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National Aeronautics and
Space Administration

**NASA-STD-P025
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DRAFT 1

**SELECTION OF METALLIC MATERIALS FOR
STRESS CORROSION CRACKING
RESISTANCE IN SODIUM CHLORIDE
ENVIRONMENTS**

NASA TECHNICAL STANDARD

FOREWORD

This Standard is approved for use by NASA Headquarters and all NASA Centers and is intended to provide a common framework for consistent practices across NASA programs.

This standard is based on MSFC-STD-3029, "Guidelines for the Selection of Metallic Materials for Stress Corrosion Cracking Resistance in Sodium Chloride Environments". In addition to the information that was in MSFC-SPEC-522B, "Design Criteria for Controlling Stress Corrosion Cracking", which was originated more than 25 years ago as a tool to control stress corrosion cracking throughout NASA programs, NASA-STD-P025 contains additional alloys in the tables, requirements for the classification of alloys, additional references, a list of the documents associated with stress corrosion research, four additional figures and information on the test methodology.

Request for information, corrections, or additions to this document may be directed to Materials, Processes, and Manufacturing Department, Metallic Materials and Processes Group, ED33, Marshall Space Flight Center, Huntsville, AL 35812. Requests for general information concerning standards should be sent to the NASA Technical Standards Program Office, ED41, MSFC, AL 35812 (telephone 256-544-2448). This and other NASA standards may be viewed and downloaded, free-of-charge from our NASA Standards Home Page: <http://standards.nasa.gov>.

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Chief Engineer

NASA-STD-P025
August 27, 2001

DRAFT 1

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Selection of Metallic Materials for Stress Corrosion Cracking Resistance in Sodium Chloride Environments

1. SCOPE

1.1 Purpose. This document defines the design criteria that shall be used for the selection of metallic materials in order to prevent failure due to stress corrosion cracking. It does not discuss other forms of environmental cracking such as corrosion fatigue, nor hydrogen embrittlement.

1.2 Application. The exposure environment is limited to alternate immersion in salt water, salt fog, seacoast, and slow strain rate in a salt solution. Alloys used for electrical wiring and other similar nonstructural electrical or electronic applications are exempt from the requirements of this document.

2. RELATED DOCUMENTS

2.1 General. The applicable documents cited in this standard are listed in this section only for reference. The specified technical requirements listed in the body of this document must be met whether or not the source document is listed in this section.

American Society For Testing And Materials (ASTM) Documents.

ASTM B117,	"Standard Practice For Operating Salt Spray (Fog) Apparatus"
ASTM G30,	"Standard Practice For Making and Using U-Bend Stress Corrosion Test Specimens"
ASTM G38,	"Standard Practice For Making and Using C-Ring Stress Corrosion Test Specimens"
ASTM G39,	"Standard Practice For Preparation and Use of Bent-Beam Stress Corrosion Test Specimens"
ASTM G44,	"Standard Practice For Evaluating Stress Corrosion Cracking Resistance of Metals and Alloys by Alternate Immersion in 3.5-Percent Sodium Chloride solution"
ASTM G47,	"Standard Test Method For Determining Susceptibility to Stress Corrosion Cracking of 2XXX and 7XXX Aluminum Alloy Products"
ASTM G49,	"Standard Practice For Preparation and Use of Direct Tension Stress Corrosion Test Specimens"
ASTM G58,	"Standard Practice For Preparation of Stress Corrosion Test Specimens for Weldments"

ASTM G64,	"Standard Classification of the Resistance to Stress Corrosion Cracking of Heat-Treatable Aluminum Alloys"
ASTM G129,	"Standard Practice For Slow Strain Rate Testing to Evaluate the Susceptibility of Metallic Materials to Environmentally Assisted Cracking"

(Requests for copies of these documents should be addressed to the American Society for Testing and Materials, 1916 Race Street, Philadelphia, PA 19103.)

2.2 Order of Precedence. Where this document is adopted or imposed by contract on a program or project, the technical requirements of this document take precedence, in the case of conflict, over the technical requirements cited in other referenced documents. Nothing in this document, however, supersedes applicable laws and regulations unless a specific exemption has been obtained.

3. DEFINITION

3.1 Stress Corrosion. Stress corrosion may be defined as the combined action of sustained tensile stress and corrosion to cause premature failure of a susceptible material. Certain metallic materials are more susceptible than others. If a susceptible material is placed in service in a corrosive environment under tension of sufficient magnitude, and the duration of service is sufficient to permit the initiation and growth of cracks, failures will occur at a stress lower than the material would normally be expected to withstand. The corrosive environment need not be severe in terms of general corrosive attack. Service failures due to stress corrosion are frequently encountered for which the surfaces of the failed parts are not visibly corroded in a general sense. If failure of a susceptible material in a corrosive environment is to be avoided, the total tensile stress (residual and applied) in service must be maintained at a safe level. Comparative stress corrosion thresholds can be determined for metallic materials under certain controlled test conditions. Estimates of the stress corrosion threshold for a specific service application must be determined for each alloy and heat treatment using a test piece, stressing procedure, and corrosive environment that are appropriate for the intended service.

4. GENERAL REQUIREMENTS

The principal variables which significantly interact to influence stress corrosion cracking are as follows:

- Alloy composition and related metallurgical factors
- Sustained surface tensile stress, either residual, assembly, or applied
- Environment, including temperature and time

Certain alloys and heat treatments in a given metal system are more resistant to stress corrosion cracking than others.

4.1 Limitations.

4.1.1 Temperature and Environment Limitations. The stress corrosion susceptibility of the alloys included in this document was determined at ambient temperature by conducting stress corrosion tests or by service experience with fabricated hardware. The majority of the stress corrosion tests were performed by exposing specimens to either 3.5-percent alternate immersion per ASTM G44 or 5-percent salt spray per ASTM B117. In many occasions, parallel tests were performed in a seacoast environment or in a high humidity cabinet. Some data generated with the slow strain rate technique also involved the use of a sodium chloride solution as the corroding agent. Use of the criteria established herein shall be limited to designs for service involving similar exposure conditions. Behavior of the listed metallic materials at elevated temperature, and/or in specific chemical environments other than those mentioned above, must be ascertained by additional testing.

4.1.2 Weldments. Weldments present a special problem in designing for resistance to stress corrosion cracking. In addition to the susceptibility of the parent metals, it is also necessary to consider the filler metal and the microstructural effects of heat and deformation introduced by the welding operations and subsequent thermal treatments. Susceptibility data are not as extensive for weldments as for alloys in mill form because of the additional variables that must be considered. Most of the design criteria for weldments in this document are limited to aluminum alloys, selected stainless steels in the 300 series, and other specific alloys listed in Table I.

4.1.3 Specific Test Data. This document is intended to provide general criteria to be used in designing for resistance to stress corrosion cracking. Specific test data and other detailed information are not included. However, a list of references is attached as Appendix A from which additional information can be obtained.

4.1.4 Data Limitations. This document does not purport to be all inclusive of factors and criteria necessary for the total control of stress corrosion cracking in alloys. Data on stress corrosion susceptibility may be insufficient for many applications involving unfamiliar materials or unusual combinations of materials and environments. To ensure adequate stress corrosion resistance in these situations, it will be necessary to conduct a detailed evaluation of susceptibility. Testing may also be necessary in those cases.

4.1.5 Defect-Free Surface Limitation. This document is based on data obtained using smooth specimens. No initial flaws were introduced. The presence of a stress concentration in the form of a notch or flaw can be a prerequisite for stress corrosion to occur. Some materials, as an example, certain types of titanium alloys, may appear immune to stress corrosion in laboratory tests using smooth specimens, but can develop severe cracking in the same environment once a flaw has been introduced.

4.2 Grain Orientation.

4.2.1 Processing Operations. Rolling, extruding, and forging are the most common processing operations employed in the production of standard wrought forms of metal. All produce a flow of metal in a predominant direction so that, microscopically, the metal is no longer isotropic. As a result, the properties of the metal vary according to the direction in which they are measured. The extent of directional variation depends on the property of interest. For susceptibility to stress corrosion cracking, the directional variation can be appreciable and must be considered in the design of fabricated hardware.

4.2.1.1 Rolling and Extruding. The anisotropy of grain orientation produced by rolling and extruding is illustrated schematically in Figure 1. Taking the rolled plate as an example, it is conventional to describe grain orientation in three directions. The direction of rolling is the longitudinal direction, the direction perpendicular to the longitudinal and in the plane of the plate is the long transverse direction, and the direction through the thickness of the plate is the short transverse direction. For certain shapes, the simple rules may not apply and grain orientation can only be established by experience with the shape and knowledge of the forming methods. As an example, consider the thick tee section illustrated in Figure 2.

4.2.1.2 Forgings. Identifying the short transverse direction of forgings also requires consideration. In a forging operation, the flow of metal is influenced and constrained by the shape of the die cavity. For complex shapes, there may be several regions where a short transverse direction exists. The direction perpendicular to the parting plane of the dies is always short transverse as illustrated in Figure 3.

4.2.2 Short Transverse Direction. The stress corrosion resistance of metals, especially aluminum alloys, is lower in the long transverse direction than it is in the longitudinal direction, however, it is worst in the short transverse direction. Figures 2 and 3 illustrate undesirable situations in which tensile stresses due to assembly have been applied in the short transverse direction. Similar situations must be avoided for optimum resistance to stress corrosion cracking.

4.3 Stress Considerations. In designing for stress corrosion resistance it is important to realize that stresses are additive and threshold stresses for susceptibility are often low. All possible sources of stress must be considered to ensure that the threshold stresses are not exceeded. Stresses resulting from operational, transportation, and storage loads are often anticipated during design. Assembly and residual stresses may not be anticipated, and in many cases have been the major contributors to stress corrosion failure. There have been stress corrosion failures where the design stresses were intermittent and of short duration, and a minor contributor to failure.

4.3.1 Examples of Assembly Stresses. Assembly stresses can result from improper tolerances during fit-up (Figures 2 and 3), overtightening, press fits, high interference fasteners, and welding.

4.3.2 Examples of Residual Stresses. Residual stresses can result from welding, machining, forming, and heat treating operations. Figure 4 illustrates the distribution and relative magnitudes of stress resulting from conventional heat treating and forming operations.

4.4 Susceptibility of Engineering Alloys.

4.4.1 Aluminum Alloys. Many aluminum alloys exhibit excellent resistance to stress corrosion cracking in all standard tempers. However, the high strength aluminum alloys, which are of primary interest in aerospace applications, must be approached cautiously. Some of these alloys are resistant only in the longitudinal grain direction, and the resistance of others varies with the specific temper. Because metallurgical processing of aluminum alloys usually results in a pronounced elongation of grains, the variation of susceptibility with grain orientation is more extensive than for other metals.

4.4.1.1 Mechanical Stress Relief. Conventional processing methods designed to optimize strength, such as rolling, forging, casting, and welding, can result in high residual stresses. These high residual stresses are usually greater in aluminum products than in wrought forms of other metals, especially in thick sections. It is for this reason that wrought, heat-treatable aluminum alloys shall be mechanically stress relieved (the TX5X or TX5XX temper designations) whenever possible. Mechanical stress relief is lost if the alloy is resolutioned, thus becoming significantly more susceptible to stress corrosion cracking.

4.4.1.2 Machining Wrought Aluminum. Both the residual stress distribution and the grain orientation must be carefully considered in designing a part to be machined from wrought aluminum. Machining will alter the stress distribution and it may also result in the exposure of a short transverse region on the surface of the finished part that will be subject to tension in service. Examples of exposure of a short transverse region on machined parts are illustrated in Figures 2 and 3.

4.4.2 Ferrous Alloys. Carbon and low alloy steels with ultimate tensile strengths below 1241 MPa (180 ksi) are generally resistant to stress corrosion cracking. Austenitic stainless steels of the 300 series, with the exception of the free machining grades (e.g., UNS S30300), are also generally resistant. The susceptibility of the martensitic stainless steels of the 400 series depends on composition and heat treatment. Precipitation hardening stainless steels vary in susceptibility from extremely high to extremely low depending on composition and heat treatment. The susceptibility of precipitation hardening stainless steels increases with decreasing heat treatment tempering temperatures. Ferritic and duplex stainless steels are not as resistant to stress corrosion cracking as are austenitic stainless steels.

4.4.3 Nickel Alloys. As a class, alloys with high nickel content are resistant to stress corrosion cracking.

4.4.4 Copper Alloys. Industrial atmospheres containing pollutants of sulfur dioxide, oxides of nitrogen, and ammonia are reported to cause stress corrosion cracking of some copper alloys. Chlorides present in marine atmospheres may also cause stress corrosion cracking, but to a lesser extent than the previously listed pollutants. Many copper alloys containing more than 20 percent zinc are susceptible to stress corrosion cracking, even in the presence of alloying additions which normally impart resistance to stress corrosion.

4.4.5 Titanium Alloys. Many titanium alloys are resistant to stress corrosion cracking in sodium chloride environments. However, alloys such as Ti-2.5% Cu, and in particular components with flaws may become susceptible. It has been reported that some titanium alloys may appear immune to stress corrosion cracking in a sodium chloride environment when using smooth specimens, however, they may crack once a flaw has been introduced. It appears that some of these alloys do not easily develop a surface alteration (e.g., a pit) for the initiation and propagation of stress corrosion cracking when they are exposed to sodium chloride environments.

4.4.6 Magnesium Alloys. The susceptibility to stress corrosion of the magnesium alloys presented in this document ranges from high to low, depending on the particular alloy. For some magnesium alloys (e.g., AZ31B, AZ61A, and AZ80A) stress relief is required to prevent stress corrosion cracking.

5. DETAILED REQUIREMENTS

5.1 Testing Of Metallic Materials For Stress Corrosion Susceptibility. This section describes the specimens and testing methods for determining susceptibility to stress corrosion cracking in NaCl environments and high humidity. The alloys included in the tables of this document were evaluated in NaCl environments, especially in alternate immersion in a salt solution or in salt spray. Data obtained in a seacoast environment and in high humidity is considered complementary. Data obtained using the slow strain rate technique exclusively is so indicated in the tables. Newer testing techniques are also described in general, but no data derived from these methods have been included in this revision.

5.1.1 Test Specimens. The material to be evaluated shall be heat treated, if required, followed by fabrication of the specimens. The stress corrosion specimens shall be fabricated in such a way that at least the short transverse grain direction is evaluated, if that direction can be identified (as in plate material). In the case of bar materials the specimens shall be fabricated in at least the transverse direction. The longitudinal and long-transverse directions have been evaluated for many alloys presented in this document for comparison purposes. There are several specimen configurations (Figure 5), however, the most commonly used to generate the data for the alloys presented in this document (Tables I, II, and III) is the 0.318-cm (0.125-in) gage length diameter round tensile specimen (Figure 5(a)). The C-ring (Figure 5(b)) is an alternative configuration. The bent-beams (Figure 5(c)) are commonly used for testing welds and the flat tensile specimens for sheet materials. It has been reported that polishing paper containing iron oxides shall not be used in specimen preparation because it can accelerate pitting during exposure of the specimens to the saline solution. All the specimens shall be cleaned prior to the exposure to the test environment.

5.1.2 Chemical Composition of the Test Materials. This test shall be performed when the chemical composition is not supplied with the material or for verification.

5.1.3 Hardness Tests. This test is recommended since the susceptibility of metallic materials tends to increase with the hardness.

5.1.4 Mechanical Properties of the Test Materials. Tensile tests are performed, usually on three specimens, and averaged values for the 0.2-percent offset yield strength, ultimate tensile strength, percent of reduction in area and elongation, and modulus of elasticity (Young's modulus) are obtained. The susceptibility of metallic materials to stress corrosion tends to increase with the strength.

5.1.5 Stressing and Exposure of Specimens to the Test Environment(s). The specimens for the stress corrosion test are typically stressed in tension to 50, 75, and 90-percent of the yield strength. These values are obtained from stress-strain data. A device and fixtures for stressing round tensile specimens are presented in Figure 6(a). The strains corresponding to the desired stress levels are measure with an extensometer while the specimens are being loaded. After loading, the stressing frames are protected with a strippable coating to protect from corrosion and to prevent galvanic interaction between the specimen and frames. Three to five replicates are typically used, which are afterwards exposed to the corrosive environment. Unstressed specimens are usually exposed simultaneously with the stressed specimens. These specimens are removed periodically (usually when failures of stressed specimens occur) or after completion of the test. C-rings and bent-beams are stressed by deflecting the specimen to calculated values corresponding to the desired stress levels. If a limited number of specimens are available for testing, or if there are equipment-related or other types of constraints, the preferred stress level to

start with shall be 75% YS, unless there is a need to meet specific customer requirements. If testing is performed at 75% YS and no failures occur, there is no need to test at a lower stress.

5.1.6 Determination of Reduction in Load Carrying Ability. After exposure, any non-failed stressed specimens are unloaded and along with the unstressed specimens are tensile tested to failure to determine reduction in load carrying ability. The effect of the corrosive environment alone is compared against the effect of both, the corrosive environment and the stress. The average load value of specimens obtained from the same material and tested in air (typically in triplicate) is used as control.

5.1.7 Test Environments. Alternate immersion in 3.5-percent NaCl and 5-percent salt spray are the most common environments used for stress corrosion evaluations. High humidity and seacoast exposure, which are less aggressive environments than the former two, have been used as complementary methods for several alloys.

5.1.7.1 Alternate Immersion in 3.5-Percent Sodium Chloride Solution per ASTM G44. This may be considered the preferred method for stress corrosion evaluations, especially for aluminum alloys and steels with low corrosion resistance. In this method the specimens are submerged in a 3.5-percent NaCl solution for 10 minutes and then removed from the solution for 50 minutes. This cycle is repeated for the entire duration of the test. During the test, the temperature of the air is maintained at $27 \pm 1^\circ\text{C}$ ($80 \pm 2^\circ\text{F}$), relative humidity at $45 \pm 10\%$, and pH at 6.8 ± 0.4 . A typical alternate immersion tester is illustrated in Figure 6(b). This tester consists of a Ferris wheel type mechanism containing six trays, in which the specimens are distributed. This mechanism rotates 60° every 10 minutes.

5.1.7.2 Five-Percent Salt Spray Per ASTM B117. This method tends to be more aggressive than alternate immersion. It has been used as a complementary test, especially for stainless steels. The apparatus consists of a chamber, an air saturator tower, a salt solution reservoir, an atomizing nozzle, specimens supports, a provision for chamber heating, a temperature controller, and two solution collectors. During the salt spray test, heated humidified air from the saturator tower is passed through the nozzle, and in the process draws up a five-percent salt solution that is sprayed at 35°C (95°F). The salt spray operates continuously, except for the interruptions necessary to inspect the specimens and remove the collected solution inside the chamber. For every 80 cm^2 (12.4 in^2) of horizontal collecting area, one to two ml are collected per hour. The pH of this solution is maintained within the range of 6.5-7.2, and the salt concentration is 5 ± 1 percent.

5.1.7.3 High Humidity. This environment is less aggressive than alternate immersion and salt spray and it is used as a complementary test. These tests are performed in a cabinet that maintains 97 ± 3 percent humidity at $38 \pm 3^\circ\text{C}$ ($100 \pm 5^\circ\text{F}$) by bubbling up compressed air through deionized water.

5.1.7.4 Seacoast Environment. This method requires a longer test duration than the standard accelerated corrosion tests performed in a laboratory and is used as a complementary test.

5.1.7.5 Slow Strain Rate. This procedure involves the application of a slow strain rate to a tensile specimen under controlled environmental conditions while monitoring load and extension of the specimen. The slow strain rate test always produces fracture of the test specimen. The degree of susceptibility is generally assessed through observation of difference in the behavior

of the material in tests conducted in a corrosive environment (e.g., 3.5-percent NaCl) from that obtain from tests conducted in a control environment (e.g., air). Several measurable and quantifiable parameters can be chosen to indicate susceptibility to stress corrosion cracking by virtue of their ability to reflect loss in ductility, as the stress corrosion failures are associated with little plastic deformation during crack propagation. Parameters that can be chosen include the area under the load-elongation curve (fracture energy), elongation at fracture, time to failure, and percent of reduction in area. The lower the values are in a corrosive environment, in comparison to those determined in an inert environment (all other experimental conditions being the same), the more susceptible the material is to stress corrosion.

5.1.7.6 New Techniques For Stress Corrosion Testing. Two relatively new techniques for stress corrosion testing are the incremental loading technique and the constant load rating technique. These techniques involve either incremental or constant rate increases in the load applied to a precracked specimen, monitoring the crack-opening displacement response for indications of crack growth. Though these techniques are promising, at this writing, they have not been standardized and require interlaboratory verification. Data obtained from these methods can help making a more informed decision for the rating of an alloy.

5.1.8 Test Duration. Experience shows that, in general, testing conventional stress corrosion samples in alternate immersion or salt spray for 30 days or until failure, whichever occurs first is sufficient to obtain reliable data. Stress corrosion ratings of alloys to be incorporated into this document shall be based on a minimum of 30 days of exposure using conventional specimens (see section 5.1.1), preferably the 0.125-in gage length diameter round tensile specimen. The test can be extended if additional data at longer exposures is desired. A 90-day exposure is very common. However, it must be noticed that most of the stress corrosion specimens used are small, and when they are exposed to the test environment for long periods of time, failures can occur due to other mechanisms that are not necessarily stress corrosion (e.g., pitting corrosion, exfoliation, etc.). Significant reduction of the cross sectional area of the specimens can induce overload failures.

5.1.9. Post-Test Examination of Specimens. The results of post-test examinations shall be considered to rate the alloy for stress corrosion resistance. Microstructural examinations (e.g., metallography and Scanning Electron Microscopy (SEM)) and residual tensile strength data can help determining if a failure was due to stress corrosion cracking or not. These techniques can also help determining if non-failed stressed specimens have stress corrosion features (e.g., intergranular cracking and excessive loss in tensile strength compared to unstressed control specimens). SEM and Metallographic views of stress corrosion failures are presented in Figures 7 through 10. .

5.1.10 Reporting of Results. The report shall include, but is not limited to the following information: name of alloy manufacturer, heat or lot number, reference to applicable specification, chemistry, product form, thickness or diameter, process history, mechanical properties, modulus of elasticity, temper, test environment, type and dimensions of the specimens, applied stress, stress direction in relation to grain orientation, number of failures, days to failure, number of replicates, test duration, and reduction in load carrying ability. If applicable, welding method or surface treatments applied shall be reported. Additional complementary information such as tables, illustrations (e.g., optical pictures, photomicrographs, etc.), or appendixes can be added as desired. Any deviations from standard procedures shall be reported.

5.2 Rating Of Alloys For Stress Corrosion Susceptibility. The alloys listed in this document were classified in three tables (Tables I, II, and III) according to their relative susceptibility to stress corrosion cracking in sodium chloride environments. A table that combines these three tables in one is also included (Table IV). Many materials in this document have ratings that vary with material condition. These ratings can be viewed in consecutive rows in Table IV. These ratings are based on testing and experience, and apply only to the environments described in this section (sodium chloride environments). In the case of borderline alloys between two classifications, a conservative approach shall be followed. An alloy can be re-classified if it is determined by additional data or further analysis. If the form of the material (plate, bar, etc.) is not indicated in the tables, the rating applies to all forms of the material. The susceptibility to stress corrosion for aluminum alloys varies with the grain orientation. The ratings presented in this document are based on the worst case stressing direction (e.g., the short transverse direction in the case of plate).

5.2.1 Stress Corrosion Ratings Based on Alternate Immersion or Salt Spray Tests. An alloy or weldment, at a specific strength level or temper, shall be added to Table I, II, or III of this document based on the performance of specimens fabricated in accordance with ASTM standard practices, stressed in the grain direction of maximum expected susceptibility (e.g., short transverse for plate and transverse for bar material), when feasible, and tested per ASTM G44 and/or B117.

5.2.1.1 Table I Requirements. Alloys, tempers, and weldments in Table I are considered highly resistant to stress corrosion cracking in 3.5-percent NaCl alternate immersion or 5-percent salt spray. An alloy or weldment can be added to this table if no stress corrosion failures occur on specimens stressed to 75-percent of the yield strength within 30 days of exposure.

5.2.1.2 Table II Requirements. Alloys, tempers, and weldments in Table II are considered moderately resistant to stress corrosion cracking in 3.5-percent NaCl alternate immersion or 5-percent salt spray. An alloy or weldment shall be added to this table if no stress corrosion failures occur on specimens stressed to 50-percent of the yield strength within 30 days of exposure.

5.2.1.3 Table III Requirements. Alloys, tempers, and weldments in Table III are considered to have low resistance to stress corrosion cracking in 3.5-percent NaCl alternate immersion or 5-percent salt spray. They shall be placed in this table if stress corrosion failures occur on specimens stressed to 50-percent of the yield strength within 30 days of exposure.

5.2.2 Stress Corrosion Ratings Based on Less Conventional Tests. Ratings of alloys based on data obtained using less conventional testing methods (e.g., slow strain rate test) can be included provided a sodium chloride solution (usually 3.5-percent) was used as the corrosive environment and the method has demonstrated that can provide results that are in agreement with those obtained by standard methods. Verification tests using alternate immersion or salt spray tests are recommended. Ratings based exclusively on those data are so indicated in the tables.

5.2.3 Stress Corrosion Ratings Based on Service Experience. Metallic materials shall be tested for stress corrosion susceptibility before they are placed in service; especially when there are sustained tensile stresses and corrosive environments involved. Any already available in-service failure data shall be used to rate an alloy in Table III only.

5.2.4 Criteria for Accepting Stress Corrosion Ratings Based on Data Obtained From Other Laboratories. Data from other well established laboratories are accepted provided the specimens and test procedures comply with standard ASTM practices for stress corrosion tests in NaCl environments and a report is provided (see section 5.1.10). This data could be subjected to verification by additional testing. Acceptable data is filed and included in the list of references for traceability purpose.

5.3 Use of Stress Corrosion Ratings in Design to Prevent Failures. Stress corrosion cracking can be reduced through the use of one or more of the following techniques:

- Reduction of stress
- Modification of the environment
- Preventive methods (e.g., undamaged paint films, etc.)
- Selection of the most resistant alloy for the expected environment as described below

The ratings presented in this document shall serve as a guide to designers for the selection of metallic materials for stress corrosion resistance. Stress corrosion failures occur suddenly with no warning signs, and the results have been catastrophic. In order to avoid these failures, the designers shall select alloys and tempers with the highest possible stress corrosion ratings that still are suitable for the intended application. However, within a class and because of the relationship between strength and susceptibility to stress corrosion cracking, it shall be a standard recommended practice to use the lowest strength material compatible with the design. The environment(s) to which the structure will be exposed (including assembly, transportation, storing, and in service environments) and the sustained tensile stresses derived from all sources (residual, assembly, and design stresses) shall be considered when making the material selection.

5.3.1 Materials Selection Criteria. This section is provided to emphasize the importance of materials selection to avoid failures due to stress corrosion.

5.3.1.1 Table I Alloys. Alloys, tempers, and weldments, which by testing and experience have shown high resistance to stress corrosion cracking (Table I) shall be used preferentially, and NASA approval is not required prior to use. All other alloys and weldments not listed in Table I, except as specifically exempted, shall be approved prior to use, assembly, or integration to a level where inspection or removal is prohibited. The procedure that shall be followed to request approval is described in paragraphs 5.4 and 5.5. The material shall be approved, when required, by the responsible materials and processes organization within NASA.

5.3.1.2 Table II Alloys. Alloys, tempers, and weldments that are moderately resistant to stress corrosion (Table II) shall be considered for use only for cases where a suitable alloy with high resistance to stress corrosion cracking cannot be found. NASA approval is required before using any alloy or weldment from Table II.

5.3.1.2.1 High Installation Stresses. Proposed utilization of materials from Table II in applications involving high installation stress, such as springs or fasteners, shall not be approved.

5.3.1.2.2 Aluminum Alloy Sheet Material. Sheet material (less than 0.64 cm (0.25 inch) thick) of the aluminum alloys and conditions listed in Table II is considered resistant to stress corrosion and does not require NASA approval.

5.3.1.3 Table III Alloys. Alloys and tempers that are highly susceptible to stress corrosion cracking (Table III) shall be considered for use only in applications where it can be demonstrated conclusively that the probability of stress corrosion is remote. The sustained tensile stress in critical grain directions, whatever its origin, is required to be significantly lower than the stress corrosion threshold of the metal, as obtained by laboratory testing per standard methods. Suitable protective measures shall be used and the environment shall not promote corrosion. Hardware fabricated from these materials shall be inspected regularly for corrosion and the potential for a stress corrosion failure shall be assessed at that time. The use of materials in Table III requires NASA approval prior to use, assembly, or integration. The rationale for the use of this materials shall be based on a detailed analysis of the potential for failure (see 5.4 and 5.5).

5.3.2 Request For Materials Approval Prior to Use, Assembly, or Integration. Fabrication of structures first and requesting material approval later is not an acceptable practice, especially if stress corrosion was not considered a design factor. Table II and III alloys in such structures require NASA approval before the structure is put in service. If the material is rejected because of safety reasons or relatively high risk for a stress corrosion failure, corrective action will need to be taken.

5.4 Assessment Of The Potential For A Stress Corrosion Failure. A complete assessment of the stress corrosion susceptibility as a potential for failure for the proposed or current use of a material from Table II or III shall be submitted to NASA. The following information shall be submitted for each application being evaluated:

- a. Part Number
- b. Part Name
- c. Next Assembly Number
- d. Manufacturer's Name, Address, and Phone Number
- e. Material. The material shall be identified as specified on the drawing. Provide specific alloy and temper designation of raw material from which the part is to be fabricated.
- f. Heat Treatment. List all thermal treatments that the part receives.
- g. Size and Form. List the approximate dimensions of the raw material from which the part is to be fabricated. Include the raw material form (bar, plate, sheet, extrusion, forgings, etc.).
- h. Sustained Tensile Stresses. Estimate all the sustained tensile stresses. Include the magnitude and the direction with respect to grain orientation. List the stresses according to their source (i.e., process residual, assembly, and design), and provide the basis on which the estimation was made. Note any special precautions to control stresses.
- i. Special Processing. Note any processes used for reducing tensile stresses (such as shot peening or stress relief treatments).

j. Weldments. Provide a stress corrosion evaluation of all weldments and submit all information that may assist in that evaluation. For each weldment, list the alloy, form, and temper of the parent metal, filler alloy (if any), welding process, whether the weld bead was removed, and post weld thermal treatment or stress relief.

k. Environment. An evaluation shall be made as to the expected corrosive environment to which the part will be exposed during its lifetime. This includes exposure during fabrication, assembly, and component storage as well as environmental conditions during use. Include length of exposure, temperature, pressure, and concentration.

l. Protective Finish. List any finishes which are applied for corrosion protection or which might affect the basic corrosion resistance of the component.

m. Function of Part. Provide the basic function of the part (or if more pertinent the assembly).

n. Effect of Failure. Provide the possible effect that failure of the part (or assembly) will have on all function or mission of the major assembly involved. Indicate whether the part or assembly is a fracture critical component (a part or assembly whose failure can lead to personal injury, loss of life, loss of a flight vehicle, hardware, ground structures, loss of property, etc.).

o. Evaluation of Stress Corrosion Susceptibility. Include the rationale on which the material selection was made and an explanation as to why no stress corrosion problems are expected.

p. Remarks. Include any additional information or explanatory notes not otherwise listed.

5.5 The Materials Usage Agreement (MUA). The MUA is the means by which approval of a material shall be requested, if required. It consists of a gathering of information necessary to determine the acceptability of the material for stress corrosion resistance for the particular application(s). It serves as a method to promote the selection of stress corrosion resistant alloys. Similar usages of the same or similar alloys can be submitted on a single MUA. The MUA requires approval by the responsible materials and processes organization. The MUA consists, but it is not limited, to the following information:

- a. Project
- b. System
- c. Subsystem
- d. Originator
- e. Originator's Organization, Address, and Phone Number
- f. Identification of Part(s)
- g. Drawings and Next Assembly Drawings
- h. Item Description

- i. Material Designation
- j. Manufacturer
- k. Specification
- m. Proposed Effectivity
- n. Material Description. Thickness, weight, and exposed area
- o. Location on Spacecraft. Habitable or nonhabitable
- p. Fracture Critical Component. Yes or no
- q. Environment. Include pressure, temperature, and duration of exposure
- r. Application
- s. Rationale

5.6 Unlisted Materials. The stress corrosion resistance of alloys and weldments not listed in this document shall be ascertained by tests conducted in an environment representative of the proposed application or by a direct comparison with similar alloys and weldments for which susceptibility is known. An MUA and a stress corrosion evaluation, or the equivalent, shall be submitted to NASA before the proposed alloy is used.

5.7 Protective Coatings. Protective coatings do not change the stress corrosion rating of alloys to which they are applied. Though there are coatings that may delay the onset of stress corrosion, they may contain imperfections or their integrity may be degraded in service. Table II and III alloys thus treated must be identified and a request for approval prior to their use, assembly, or integration shall be submitted to NASA through the MUA and stress corrosion evaluation method or the equivalent process.

5.8 Surface Treatments. Surface treatments, such as carburizing or nitriding, which locally modify the compositional or thermal treatment, may adversely affect the stress corrosion rating of materials to which they are applied. All materials thus treated must be identified and an MUA and stress corrosion evaluation forms, or the equivalent, shall be submitted to NASA for approval prior to their use.

6. NOTES

6.1 Intended Use. This document is intended to establish design requirements for the selection of metals used to fabricate space hardware and ground support equipment so that stress corrosion failures are prevented.

6.2 Caution Against Misapplications of this Document. The ratings presented in this document apply only to the environments described.

6.3 Keywords.

alternate immersion
materials
materials selection
metals
salt fog
salt spray
salt water
stress corrosion
stress corrosion cracking
stress corrosion ratings

DRAFT 1

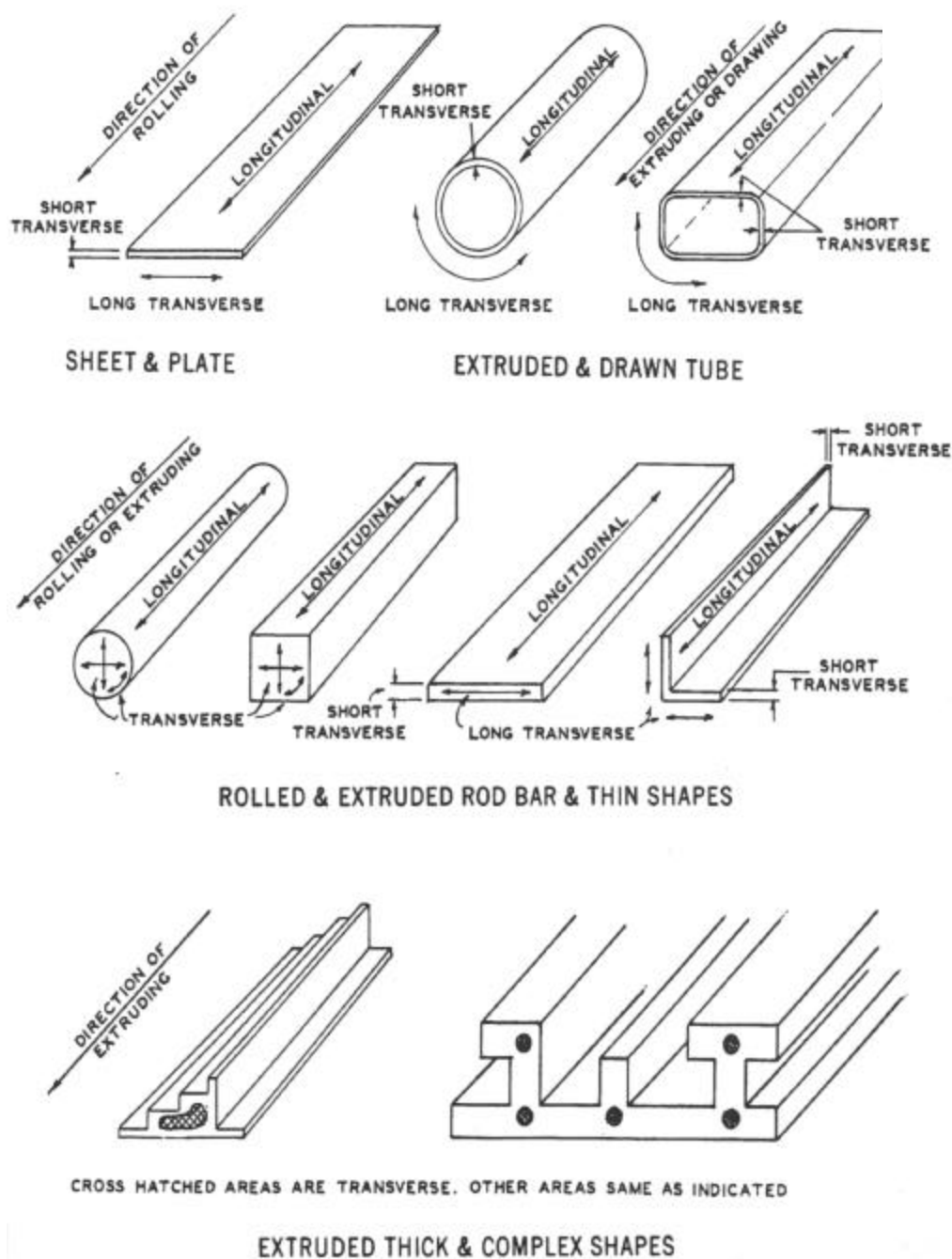
NASA-STD-P025
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FIGURE 1. Grain Orientation In Standard Wrought Forms

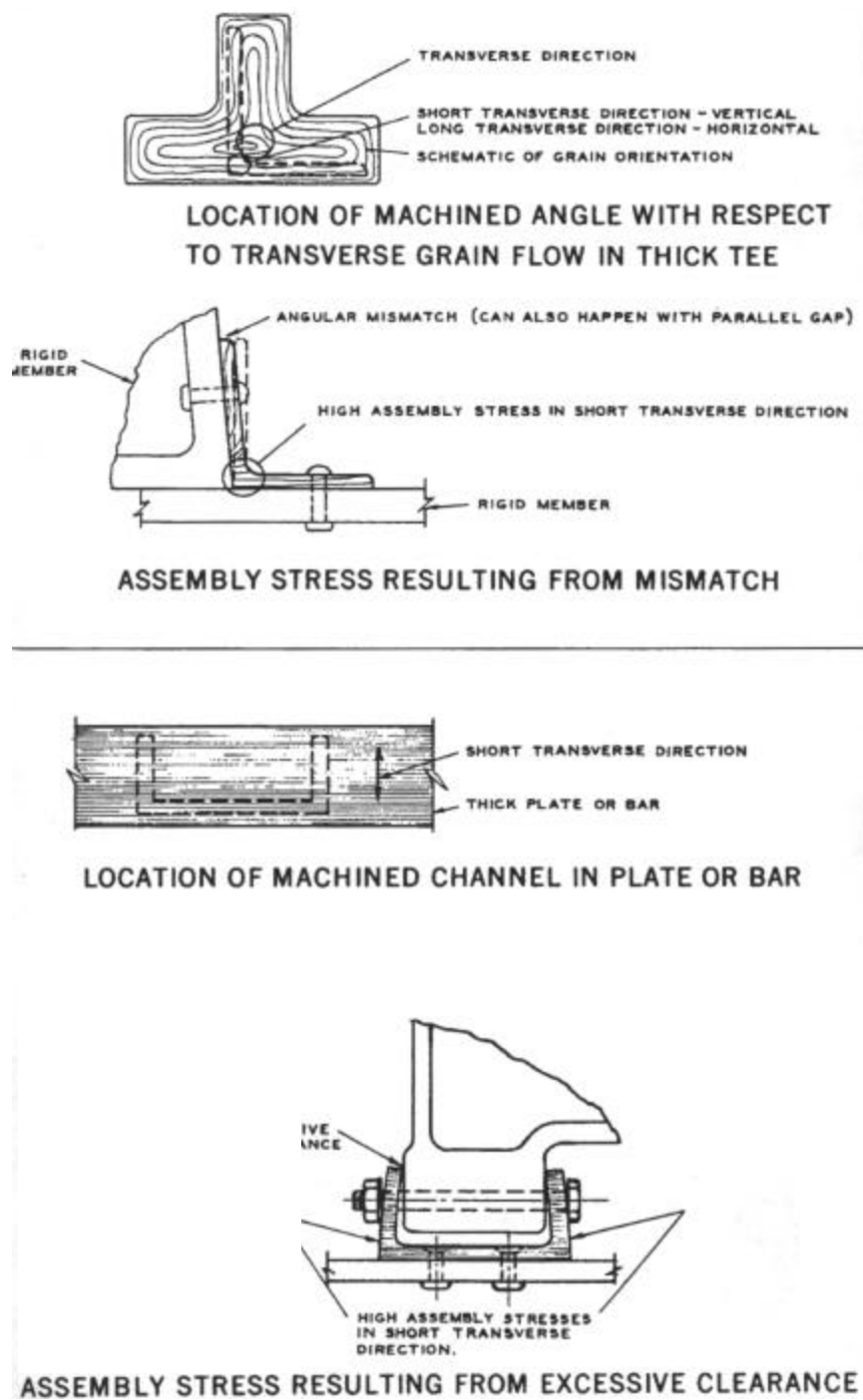
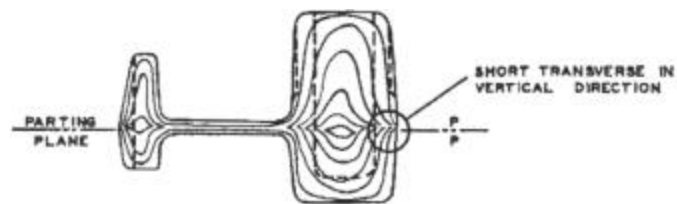
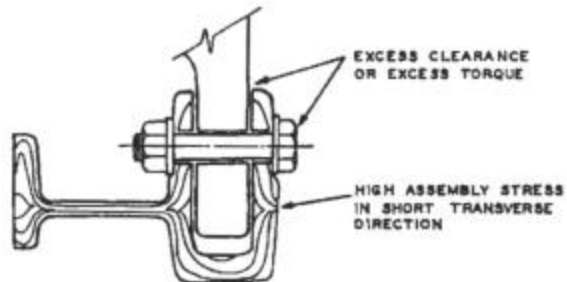


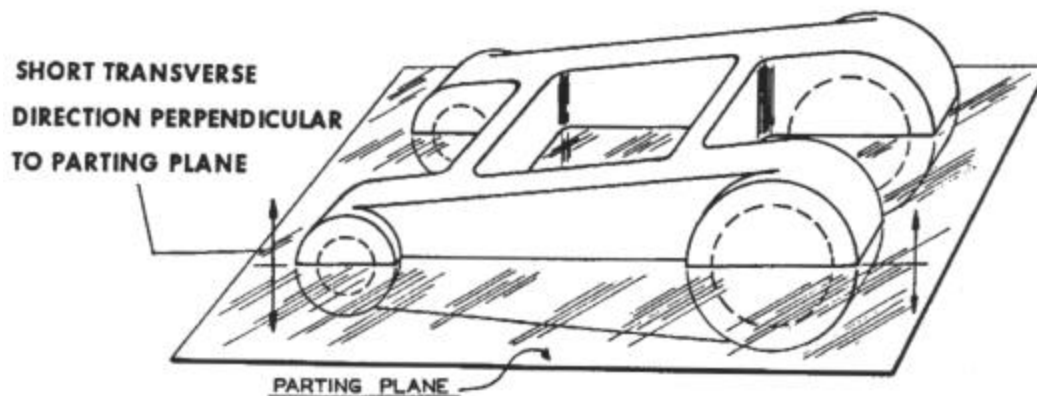
FIGURE 2. Examples of Tensile Stresses in Short Transverse Direction Applied During Assembly.



CROSS SECTION OF DIE FORGING SHOWING OUTLINE OF MACHINED PART

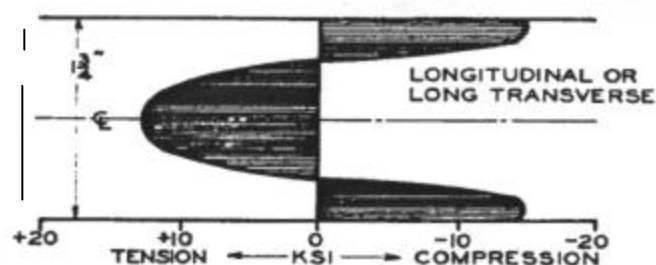


ASSEMBLY STRESS IN MACHINED FORGING WITH EXCESSIVE CLEARANCE

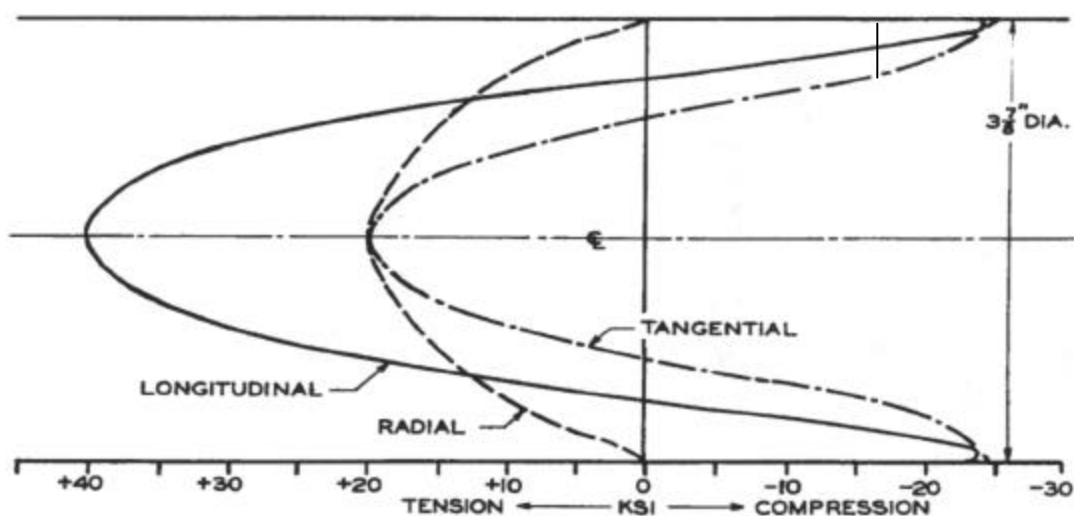


TYPICAL DIE FORGING, INTERFERENCE FIT BUSHINGS OR PINS IN HOLES SHOWN BY DASHED LINES IMPOSE SUSTAINED RESIDUAL TENSILE STRESSES IN TRANSVERSE DIRECTION

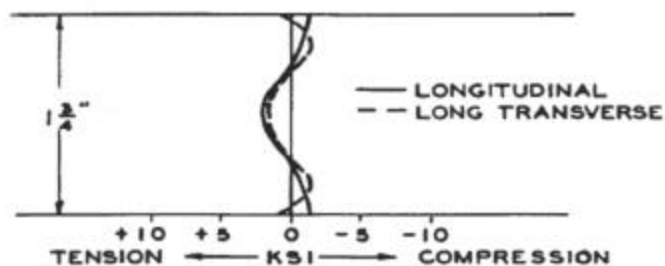
FIGURE 3. Examples of Tensile Stresses in Short Transverse Direction Resulting From Assembly.



7075-T6 PLATE, QUENCHED IN COLD WATER AND NOT STRESS RELIEVED.



7075-T6 ROD, QUENCHED IN COLD WATER AND NOT STRESS RELIEVED.

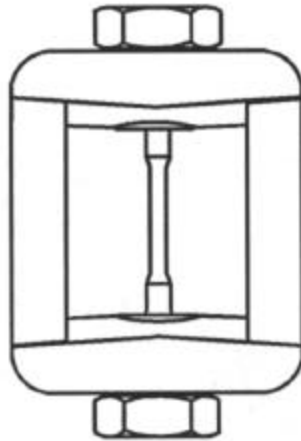


7075-T651 PLATE, STRETCHED 2% AFTER COLD WATER QUENCH.

FIGURE 4. Typical Residual Stress Distribution in 7075 Aluminum Alloy.

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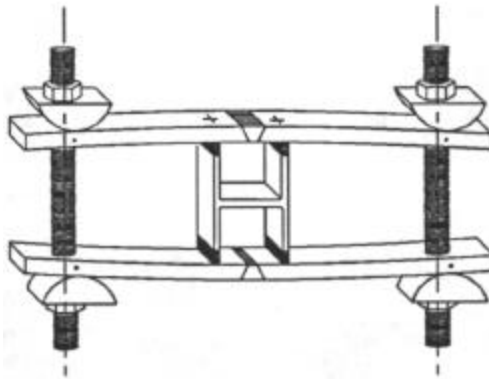
NASA-STD-P025
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(a) Round Tensile Specimen
and Stressing Frames

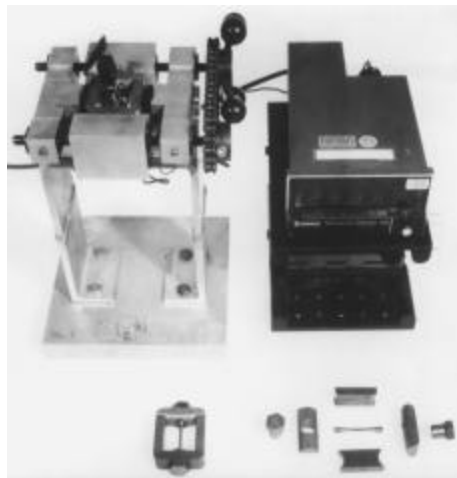


(b) C-Ring



(c) Bent-Beam Assembly

FIGURE 5. Typical Stress Corrosion Assemblies.



(a) Device and Frames Used to Stress Round Tensile Specimens



(b) Alternate Immersion Tester



(c) Salt Spray Cabinet

FIGURE 6. Typical Equipment Used For Stress Corrosion Evaluations.

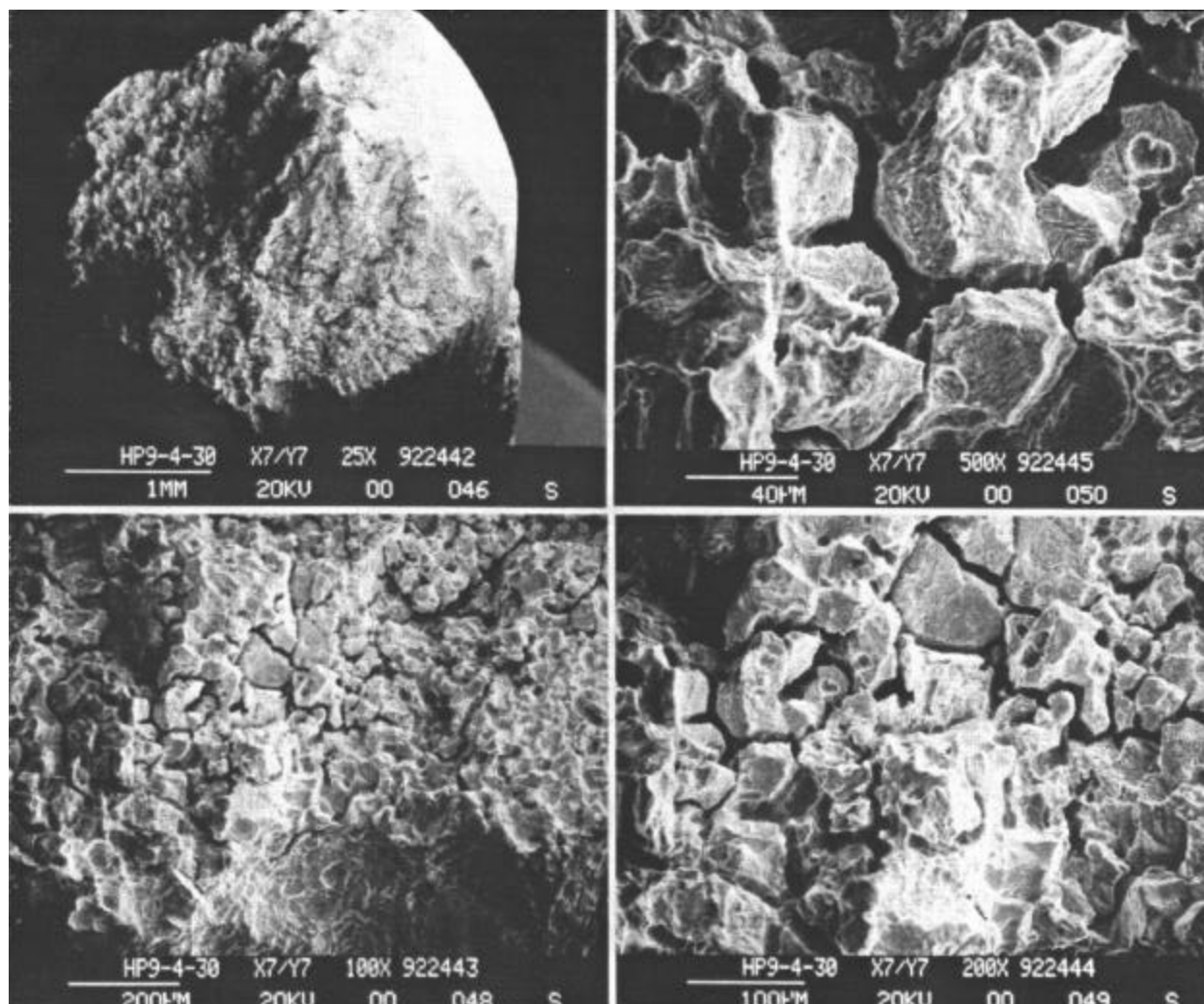
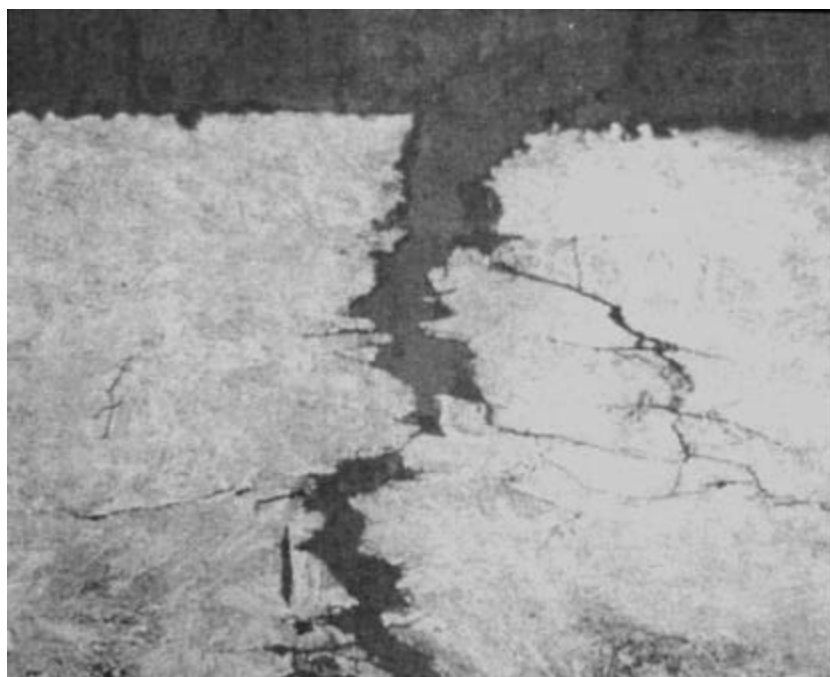
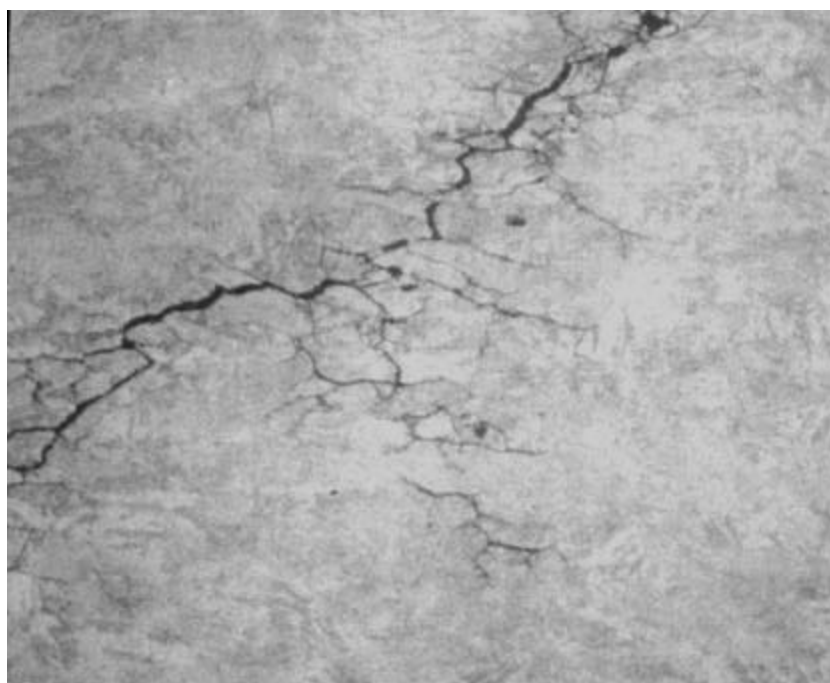
**HP 9-4-30 WELD**

FIGURE 7. Typical Scanning Electron Microscope Views of a Stress Corrosion Cracking Failure.



LONGITUDINAL MAG. 200X



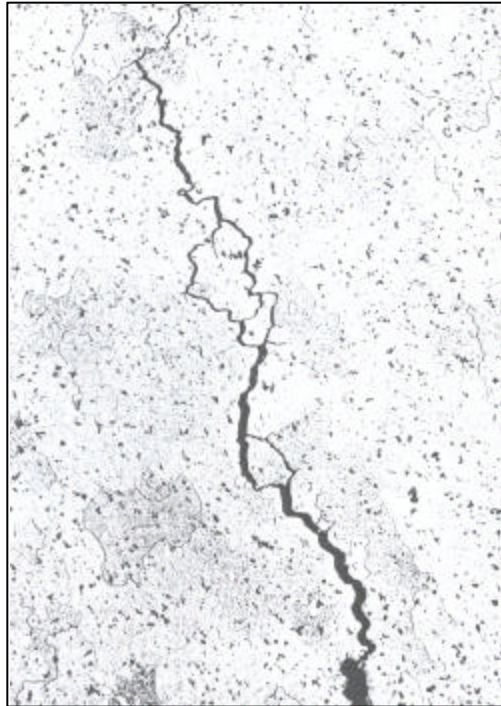
TRANSVERSE MAG. 200X

MARAGING STEEL 200

FIGURE 8. Typical Metallographic Views of a Stress Corrosion Cracking Failure.

DRAFT 1

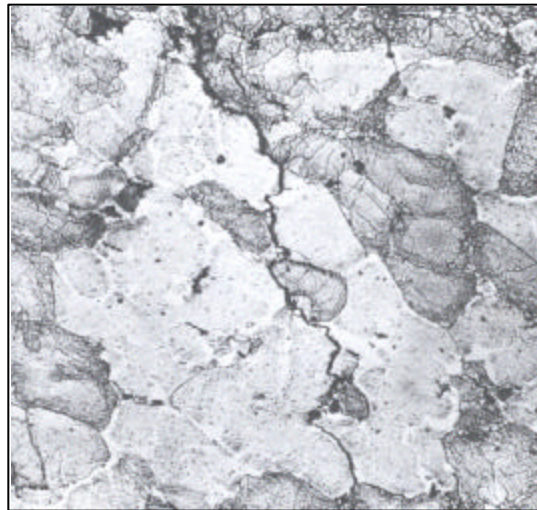
NASA-STD-P025
August 27, 2001



TRANSVERSE

MAG. 100X

FIGURE 9. Metallographic View of an Aluminum 2024-T4 Stress Corrosion Cracking Failure.



TRANSVERSE

MAG. 100X

FIGURE 10. Photomicrograph Of An Aluminum 7075-T6 Stress Corrosion Cracking Failure.

TABLE I-A. Ferrous Alloys With High Resistance To Stress Corrosion Cracking
In Sodium Chloride Environments

UNS Number	Alloy	Condition
G10900 (example)	Carbon Steel, 1000 Series	Below 1241MPa (180 ksi) UTS
G43400, K24728, etc.	Low Alloy Steel (e.g., 4340, D6AC, 4130, etc.)	Below 1241MPa (180 ksi) UTS
K08500	Music Wire	Cold Drawn
G10950	1095 Spring Steel	Tempered
K31820	HY-80 Steel	Tempered
Unknown	HY-130 Steel	Tempered
Unknown	HY-140 Steel	Tempered
Unknown	ASP 11	Aged
S20500 (example)	200 Series Stainless Steel (Unsensitized)	All
S31600 (example)	300 Series Stainless Steel (Unsensitized) ⁽¹⁾	All
S43000 (example)	400 Series Ferritic Stainless Steel	All
S24100	Nitronic 32, also known as 18-2 Mn	Annealed
S24000	Nitronic 33 ⁽²⁾ , also known as 18-3 Mn	Annealed
S21900	Nitronic 40, formerly 21-6-9 ⁽²⁾	Annealed
S21800	Nitronic 60	20% and 50% Cold Drawn
S66286	A286 Stainless Steel	All
S35000	AM 350 Stainless Steel	SCT 1000 ⁽³⁾ and Above
S35500	AM 355 Stainless Steel	SCT 1000 ⁽³⁾ and Above
S36200	AM 362 (Almar 362) Stainless Steel	3 Hours At 538°C (1000°F)
N08020	Carpenter 20Cb3 Stainless Steel	All
S45000	Custom 450 Stainless Steel	H1000 ⁽⁴⁾ and Above
S45500	Custom 455 Stainless Steel	H1000 ⁽⁴⁾ and Above
S15500	15-5 PH Stainless Steel	H1000 ⁽⁴⁾ and Above
S15700	PH 15-7 Mo Stainless Steel	CH900 ⁽⁵⁾
S17700	17-7 PH Stainless Steel	CH900 ⁽⁵⁾
K91472	HP9-4-20	All
Unknown	904L Stainless Steel ⁽⁶⁾	Annealed
N08367	AL-6XN ⁽⁶⁾	Annealed
S31803	ES 2205 ⁽⁶⁾	Annealed
S32950	7 Mo Plus ⁽⁶⁾	Annealed
N08026	20 Mo-6	Annealed
N08024	20 Mo-4	Annealed

Notes:

(1) Including weldments of 304L, 316L, 321, and 347. Excluding the free machining grades (e.g., 303).

(2) Including weldments.

(3) SCT 1000 = Sub-zero cooling and tempering at 538°C (1000 °F).

(4) H1000 = Hardened at 538°C (1000 °F).

(5) CH900 = Cold worked and aged at 482°C (900°F).

(6) Evaluated with the Slow Strain Rate Technique.

Chemical composition of ferrous alloys listed in this table with unknown UNS numbers:

HY-130: 0.12 C, 0.6-0.9 Mn, 4.75-5.25 Ni, 0.4-0.7 Cr, 0.3-0.65 Mo, 0.02 Ti, 0.05-0.10 V, 0.15 Cu, Bal Fe
HY-140: 0-0.12 C, 0.6-0.9 Mn, 0.2-0.35 Si, 4.75-5.25 Ni, 0.4-0.7 Cr, 0.3-0.65 Mo, 0.05-0.1 V, 0.02 Ti, 0-0.15 Cu, Bal Fe

ASP 11: 0-0.04 C, 0-0.8 Si, 0-1.5 Mn, 0-0.3 Cu, 5.3-6.9 Ni, 23.5-25 Cr, 1.45-1.95 Mo, 0.3-0.5 Nb, 0.001-0.003 B, Bal Fe

904L: 0.02 C max., 2 Mn max., 1 Si max., 0.03 P max., 0.015 S max., 19-23 Cr, 23-28 Ni, 4-5 Mo, 1-2 Cu

TABLE 1B. Aluminum Alloys With High Resistance to Stress Corrosion Cracking
in Sodium Chloride Environments⁽⁵⁾

Wrought			Cast		
UNS Number	Alloy ⁽¹⁾	Temper ⁽²⁾	UNS Number	Alloy	Temper
A91090 (example)	1000 Series	All	A03190, A13190	319.0, A319.0	As Cast
A92011	2011	T8	A03330, A13330	333.0, A333.0	As Cast
A92024	2024 Rod, Bar	T8	A03550, A33550	355.0, C355.0	T6
A92219	2219	T6, T8	A03560, A13560	356.0, A356.0	All
A92618	2618	T6	A03570	357.0	All
A93002 (example)	3000 Series	All	A03580	358.0 (B358.0 or Tens-50)	All
A95005 (example)	5000 Series	All ^{(3), (4)}	A03590	359.0	All
A96061 (example)	6000 Series	All	A03800, A13800	380.0, A380.0	As Cast
A97049	7049	T73	A05140	514.0 formerly 214	As Cast ⁽⁴⁾
A97050	7050	T73	A05180	518.0 formerly 218	As Cast ⁽⁴⁾
A97075	7075	T73	A05350	535.0 formerly Almag 35	As Cast ⁽⁴⁾
A97149	7149	T73	A07100	710.0 formerly A712.0	As Cast
A97475	7475	T73	A07110	711.0 formerly C712.0	As Cast

Notes:

- (1) Including weldments of the weldable alloys.
- (2) Including mechanically stress relieved (TX5X or TX5XX) tempers when applicable.
- (3) High magnesium alloys 5456, 5053, and 5086 shall be used in controlled tempers (H111, H112, H116, H117, H323, H343) for resistance to stress corrosion cracking and exfoliation.
- (4) Alloys with magnesium content greater than 3.0 percent are not recommended for high temperature application, 66° C (150°F) and above.
- (5) Because metallurgical processing of aluminum alloys usually results in a pronounced elongation of grains, the variation of susceptibility with grain orientation is more extensive than for other metals. The ratings presented in this document are for the direction of maximum susceptibility (short transverse direction for plate, transverse direction for bar, etc.). For specific stress corrosion performance ratings of heat-treatable wrought aluminum alloys in various mill product forms and in other directions see MIL-HDBK-5, Table 3.1.2.3.1, or ASTM G64.

TABLE I-C. Copper Alloys With High Resistance To Stress Corrosion Cracking In Sodium Chloride Environments

UNS Number	CDA ⁽¹⁾ Number	Condition (% Cold Rolled) ⁽²⁾
C11000	110	37
C17000	170	AT ⁽³⁾ , HT ⁽⁴⁾
C17200	172	AT ⁽³⁾ , HT ⁽⁴⁾
C19400	194	37
C19500	195	90
C23000	230	40
C28000	280	0
C42200	422	37
C44300	443	10
C51000	510	37
C52100	521	37
C52400	524	0
C60600	606	0
C61900	619	40 (9% B phase)
C61900	619	40 (95% B phase)
C63800	638	0
C65500	655	0
C68800	688	40
C70400	704	0
C70600	706	50
C71000	710	0
C71500	715	0
C72500	725	40
C75200	752	50
Notes:		
(1) Copper Development Association.		
(2) Maximum percent cold rolled for		
(3) AT - Annealed and precipitation hardened.		
(4) HT - Work hardened and precipitation hardened.		

TABLE 1D. Nickel Alloys With High Resistance to Stress Corrosion Cracking
in Sodium Chloride Environments

UNS Number	Alloy	Condition
N14052	Glass Seal 52 CR (51 Ni-49Fe)	All
K93601	Invar 36 (Including weldments ⁽¹⁾)	All
N10001	Hastelloy B	Solution Heat Treated
N10665	Hastelloy B2 ⁽¹⁾	Annealed
N10002	Hastelloy C	All
N06455	Hastelloy C-4 ⁽¹⁾	Annealed
N06022	Hastelloy C-22 ⁽¹⁾ (Including weldments ⁽¹⁾)	Annealed
N10276	Hastelloy C-276 ⁽¹⁾ (Including weldments ⁽¹⁾)	Annealed
N06030	Hastelloy G-30 ⁽¹⁾	Annealed
N06002	Hastelloy X	All
N08800	Incoloy 800	All
N08825	Incoloy 825	All
N09901	Incoloy 901	All
N19903	Incoloy 903	All
N06600	Inconel 600 (Including weldments)	Annealed
N06625	Inconel 625	Annealed
N07718	Inconel 718 (Including weldments)	All
N07750	Inconel X750	All
N05500	Monel K500 (Including weldments)	All
N09902	Ni-Span-C 902	All
N07041	Rene 41	All
unknown	Unitemp 212	All
N07001	Waspaloy	All
Not assigned	NASA-23	All
Notes: (1) Evaluated with the Slow Strain Rate Technique. Chemical composition of nickel alloys listed in this table with unknown UNS numbers: <i>Unitemp 212</i> : 25Ni, 16Cr, 4.1Ti, 0.57Cb, 0.06C, 0.1B, 0.07Zr, Bal Fe <i>NASA-23</i> : 30Ni, 14Co, 9Cr, 2.5Nb, 2Ti		

TABLE IE. Miscellaneous Alloys With High Resistance to Stress Corrosion Cracking
In Sodium Chloride Environments

UNS Number	Alloy	Condition
Unknown	Beryllium S-200C	Annealed
R30605	HS 25 (L-605)	All
R30188	HS-188 ⁽¹⁾	All
R30035	MP-35-N	Cold Worked and Aged
R30159	MP-159	Cold Work and Aged
R56320	Titanium 3Al-2.5V	All
R54520	Titanium 5Al-2.5Sn	All
R56400	Titanium 6Al-4V	All
R56410	Titanium 10V-2Fe-3Al	All
R58010	Titanium 13V-11Cr-3Al	All
unknown	Titanium IMI 550	All
M15100	Magnesium M1A	All
unknown	Magnesium LA141	Stabilized
unknown	Magnesium LAZ933	All
Notes: (1) Including weldments. Chemical composition of various miscellaneous alloys listed in this table with unknown UNS numbers: <i>Beryllium S-200C</i> : 98Be, 2BeO, 0.16max Al, 0.15max C, 0.18max Fe, 0.08max Mg, 0.08max Si <i>Magnesium LA141</i> : 1.2Al, 0.15Mn, 14Li		

TABLE II-A. Ferrous Alloys With Moderate Resistance to Stress Corrosion Cracking
in Sodium Chloride Environments

UNS Number	Alloy	Condition
G10900 (example)	Carbon Steel, 1000 Series	1241 to 1379 MPa (180 to 200 ksi) UTS
G43400, K24728, etc.	Low Alloy Steel (4340, D6AC, 4130, etc.)	1241 to 1379 MPa (180 to 200 ksi) UTS
S21800	Nitronic 60 ⁽¹⁾	Annealed
S43000 (example)	400 Series Martensitic Stainless Steel, except 440C	(2)
S35000	AM350 Stainless Steel	Below SCT 1000
S35500	AM355 Stainless Steel	Below SCT 1000
S45000	Custom 450 Stainless Steel	Below H1000
S45500	Custom 455 Stainless Steel	Below H1000
S13800	PH 13-8 Mo Stainless Steel	All
S15500	15-5 PH Stainless Steel	Below H1000
S17400	17-4 PH Stainless Steel ⁽³⁾	All
K91283	HP 9-4-30	All
Notes: (1) This alloy may be considered borderline between Tables I and II. (2) Tempering between 371°C and 593°C (700 °F and 1100°F) shall be avoided because corrosion and stress corrosion cracking resistance is lowered. (3) For better stress corrosion resistance tempering at 621°C (1150°F) is recommended.		

TABLE II-B. Magnesium Alloys With Moderate Resistance to Stress Corrosion Cracking in Sodium Chloride Environments

UNS Number	Alloy	Condition
M11311	AZ31B	All
M16600	ZK60A	All

TABLE II-C. Aluminum Alloys With Moderate Resistance to Stress Corrosion Cracking in Sodium Chloride Environments ^{(1), (2) (3) (4)}

Wrought		
UNS Number	Alloy	Condition
A92024	2024 Rod, Bar, Extrusion	T6, T62
A92024	2024 Plate, Extrusions	T8
A92048	2048 Plate	T8
A92124	2124 Plate	T8
Not assigned	2195 Al-Li	All
A94032	4032	T6
A95083	5083	All ⁽³⁾
A95086	5086	All ⁽³⁾
A95456	5456	All ⁽³⁾
A97001	7001	T75, T76
A97049	7049	T76
A97050	7050	T736, T76
A97075	7075	T76
A97175	7175	T736, T76
A97475	7475	T76
A97178	7178	T76
Notes: (1) Mechanically stress relieved products (TX5X or TX5XX) shall be specified where possible. (2) Sheet, unmachined extrusions, and unmachined plate are the most resistant forms. (3) Except for the controlled tempers listed in Footnote 4 of Table I-B, Aluminum Alloys. These alloys are not recommended for high temperature applications, 66°C (150°F) and above. (4) Because metallurgical processing of aluminum alloys usually results in a pronounced elongation of grains, the variation of susceptibility with grain orientation is more extensive than for other metals. The ratings presented in this document are for the direction of maximum susceptibility (short transverse direction for plate, transverse direction for bar, etc.). For specific stress corrosion performance ratings of heat-treatable wrought aluminum alloys in various mill product forms and in other directions see MIL-HDBK-5, Table 3.1.2.3.1, or ASTM G64. Chemical composition of 2195 Al-Li: 0.25-0.60Ag, 3.7-4.30Cu, 0-0.15Fe, 0.8-1.2Li, 0.25-0.80Mg, 0-0.25Mn, 0-0.12Si, 0-0.10Ti, 0-0.25Zn, 0.08-0.16Zr, Bal Al		

TABLE III-A. Ferrous Alloys With Low Resistance to Stress Corrosion Cracking
in Sodium Chloride Environments

UNS NUMBER	ALLOY	CONDITION
G10900 (example)	Carbon Steel, 1000 Series	Above 1379 MPa (200 ksi) UTS
G43400, K24728, etc.	Low Alloy Steel (4340, D6AC, 4130, etc.)	Above 1379 MPa (200 ksi) UTS
T20811	H-11 Tool Steel	Above 1379 MPa (200 ksi) UTS
S44004	440C Stainless Steel	All
K92810	18 Ni Maraging Steel ⁽¹⁾ , 200 Grade	Aged at 482°C (900°F)
K92890	18 Ni Maraging Steel, 250 Grade	Aged at 482°C (900°F)
K93120	18 Ni Maraging Steel, 300 Grade	Aged at 482°C (900°F)
unknown	18 Ni Maraging Steel, 350 Grade	Aged at 482°C (900°F)
S15700	PH 15-7Mo Stainless Steel	All except CH900
S17700	17-7 PH Stainless Steel	All except CH900
H93100	AISI 9310	Carburized
K88165	M-50 NIL	Carburized
unknown	CRB-7 Stainless Steel	All
K91283 (weldments)	HP9-4-30 Weldments	All
K92580	AerMet 100	H875 and H900
S32550	Ferrallium 255 ⁽²⁾	Annealed
S30300 and S30323	Free Machining 303 and 303 SE Stainless Steels ⁽²⁾	Annealed
Notes: (1) Carpenter NiMark (2) Evaluated by using the Slow Strain Rate Technique. Chemical composition of ferrous alloys listed in this table with unknown UNS numbers: <i>18 Ni Maraging Steel, 350 Grade:</i> per MIL-S-46850 <i>CRB-7 Stainless Steel:</i> 1.1C, 0.40Mn, 0.3Si, 14Cr, 2Mo, 1V, 0.25Cb		

**TABLE III-B. Aluminum Alloys With Low Resistance to Stress Corrosion
Cracking in Sodium Chloride Environments ^{(1) (2) (3)}**

WROUGHT			CAST		
UNS Number	Alloy	Condition	UNS Number	Alloy	Condition
A92011	2011	T3, T4	A02950	295.0 (195)	T6
A92014	2014	All	A02960	296.0 formerly B295.0 or B195	T6
A92017	2017	All	A05200	520.0 (220)	T4
A92024	2024	T3, T4	A07070	707.0 (607, Ternalloy 7)	T6
A92024	2024 Forgings	T6, T62, T8	A07120	712.0 formerly D712.0, D612, or 40E	As Cast
A92024	2024 Plate	T62			
A92090	Al-Li 2090	T8E41			
A92219	2219	T3, T4			
Unknown	BS L93	T6			
A97001	7001	T6			
A97005	7005	All			
A97039	7039	All			
A97075	7075	T6			
A97175	7175	T6			
A97079	7079	T6			
A97178	7178	T6			
A97475	7475	T6			
Notes:					
(1) Mechanically stress relieved products (TX5X or TX5XX) shall be specified where possible.					
(2) Sheet, unmachined extrusions, and unmachined plate are the least susceptible forms.					
(3) Because metallurgical processing of aluminum alloys usually results in a pronounced elongation of grains, the variation of susceptibility with grain orientation is more extensive than for other metals. The ratings presented in this document are for the direction of maximum susceptibility (short transverse direction for plate, transverse direction for bar, etc.). For specific stress corrosion performance ratings of heat-treatable wrought aluminum alloys in various mill product forms and in other directions see MIL-HDBK-5, Table 3.1.2.3.1, or ASTM G64.					

TABLE III-C. Copper Alloys With Low Resistance to Stress Corrosion Cracking
in Sodium Chloride Environments

UNS Number	CDA ⁽¹⁾ Number	Condition ⁽²⁾ % Cold Rolled
C26000	260	50
C35300	353	50
C44300	443	40
C67200	672	50, Annealed
C68700	687	10, 40
C76200	762	A, 25, 50
C76600	766	38
C77000	770	38, 50, Annealed
C78200	782	50
Notes: (1) Copper Development Association. (2) Ratings based on listed conditions only.		

TABLE III-D. Magnesium Alloys With Low Resistance to Stress Corrosion Cracking
in Sodium Chloride Environments

UNS Number	Alloy	Condition
M11610	AZ61A	All
M11800	AZ80A	All

**TABLE IV. COMBINED TABLE FOR THE RELATIVE RESISTANCE TO STRESS CORROSION CRACKING OF METALLIC MATERIALS IN SODIUM CHLORIDE ENVIRONMENTS
(COMBINES TABLES IA THROUGH IIID)**

Material	UNS No. (1)	Alloy	Condition	Table		
				I	II	III
Ferrous Alloys	G10900 (example)	Carbon Steel, 1000 Series	Below 1241 MPa (180 ksi) UTS	X		
	G10900 (example)	Carbon Steel, 1000 Series	1241 to 1379 MPa (180 to 200 ksi) UTS		X	
	G10900 (example)	Carbon Steel, 1000 Series	Above 1379 MPa (200 ksi) UTS			X
	G43400, K24728, etc.	Low Alloy Steel (e.g., 4340, D6AC, 4130, etc.)	Below 1241 MPa (180 ksi) UTS	X		
	G43400, K24728, etc.	Low Alloy Steel (4340, D6AC, 4130, etc.)	1241 to 1379 MPa (180 to 200 ksi) UTS		X	
	G43400, K24728, etc.	Low Alloy Steel (4340, D6AC, 4130, etc.)	Above 1379 MPa (200 ksi) UTS			X
	K08500	Music Wire	Cold Drawn	X		
	G10950	1095 Spring Steel	Tempered	X		
	K31820	HY-80 Steel	Tempered	X		
	Unknown UNS No.	HY-130 Steel	Tempered	X		
	Unknown UNS No.	HY-140 Steel	Tempered	X		
	Unknown UNS No.	ASP 11	Aged	X		
	S20500 (example)	200 Series Stainless Steel (Unsensitized)	All	X		
	S31600 (example)	300 Series Stainless Steel (Unsensitized) (2)	All	X		
	S30300 and S30323 (examples)	Free machining grades of the 300 series (e.g., 303, 303 SE) Stainless Steels (8)	Annealed			X
	S43000 (example)	400 Series Ferritic Stainless Steel	All	X		
	S43000 (example)	400 Series Martensitic Stainless Steel, except 440C	See Note (9)		X	
	S44004	440C Stainless Steel	All			X
	S24100	Nitronic 32, also known as 18-2 Mn	Annealed	X		
	S24000	Nitronic 33 (3), also known as 18-3 Mn	Annealed	X		
	S21900	Nitronic 40 Formerly 21-6-9 (3)	Annealed	X		
	S21800	Nitronic 60	20% and 50% Cold Drawn	X		
	S21800	Nitronic 60 (4)	Annealed		X	
	S66286	A286 Stainless Steel	All	X		
	S35000	AM 350 Stainless Steel	SCT 1000 (5) and Above	X		
	S35000	AM350 Stainless Steel	Below SCT 1000		X	
	S35500	AM 355 Stainless Steel	SCT 1000 (5) and Above	X		
	S35500	AM355 Stainless Steel	Below SCT 1000		X	
	S36200	AM 362 (Almar 362) SS	3 Hours At 538°C (1000°F)	X		
	N08020	Carpenter 20Cb3 Stainless Steel	All	X		
	S45000	Custom 450 Stainless Steel	H1000 (6) and Above	X		
	S45000	Custom 450 Stainless Steel	Below H1000		X	
	S45500	Custom 455 Stainless Steel	H1000 (6) and Above	X		
	S45500	Custom 455 Stainless Steel	Below H1000		X	
	S15500	15-5 PH Stainless Steel	H1000 (6) and Above	X		
	S15500	15-5 PH Stainless Steel	Below H1000		X	
	S15700	PH 15-7 Mo Stainless Steel	CH900 (7)	X		
	S15700	PH 15-7Mo Stainless Steel	All except CH900			X
	S17700	17-7 PH Stainless Steel	CH900 (7)	X		
	S17700	17-7 PH Stainless Steel	All except CH900			X
	K91472	HP9-4-20	All	X		
	Unknown UNS No.	904L Stainless Steel (8)	Annealed	X		

TABLE IV. COMBINED TABLE FOR THE RELATIVE RESISTANCE TO STRESS CORROSION CRACKING OF METALLIC MATERIALS IN SODIUM CHLORIDE ENVIRONMENTS (CONT'D)
(COMBINES TABLES IA THROUGH IIID)

Material	UNS No.	Alloy	Condition	Table		
				I	II	III
Ferrous Alloys (Continuation)	N08367	AL-6XN ⁽⁸⁾	Annealed	X		
	S31803	ES 2205 ⁽⁸⁾	Annealed	X		
	S32950	7 Mo Plus ⁽⁸⁾	Annealed	X		
	N08026	20 Mo-6	Annealed	X		
	N08024	20 Mo-4	Annealed	X		
	S13800	PH 13-8 Mo Stainless Steel	All		X	
	S17400	17-4 PH Stainless Steel ⁽¹⁰⁾	All		X	
	K91283	HP 9-4-30	All		X	
	T20811	H-11 Tool Steel	Above 1379 MPa (200 ksi) UTS			X
	K92810	18 Ni Maraging Steel ⁽¹¹⁾ , 200 Grade	Aged at 482°C (900°F)			X
	K92890	18 Ni Maraging Steel, 250 Grade	Aged at 482°C (900°F)			X
	K93120	18 Ni Maraging Steel, 300 Grade	Aged at 482°C (900°F)			X
	unknown	18 Ni Maraging Steel, 350 Grade	Aged at 482°C (900°F)			X
	H93100	AISI 9310	Carburized			X
	K88165	M-50 NIL	Carburized			X
	unknown	CRB-7 Stainless Steel	All			X
	K91283 (weldments)	HP9-4-30 Weldments	All			X
	K92580	AerMet 100	H875 and H900			X
	S32550	Ferrallium 255 ⁽⁸⁾	Annealed			X
Aluminum Alloys - Wrought See Notes (12), (13), (14), and (15)	A91090 (example)	1000 Series	All	X		
	A92011	2011	T8	X		
	A92011	2011	T3, T4			X
	A92024	2024 Rod, Bar	T8	X		
	A92024	2024 Rod, Bar, Extrusion	T6, T62		X	
	A92024	2024 Plate, Extrusions	T8		X	
	A92024	2024 Plate	T62			X
	A92024	2024	T3, T4			X
	A92024	2024 Forgings	T6, T62, T8			X
	A92048	2048 Plate	T8		X	
	A92124	2124 Plate	T8		X	
	Not assigned	2195 Al-Li	All		X	
	A92219	2219	T6, T8	X		
	A92219	2219	T3, T4			X
	A92618	2618	T6	X		
	A93002 (example)	3000 Series	All	X		
	A94032	4032	T6		X	

**TABLE IV. COMBINED TABLE FOR THE RELATIVE RESISTANCE TO STRESS CORROSION CRACKING OF METALLIC MATERIALS IN SODIUM CHLORIDE ENVIRONMENTS (CONT'D)
(COMBINES TABLES IA THROUGH IIID)**

Material	UNS No.	Alloy	Condition	Table		
				I	II	III
Aluminum Alloys - Wrought See Notes (12), (13), (14), and (15) (Continuation)	A95005 (example)	5000 Series	See footnotes (16) and (17)	X		
	A95083	5083	See footnote (16)		X	
	A95086	5086	See footnote (16)		X	
	A95456	5456	See footnote (16)		X	
	A96061 (example)	6000 Series	All	X		
	A97001	7001	T75, T76		X	
	A97049	7049	T73	X		
	A97049	7049	T76		X	
	A97050	7050	T73	X		
	A97050	7050	T74, T76		X	
	A97075	7075	T73	X		
	A97075	7075	T76		X	
	A97075	7075	T6			X
	A97149	7149	T73	X		
	A97175	7175	T74, T76		X	
	A97178	7178	T76		X	
	A97475	7475	T73	X		
	A97475	7475	T76		X	
	A92014	2014	All			X
	A92017	2017	All			X
	A92090	Al-Li 2090	T8E41			X
	unknown	BS L93	T6			X
	A97001	7001	T6			X
	A97005	7005	All			X
	A97039	7039	All			X
	A97175	7175	T6			X
	A97079	7079	T6			X
	A97178	7178	T6			X
	A97475	7475	T6			X
Aluminum Alloys -Cast	A03190, A13190	319.0, A319.0	As Cast	X		
	A03330, A13330	333.0, A333.0	As Cast	X		
	A03550, A33550	355.0, C355.0	T6	X		
	A03560, A13560	356.0, A356.0	All	X		
	A03570	357.0	All	X		
	A03580	358.0 (B358.0 or Tens -50)	All	X		
	A03590	359.0	All	X		
	A03800, A13800	380.0, A380.0	As Cast	X		
	A05140	514.0 formerly 214	As Cast (17)	X		
	A05180	518.0 formerly 218	As Cast (17)	X		
	A05350	535.0 formerly Almag 35	As Cast (17)	X		
	A07100	710.0 formerly A712.0	As Cast	X		
	A07110	711.0 formerly C712.0	As Cast	X		
	A02950	295.0 (195)	T6			X
	A02960	296.0 formerly B295.0 or B195	T6			X
	A05200	520.0 (220)	T4			X
	A07070	707.0 (607, Ternalloy 7)	T6			X
	A07120	712.0 formerly D712.0, D612, or 40E	As Cast			X

TABLE IV. COMBINED TABLE FOR THE RELATIVE RESISTANCE TO STRESS CORROSION CRACKING OF METALLIC MATERIALS IN SODIUM CHLORIDE ENVIRONMENTS (CONT'D) (COMBINES TABLES IA THROUGH IIID)						
Material	UNS No.	Alloy	Condition (% Cold Rolled)	Table		
				I	II	III
Copper Alloys (18), (19)	C11000	110	37	X		
	C17000	170	AT (20), HT (21)	X		
	C17200	172	AT (20), HT (21)	X		
	C19400	194	37	X		
	C19500	195	90	X		
	C23000	230	40	X		
	C28000	280	0	X		
	C42200	422	37	X		
	C44300	443	10	X		
	C51000	510	37	X		
	C52100	521	37	X		
	C52400	524	0	X		
	C60600	606	0	X		
	C61900	619	40 (9% B phase)	X		
	C61900	619	40 (95% B phase)	X		
	C63800	638	0	X		
	C65500	655	0	X		
	C68800	688	40	X		
	C70400	704	0	X		
	C70600	706	50	X		
	C71000	710	0	X		
	C71500	715	0	X		
	C72500	725	40	X		
	C75200	752	50	X		
	C26000	260	50			X
	C35300	353	50			X
	C44300	443	40			X
	C67200	672	50, Annealed			X
	C68700	687	10, 40			X
	C76200	762	A, 25, 50			X
	C76600	766	38			X
	C77000	770	38, 50 Annealed			X
	C78200	782	50			X
Nickel Alloys	N14052	Glass Seal 52 CR (51Ni-49Fe)	All	X		
	K93601	Invar 36 (Including weldments (8))	All	X		
	N10001	Hastelloy B	Solution Heat Treated	X		
	N10665	Hastelloy B2 (8)	Annealed	X		
	N10002	Hastelloy C	All	X		
	N06455	Hastelloy C-4 (8)	Annealed	X		
	N06022	Hastelloy C-22 (8) (Including weldments (8))	Annealed	X		
	N10276	Hastelloy C-276 (8) (Including weldments (8))	Annealed	X		
	N06030	Hastelloy G-30 (8)	Annealed	X		

TABLE IV. COMBINED TABLE FOR THE RELATIVE RESISTANCE TO STRESS CORROSION CRACKING OF METALLIC MATERIALS IN SODIUM CHLORIDE ENVIRONMENTS (CONT'D) (COMBINES TABLES IA THROUGH IIID)						
Material	UNS No.	Alloy	Condition	Table		
				I	II	III
Nickel Alloys (Continuation)	N06002	Hastelloy X	All	X		
	N08800	Incoloy 800	All	X		
	N08825	Incoloy 825	All	X		
	N09901	Incoloy 901	All	X		
	N19903	Incoloy 903	All	X		
	N06600	Inconel 600 (Including weldments)	Annealed	X		
	N06625	Inconel 625	Annealed	X		
	N07718	Inconel 718 (Including weldments)	All	X		
	N07750	Inconel X750	All	X		
	N05500	Monel K500 (Including weldments)	All	X		
	N09902	Ni-Span-C 902	All	X		
	N07041	Rene 41	All	X		
	Unknown UNS No.	Unitemp 212	All	X		
	N07001	Waspaloy	All	X		
	No UNS No. assigned	NASA-23	All	X		
Titanium Alloys	R56320	Titanium 3Al-2.5V	All	X		
	R54520	Titanium 5Al-2.5Sn	All	X		
	R56400	Titanium 6Al-4V	All	X		
	R56410	Titanium 10V-2Fe-3Al	All	X		
	R58010	Titanium 13V-11Cr-3Al	All	X		
	Unknown UNS No.	Titanium IMI 550	All	X		
Magnesium Alloys	M15100	Magnesium M1A	All	X		
	Unknown UNS No.	Magnesium LA141	Stabilized	X		
	Unknown UNS No.	Magnesium LAZ933	All	X		
	M11311	AZ31B	All		X	
	M16600	ZK60A	All		X	
	M11610	AZ61A	All			X
	M11800	AZ80A	All			X
Miscellaneous Alloys	Unknown UNS No.	Beryllium S-200C	Annealed	X		
	R30605	HS 25 (L-605)	All	X		
	R30188	HS-188 (3)	All	X		
	R30035	MP-35-N	Cold Worked and Aged	X		
	R30159	MP-159	Cold Worked and Aged	X		

Notes for Table IV:

- (1) UNS = Unified Numbering System
- (2) Including weldments of 304L, 316L, 321, and 347. Excluding the free machining grades (e.g., 303, 303SE).
- (3) Including weldments.
- (4) This alloy may be considered borderline between Table I and II.
- (5) SCT 1000 = Sub-zero cooling and tempering at 538°C (1000 °F).
- (6) H1000 = Hardened at 538°C (1000 °F).
- (7) CH900 = Cold worked and aged at 482°C (900°F).
- (8) Evaluated with the Slow Strain Rate Technique.
- (9) Tempering between 371°C and 593°C (700 °F and 1100°F) shall be avoided because corrosion and stress corrosion cracking resistance is lowered.
- (10) For better stress corrosion resistance tempering at 621°C (1150°F) is recommended.
- (11) Carpenter NiMark
- (12) Mechanically stress relieved products (TX5X or TX5XX) shall be specified where possible.
- (13) Sheet, unmachined extrusions, and unmachined plate are the least susceptible forms.
- (14) Including weldments of the weldable alloys.
- (15) Because metallurgical processing of aluminum alloys usually results in a pronounced elongation of grains, the variation of susceptibility with grain orientation is more extensive than for other metals. The ratings presented in this document are for the direction of maximum susceptibility (short transverse direction for plate, transverse direction for bar, etc.). For specific stress corrosion performance ratings of heat-treatable wrought aluminum alloys in various mill product forms and in other directions see MIL-HDBK-5, Table 3.1.2.3.1, or ASTM G64.
- (16) High magnesium alloys 5456, 5083, and 5086 shall be used in controlled tempers (H111, H112, H116, H117, H323, H343) for resistance to stress corrosion cracking and exfoliation. These alloys are not recommended for high temperature applications, 66°C (150°F) and above.
- (17) Alloys with magnesium content greater than 3.0 percent are not recommended for high temperature application, 66° C (150°F) and above.
- (18) Designation of the alloys is from the Copper Development Association.
- (19) The maximum percent cold rolled for which stress corrosion data is available is presented under the condition column. Ratings based on listed conditions only.
- (20) AT - Annealed and precipitation hardened.
- (21) HT - Work hardened and precipitation hardened.

Chemical composition of alloys listed in this table with unknown UNS numbers:

HY-130: 0.12 C, 0.6-0.9 Mn, 4.75-5.25 Ni, 0.4-0.7 Cr, 0.3-0.65 Mo, 0.02 Ti, 0.05-0.10 V, 0.15 Cu, Bal Fe

HY-140: 0-0.12 C, 0.6-0.9 Mn, 0.2-0.35 Si, 4.75-5.25 Ni, 0.4-0.7 Cr, 0.3-0.65 Mo, 0.05-0.1 V, 0.02 Ti, 0-0.15 Cu, Bal Fe

ASP 11: 0-0.04 C, 0-0.8 Si, 0-1.5 Mn, 0-0.3 Cu, 5.3-6.9 Ni, 23.5-25 Cr, 1.45-1.95 Mo, 0.3-0.5 Nb, 0.001-0.003 B, Bal Fe

904L: 0.02 C max., 2 Mn max., 1 Si max., 0.03 P max., 0.015 S max., 19-23 Cr, 23-28 Ni, 4-5 Mo, 1-2 Cu

Unitemp 212: 25 Ni, 16 Cr, 4.1 Ti, 0.57 Cb, 0.06 C, 0.1 B, 0.07 Zr, Bal Fe

NASA-23: 30 Ni, 14 Co, 9 Cr, 2.5 Nb, 2 Ti

Beryllium S-200C: 98 Be, 2 BeO, 0.16 max Al, 0.15 max C, 0.18 max Fe, 0.08 max Mg, 0.08 max Si

Magnesium LA141: 1.2 Al, 0.15 Mn, 14 Li

Al-Li 2195: 0.25-0.60 Ag, 3.7-4.30 Cu, 0-0.15 Fe, 0.8-1.2 Li, 0.25-0.80 Mg, 0-0.25 Mn, 0-0.12 Si, 0-0.10 Ti, 0-0.25 Zn, 0.08-0.16 Zr, Bal Al

18 Ni Maraging Steel, 350 Grade: per MIL-S-46850

CRB-7 Stainless Steel: 1.1 C, 0.40 Mn, 0.3 Si, 14 Cr, 2 Mo, 1 V, 0.25 Cb

APPENDIX A.

{TC}Stress Corrosion References

No.	File No.	Reference
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