

Distribution authorized to U.S. Gov't. agencies and their contractors; Administrative/Operational Use; M<ay 1962. Other requests shall be referred to Aeronautical Systems Div., Wright-Patterson AFB, OH 45433.

AUTHORITY

RADC ltr, 26 Jul 1963

THIS PAGE IS UNCLASSIFIED

AD 281 712

62-4-5

ASD-TR-61-713

RESEARCH ON THE BASIC NATURE OF STRESS CORROSION FOR VARIOUS STRUCTURAL ALLOYS AT ROOM AND ELEVATED TEMPERATURE

TECHNICAL REPORT No. ASD-TR-61-713

MAY 1962

DIRECTORATE OF MATERIALS AND PROCESSES
AERONAUTICAL SYSTEMS DIVISION
AIR FORCE SYSTEMS COMMAND
WRIGHT-PATTERSON AIR FORCE BASE, OHIO

Project No. 7351, Task No. 735106

(Prepared under Contract No. AF 33(616)-7612
by Armour Research Foundation, Chicago, Ill.
Frank A. Crossley, author)

NOTICES

Qualified requesters may obtain copies of this report from the Armed Services Technical Information Agency, (ASTIA), Arlington Hall Station, Arlington 12, Virginia.

This report has been released to the Office of Technical Services, U.S. Department of Commerce, Washington 25, D.C., for sale to the general public.

Copies of this report should not be returned to the Aeronautical Systems Division unless return is required by security considerations, contractual obligations, or notice on a specific document.

400 - July 1962 - 41-1782 & 1783

FOREWORD

This report was prepared by Armour Research Foundation, Chicago, Illinois, under USAF Contract No. AF 33(616)-7612. The contract was initiated under Project No. 7351, "Metallic Materials," Task No. 735106, "Behavior of Metals." The work was administered under the direction of Directorate of Materials and Processes, Deputy Commander/Technology, Aeronautical Systems Division, Wright-Patterson Air Force Base, Ohio. Lt. R. T. Ault was the project engineer.

This report covers work done from 15 October 1960 to 14 December 1961.

Armour Research Foundation personnel who made major contributions to the program were: F. A. Crossley, project leader; T. Niemcyzk, project technician; B. J. Steng, project technician; H. Sheriff, technician, Creep Test Laboratory; J. R. Dvorak, metallographer; and R. F. Dragen, metallographer. The data reported herein are recorded in ARF Logbooks Nos. C-10609, C-11162, and C-11316, assigned to Project No. ARF 2206. This report is identified internally as ARF 2206-6.

ABSTRACT

The relationship between quantity of ASTM sea salt, varying from 0.0002 to 0.02 g/sq in., and thickness of anodized film--0, 2, and 8 microinches--in elevated temperature stress-corrosion cracking of the titanium alloys Ti-6Al-4V and B-120VCA was investigated. Exposure conditions were 800°F-25,000 psi-190 hr for the former alloy and 600°F-100,000 psi-190 hr for the latter. Damage was progressively greater with increasing quantity of salt. The anodized films appeared to be of no benefit to the Ti-6Al-4V alloy; however, it appeared that limited protection was afforded B-120VCA.

The alloys: 2024-T86, 7075-T6, ZK-60A-T5, 17-7 PH RH 950, and B-120VCA in two conditions of grain size and two conditions of surface treatment were tested as follows: tensile test in air at room temperature, and in distilled water and ASTM sea water at 32°, 75°, and 212°F; and statically loaded at 90% of the yield strength in media of air, water, and ASTM sea water at room temperature.

Other evaluations made were as follows: effect of surface contamination on the susceptibility of B-120VCA to premature failure in ASTM sea water; effect of ion species on the susceptibility of ZK-60A, 17-7 PH, and B-120VCA to stress corrosion or premature failure in static load tests; and behavior of weldments of B-120VCA in tensile and static load testing in ASTM sea water.

The results indicate that B-120VCA is more resistant to failure than 17-7 PH under the conditions of these experiments. However, weldments of B-120VCA failed in the elastic region when tensile tested in ASTM sea water.

PUBLICATION REVIEW

This report has been reviewed and is approved.

FOR THE COMMANDER:

W. J. Trapp

W. J. Trapp
Chief, Strength and Dynamics Branch
Metals and Ceramics Laboratory
Directorate of Materials and Processes

TABLE OF CONTENTS

LIST OF ILLUSTRATIONS

LIST OF ILLUSTRATIONS (Cont.)

LIST OF TABLES

LIST OF TABLES (Cont.)

I. INTRODUCTION

In laboratory tests certain materials for aircraft and missile construction were observed to fail prematurely when subjected to stress approximating their yield strength in the presence of aqueous salt (ASTM sea water) solution. The materials were: aluminum alloy 2024-T86, magnesium alloy ZK-60A, precipitation hardenable stainless steel 17-7 PH, and titanium alloy B-120VCA (1). The fact that failures of this type have occurred on aircraft structures indicates a problem in need of elucidation.

Another problem of consequence is the stress corrosion of titanium-base alloys by chloride salts at elevated temperatures. Apparently there is little cause for concern for titanium-base alloy parts incorporated in airplanes presently flying. The upper temperature limit and the stress conditions for these applications are not within the critical zone as defined by laboratory tests for the particular alloys involved. However, newer developments are cause for apprehension. Specifically, it is desired to push the temperature limit for titanium application higher--that is, into the region where salt stress corrosion proceeds at a high rate. Also, a newly developed alloy, B-120VCA, which shows promise of being widely used in aircraft and missiles, has been shown in laboratory tests to have a lower temperature limit for severe damage than alloys like Ti-6Al-4V. Since this heat-treatable alloy was tested in a high-strength condition, this may be a reflection of the greater notch sensitivity.

It is known that the rate of stress-corrosion cracking is dependent upon the amount of salt present. In laboratory tests applied salt concentrations have, for the most part, been greatly in excess of accumulations that one might expect in service. One of the reasons why titanium alloys may appear to perform better in service in marine atmosphere than one might suppose based upon laboratory tests is that salt accumulations are smaller than the amounts usually applied in tests. Also, it is known that anodized films afford some protection. Important questions which need quantitative answers are: (1) what protection is given by an anodized film, and (2) what is the influence of salt concentration?

In regard to premature failure in aqueous salt solution the objectives of the current program are to: (1) define the conditions under which such failures occur and (2) to develop information which will contribute to understanding the mechanism involved. Materials of this part of the program are: the aluminum alloys 2024-T86 and 7075-T6, ZK-60A, 17-7 PH, and B-120VCA. Test methods consist of dynamic tensile and static load testing in air, distilled water, and ASTM standard sea water. Dynamic tensile tests were conducted on a "hard" machine capable of detecting the occurrence of cracks which cause a drop in load of 20 pounds (equivalent to about 900 psi for the specimen

---

Manuscript released by author November 1961 for publication as an ASD Technical Report.

geometry used). Dynamic tensile tests were conducted at nominal temperatures of 32°, 75°, and 212°F for aqueous environments. Static load (tensile) tests were conducted at room temperature only. All materials were evaluated as age-hardened sheet in two grain size conditions and two surface conditions: freshly ground under the test medium and with a protective film on the surface. Selection of these two surface conditions was based upon current work in the area of fracture mechanics and the influence of test environments. The work indicates that factors of importance are reproducibility of the surface condition and the presence or absence of a surface film, eg., the natural oxide. The first factor is important in order that results of independent investigators may be mutually reproducible and correlated. The second factor has been shown to have significant influence in single crystal work, and in work on polycrystalline manganese bronze of the author's experience (2).

In regard to elevated temperature salt stress corrosion of titanium-base alloys, the objective is to define the relationship between thickness of protective anodized film, quantity of salt present, and specimen life or degree of damage after 190 hours' exposure. Evaluations were made at single exposure temperatures of 600° and 800°F for sheet B-120VCA and Ti-6Al-4V alloys, respectively.

II. EXPERIMENTAL PROCEDURES

A. Materials

The materials of this investigation, their sources, gages, and nominal or actual compositions are given in Table 1. The materials were evaluated in the as-received condition with respect to microstructure and in a coarser grain size condition with the exception of B-120VCA. The second microstructural condition of this alloy was of finer grain size produced by cold rolling and recrystallization. Grain coarsening of the other alloys was accomplished by annealing at relatively high temperatures. Grain coarsening temperature of the aluminum and the magnesium alloys was limited to 900°F due to grain boundary melting. Treatments to produce the second grain size and the grain size of the materials evaluated are given in Table 2. Grain coarsening treatments were arrived at by trial. The materials initially were relatively coarse grained and, except for ZK-60A, were quite resistant to grain growth.

The invoice accompanying the B-120VCA material indicated that it could be aged to the desired strength level in 24 hours at 900°F. However, after such a treatment the tensile properties were little different from the as-received or solution-treated properties. An aging study monitored by hardness measurements indicated that aging should be for 40 hours at 900°F. Aging heat treatments were carried out in a positive pressure, static argon gas atmosphere. Titanium sponge was placed in the hot zone between the test pieces and the entrance end of the retort for gettering residual impurity gases. After heat treatment 0.5 mil was pickled from each surface. The pickle bath--consisting of an aqueous solution of 3% HF, 30% HNO_3, and 5% H_2O_2--was operated at 150°F. The finer grained material was produced by cold rolling 0.090 in. material to 50% reduction, and recrystallizing at 1325°F for 1 hr followed by air cooling. Because of the size of sheet the recrystallization treatment was done in air. A total of 4 mils of surface was removed by pickling in order to insure removal of contamination.

It was originally planned to evaluate the 17-7PH material in the TH 1050 condition. However, in this condition the material exhibited a yield strength of only 140,000 psi--about 40,000 psi below the desired level. Therefore, the RH 950 treatment was employed.

The "ground" surface condition was prepared by abrading with 120-150T Porter Cable abrasive under the test medium. For tests in aqueous media the reduced section was not permitted to dry between grinding and testing. This was to insure that the molecular species adsorbed on the surface would be the test medium. The other surface condition evaluated was a protective film. The aluminum alloys, 2024 and 7075, were anodized according to the procedure AMS specification 2471 while the magnesium alloy, ZK-60A, was chromated following the procedure AMS specification 2475A. The stainless steel, 17-7 PH, was passivated by holding in a 25% HNO_3 solution at 120°F for 30 minutes. The titanium alloy, B-120VCA, was anodized to a film thickness of 8 microinches as described below. All test specimens were longitudinal with respect to the rolling direction.

B. Elevated Temperature Salt Stress Corrosion

The elevated temperature salt stress corrosion tests were conducted in 20:1 lever arm creep test stands. Sheet test specimens contained a 2 x 1/4 in. reduced section. The salt was applied by spreading 0.05 ml of salt solutions of concentrations: 10, 1, and 0.1% ASTM sea salt (7 parts NaCl to 1 part $MgCl_2$) over one side of the 1 in. center part of the reduced section. The solutions were allowed to evaporate to dryness before the specimens were placed in the test stands. Exposures were for 190 hours at temperatures of 600°F for B-120VCA and 800°F for Ti-6Al-4V. The stresses applied were estimated to produce not more than 0.2% creep deformation, and were 100,000 psi for B-120VCA and 25,000 psi for Ti-6Al-4V. Specimens of each alloy were evaluated in three surface conditions: freshly pickled, with 2-microinch anodized film, and with 8-microinch anodized film. Anodizing was carried out in a 1% KOH solution. The thinner film was produced by anodizing for 30 sec at 18 volts; the thicker film was produced by anodizing for 15 sec at 68 volts followed by 15 sec at 74 volts. The latter procedure resulted in a more uniform film than anodizing for 30 sec at 74 volts. After elevated temperature exposure, specimens were tensile tested at room temperature.

C. Tensile Testing in Aqueous Media

Sheet test specimens for tensile tests contained a 2 3/8 by 3/8 in. reduced section except the finer grained B-120VCA and the coarser grained 17-7 PH specimens. Since a number of the 3/8 in. width specimens of these alloys in the as-received condition failed in the pin hole, the materials processed to change the grain size of these two alloys were machined to 1/4 in. width. The tests were made on a Riehle machine of 20,000-lb capacity. A constant cross-head speed of 0.2 in./min was used in all testing. For tests in aqueous media at room temperature the medium was contained in a 1 in. plastic tube surrounding the reduced section of the test specimen. The container was sealed at the bottom by means of a rubber stopper slotted to accommodate the test specimen. Dow Corning stopcock grease was used to complete the seal between the specimen and the rubber base plug. Tests conducted above or below room temperature had the medium contained in a 2 1/2-in. diameter Pyrex tube reduced at the base to 1 1/2-in. diameter. The base was sealed by means of a rubber stopper with a hole in the center to accommodate the lower pull arm, about which the seal was made. The lower pull arm pin was coated with Ray-Bond adhesive R-81001 (Raybestos-Manhattan, Inc.), in order to prevent electrochemical effects external to the test specimen. Thermocouples in contact with the specimen under the test medium were also coated. For tests at 212°F a resistance heating coil was wound around the Pyrex tube; for tests at 32°F crushed ice was added to the medium. Load-strain curves were recorded autographically. A drop in load of 20 lb was readily detectable.

D. Static Load Tests in Aqueous Media

Static load tests in aqueous media were conducted at room temperature only. Test loads were equivalent to about 90% of the 0.2% off-set yield strength, and test duration was 240 hr or rupture whichever occurred earlier. The aqueous media were contained in 1 in. plastic tubes in the manner described above for tensile tests. Specimens surviving the exposures were tensile tested.

E. Evaluation of Weldments of B-120VCA

Since the grain size of weldments in B-120VCA is usually much larger than the parent grain size, an evaluation by the above means (tensile test and static load) was made of welded specimens. Welds were longitudinal with respect to the rolling direction and were tested in the longitudinal direction. Bead welds on 0.062 in. sheet were made by the tungsten inert gas process, operating at 10 volts and 95-100 amps current. Welds were made under three sets of conditions: (1) normal conditions, (2) a 300 gauss magnetic field parallel to the welding electrode imposed and field direction alternated at the rate of 10 cps, and (3) 250 gauss magnetic field imposed and field direction alternated at the rate of 2 cps. The last two conditions were for the purpose of refining the weld grain size. Experiments exploring various means including mechanical vibration and magnetic stirring for refining weld grain size of B-120VCA indicated magnetic stirring to be more effective (3). Aging of the welded specimens was done at 900°F for 40 hr and was followed by a flash anneal at 1000°F for 40 min to improve ductility.

III. RESULTS AND DISCUSSION

A. Microstructure of Materials

Table 2 summarizes the heat treatments applied to the test materials and the grain size measurements. Representative microstructures are shown in Figs. 1 through 10. Only the 17-7PH in both grain size conditions and the ZK-60A in the as-received condition were equiaxed. Therefore, grain measurements are given in terms of the average dimensions of the major and minor axes of the grains. The microstructure of the cold-rolled and recrystallized B-120VCA alloy (see Fig. 10) was quite varied. Apparently much of the structure recrystallized by secondary recrystallization.

B. Elevated Temperature Salt Corrosion

All specimens of Ti-6Al-4V and B-120VCA survived the stress-corrosion exposures. A control specimen of Ti-6Al-4V alloy exhibited 0.17% creep under the exposure conditions of 25,000 psi stress at 800°F for 190 hr, while a control specimen of B-120VCA exhibited 0.055% creep under the conditions of 100,000 psi stress at 600°F for 190 hr. Post-exposure tensile properties for the two alloys are given in Tables 3 and 4, respectively. Tensile elongation as an indication of the extent of stress-corrosion damage is plotted in Figs. 11 and 12 versus the salt concentrations on the surface.

The Ti-6Al-4V alloy exhibited significant stress-corrosion effects only at the highest salt level. Anodizing does not appear to have had any effect under these exposure conditions.

Metallographic examination of specimens exposed to the heaviest salt concentration all exhibited surface corrosion and occasional pits. The latter are probably the loci of individual salt crystals. However, no cracks were observed. This finding is essentially is agreement with those for accelerated sodium chloride stress-corrosion testing carried out by the titanium producers. The conditions of the current investigation represent borderline conditions between cracking and no cracking defined by the earlier investigations of the producers (4).

Figure 12 indicates that the B-120VCA alloy is susceptible to some extent even at the lowest salt level, and stress-corrosion damage increased with increased quantity of salt. The data suggest that the anodizing treatment may have been beneficial. However, the degree of protection afforded under the conditions of this evaluation was not very great.

Metallographic examination of specimens exposed to the highest salt concentration showed the presence of transgranular stress-corrosion cracks in the unanodized specimen and in 2-microinch oxide film specimen. Excluding the crack from which the tensile fracture initiated, the metallographic sample from the former specimen contained 5 cracks of length varying from 0.002 to 0.004 in., while the sample from the latter specimen exhibited 17 cracks of lengths varying from 0.002 to 0.007 in. No cracks were observed in the sample from the 8-microinch film specimen examined. The cracks exhibited very little branching and appeared to follow along crystallographic directions closest to being transverse to the stress axis. Examples of stress-corrosion cracks observed in the unanodized and in the 2-microinch anodized film specimens are shown in Figs. 13 and 14, respectively.

It should be pointed out that applying salt solutions of different concentrations as was done in this evaluation had the primary effect of varying the size of the deposited salt crystals. The edge dimensions of the salt crystals as observed on the B-120VCA specimens were 0.04, 0.005, and 0.0009 to 0.00009 in., for the highest, intermediate and lowest salt levels, respectively. At the lowest level the 0.0009 in. crystals were rare, while the 0.00009 in. were common and concentrated in the grain boundaries. The grain structure on the surface of the as-received B-120VCA could be readily discerned at low magnification because of marked depression of the grain boundaries. This is shown in Fig. 15. Apparently the last liquid to evaporate resided in the grain boundary depressions, and the most dilute solution did not become saturated until evaporation had reduced the liquid volume to that in the grain boundaries, resulting in a concentration of the salt in these locations. The cold-rolled, recrystallized and pickled material exhibited this phenomenon to a much less marked extent, as shown by Figure 16.

C. Tensile Properties in Various Media

The data for tensile test in media of air, distilled water, and ASTM sea water at room temperature, and for the two aqueous media at 32° and 212°F are summarized in Tables 5 to 14. Tensile elongations as a function of temperature are plotted for each of five basic materials in Figs. 17 to 21. There was no significant change in the tensile properties of 2024-T86 for the variables imposed in this investigation. The 7075-T6 alloy similarly exhibited no tensile test property dependence on test medium, temperature or surface condition. It may be noted, however, that the grain-coarsened material had lower strength and higher ductility than the as-received material.

The two surface conditions of the ZK-60A behaved similarly in the various media. Tests in air and water gave approximately the same results; the average elongation was somewhat higher for tests in air compared to tests in water. Tests in ASTM sea water resulted in lower elongation than testing in the other media; and comparing the aqueous media this difference increased with increasing temperature. The high elongations in water solution are due to the occurrence of stress-corrosion cracks throughout the reduced section. Chromating leaves a very rough surface on ZK-60A alloy, and cracks originate at the base of the deeper pits as shown by Fig. 22, which is a photomicrograph of a specimen tensile tested in air. Five such cracks were observed in the particular metallographic sample represented.

The grain-coarsening heat treatment of 2000°F for 4 hours was very detrimental to the tensile ductility of 17-7PH in the RH 950 condition, as shown by Fig. 20.* This heat treatment which was done in air apparently caused grain boundary oxidation to a depth of about 0.001 in. as illustrated by Fig. 23. However, surface grinding to remove 3 mils and consequently the damaged layer from each surface produced a tensile elongation of 3.3% in one specimen but only 0.8% in another. It is possible that due to distortion 3 mils were not removed over the entire surface of the latter. Therefore, it appears that the damage was limited to the surface layers. In the as-received, fine-grain size condition the stainless steel exhibited somewhat higher elongation in ASTM sea water at 32°F than in distilled water. At room temperature this relationship is reversed but smaller in magnitude. There does not appear to be a significant difference at 212°F. In the grain-coarsened condition all tests in aqueous media produced tensile elongations of less than 1%, while tests in air at room temperature resulted in elongations of 1% or slightly more.

The fine-grained B-120VCA alloy had somewhat lower strength and higher ductility compared to the as-received coarse-grained material, as shown by the data of Tables 13 and 14 and Fig. 21. Tensile elongation tended to increase modestly with increasing test temperature for this alloy; this increase was perhaps due to temperature, per se, since the matrix is body-centered cubic. In general, tensile elongation was slightly lower in ASTM sea water than in water.

D. Stress-Corrosion Susceptibility in Various Media

The results of subjecting the test materials to loads of 90% yield strength (0.2% offset) in the presence of air, distilled water, and ASTM sea water for 240 hours are summarized in Tables 15 to 24, and Figs. 24 to 26. Occasionally there was a leak which necessitated interrupting the test in order to stop it. In such cases failure frequently occurred very soon after the reapplication of the load. Also, failures in the lower pin hole were very often associated with a leak condition. Tests in which leak conditions prevailed upon initial loading are so indicated in the tables. The term "interface" in the last column of some of the tables from No. 19 through 25 refers to the air/aqueous solution interface. All of the aluminum alloys specimens survived the exposures as shown by Fig. 24. Post-exposure tensile testing indicated that the fine-grained surface specimens and coarse-grained, anodized specimens of 2024-T86, and a coarse-grained, surface-ground specimen of 7075-T6 suffered damage as a result of the exposure in ASTM sea water. The coarse-grained 7075 alloy was inadvertently loaded to 118% of the yield strength rather than the intended 90%.

---

* In plotting the elongation data for 17-7 PH and B-120VCA, single values are used in cases where one of the duplicate specimens failed in a pin hole, except in the case where in spite of the fact that failure occurred in a pin hole the elongation was greater than for the duplicate specimen which failed in the gage length.

Figure 25 and Tables 19 and 20 summarize the results for static load exposure in various media for ZK-60A alloy. The coarse-grained material in the surface-ground condition was inadvertently stressed to 106% of the yield strength rather than the intended 90%. The data suggest that the fine-grain, surface-ground condition is more resistant to stress-corrosion cracking in the aqueous media than the fine-grain, film condition; and the coarse-grain, film condition is more resistant to stress-corrosion cracking than either. The position of the coarse-grain, surface-ground condition is somewhat uncertain because of the unequivalent load; however, it appears to be on a par with the coarse-grain, film condition. Figure 27 shows a stress corrosion crack in a fine-grain, film condition specimen exposed to ASTM sea water.

Static load exposure results for 17-7PH are given in Fig. 26 and Tables 21 and 22. Failures during exposure occurred in water and ASTM sea water. Failures were more numerous in the coarse-grain material, and they occurred in much shorter times. The most frequent site of fracture was at the base of the container suggesting a concentration cell effect. Similar behavior was reported by Ault for AM-350 alloy (5). However, fracture at the air/solution interface was almost as frequent. The poorer performance of the coarse-grain material was very likely related to the surface condition discussed above.

Static load results for B-120VCA are summarized in Fig. 26 and Tables 23 and 24. A number of specimens in the as-received (coarse grain) condition fractured in the pin hole, either during exposure or during subsequent tensile testing. Consequently when the fine grain material was machined to test specimens at some later time the width of the reduced section was changed from 3/8 to 1/4 in. The theoretical stress concentration of the pin hole was 2.4. Pin hole fractures during exposure were associated with the presence of aqueous solution. In the case of the surface-ground condition, specimens were entirely immersed in the medium for the grinding, and undoubtedly traces of solution remained in the pin holes. In the case of the film condition specimen (specimen No. 12), the container developed a leak which probably led to wetting of the lower pin hole where fracture occurred.

None of the fine-grain specimens failed during exposure,and none gave unequivocal indications of having suffered damage during exposure in subsequent tensile testing. In comparison to the performance of the coarse-grain material, this may be the result of a lower stress at the pin hole because of the more favorable geometry of the fine-grain specimens. It appears that B-120VCA performs much more favorably under these conditions than 17-7 PH.

E. Effect of Ion Species on Stress Corrosion Cracking

The three materials, ZK-60A, 17-7 PH, and B-120VCA, which gave indications of being susceptible to premature failure or stress corrosion cracking in ASTM sea water under static load conditions were further evaluated to determine the effect of ion species on their behavior. The ASTM sea water has a molarity of 0.60 assuming 3.5% NaCl in place of the actual 3% NaCl-0.5% $MgCl_2$. Specimens of the three alloys were exposed under static loads of 90% of the 0.2% offset yield strength in 0.60 molar solutions of the following salts: NaCl, KCl, CsCl, NaBr, and NaI. In testing performed up to this point failure either occurred in less than 60 hr, or there was no failure for the 240 hr exposure. Therefore, in these tests exposure times were at least 96 hr but did not exceed 175 hr. Specimens were evaluated in the surface condition: freshly ground under the test medium.

The results of these tests are summarized in Table 26. All of the B-120VCA specimens survived the exposures and in subsequent tensile test evaluation exhibited no deterioration of mechanical properties. For the other two materials molar conductance versus time to failure is plotted in Fig. 28. The molar conductances at 18°C (64°F) were taken from the International Critical Tables for 0.5 molar solutions--data were not complete for a temperature of 25°C (77°F) (6). Considering the sodium salts of the halide series it appears that time to failure is longer for increasing molar conductance. Also considering the behavior of 17-7 PH in the series of chloride salts it again appears from these very limited data that time to failure tends to increase with increasing molar conductance. It may be noted that with a single exception the ZK-60A specimens failed either in a pin hole or at the base of the cup. Similarly three of the four 17-7 PH failures occurred in a pin hole or at the base of the cup. Under the conditions of these tests there is a decided preference for crevice, or concentration cell, corrosion.

A single specimen of the ZK-60A alloy survived for more than an order of magnitude longer than the other magnesium alloy specimens. This specimen was exposed to an aqueous solution of KCl. Specimens exposed to the CsCl solution exhibited many transverse cracks in the test section, while all of the other magnesium alloy specimens either had no cracks observable at 30X or only a few small cracks (about 0.04 in. long) within 1/16 in. of the fracture.

Consideration of the ionic conductance and the effect of ionic conductance on the changes in composition in the anode and cathode areas of an electrolytic system suggests that the apparent correlation exhibited by Fig. 28 is merely superficial and the relationship between species of anion, cation, test material, and stress corrosion behavior is, needless to say, very complex. It is especially interesting that the CsCl solution did not produce stress-corrosion failure in 17-7 PH although the other two chloride salts did. Of course, an uncontrolled variable of considerable importance in these tests was oxygen content. This is especially important because of high proportion of failures at crevice sites.

F. Behavior of B-120VCA Weldments Under Tensile Stress in ASTM Sea Water

Longitudinal weld specimens of B-120VCA in the aged condition were tensile tested in air and in ASTM sea water and evaluated for premature failure under static load equal to 90% of the yield strength in air and ASTM sea water. Weldments were bright and shiny in appearance, and there was no evidence of contamination. The aging treatment was 900°F for 40 hr followed by a flash anneal of 1000°F for 40 min. The specimens were then pickled to remove a total of 1 mil. The results are given in Table 27.

The weldments were of lower strength and ductility than the parent metal (see Table 14). Tensile testing in ASTM sea water resulted in failures in the elastic region for all welded specimens. Under static load conditions at 150,000 psi, specimens tested in air environment survived 96 hr exposure and exhibited no deterioration of mechanical properties in subsequent tensile testing. However, in ASTM sea water all specimens failed within 1 minute of the application of a load of 110,000 psi. Thus the behavior of the welded structure is in marked contrast to that of the base metal, but is similar to the behavior experienced with specimens which were intentionally contaminated during heat treatment (refer to Table 25) and with the behavior of base metal evaluated in a similar manner in a prior program. In the prior work, aged material failed on loading to the 0.2% offset yield strength in a somewhat different environment--the specimen was wetted by a wick system fed by a 10% aqueous solution of ASTM sea salt (7 parts NaCl, 1 part Mg_2Cl) (1).

The surface appearance of the bead-on-plate weld indicated that both conditions of magnetic stirring reduced the grain dimension by a factor of two as measured along a line parallel to the weld and displaced 1/32 in. from the centerline. However, microexamination of transverse sections of the welded specimens indicated that only the 2 cps-250 gauss condition produced refinement in depth, and this refinement was limited to about 30% reduction in the grain dimension measured perpendicular to the plane of the sheet. The weld grain structures are indicated by the fractographs shown in Fig. 28 which shows specimens that failed under static load in the ASTM sea water environment. In all cases failure appears to have initiated at the center of the front face of the weld.

IV. SUMMARY AND CONCLUSIONS

The effect of quantity of salt present and thickness of oxide film (applied by anodizing) on hot salt stress corrosion was evaluated for B-120VCA at 600°F under 100,000 psi and Ti-6Al-4V at 800°F under 25,000 psi. All test specimens survived the 190 hr exposure. There was a definite effect due to salt quantity. There was significant damage (amounting to an average 40% loss in tensile elongation) to Ti-6Al-4V alloy only at the highest salt concentration of 0.02 g/sq in. Under these test conditions anodizing appeared to have no effect. The B-120VCA alloy exhibited stress corrosion damage even at the lowest salt concentration of 0.0002 g/sq in. In this case it did appear that the anodized films were somewhat beneficial; however, the degree of protection afforded left much to be desired.

The alloys 2024-T86, 7075-T6, ZK-60A T5, 17-7 PH, and B-120VCA were tensile tested in air at room temperature, and in distilled water and in ASTM sea water at 32°, room temperature, and 212°F. The materials were tested in two grain size conditions and two surface conditions. One surface condition was freshly ground under the test medium, and the other was a protective film condition. The latter was an anodized film for the two aluminum alloys and B-120VCA titanium alloy; chromate film for the magnesium alloy, ZK-60A; and a thin oxide film by passivation for the stainless steel, 17-7 PH.

There was no significant effect on the tensile properties of the two aluminum alloys due to the variables imposed in this investigation. Except for slightly lowered tensile elongation for the coarser-grained material for tests conducted in air, there was no significant difference in tensile elongation for the two surface conditions and the two grain sizes for the magnesium alloy. Tensile elongations were lower in ASTM sea water than in distilled water, and this difference increased with increasing temperature. Tests in distilled water at 212°F resulted in very high elongations of 17 to 36% due to multiple cracking throughout the test section.

The grain-coarsening treatment of 2000°F for 4 hr was very detrimental to the tensile ductility of 17-7 PH in the RH 950 condition due to grain boundary oxidation to a depth of about 1 mil. It appears that this is corrected if sufficient material is removed from the surface. Considering the finer grain size (as-received) material there was very little effect of temperature for tests in water; however, there was a progressive decrease in tensile elongation with increasing temperature for tests in ASTM sea water--this was true for both surface conditions. Tensile elongation for the coarser grain condition was less than 1% for all tests in aqueous media, and was less than 1.5% for tests in air.

The finer grain size condition of the B-120VCA alloy was of lower strength and higher elongation than the coarser grain (as-received) material. This was true for all test conditions. With a single exception tensile elongation increased with increasing test temperature. The exception was the fine-grain, ground-surface specimens tested in ASTM sea water in the temperature range from 32°F to room temperature. This increase was perhaps due to temperature per se since the matrix of B-120VCA alloy is body-centered cubic. Tensile elongation was always lower in ASTM sea water than in distilled water for the fine-grain size material and for the coarse-grain material in the anodized condition; but this was not true of the coarse-grain material in the ground condition.

Static load exposures for 240 hr in test media of air, distilled water, and ASTM sea water at room temperature were applied to the five alloys in the two grain size conditions and two surface conditions as discussed above. All specimens of the aluminum alloys survived the exposure. Post-exposure tensile testing indicated damage, i.e., some loss of tensile elongation, from ASTM sea water to the following material conditions: (1) fine-grain, surface ground 2024-T86, (2) coarse-grain, anodized 2024-T86, and coarse-grain, surface ground 7075-T6 perhaps. (The coarse-grain 7075 was inadvertently loaded to 118% of the yield strength rather than intended 90%.)

In ASTM sea water, material conditions of ZK-60A had increasing life in the order: fine-grain, surface film; fine-grain, ground; and coarse-grain, surface film. Although the coarse-grain, ground condition had the longest life of all, i.e., 0.2-0.5 hr, it was not tested under comparable conditions--a load of 106% of the yield strength was inadverently applied.

A single magnesium specimen survived the 240 hr exposure to distilled water. It was in the coarse-grain, film condition. Post-exposure tensile testing showed a 95% decrease in the tensile elongation. The duplicate test specimen failed in 5.6 hr in an upper pin hole.

All material conditions except the coarse-grain, surface film exhibited loss of tensile ductility after the 240 hr exposure in air. Ductility losses were in the range from 48 to 58% of the tensile elongation.

Considering 17-7 PH, the fine-grain material was less susceptible to failure in the aqueous media than the coarse-grain material, and the passivated condition was less susceptible than the ground condition except for the coarse-grain condition in sea water. The ASTM sea water was the most severe medium with earliest failures occurring in 8.2 hr (in the upper pin hole) for the finegrain ground material and 2 min for the coarse-grain, passivated condition.

All specimens of the fine-grain B-120VCA alloy survived the 240 hr exposures in the various media. There were no unequivocal indications of loss of ductility in post-exposure tensile tests. Material in the coarse-grain (as-received) condition was very susceptible to failure through the pin holes. All three specimens which failed during static load exposure (in ASTM sea water) fractured through a pin hole, while half of all specimens tensile tested after exposure fractured through a pin hole. The theoretical stress concentration of the pin hole was 2.4. The applied load in the case of the fine-grain material was only 67% of that for the coarse-grain material since after the experience with the coarse-grain material the reduced section was made narrower on the fine-grain specimens. No failures of B-120VCA occurred during static load exposures in air or water. It appears that B-120VCA performs much more favorably under these conditions than 17-7 PH.

The effect of surface contamination on the behavior of B-120VCA under static load in an environment of ASTM sea water was evaluated. Contamination was effected by aging in air at 900°F for 40 hr. Various amounts of material up to 2 mils were removed from the surface by pickling in 3% HF-30% HNO_3-5% H_2O_2 aqueous solution at 150°F. Two out of four as-contaminated specimens failed within 1 min of loading to 90% of the yield strength. All other specimens survived exposures of 240 hr. The best ductility for duplicate specimens was obtained for those pickled just to the point of removal of the surface discoloration; this amounted to 0.15 and 0.25 mils total reductions in thickness. The ductility in this case was, in fact, superior to that of material aged in argon atmosphere and subsequently pickled to remove 1 mil total thickness. Thus, it appears that surface contamination is an important factor in the premature failure of B-120VCA stressed in the presence of salt solution.

Three materials ZK-60A, 17-7PH, and B-120VCA in the as-received, ground surface condition were statically loaded at 90% of their respective yield strengths in aqueous environments of 0.6 molar concentrations of the following salts: NaCl, KCl, CsCl, NaBr, and NaI. Exposure times ranged from 96 hr to 175 hr. All of the B-120VCA specimens survived, and no loss of mechanical properties was experienced in subsequent tensile testing. With a single exception, all magnesium alloy specimens failed in 0.12 hr or less. The excepted specimen failed in 2.3 hr of exposure in KCl solution; however, its duplicate failed in 0.03 hr. The reason for this is unknown. Specimens of 17-7PH exposed to solutions of NaCl and KCl failed in times of 19.2 to 57.0 hr; while all other specimens survived and gave no evidence of damage in subsequent tensile testing. Attempts to correlate these results with the characteristics of the electrolytes were unrewarding, although molar conductance may be a factor.

Longitudinal weld specimens of B-120VCA in the aged condition were tensile tested in air and in ASTM sea water, and also statically loaded in these media. Two-thirds of the specimens were magnetically stirred during welding in a mostly unsuccessful effort to refine the grain size. Specimens tensile tested in air exhibited tensile yield strengths from 159,000 to 184,000 psi and elongations from 1.2 to 2.6%. However, fracture initiated in the elastic region of specimens tensile tested in ASTM sea water. Specimens statically loaded in air at 150,000 psi survived the 96 hr exposure and gave no evidence of loss in mechanical properties upon subsequent tensile testing. Specimens statically loaded in ASTM sea water at 110,000 psi failed in 1 min or less.

The behavior of the welded B-120VCA was in marked contrast to that of the parent material, but was similar to that of the material intentionally contaminated during the aging heat treatment. Also, in prior work a different heat of aged material failed on loading to the 0.2% offset yield strength in a somewhat different environment--the specimen was wetted by a wick system fed by a 10% aqueous solution of ASTM sea salt. Care was taken to keep the welds free of contamination (weldments were bright and shiny in appearance), and after the post-weld aging treatment 1 mil total thickness was removed by pickling. It is not known whether to lay this behavior at the door of contamination, or coarse grain size, or to yet another cause at present undefined.

To recapitulate the findings of this investigation:

(1) Quantity of salt is a factor in the elevated temperature chloride salt stress corrosion of the titanium alloys B-120VCA and Ti-6Al-4V. The former alloy was exposed at 600°F and the latter at 800°F under stresses to produce approximately 0.2% creep deformation in 190 hr. Anodized films were of no benefit to the Ti-6Al-4V alloy; and were of limited benefit to B-120VCA.

(2) Tensile properties of the aluminum alloys 2024-T86 and 7075-T6 were not significantly changed for tests conducted in media of water or ASTM sea water at temperatures of 32°, 76°, and 212°F.

(3) Tensile properties of ZK-60A were markedly influenced by the test media: water and ASTM sea water, apparently reflecting a competition between plastic straining and stress-corrosion cracking.

(4) Tensile properties of 17-7 PH at room temperature were not significantly different for tests in media of air, water, and ASTM sea water. There was a trend towards lower tensile elongation with increasing temperature of the aqueous media.

(5) The B-120VCA alloy exhibited decreasing tensile elongation at room temperature for the various test media in the order: air, water, and ASTM sea water. Also tensile elongation increased gradually with increasing temperature of the aqueous media.

(6) Considering the test materials in the as-received microstructural condition, exposures in air under loads of 90% of the tensile yield strength for 240 hr were not detrimental to tensile properties.

The same conditions except for water as the test environment were detrimental to ZK-60A and, apparently, to 17-7 PH. Surface-ground specimens of ZK-60A exhibited an order of magnitude longer life than chromated specimens. The single specimen of 17-7 PH which failed during the exposure was a surface-ground one.

The ASTM sea water environment, static load tests resulted in damage to the following material conditions: 2024-T86 surface-ground; ZK-60A surface-ground, and chromated; 17-7 PH surface-ground, and passivated; and B-120VCA surface-ground, and anodized.

The effect on B-120VCA was aggravated by the notch-sensitivity of this material in the high-strength condition. The three (of four) test specimens which failed prematurely fractured through a pin hole. Similarly, a number of these specimens failed through the pin hole in tensile tests.

(7) Under the conditions of this investigation B-120VCA was more resistant to deterioration of tensile properties and to failure than 17-7 PH. However, weldments of B-120VCA tensile tested in ASTM sea water failed in the elastic region. Weldments of 17-7 PH were not evaluated.

(8) Surface contamination of B-120VCA due to exposure to the atmosphere during aging at 900° F was damaging to tensile properties in sea water environment. It appears that properties are best restored by pickling off the least amount of material necessary to effect removal of the contaminated layers.

In view of the limited testing for each set of conditions these findings should be regarded as tentative.

REFERENCES

1. F. A. Crossley, C. J. Reichel, and C. R. Simcoe (Armour Research Foundation), "The Determination of the Effects of Elevated Temperatures on the Stress Corrosion Behavior of Structural Materials," WADD TR 60-191, March, 1960, Materials Central, Wright Air Development Division, Ohio, Contract No. AF 33(616)-6392.

2. F. A. Crossley and C. R. Simcoe (Armour Research Foundation), "A Study of Stress-Induced Delayed Failure in High-Strength Brasses," Report No. ARF 2159-8, November 10, 1960, Bureau of Ships, Department of the Navy, Contract No. NObs-77020.

3. Armour Research Foundation, "Investigation of Heat Treatment and Welding Characteristics of B-120VCA Titanium Alloy Sheet," Part II, Bureau of Weapons, Department of the Navy, Contract No. NOw 61-0351-c (ARF Project No. 2211).

4. "Progress Report on the Salt Corrosion of Titanium Alloys at Elevated Temperatures and Stress," TML Report No. 88, November 20, 1957, Defense Metals Information Center, Battelle Memorial Institute, Columbus, Ohio, p. 11.

5. R. T. Ault, "Stress Corrosion of Notched and Unnotched AM-350 Alloy," WADD TR 60-95, May, 1960, Materials Central Project No. 7360, Wright Air Development Division, Ohio.

6. International Critical Tables, McGraw-Hill Book Co., Inc. (1929) Vol. VI, pp. 232 ff.

TABLE 1

MATERIALS, SOURCES, AND NOMINAL COMPOSITION

Alloy	Heat No.	Source	Base Metal	Nominal Composition, Weight per cent
2024-T86	CH 37600-D	Aluminum Co. of America	Al	Cu 4.5, Mg 1.5, Mn 0.6
Al Clad 7075-T6		Aluminum Co. of America	Al	Zn 5.5, Mg 2.5, Cu 1.5, Cr 0.3, Mn 0.3 max.
ZK-60A-T5	44166	Dow Chemical Co., Midland, Mich.	Mg	Zn 5.5, Zr 0.45 min.
17-7PH	890606	Ducommun Metals & Supply Co.	Fe	Cr 16.96, Ni 7.34, Al 1.06, Mn 0.50, Si 0.48, C 0.07, S 0.013, P 0.013*
B 120 VCA (0.0625 in.)	M 9858	Titanium Metals Corp. of America	Ti	V 13.5, Cr 11.2, Al 2.8, Fe 0.2, N 0.025, C 0.027, H 0.008*
B 120 VCA (0.090 in.)	D 170	Titanium Metals Corp. of America	Ti	V 13.4, Cr 10.7, Al 3.1, Fe 0.2, N 0.018, C 0.025, H 0.006*
Ti-6Al-4V (0.0625 in.)	M-8507	Titanium Metals Corp. of America	Ti	Al 5.9, V 4.1, Fe 0.16, C 0.016, N 0.013, H 0.006*

* Actual composition (from supplier).

TABLE 2

CONDITION AND GRAIN SIZE OF MATERIALS

Alloy	Gage, in.	Treatment to Change Grain Size	Heat Treatment	Average Grain Dimensions (10^{-4} in.) Longitudinal Direction	Average Grain Dimensions (10^{-4} in.) Transverse Direction
			Finer Grain Size		
2024-T86	0.060	None	As-received	18	4.4
7075-T6	0.060	None	As-received	43	9.6
ZK-60A-T5	0.107	None	As-received	0.6 equiaxed	
17-7PH RH950	0.062	None	1750°F(10min)AC, -100°F(8hr), 950°F(1hr)AC	3.5 equiaxed	
B-120VCA	0.042	Cold rolled 50% Annealed 1325°F(1hr)AC	900°F(48hr)AC	9.3-130	8.4
			Coarser Grain Size		
2024-T86	0.060	900°F(30hr)WQ	Cold rolled 6%, aged 375°F (8hr)AC	38	13
7075-T6	0.060	900°F(30hr)WQ	250°F(24hr)AC	126	6.2
ZK-60A	0.107	900°F(4hr)WQ	275°F(48hr)AC	18	4.0
17-7PH RH950	0.062	2000°F(4hr)AC	1750°F(10min)AC, -100°F(8hr), 950°F(1hr)AC	7.1 equiaxed	
B-120 VCA	0.062	None	900°F(40hr)AC	40	22

TABLE 3

POST-EXPOSURE TENSILE PROPERTIES OF Ti-6Al-4V SPECIMENS STRESS CORROSION TESTED AT 800°F IN PRESENCE OF ASTM SEA SALT

Spec. No.	Oxide Film Thickness, Microin.	Salt Concn., g/in.^{2}	0.2% Offset Yield Strength, ksi	UTS, ksi	Elong., (in 2 in.) %	No. of Cracks in Fracture Surface	Max. Depth of Stress Corrosion Penetration, in.
C1	None	None	136	140	11.4	0	
1	2	*	134	140	11.2	--	
2	2	*	136	141	13.1	--	
3	8	*	136	141	12.0	--	
4	8	*	135	140	15.5	--	
C2	8	None	135	138	9.6	--	
C7	None	0.0002	136	142	10.6	0	
C8	None	0.0002	136	142	11.0	0	
C5	None	0.002	137	141	11.5	0	
C6	None	0.002	139	143	10.2	0	
C3	None	0.02	137	142	9.7	a	
C4	None	0.02	132	136	5.6	a	
C13	2	0.0002	138	143	10.8	0	
C14	2	0.0002	141	145	10.9	0	
C11	2	0.002	135	141	10.8	0	
C12	2	0.002	135	140	11.0	0	
C9	2	0.02	134	138	9.7	1	0.006
C10	2	0.02	132	136	4.9	3	0.007
C19	8	0.0002	137	143	11.3	0	
C20	8	0.0002	139	143	11.4	0	
C17	8	0.002	142	143	10.4	0	
C18	8	0.002	138	144	7.2	1	0.006
C15	8	0.02	138	142	5.5	1	0.007
C16	8	0.02	139	143	5.5	4	0.007

* Not exposed to elevated temperature stress corrosion

a Not determinable at X30

TABLE 4

POST-EXPOSURE TENSILE PROPERTIES OF B-120VCA SPECIMENS STRESS CORROSION TESTED AT 600°F IN THE PRESENCE OF ASTM SEA SALT

Spec. No.	Oxide Film Thickness, Microin.	Salt Concn., g/in.^{2}	0.2% Offset Yield Strength, ksi	UTS, ksi	Elong., (in 2 in.) %
Base properties of unexposed specimens[*]			191	208	3.2
C1	None	None	142	186	1.3[+]
C2	8	None	196	206	3.5
C13	None	0.0002	198	205	2.0
C14	None	0.0002			3.3
C5	None	0.002	196	197	1.1
C12	None	0.002	170	170	0.4
C3	None	0.02	196	196	0.4
C4	None	0.02	192	197	0.6
C10	2	0.0002	195	201	2.0
C11	2	0.0002	201	210	3.7
C8	2	0.002	205	214	2.8
C9	2	0.002	145	160	0.2[+]
C6	2	0.02	185	189	1.1
C7	2	0.02	192	197	1.1
C19	8	0.0002	186	190	1.5
C20	8	0.0002	200	209	4.2
C17	8	0.002	193	193	0.4
C18	8	0.002	186	195	1.3
C15	8	0.02	195	201	1.3
C16	8	0.02	191	198	0.4

[*] Average for 2 specimens

[+] Fractured through pin hole

TABLE 5

TENSILE PROPERTIES OF FINE-GRAINED 2024-T86 ALUMINUM ALLOY IN VARIOUS MEDIA

Test Medium	Test Temp, °F	Spec. No.	Yield Strength (0.2% Offset), ksi	Ultimate Tensile Strength, ksi	Elong., (in 2 in.) %
			Ground Surface		
Air	75	13	71.7	77.1	4.4
		14	73.2	74.7	4.3
Water	32	17	71.3	73.7	4.4
		18	69.6	74.3	4.0
	75	15	73.5	76.2	4.0
		16	71.9	74.3	3.9
	210	19	68.5	70.5	3.7
		20	67.5	69.0	4.7
ASTM Sea Water	32	23	75.3	78.0	4.2
		24	75.1	77.8	4.2
	75	21	73.5	76.1	3.9
		22	73.8	76.6	4.2
	210	25	69.2	70.7	4.5
		26	68.0	70.6	4.4
			Filmed Surface		
Air	75	31	71.6	75.8	3.9
		32	71.5	75.2	3.5
Water	32	35	73.7	77.4	3.4
		36	74.9	78.1	3.7
	75	33	72.5	75.5	4.2
		34	69.4	76.0	3.7
	210	37	67.9	69.2	4.7
		38	65.9	70.1	4.4
ASTM Sea Water	32	41	72.7	76.4	3.9
		42	67.6	78.1	3.9
	75	39	73.0	76.1	4.5
		40	72.1	75.7	4.2
	210	43	67.2	69.2	3.0
		44	67.9	69.5	4.5

TABLE 6

TENSILE PROPERTIES OF COARSE-GRAINED 2024-T86 ALUMINUM ALLOY IN VARIOUS MEDIA

Test Medium	Test Temp, °F	Spec. No.	Yield Strength (0.2% Offset), ksi	Ultimate Tensile Strength, ksi	Elong., (in 2 in.) %
Ground Surface					
Air	75	83	66.9	69.3	3.2
		84	63.8	70.1	5.0
Water	32	91	67.9	70.8	5.0
		92	68.4	70.6	4.4
	75	89	67.2	70.0	4.7
		90	56.9	64.0	3.0
	210	93	64.1	66.1	3.4
		94	63.8	66.4	4.4
ASTM Sea Water	32	97	68.9	72.0	4.9
		98	67.6	72.0	3.5
	75	95	68.2	70.4	3.7
		96	67.8	69.7	3.0
	210	99	62.6	65.9	4.5
		100	60.3	64.7	4.2
Filmed Surface					
Air	75	101	67.8	70.8	4.9
		102	66.4	71.4	4.2
Water	32	109	70.3	73.6	4.4
		110	69.7	74.8	4.0
	75	107	—	70.7	4.4
		108	65.4	68.8	3.7
	210	111	62.0	65.9	2.5
		112	62.4	65.6	4.0
ASTM Sea Water	32	103	66.4	69.9	2.4
		104	63.7	72.3	4.4
	75	113	71.7	73.9	4.2
		114	70.7	73.3	3.9
	210	105	63.0	67.4	3.7
		106	61.4	67.1	4.2

TABLE 7

TENSILE PROPERTIES OF FINE-GRAINED 7075-T6 ALUMINUM ALLOY IN VARIOUS MEDIA

Test Medium	Test Temp, °F	Spec. No.	Yield Strength (0.2% Offset), ksi	Ultimate Tensile Strength, ksi	Elong., (in 2 in.) %
			Ground Surface		
Air	75	13	71.6	79.1	9.1
		14	72.5	80.8	9.0
Water	32	17	71.3	79.4	8.4
		18	67.4	79.6	8.6
	75	15	71.9	79.6	7.1
		16	71.1	79.1	6.7
	210	19	65.6	70.2	9.2
		20	66.4	69.8	9.6
ASTM Sea Water	32	23	72.4	82.7	7.9
		24	74.3	82.7	7.6
	75	21	73.1	80.4	7.7
		22	73.2	80.1	7.1
	210	25	67.5	70.4	8.4
		26	68.0	71.1	7.4
			Filmed Surface		
Air	75	31	70.6	77.9	7.1
		32	65.1	75.2	7.1
Water	32	35	73.6	82.0	8.6
		36	73.1	81.9	7.7
	75	33	71.5	80.6	7.9
		34	70.7	80.7	8.4
	210	37	60.5	72.1	8.2
		38	67.6	72.5	9.2
ASTM Sea Water	32	41	75.2	82.8	7.4
		42	72.8	82.1	8.1
	75	39	72.2	81.9	7.2
		40	70.9	81.7	7.4
		43	66.8	71.1	9.2
		44	65.7	70.3	10.4

TABLE 8

TENSILE PROPERTIES OF COARSE-GRAINED 7075-T6 ALUMINUM ALLOY IN VARIOUS MEDIA

Test Medium	Test Temp, °F	Spec. No.	Yield Strength (0.2% Offset), ksi	Ultimate Tensile Strength, ksi	Elong., (in 2 in.) %
			Ground Surface		
Air	75	83	62.5	77.6	10.9
		84	63.8	77.3	11.9
Water	32	91	63.5	78.8	11.6
		92	67.2	77.4	10.9
	75	89	61.2	74.9	10.9
		90	63.3	76.5	11.3
	210	93	62.7	70.0	12.8
		94	61.2	69.9	13.1
ASTM Sea Water	32	97	68.6	78.6	10.6
		98	67.8	79.4	11.6
	75	95	64.9	77.7	11.9
		96	65.0	77.5	10.9
	210	99	62.1	69.0	10.1
		100	62.8	68.6	5.7
			Filmed Surface		
Air	75	101	64.0	77.4	10.1
		102	64.1	76.8	10.9
Water	32	109	68.8	81.0	11.6
		110	69.6	80.6	11.7
	75	107	65.5	76.3	11.1
		108	64.9	76.6	11.3
	210	85	64.0	71.0	11.3
		111	59.3	68.6	10.6
ASTM Sea Water	32	103	69.4	80.6	11.6
		104	71.3	81.4	11.6
	75	105	69.0	80.6	11.3
		106	68.2	79.7	10.7
	210	86	63.2	70.9	7.9
		87	63.6	70.8	8.2

TABLE 9

TENSILE PROPERTIES OF FINE-GRAINED ZK-60A T5 MAGNESIUM ALLOY IN VARIOUS MEDIA

Test Medium	Test Temp, °F	Spec. No.	Yield Strength (0.2% Offset), ksi	Ultimate Tensile Strength ksi	Elong., (in 2 in.) %
			Ground Surface		
Air	75	13	40.8	48.4	8.2
		14	38.4	48.3	9.5
Water	32	17	40.0	47.6	5.0
		18	42.6	49.9	5.5
	75	15	36.4	46.1	5.4
		16	39.2	46.0	6.5
	210	19	28.5	33.0	28.0[c]
		20	28.0	33.0	30.0[c]
ASTM Sea Water	32	23	43.0	46.4	3.0[b]
		24	35.8	46.6	2.4[*b]
	75	21	41.0	43.6	2.0[c]
		22	40.4	42.6	2.7[c]
	210	25	27.6	33.5	8.9[b]
		26	27.4	33.1	8.7[b]
			Filmed Surface		
Air	75	31	39.8	47.8	9.1
		32	42.7	50.3	6.2
Water	32	35	40.6	50.3	5.0
		36	45.1	53.2	4.0
	75	33	32.3	47.2	7.1
		34	40.2	46.6	6.6
	210	37	25.5	32.3	40.0[c]
		38	27.7	32.3	32.0[c]
ASTM Sea Water	32	41	30.2	44.1	3.5[b]
		42	34.2	48.9	3.9[b]
	75	39	40.4	42.8	2.9[a]
		40	40.9	43.6	2.7[a]
	210	43	28.6	32.8	8.4[a]
		44	26.2	33.0	7.3[a]

* - Fracture at pin hole.

a - Deep cracks near fracture.

b - Small cracks near fracture.

c - Cracks throughout section exposed to medium.

TABLE 10

TENSILE PROPERTIES OF COARSE-GRAINED ZK-60A MAGNESIUM ALLOY IN VARIOUS MEDIA

Test Medium	Test Temp, °F	Spec. No.	Yield Strength (0.2% Offset), ksi	Ultimate Tensile Strength, ksi	Elong., (in 2 in.) %
			Ground Surface		
Air	75	83	34.8	44.7	5.7
		84	32.8	44.6	7.7
Water	32	91	36.6	47.2	7.1
		92	37.5	45.6	1.8
	75	89	36.3	44.2	6.1
		90	37.0	44.6	5.4
	210	93	28.8	32.0	14.8[a]
		94	25.8	29.6	20.1[a]
ASTM Sea Water	32	97	40.8	44.1	1.8
		98	41.7	45.2	2.3
	75	95	37.5	41.9	2.0
		96	40.4	41.3	2.0
	210	99	26.8	30.6	5.4
		100	26.7	29.9	6.9
			Filmed Surface		
Air	75	101	40.9	45.7	6.2
		102	42.8	45.9	5.2
Water	32	109	44.0	48.9	5.9
		110	44.4	48.6	5.4
	75	107	41.8	45.2	5.9
		108	39.8	46.8	6.2
	210	111	28.4	32.1	19.2
		112	29.6	33.3	19.8
ASTM Sea Water	32	115	43.1	47.8	1.7
		116	41.2	46.5	1.7
	75	113	38.2	41.8	2.7
		114	40.9	43.4	1.8
	210	117	27.4	33.0	5.2
		118	23.7	31.9	8.1

a - Cracks throughout section exposed to medium.

TABLE 11

TENSILE PROPERTIES OF FINE-GRAINED 17-7PH RH 950 STAINLESS STEEL IN VARIOUS MEDIA

Test Medium	Test Temp, °F	Spec. No.	Yield Strength (0.2% Offset), ksi	Ultimate Tensile Strength, ksi	Elong., (in 2 in.) %
			Ground Surface		
Air	75	16	208	212	4.1
Water	32	54	209	213	4.4
		18	201	206	1.7
	75	52	203	216	4.4
		53	214	221	3.2
	210	19	182	202	3.4
		20	188	197	1.9
ASTM Sea Water	32	23	211	222	8.7
		24	212	218	4.8
	75	21	212	215	3.1
		22	209	214	3.4
	210	25	185	202	2.1
		26	187	203	3.4
			Filmed Surface		
Air	75	31	204	213	4.1
		32	194	211	3.8
Water	32	35	207	---	3.1
		36	195	221	5.1
	75	33	201	214	5.6
		34	209	219	5.0
	210	37	194	202	1.7
		38	180	202	4.3
ASTM Sea Water	32	41	220	221	4.1
		42	212	220	7.3
	75	39	209	214	3.8
		40	202	210	4.4
	210	43	180	201	3.2
		44	196	201	1.0

TABLE 12

TENSILE PROPERTIES OF COARSE-GRAINED 17-7PH RH 950 STAINLESS STEEL IN VARIOUS MEDIA

Test Medium	Test Temp, °F	Spec. No.	Yield Strength (0.2% Offset), ksi	Ultimate Tensile Strength, ksi	Elong., (in 2 in.) %
			Ground Surface		
Air	75	83	178	181	1.3
		84	172	177	1.3
Water	32	91	180	188	0.9
		92	166	182	0.7
	75	89	176	178	0.7
		90	140	141	0.4
	210	93	--	113	0.2
		94	106	107	0.0*
ASTM Sea Water	32	97	170	177	0.5
		98	179	182	0.7
	75	95	168	168	0.4
		96	175	175	0.4
	210	99	111	113	0.2
		100	109	112	0.2
			Filmed Surface		
Air	75	101	172	176	1.1
		102	181	183	0.9
Water	32	109	179	181	0.7
		110	172	174	0.5
	75	107	181	182	0.7
		108	158	181	0.7
	210	111	--	98	0.0*
		112	109	110	0.4
ASTM Sea Water	32	103	174	183	0.7
		104	167	170	0.4
	75	87	180	180	0.4
		88	177	177	0.4
	210	105	112	113	0.2
		106	114	114	0.2

* Fractured at pin hole.

TABLE 13

TENSILE PROPERTIES OF FINE-GRAINED B-120VCA TITANIUM ALLOY IN VARIOUS MEDIA

Test Medium	Test Temp, °F	Spec. No.	Yield Strength (0.2% Offset), ksi	Ultimate Tensile Strength, ksi	Elong., (in 2 in.) %
			Ground Surface		
Air	75	83	173	192	4.6
		84	183	199	6.6
Water	32	91	198	215	3.9
		92	179	195	3.4
	75	89	176	193	4.8
		90	169	192	4.4
	210	93	161	187	4.8
		94	172	192	5.5
ASTM Sea Water	32	97	187	198	3.3
		98	194	210	5.8
	75	95	186	205	5.9
		96	201	210	2.0
	210	99	174	198	6.4
		100	164	185	6.4
			Filmed Surface		
Air	75	101	175	189	5.3
		102	180	196	5.5
Water	32	109	196	208	4.3
		110	190	---	2.5
	75	107	175	186	3.5
		108	184	198	4.6
	210	111	157	177	4.6
		112	160	183	6.1
ASTM Sea Water	32	116	192	200	2.4
	75	113	180	195	3.5
		114	191	206	4.2
	210	117	180	199	4.4
		118	178	194	3.7

TABLE 14

TENSILE PROPERTIES OF COARSE-GRAINED B-120VCA TITANIUM ALLOY IN VARIOUS MEDIA

Test Medium	Test Temp, °F	Spec. No.	Yield Strength (0.2% Offset), ksi	Ultimate Tensile Strength, ksi	Elong., (in 2 in.) %
			Ground Surface		
Air	75	13	194	210	3.5
		14	188	206	2.9
Water	32	17	193	203	3.2*
		18	185	199	2.2
	75	15	187	204	3.4
		16	175	184	0.2*
	210	19	171	191	5.1
		20	170	188	4.1
ASTM Sea Water	32	23	194	200	0.2*
		24	194	202	1.7
	75	21	194	207	2.9
		22	190	199	1.0*
	210	25	165	185	4.4
		26	161	180	4.1
			Filmed Surface		
Air	75	31	183	199	4.1
		32	169	189	4.3
Water	32	35	194	205	2.1
		36	189	202	2.2
	75	33	184	196	2.6
		34	240	240	0.0*
	210	37	151	189	5.1
		38	153	191	4.8
ASTM Sea Water	32	41	161	161	0.0*
		42	186	199	1.2
	75	39	182	190	0.9*
		40	186	195	2.1
		43	149	150	0.0*
		44	168	188	3.4

* Fractured through pin hole.

TABLE 15

POST-EXPOSURE TENSILE PROPERTIES OF FINE-GRAINED 2024-T86 ALUMINUM ALLOY SPECIMENS WHICH SURVIVED SUSTAINED LOAD TEST

Exposure Medium (Load 90% YS, 240 hr)	Spec. No.	Yield Strength (0.2% Offset), ksi	Ultimate Tensile Strength, ksi	Elong., (in 2 in.) %
		Ground Surface		
No exposure*		72.4	75.9	4.4
Air	1	73.6	76.2	4.4
	4	73.2	75.9	3.8
Water	2	71.8	74.6	3.4
	5	69.6	74.7	3.4
ASTM Sea Water	3	74.1	75.6	1.8
	6	71.2	72.0	0
		Filmed Surface		
No exposure*		71.6	75.5	3.7
Air	7	72.9	76.0	3.5
	8	74.2	76.4	3.4+
Water	9	75.1	77.1	4.2
	10	72.5	75.2	4.0
ASTM Sea Water	11	72.9	75.3	3.5
	12	73.2	75.9	3.4

* Average for two specimens.

\+ Fractured at pin hole.

TABLE 16

POST-EXPOSURE TENSILE PROPERTIES OF COARSE GRAINED 2024-T86 ALUMINUM ALLOY SPECIMENS WHICH SURVIVED SUSTAINED LOAD TESTS

Exposure Medium (Load 90% YS, 240 hr)	Spec. No.	Yield Strength (0.2% Offset), ksi	Ultimate Tensile Strength, ksi	Elong., (in 2 in.) %
		Ground Surface		
No exposure*		65.4	69.7	4.0
Air	85	67.7	72.0	4.0
	86	69.5	72.5	4.2
Water	87	70.4	73.1	4.2
	88	67.7	72.5	2.7
ASTM Sea Water	117	68.3	71.9	4.0
		Filmed Surface		
No exposure*		67.1	71.1	4.5
Air	77	65.9	71.9	3.0
	78	69.9	72.4	3.5
Water	79	70.7	73.0	1.8
	80	70.2	72.4	3.9
ASTM Sea Water	81	67.0	71.9	2.4
	82	69.0	71.0	1.8

* Average for two specimens.

TABLE 17

POST-EXPOSURE TENSILE PROPERTIES OF FINE GRAINED 7075-T6 ALUMINUM ALLOY SPECIMENS WHICH SURVIVED SUSTAINED LOAD TESTS

Exposure Medium (Load 90% YS, 240 hr)	Spec. No.	Yield Strength (0.2% Offset), ksi	Ultimate Tensile Strength ksi	Elong., (in 2 in.) %
		Ground Surface		
No exposure*		72.0	80.0	9.0
Air	1	73.6	79.0	8.6
	4	71.7	78.2	7.0
Water	2	73.0	79.8	8.0
	5	73.4	79.8	6.7
ASTM Sea Water	3	72.8	79.5	8.0
	6	72.8	79.3	9.0
		Filmed Surface		
No exposure*		67.8	78.8	7.1
Air	7	71.8	79.5	7.1
	8	70.8	78.2	7.4
Water	9	72.6	79.4	8.1
	10	72.2	79.7	6.7
ASTM Sea Water	11	73.7	80.0	7.1
	12	73.3	80.0	7.9

* Average for two specimens.

TABLE 18

POST-EXPOSURE TENSILE PROPERTIES OF COARSE-GRAINED 7075-T6 ALUMINUM ALLOY SPECIMENS WHICH SURVIVED SUSTAINED LOAD TESTS

Exposure Medium (Load 118% YS, 240 hr)	Spec. No.	Yield Strength (0.2% Offset), ksi	Ultimate Tensile Strength, ksi	Elong., (in 2 in.) %
		Ground Surface		
No exposure*		63.2	77.4	11.6
Air	71	72.7	80.2	10.2
	72	71.0	79.8	10.2
Water	73	71.9	80.3	11.1
	74	72.6	79.7	10.6
ASTM Sea Water	75	72.1	79.9	10.4
	76	69.8	77.2	4.7
		Filmed Surface		
No exposure*		64.0	77.1	10.4
Air	77	72.8	79.6	8.1
	78	72.6	80.0	10.2
Water	79	70.5	79.9	10.6
	80	71.5	80.1	10.7
ASTM Sea Water+	81	69.3	79.1	10.6
	82	72.9	79.6	10.9

---

* Average for two specimens.

\+ 90% yield strength.

TABLE 19

POST-EXPOSURE TENSILE PROPERTIES OF FINE GRAINED ZK-60A MAGNESIUM ALLOY SPECIMENS WHICH SURVIVED SUSTAINED LOAD TESTS

Exposure Medium (Load 90% YS, 240 hr)	Spec. No.	Yield Strength (0.2% Offset), ksi	Ultimate Tensile Strength, ksi	Elong., (in 2 in.) %	Failed During Exposure	
					Time, hr	Location
			Ground Surface			
No exposure*		39.6	48.4	8.8		
Air	1	36.1	45.8	5.7		
	6	46.0	49.2	3.4		
Water	2	----	----	---	10.7	Base of cup
	5	----	----	---	24.4	Interface
ASTM Sea Water	3	----	----	---	0.1+	Pin hole
	4	----	----	---	<0.1	Interface
			Filmed Surface			
No exposure*		41.2	49.0	7.7		
Air	9	46.5	49.2	2.0		
	10	45.4	48.4	5.2		
Water	7	----	----	---	2.0	Gage length
	8	----	----	---	0.2	Gage length
ASTM Sea Water	11	----	----	---	0.02	Interface
	12	----	----	---	0.02	Gage length

* Average for two specimens.

\+ Fractured at pin hole.

TABLE 20

POST-EXPOSURE TENSILE PROPERTIES OF COARSE-GRAINED ZK-60A MAGNESIUM ALLOY SPECIMENS WHICH SURVIVED SUSTAINED LOAD TESTS

Exposure Medium (240 hr)	Spec. No.	Yield Strength (0.2% Offset), ksi	Ultimate Tensile Strength, ksi	Elong., (in 2 in.) %	Failed During Exposure	
					Time, hr	Location
		Ground Surface (Load 106% YS)				
No exposure*		33.8	44.6	6.7		
Air	72	46.7	46.7	2.8		
Water	73	----	----	---	27.2	1/4 in. above interface
	74	----	----	---	27.1	Interface
ASTM Sea Water	75	----	----	---	0.5	Bottom pin hole
	76	----	----	---	0.27	Gage length
		Filmed Surface (Load 90% YS)				
No exposure*		41.8	45.8	5.7		
Air	77	41.1	46.5	5.9		
	78	36.6	47.1	6.2		
Water	79	39.6	44.7	0.3+		
	80	----	----	---	5.6	Upper pin hole
ASTM Sea Water	81	----	----	---	0.2	Top fillet
	82	----	----	---	0.2	Interface

* Average for two specimens.

\+ Fractured at pin hole.

Note: Pin holes of filmed specimens were too small and were opened up after application of chromate coating. Therefore, surfaces of pin holes were not chromated.

TABLE 21

POST-EXPOSURE TENSILE PROPERTIES OF FINE-GRAINED 17-7PH STAINLESS STEEL SPECIMENS WHICH SURVIVED SUSTAINED LOAD TESTS

Exposure Medium (Load 90% YS, 240 hr)	Spec. No.	Yield Strength (0.2% Offset), ksi	Ultimate Tensile Strength, ksi	Elong., (in 2 in.) %	Failed During Exposure	
					Time, hr	Location
			Ground Surface			
No exposure*		208	212	4.1		
Air	4	184	215	3.6		
	5	210	217	5.0		
Water	6	---	---	---	19.7	Interface
	7	213	218	4.4		
ASTM Sea Water	8	---	---	---	16.7	Base of cup
	9	---	---	---	8.2	Top pin hole
			Filmed Surface			
No exposure*		199	212	3.9		
Air	10	213	219	3.8		
	11	209	213	4.8		
Water	12	209	215	3.2		
	49	212	217	4.1		
ASTM Sea Water	50	206	210	3.4		
	51	---	---	---	26.6	Interface

* Average for two specimens.

TABLE 22

POST-EXPOSURE TENSILE PROPERTIES OF COARSE-GRAINED 17-7PH STAINLESS STEEL SPECIMENS WHICH SURVIVED SUSTAINED LOAD TESTS

Exposure Medium (Load 90% YS, 240 hr)	Spec. No.	Yield Strength (0.2% Offset), ksi	Ultimate Tensile Strength, ksi	Elong., (in 2 in.) %	Failed During Exposure Time, hr	Failed During Exposure Location
			Ground Surface			
No exposure*		175	179	1.3		
Air	71	172	172	0.2		
	72	149	154	0.2		
Water	73	---	---	---	0.45	Base of cup
	74	---	---	---	0.50	Base of cup+
ASTM Sea Water	75	---	---	---	0.20	Interface
	76	---	---	---	0.10	Interface
			Filmed Surface			
No exposure		176	180	1.0		
Air	77	169	178	0.8		
	81	176	184	0.7		
Water	79	---	---	---	0.10	Lower pin hole
	80	---	---	---	0.05	Base of cup
ASTM Sea Water	78	---	---	---	0.05	Top of gage length
	82	---	---	---	0.03	Base of cup

* Average for two specimens

\+ Leak

TABLE 23

POST-EXPOSURE TENSILE PROPERTIES OF FINE-GRAINED B-120VCA TITANIUM ALLOY SPECIMENS WHICH SURVIVED SUSTAINED LOAD TESTS

Exposure Medium (Load 90% YS, 240 hr)	Spec. No.	Yield Strength (0.2% Offset), ksi	Ultimate Tensile Strength, ksi	Elong., (in 2 in.) %
		Ground Surface		
No exposure*		178	196	5.6
Air	71	164	193	3.8
	72	181	198	3.9
Water	73	188	201	5.2
	74	183	198	6.5
ASTM Sea Water	75	142	179	1.7
	76	178	194	4.5
		Filmed Surface		
No exposure*		178	192	5.4
Air	77	184	199	5.1
	78	214	214	1.8
Water	79	181	196	7.4
	80	190	204	3.9
ASTM Sea Water	81	194	205	3.0
	82	175	181	3.0

* Average for two specimens.

TABLE 24

POST-EXPOSURE TENSILE PROPERTIES OF COARSE-GRAINED B-120VCA TITANIUM ALLOY SPECIMENS WHICH SURVIVED SUSTAINED LOAD TESTS

Exposure Medium (Load 90% YS, 240 hr)	Spec. No.	Yield Strength (0.2% Offset), ksi	Ultimate Tensile Strength, ksi	Elong., (in 2 in.) %	Failed During Exposure	
					Time, hr	Location
			Ground Surface			
No exposure*		191	208	3.2		
Air	3	193	204	2.7+		
Water	4	193	194	0.0+		
	5	191	203	2.1		
ASTM Sea Water	6	---	---	--	6.3	Pin hole**
	7	---	---	--	0.02	Pin hole
			Filmed Surface			
No exposure*		176	194	4.1		
Air	8	---	120	0.0+		
Water	9	189	192	0.0+		
	10	189	200	3.2		
ASTM Sea Water	11	195	205	3.6		
	12	---	---	---	55.5	Pin hole**

* Average for two specimens

** Leak

\+ Tensile test fracture through pin hole.

TABLE 25

EFFECT OF SURFACE CONTAMINATION OF B-120VCA TITANIUM ALLOY ON SUSCEPTIBILITY TO STRESS-CORROSION CRACKING

		Post-Exposure Tensile Properties[*]			Failed During Exposure	
Spec. No.	Surface Removal by Pickling, mils	YS, ksi	UTS, ksi	Elong., (in 2 in.) %	Time, hr	Location
S1	None	179	180	0.6		
S3	None	---	---	---	On loading	Interface
S10	None	---	---	---	0.017	Interface
S11[+]	None	191	197	0.9		
S13	0.25[a]	193	205	4.9		
S14	0.15[a]	195	208	4.0		
S4	0.25	193	205	3.5		
S5	0.25	194	197	0.8		
S6	1	190	193	1.6		
S7	1	193	197	1.2		
S8	2	186	199	4.9		
S9	2	---	190	0.9		

[*] Exposure time was 240 hr except where indicated to be otherwise.

[+] Exposure stress 70% of yield strength while all others stressed to 90% of yield strength.

[a] Discoloration only.

TABLE 26

EFFECT OF ION SPECIES ON STRESS CORROSION CRACKING IN AQUEOUS MEDIUM

Salt Medium (0.6N)	Failure (Load 90% Yield Strength) Time (hr)	Failure (Load 90% Yield Strength) Location	Post-Exposure Tensile Properties of 96 hr Survivors YS (ksi)	UTS (ksi)	Elong. (in 2 in.) (%)
			ZK-60A		
NaCl	0.05	Upper pin hole	---	---	---
	0.05	Upper pin hole	---	---	---
KCl	0.03	Interface	---	---	---
	2.3	Base of cup	---	---	---
CsCl	0.03	Base of cup	---	---	---
	0.03	Base of cup	---	---	---
NaBr	0.07	Base of cup	---	---	---
	0.08	Lower pin hole	---	---	---
NaI	0.07	Upper pin hole	---	---	---
	0.12	Upper pin hole	---	---	---
			17-7 PH RH 950		
NaCl	31.0	Base of cup	---	---	---
	24.2	Base of cup	---	---	---
KCl	57.0	Top fillet	---	---	---
	19.2	Lower pin hole	---	---	---
CsCl	NF 142*		207	219	3.6
	NF 142		215	217	3.1
NaBr	NF 96		201	216	4.6
	NF 96		214	217	5.1
NaI	NF 120		216	219	4.8
	NF 120		197	217	5.8
			B-120VCA		
NaCl	NF 175		195	206	3.3
	NF 120		196	208	4.2
KCl	NF 96		198	211	3.7
	NF 96		194	207	5.2
CsCl	NF 142		193	203	3.8
	NF 142		190	202	4.1
NaBr	NF 96		202	206	3.7
	NF 96		193	205	4.5
NaI	NF 120		192	205	4.2
	NF 120		194	205	4.3

* NF - no failure in the time given.

TABLE 27

TENSILE PROPERTIES OF LONGITUDINAL GRAIN-REFINED WELDMENTS IN B-120VCA TITANIUM ALLOY

Welding Conditions	Static Load Exposure Medium (110,000 psi, 96 hr)	Test Medium	Tensile Properties YS(ksi)	Tensile Properties UTS(ksi)	Tensile Properties Elong.(%)	Time to Failure, min
Normal	No exposure	Air	184	190	1.2	----
	No exposure	Air	178	186	1.6	----
	No exposure	Salt solution	---	147	0.4	----
	Air*	Air	199	199	1.0	NF++
	Salt solution**	Air	---	---	---	0.5
			---	---	---	0.5
Magnetic stir 10 cps, 300 gauss+	No exposure	Air	166	175	1.9	----
	No exposure	Air	171	174	1.2	----
	No exposure	Salt solution	---	120	0.6	----
	Air*	Air	166	174	1.2	NF++
	Salt solution	Air	---	---	---	0.5
			---	---	---	1
Magnetic stir 2 cps, 250 gauss	No exposure	Air	159	181	1.8	----
	No exposure	Air	174	181	2.6	----
	No exposure	Salt solution	---	136	0.3	----
	Air*	Air	168	184	2.7	NF++
	Salt solution**	Air	---	---	---	0.5
			---	---	---	1

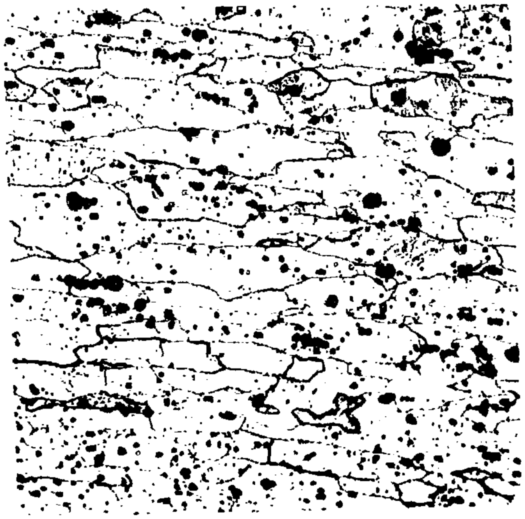
---

* Static load of 150,000 psi, i.e., 90% of the lowest yield strength in air of the three groups.

** Static load of 110,000 psi, i.e., 90% of the lowest fracture strength of the three groups for tensile tests in ASTM sea water.

\+ Measured at weld area under conditions of no welding.

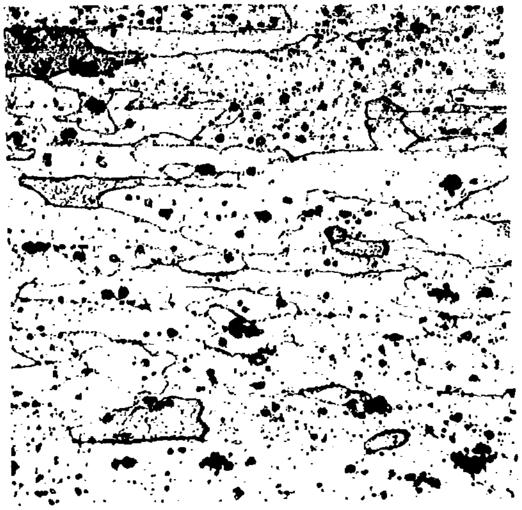
++ No failure in 96 hr.



Neg. No. 21876 X 250

Fig. 1

2024-T86, as-received.

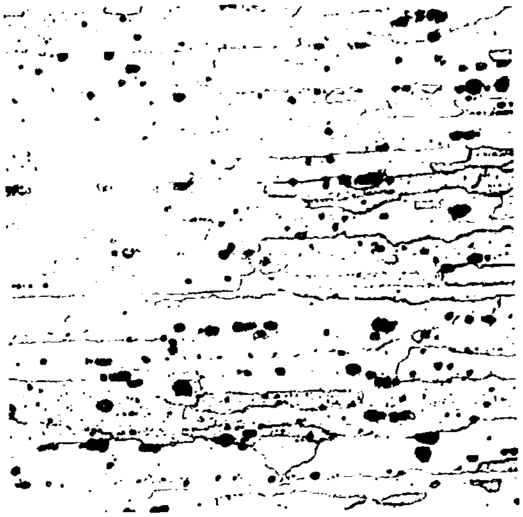


Neg. No. 21875 X 250

Fig. 2

2024-T86, grain coarsening anneal of 900°F-30 hr-WQ, cold rolled 6%, aged 375°F-8 hr-AC.

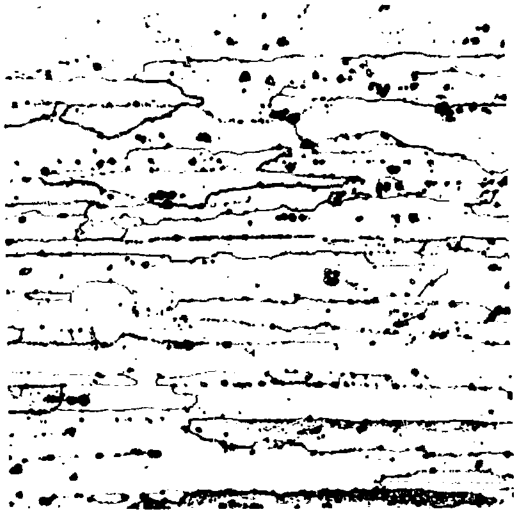
Etchant: 20% conc. HF, 20% conc. HNO_3, balance glycerine.



Neg. No. 21878 X 250

Fig. 3

7075-T6, as-received.

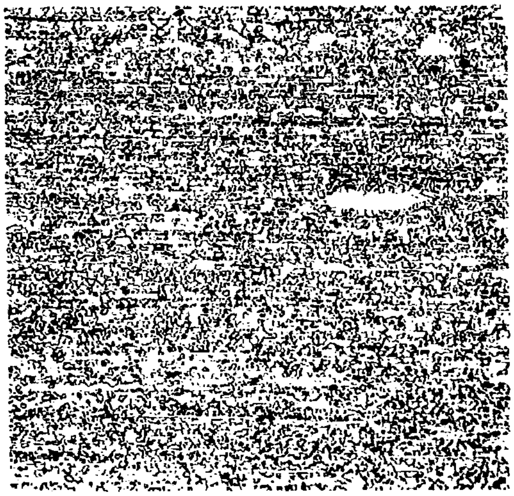


Neg. No. 21877 X 250

Fig. 4

7075-T6, grain coarsening anneal of 900°F-30 hr-WQ, aged 250°F-24 hr-AC.

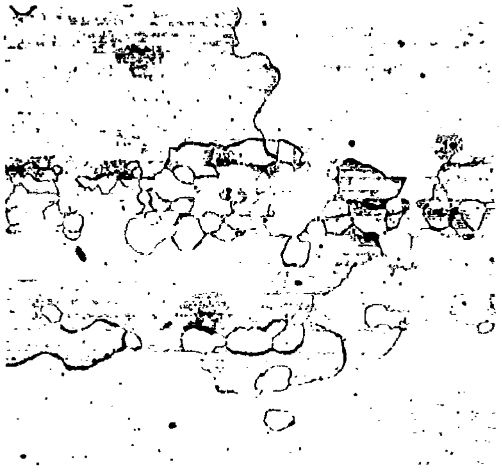
Etchant: Keller's



Neg. No. 21874 X 250

Fig. 5

ZK-60A-T5, as-received.



Neg. No. 21873 X 250

Fig. 6

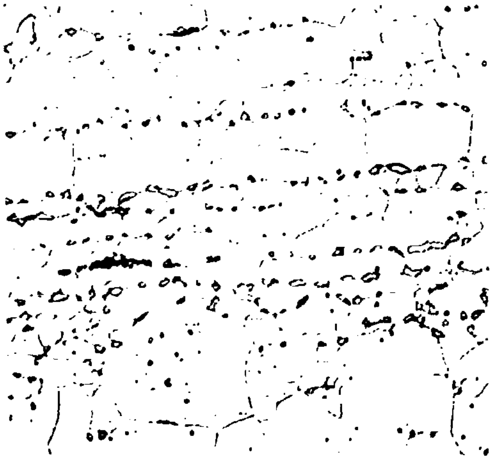
ZK-60A, grain coarsening anneal of 900°F-4 hr-WQ, aged 275°F-48 hr-AC.

Etchant: 60% ethylene glycol, 20% glacial acetic acid, 1% conc. HNO_3, balance distilled water.

Neg. No. 21872 X 250

Fig. 7

17-7 PH as-received plus RH 950 treatment: 1750°F-10 min-AC, -100°F-8hr, 950°F-1hr-AC.



Neg. No. 21871 X 250

Fig. 8

17-7 PH, grain coarsening anneal of 2000°F-4hr-AC, RH 950 treatment: 1750°F-10 min-AC, -100°F-8hr, 950°F-1hr-AC.

Etchant: electrolytic bath of 5% chromic acid.

Neg. No. 21869 X 250

Fig. 9

B-120VCA, as-received plus 900°F-40hr-AC.

Neg. No. 21870 X 250

Fig. 10

B-120VCA, grain refinement treatment of 50% cold roll, 1325°F-1hr-AC, 900°F-48hr-AC.

Etchant: 20% conc. HF, 20% conc. HNO_3, balance glycerine.

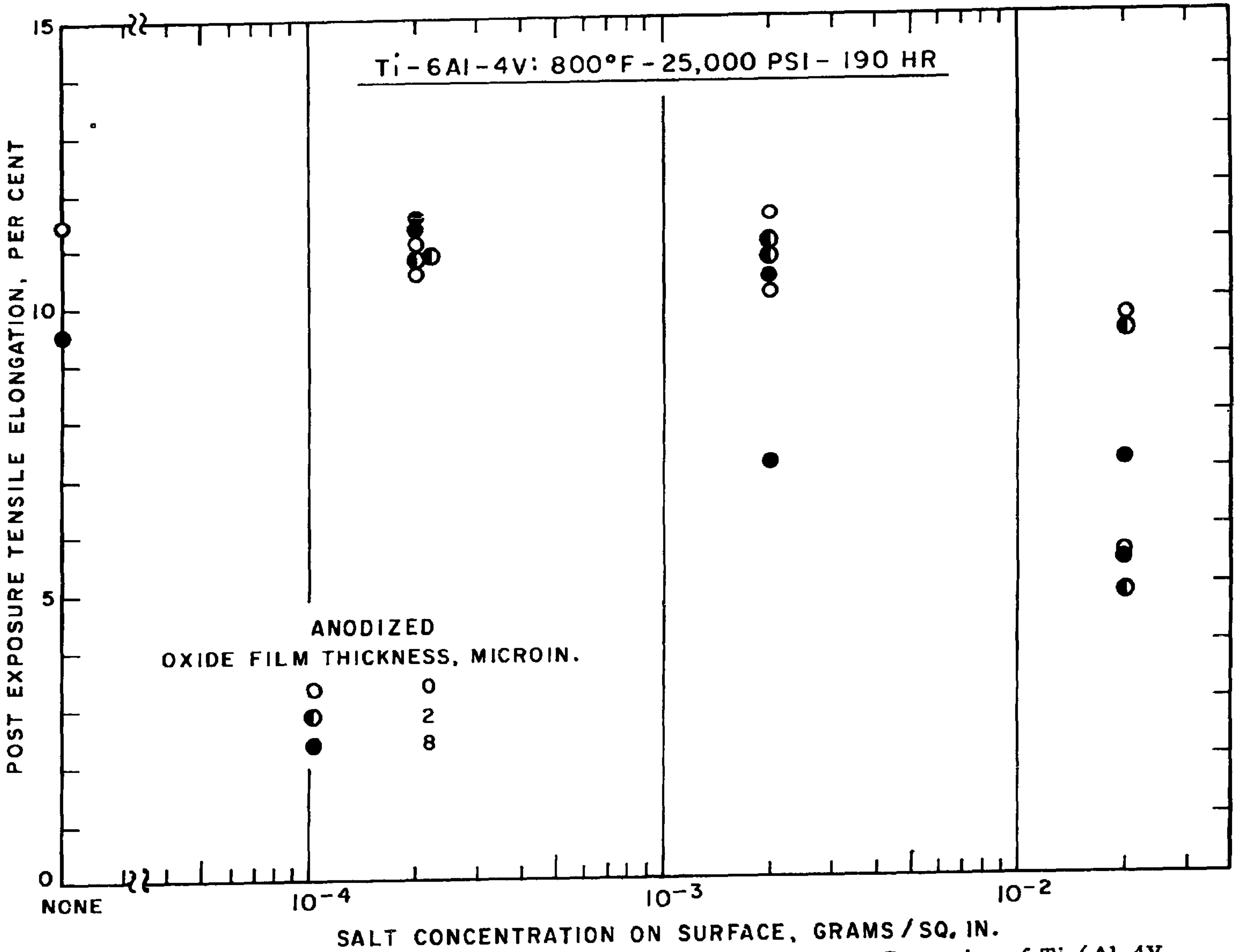


Fig. 11 - Effect of Anodizing and of Salt Concentration on the Stress Corrosion of Ti-6Al-4V Titanium Alloy at 800°F.

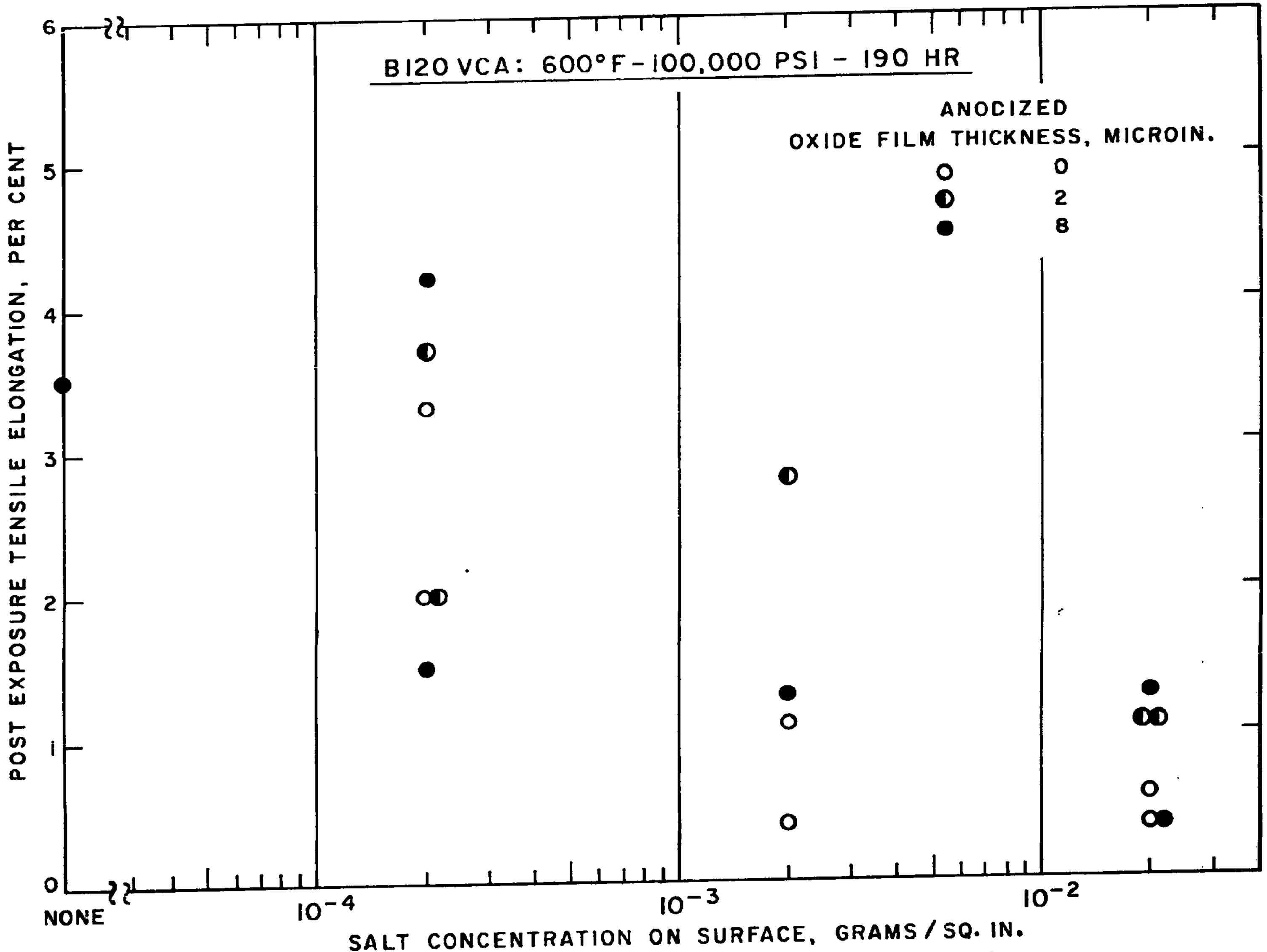


Figure 12 - Effect of Anodizing and Salt Concentration on the Stress Corrosion Of B-120 VCA Titanium Alloy at 600°F.

Neg. No. 21866 X 250

Fig. 13

B-120VCA specimen No. C3, stress-corrosion crack due to exposure to 0.02 g/sq in. ASTM sea salt concentration at 600°F under 100,000 psi stress for 190 hr.

Neg. No. 21868 X 250

Fig. 14

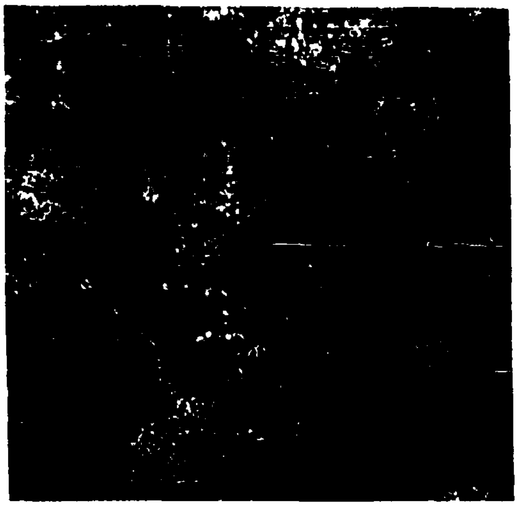
B-120VCA specimen No. C6 with 2 micro-inch anodized film. Stress-corrosion cracks due to exposure to 0.02 g/sq in. ASTM sea salt concentration at 600°F under 100,000 psi stress for 190 hr.

Etchant: 20% conc. HF, 20% conc. HNO_3, balance glycerine.

Neg. No. 21879 X 250

Fig. 15

Surface of as-received B-120VCA showing grain boundary depressions.



Neg. No. 21880 X 250

Fig. 16

Surface of grain-refined B-120VCA showing that grain boundary depressions are much less marked than in as-received material.

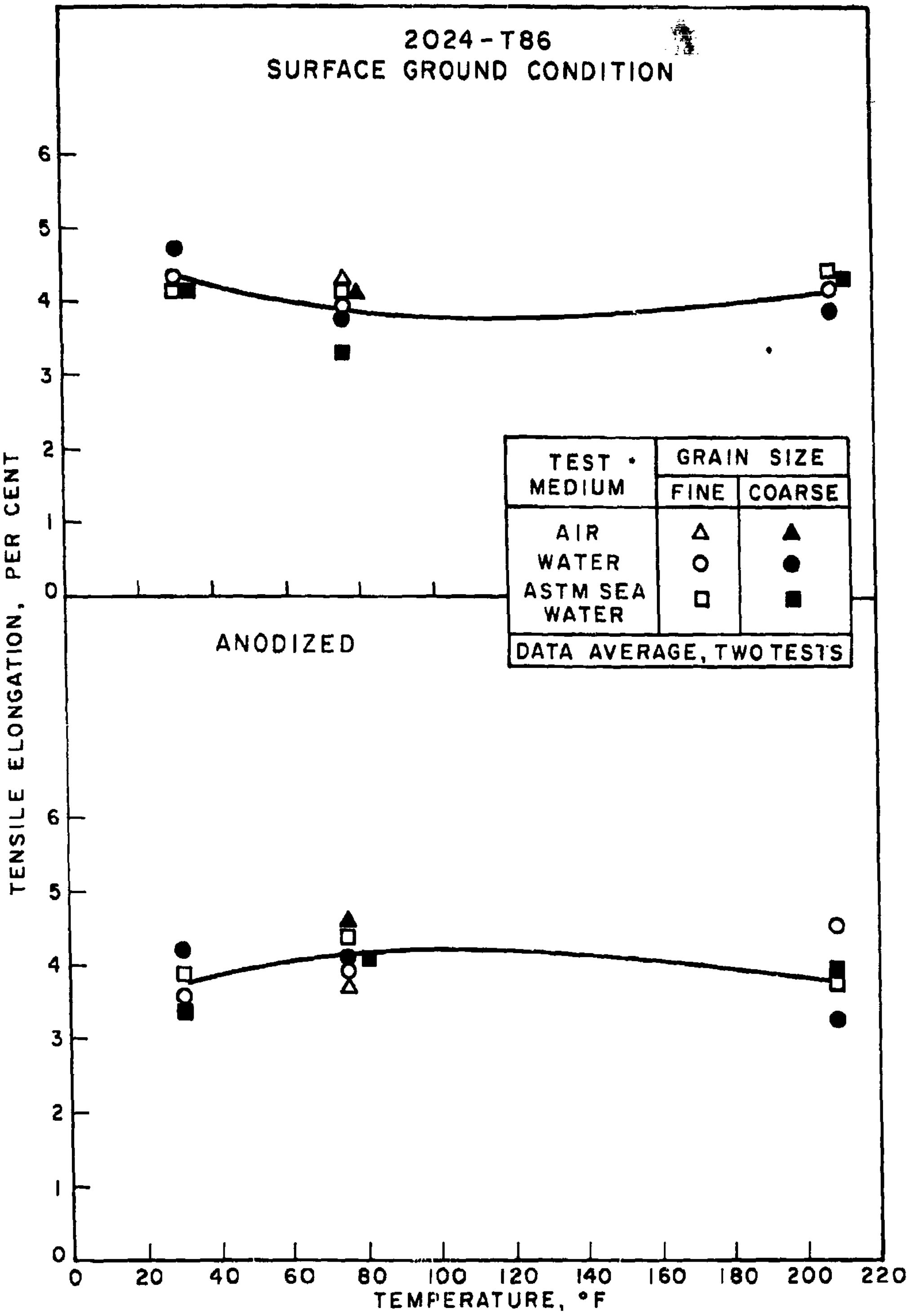


Fig. 17 - Tensile Elongation of 2024-T86 Aluminum Alloy for Tests in Various Media.

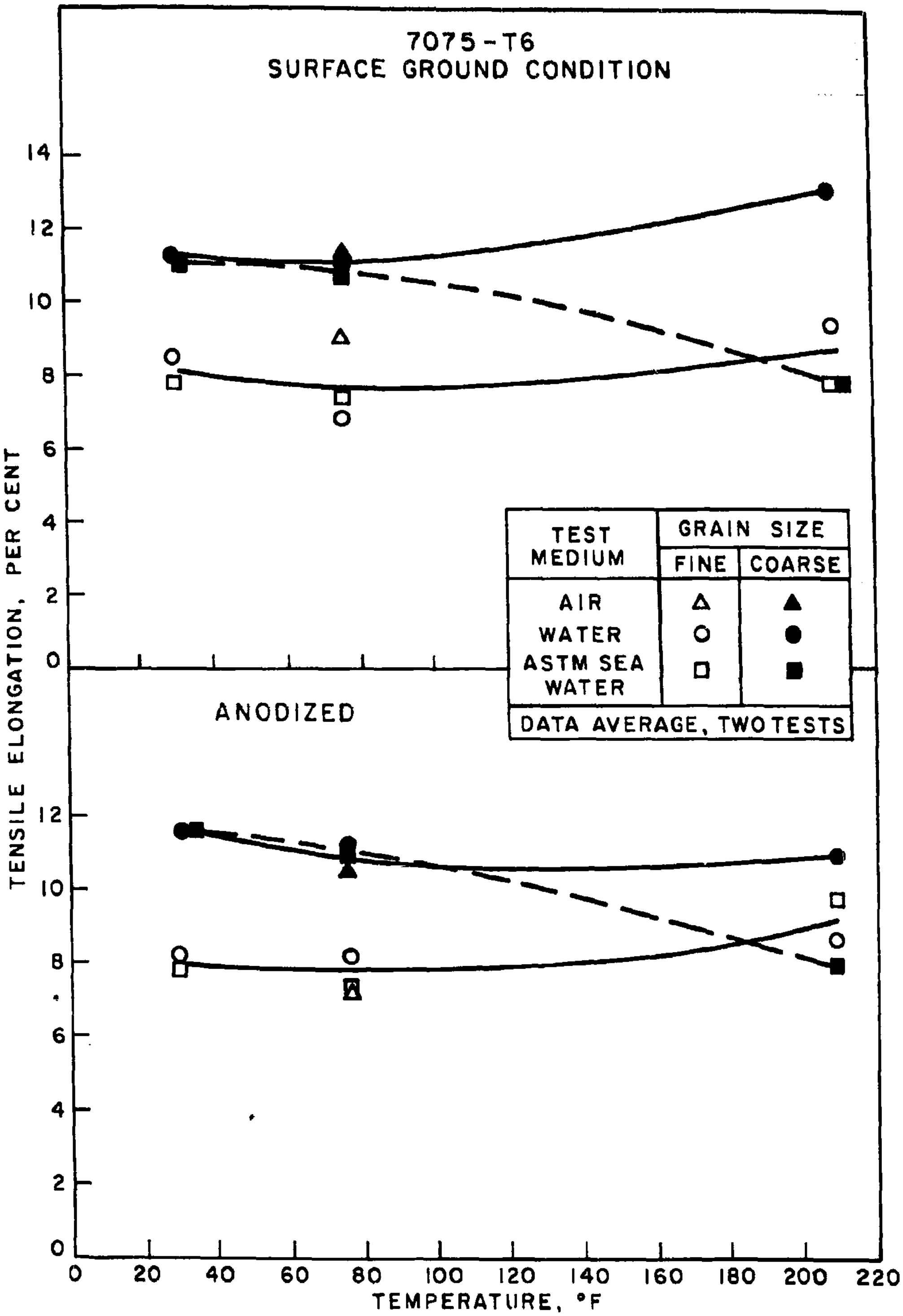


Fig. 18 - Tensile Elongation of 7075-T6 Aluminum Alloy for Tests in Various Media.

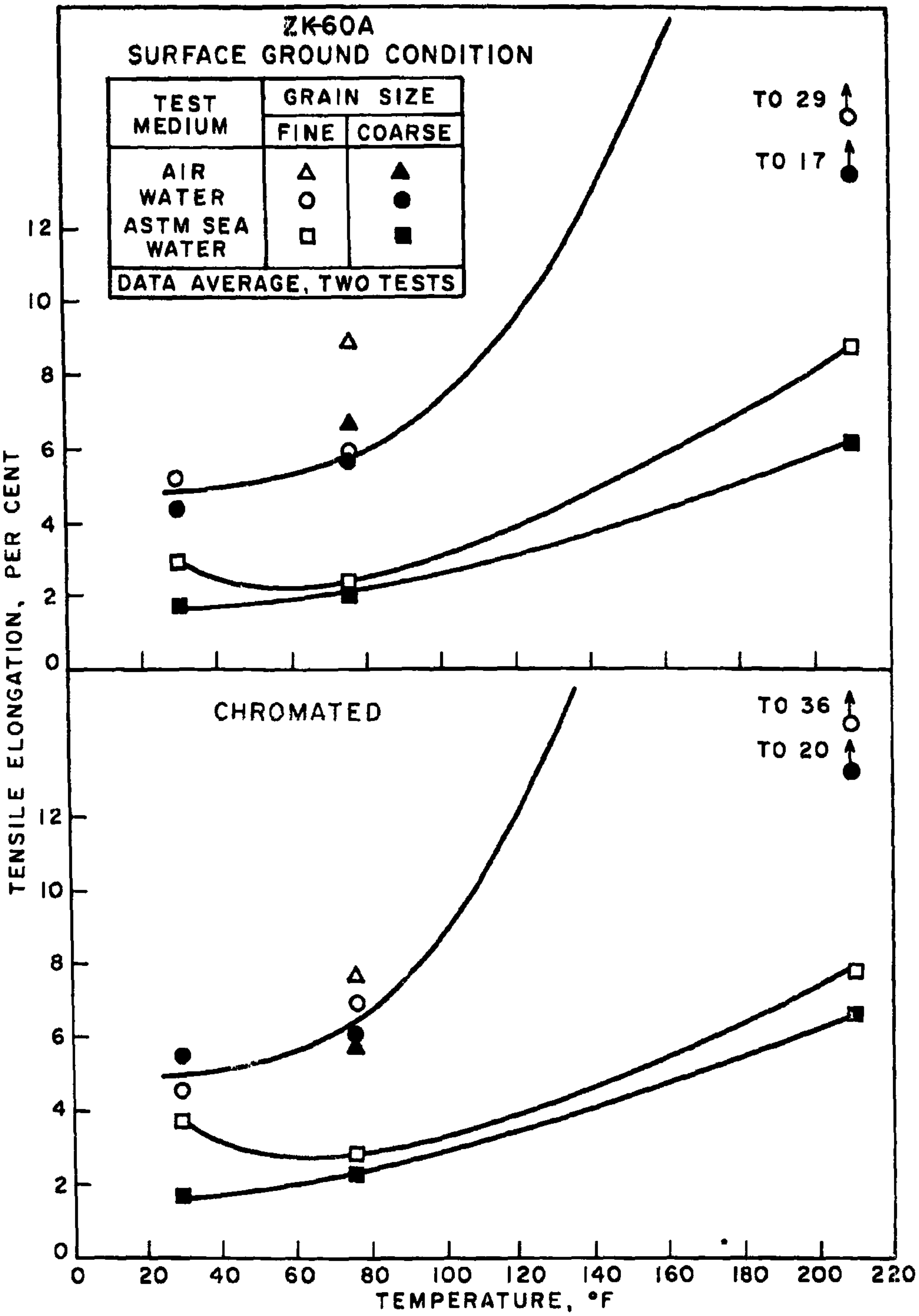


Fig. 19 - Tensile Elongation of ZK-60A Magnesium Alloy for Tests in Various Media.

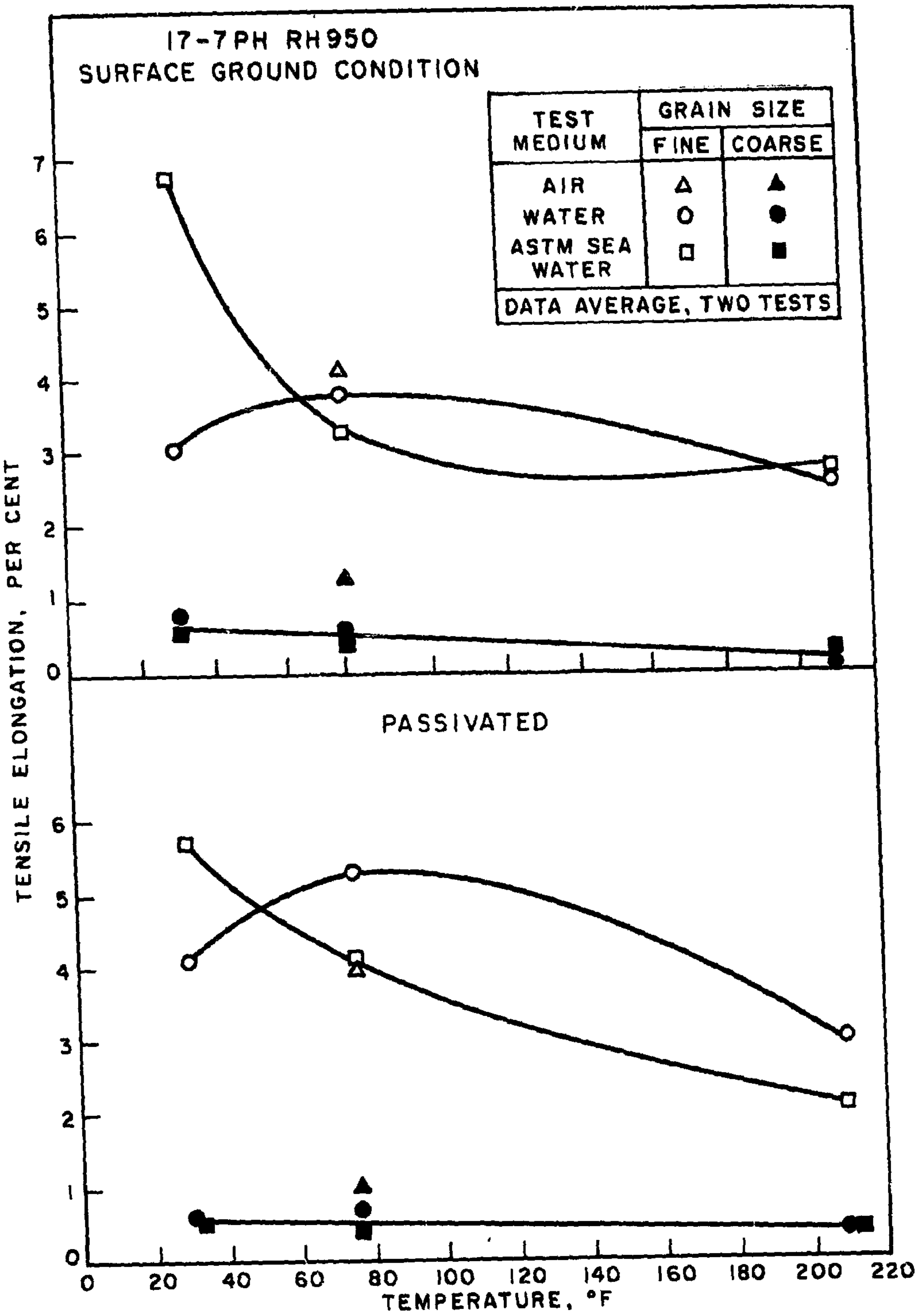


Fig. 20 - Tensile Elongation of 17-7PH RH 950 Stainless Steel for Tests in Various Media.

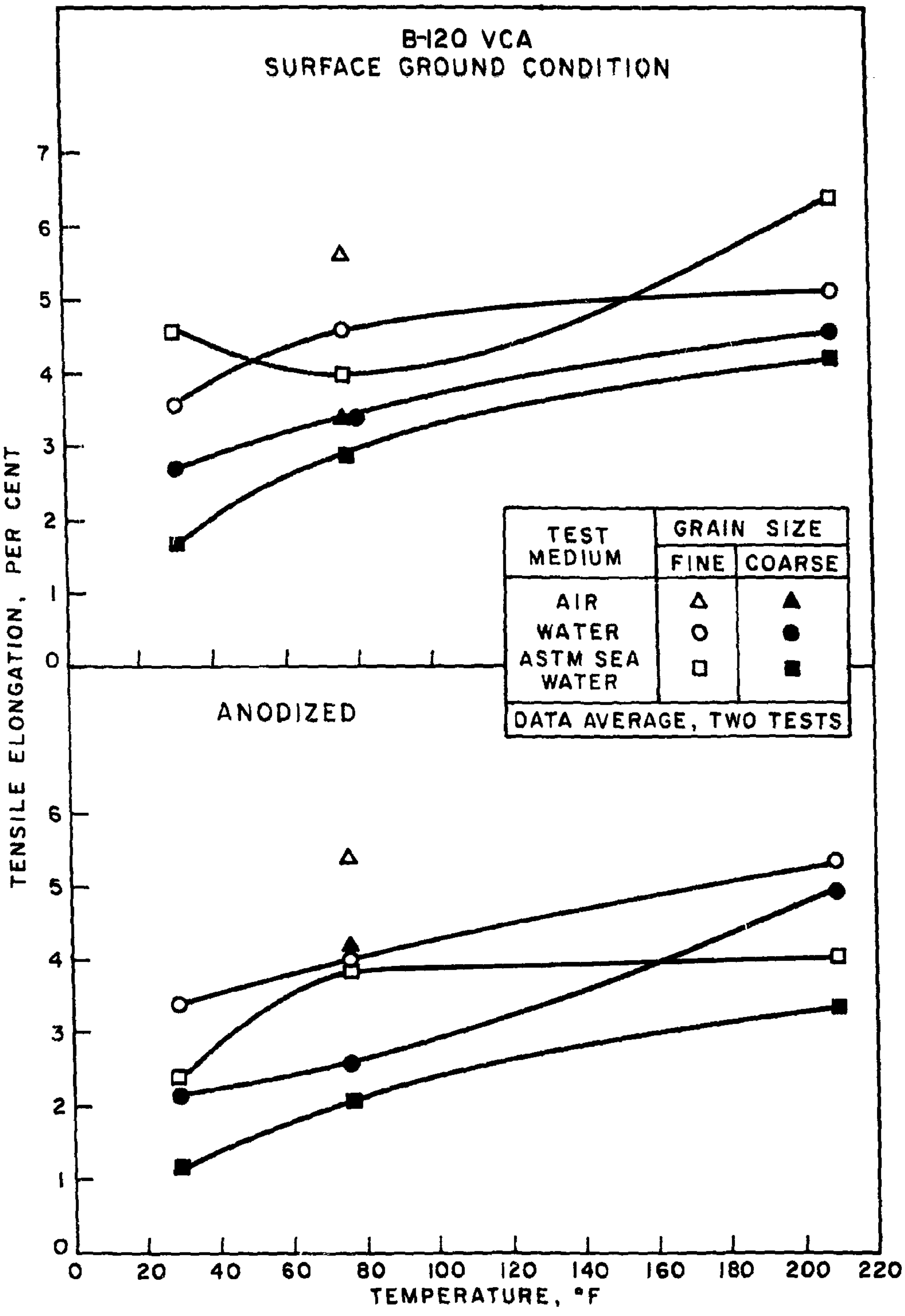


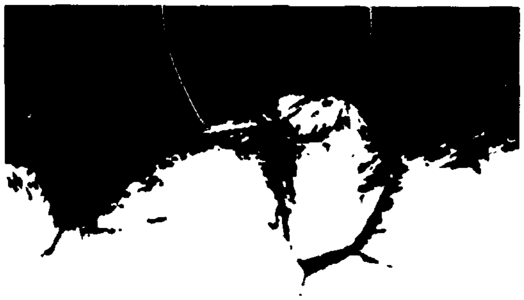
Fig. 21 - Tensile Elongation of B-120 VCA Titanium Alloy for Tests in Various Media.

Neg. No. 21867 X 250

Fig. 22

ZK-60A chromated specimen tensile tested in air. Crack initiated at a pit produced by the chromating process.

Etchant: 60% ethylene glycol, 20% glacial acetic acid, 1% conc. HNO_3, balance distilled water.



Neg. No. 21799 X 500

Fig. 23

17-7PH, apparently grain boundary oxidation which occurred during grain coarsening anneal of 2000°F-4 hr in air. Unetched.

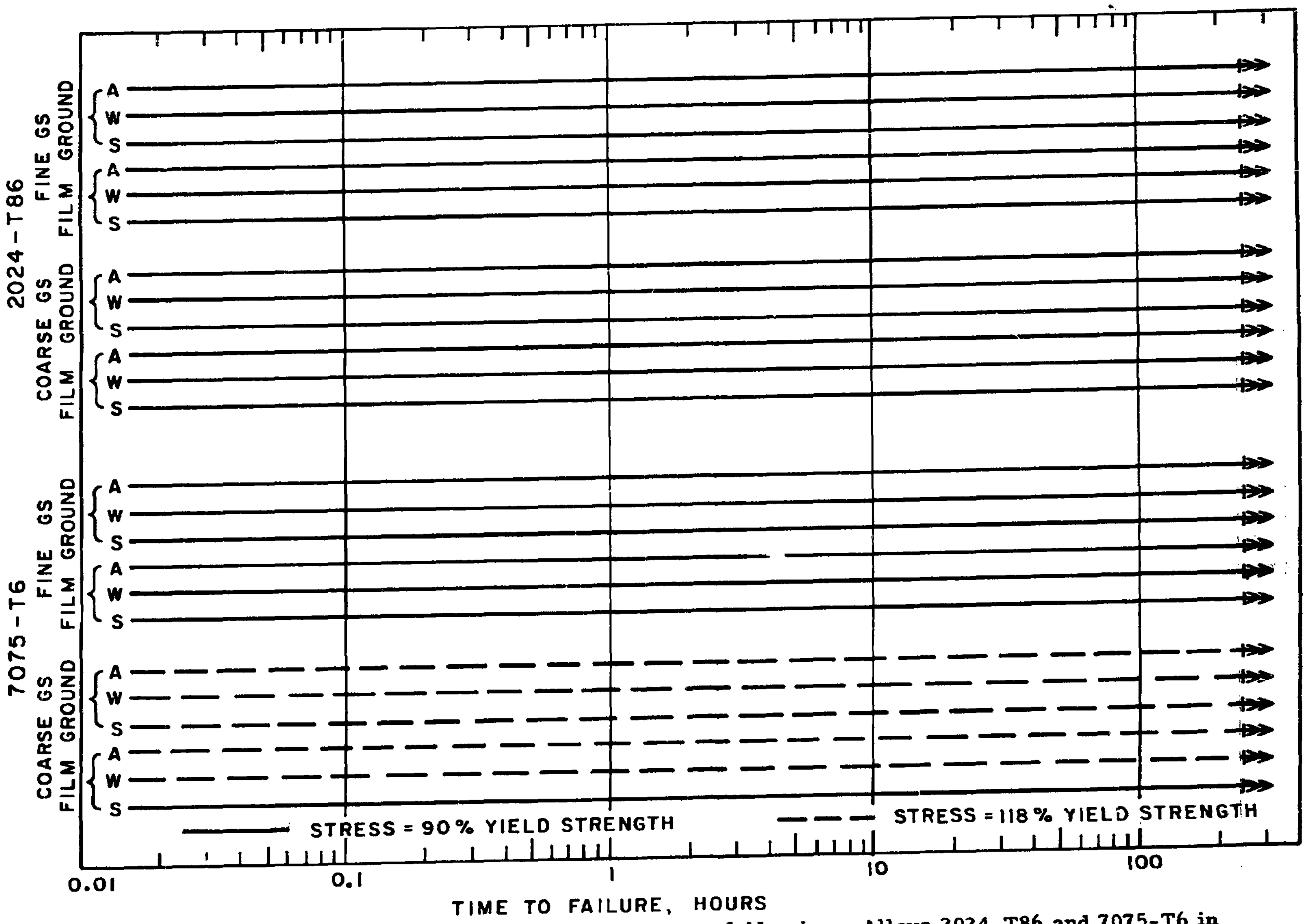


Fig. 24 - Summary of Results for Static Load Exposure of Aluminum Alloys 2024-T86 and 7075-T6 in Media of Air, Water, and ASTM Sea Water

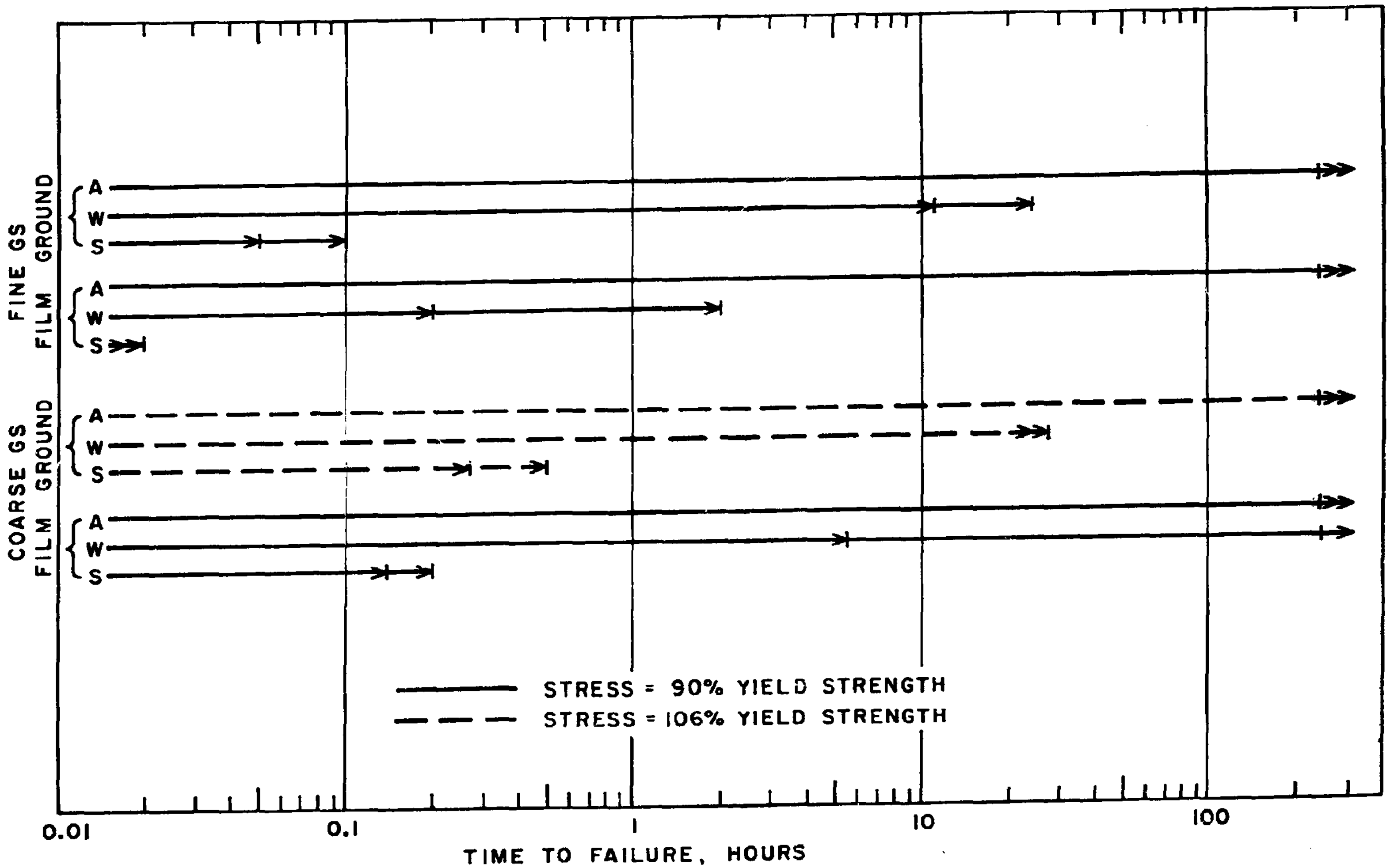


Fig. 25 - Summary of Results for Static Load Exposure of ZK-60A in Media of Air, Water, and ASTM Sea Water

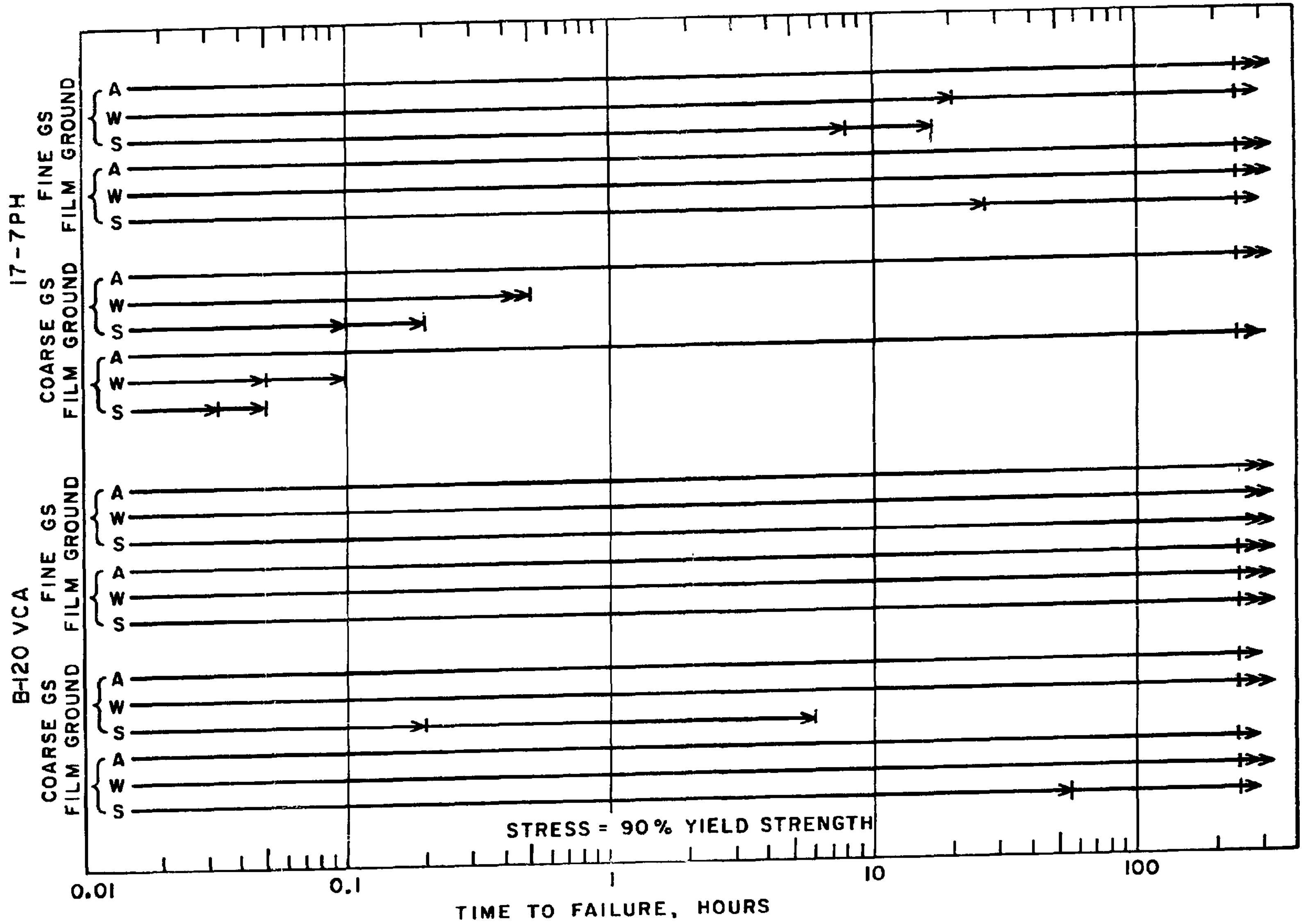


Fig. 26 - Summary of Results for Static Load Exposure of 17-7PH and B-120 VCA in Media of Air, Water, and ASTM Sea Water

Neg. No. 21864 X 250

Fig. 27

ZK-60A stress-corrosion cracks in fine-grain chromated specimen which failed in ASTM sea water under a load of 90% of the yield strength in about 1 min.

Etchant: 60% ethylene glycol, 20 glacial acetic acid, 1% conc. HNO_3, balance distilled water.

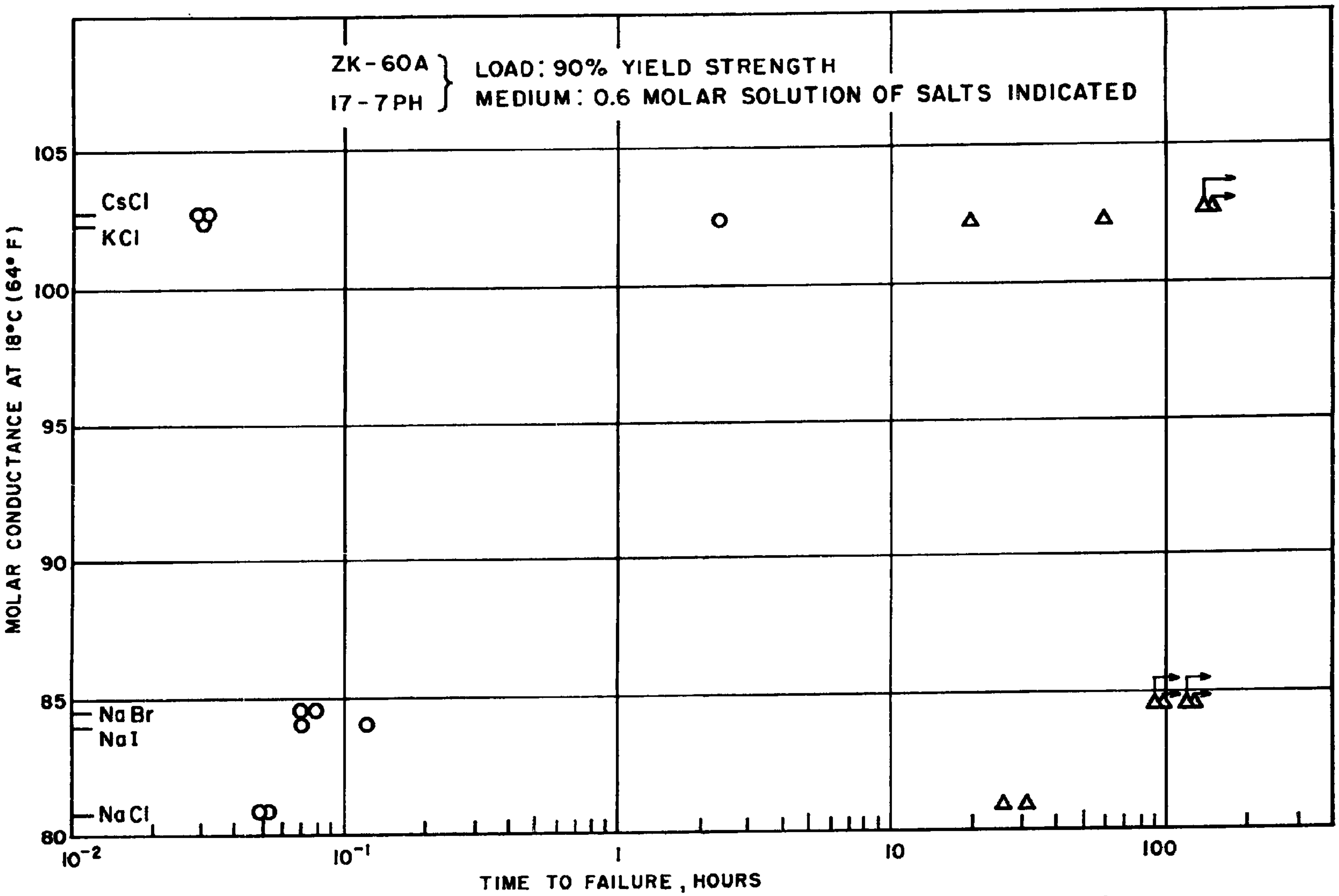
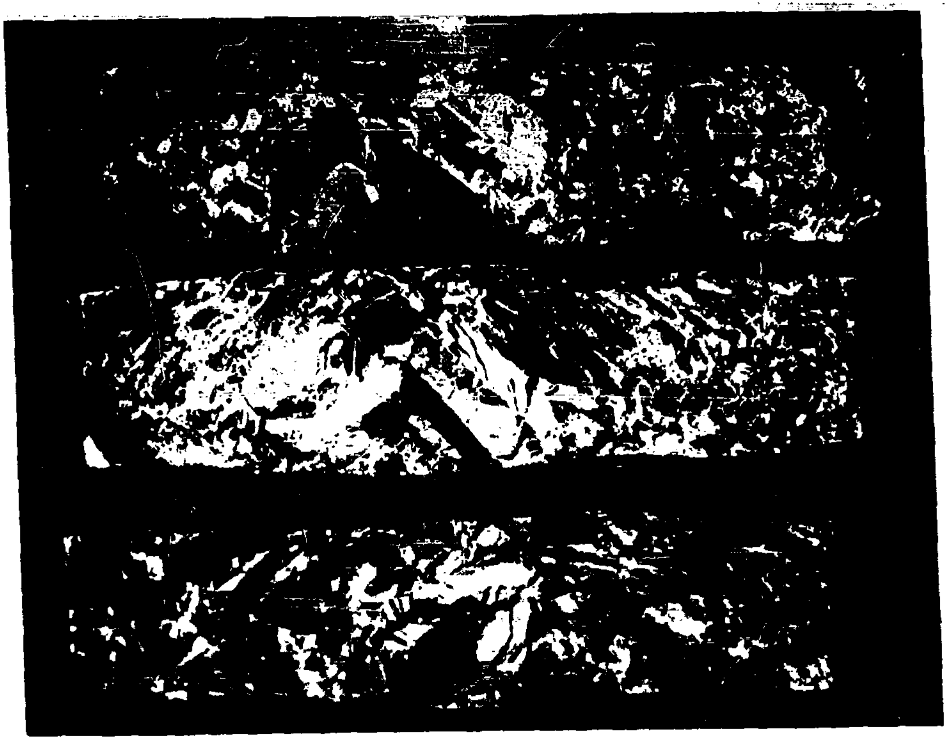


Figure 28 - Molar Conductance of Salt Solution versus Time to Failure for Stressed Specimens Of ZK-60A and 17-7PH Alloys.



Neg. No. 22006 X 18

Fig. 29

Fracture surfaces of B-120VCA weldments which failed within 1 min of loading to 110,000 psi in ASTM sea water. Top--normal weld. Middle--magnetically stirred by 300 gauss field under conditions of polarity reversal at the rate of 10 cps. Bottom--magnetically stirred by 250 gauss field under conditions of polarity reversal at the rate of 2 cps.

Aeronautical Systems Division. Dir/Materials and Processes. Metals and Ceramics Lab. Wright-Patterson AFB, Ohio.
Rpt Nr ASD-TR-61-713. RESEARCH ON THE BASIC NATURE OF STRESS CORROSION FOR VARIOUS STRUCTURAL ALLOYS AT ROOM AND ELEVATED TEMPERATURE. Final report, May 62, 60p. incl illus., tables, 6 refs.

Unclassified Report

The relationship between quantity of ASTM sea salt, varying from 0.0002 to 0.02 g/sq in., and thickness of anodized film--0, 2, and 8 micro-inches--in elevated temperature stress-corrosion cracking of the titanium alloys Ti-6Al-4V and B-120VCA was investigated.

(over)

Exposure conditions were 800°F-25,000 psi-190 hr for the former alloy and 600°F-100,000 psi-190 hr for the latter. Damage was progressively greater with increasing quantity of salt. The anodized films appeared to be of no benefit to the Ti-6Al-4V alloy; however, it appeared that limited protection was afforded B-120VCA.

The alloys: 2024-T86, 7075-T6, ZK-60A-T5, 17-7 PH RH 950, and B-120VCA in two conditions of grain size and two conditions of surface treatment were tested as follows: tensile test in air at room temperature, and in distilled water and ASTM sea water at 32°, 75°, and 212°F; and statically loaded at 90% of the yield strength in media of air, water, and ASTM sea water at room temperature.

1. Applied mechanics
2. Behavior of metals
3. Stress corrosion

I. AFSC Project 7351, Task 735106
II. Contract AF 33 (616)-7612
III. Armour Research Foundation, Chicago, Ill.
IV. F. A. Crossley
V. Aval fr OTS
VI. In ASTIA collection

Aeronautical Systems Division. Dir/Materials and Processes. Metals and Ceramics Lab. Wright-Patterson AFB, Ohio.
Rpt Nr ASD-TR-61-713. RESEARCH ON THE BASIC NATURE OF STRESS CORROSION FOR VARIOUS STRUCTURAL ALLOYS AT ROOM AND ELEVATED TEMPERATURE. Final report, May 62, 60p. incl illus., tables, 6 refs.

Unclassified Report

The relationship between quantity of ASTM sea salt, varying from 0.0002 to 0.02 g/sq in., and thickness of anodized film--0, 2, and 8 micro-inches--in elevated temperature stress-corrosion cracking of the titanium alloys Ti-6Al-4V and B-120VCA was investigated.

(over)

Exposure conditions were 800°F-25,000 psi-190 hr for the former alloy and 600°F-100,000 psi-190 hr for the latter. Damage was progressively greater with increasing quantity of salt. The anodized films appeared to be of no benefit to the Ti-6Al-4V alloy; however, it appeared that limited protection was afforded B-120VCA.

The alloys: 2024-T86, 7075-T6, ZK-60A-T5, 17-7 PH RH 950, and B-120VCA in two conditions of grain size and two conditions of surface treatment were tested as follows: tensile test in air at room temperature, and in distilled water and ASTM sea water at 32°, 75°, and 212°F; and statically loaded at 90% of the yield strength in media of air, water, and ASTM sea water at room temperature.

1. Applied mechanics
2. Behavior of metals
3. Stress corrosion

I. AFSC Project 7351, Task 735106
II. Contract AF 33 (616)-7612
III. Armour Research Foundation, Chicago, Ill.
IV. F. A. Crossley
V. Aval fr OTS
VI. In ASTIA collection