Stress-corrosion cracking (SCC) is a cracking phenomenon caused by the conjoint action of a tensile stress and the presence of a specific corrosive environment. For such cracks to develop on a structure, three conditions must be met simultaneously. A specific crack-promoting environment must be present, the metallurgy of the material must be susceptible to SCC, and the tensile stresses must be above some threshold value.

Stress-corrosion cracking can result in catastrophic failure, often without any prior warning. Many different mechanisms for SCC have been proposed, but in general, these mechanisms can be divided into two general groups: anodic dissolution mechanisms and cathodic mechanisms. The parameters that control SCC can be divided into materials, environmental, and mechanical parameters.

Stress-corrosion cracking failures resemble brittle fracture. This means that typically little, if any, indication of metal ductility is visible at the origin of fracture. The cracking actually is a form of subcritical flaw growth, either intergranular or transgranular, depending on the particular combination of microstructure, environment, and strain rate. However, it is more difficult to design against environmentally assisted cracking than against fracture. Reasons for this difficulty include compositional, mechanical, and metallurgical synergisms, and the consequent need to consider a range of environmental variables, as well as their variations with time and their interactions with loading and metallurgical variables. This article overviews SCC susceptibility testing, and describes constant extension testing and the most suitable types of specimens.

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Tests for Stress-Corrosion

Stress-corrosion cracking is a time-dependent process in which a metallurgically susceptible material fractures prematurely due to the synergistic interaction of a corrosive environment and sustained tensile stress at the metal surface. The tensile stress may be residual stress resulting from heat treatment or fabrication of the metal, may be developed by external loading, or may be a combination of these conditions.

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SCC susceptibility tests
To determine the susceptibility of alloys to SCC, several types of tests are available. If the objective is to predict service behavior or to screen alloys for service in a specific environment, it is often necessary to find SCC information in a relatively short period of time. This requires acceleration of testing by increasing the severity of the environment or the critical test parameters. Testing can be accelerated by raising the temperature or the concentration of corrosive species, and by electrochemical stimulation. Parameters that can be changed to shorten the testing time include the application of higher stresses, continuous straining, and precracking, which allows bypassing of the crack-nucleation phase of the SCC sequence.

Stress-corrosion specimens can be divided into two categories: smooth and precracked or notched. Further distinctions can be made in the loading mode, such as constant deflection, constant load, and constant extension or strain rate.

During the production of wrought alloys, the metal is forced predominantly in one direction, so that the grains are elongated in the direction of flow. Because it is important to relate the application of stress and the grain flow direction, two conventions have been chosen to relate the parameters.

In one system, which is primarily for smooth specimens, the three stressing directions are designated by indicating the direction of the stress, namely longitudinal (L), long-transverse (LT), transverse (T), and short transverse (ST).

A second system, which is particularly useful for precracked specimens, indicates both the cracking plane and the direction of crack propagation. Three letters (L, T, and W) indicate three perpendicular directions: L for the longitudinal direction, T for the thickness direction, and W for the width direction. The crack plane is indicated by the direction normal to the crack plane.

Fig. 1 — Grain orientations in standard wrought forms of alloys.
Cracking
to the crack, and the crack propagation is indicated by one of the directions L, T, or W. Figure 2 shows the various fracture plane orientations.

Other parameters that play an important role in SCC testing are surface condition and residual stress. The nucleation of stress-corrosion cracks strongly depends on initial surface reactions. The surface condition of the test specimens, particularly smooth specimens, has a significant effect on the test results. Smooth test specimens are often tested with a mechanically (machined or abraded) or (electro)chemically treated surface. It is very important to avoid or to remove machining marks or scratches perpendicular to the loading direction.

**Constant extension testing**

Smooth SCC specimens allow for the evaluation of the total SCC life, which includes crack nucleation and propagation. Specimens may be tested under constant extension or strain, constant load, and constant extension or strain rate. The selection of a specific test method for SCC strongly depends on the particular service application and the time allowed for testing.

Constant-extension or constant-strain tests on smooth specimens do not require elaborate fixtures. Depending on the specific configuration of the test articles, different types of constant-extension tests are available. The most common types are bent-beam, U-bend, C-ring, and tensile type specimens.

- **Bent-beam specimens:** The different types of bent-beam specimens are illustrated in Fig. 3. These specimens are for sheet, plate, and flat-extruded materials, or wires and extrusions with a circular cross section. Specimens may be bent in several ways, depending on dimensions. They may be stressed by bending in a stressing device while restraining the ends. During stress-corrosion testing, both specimen and stressing devices are exposed to the test environment. The most simple loading arrangement is the two-point loaded bent-beam, which is suitable only for relatively thin sheet or wire material. The elastic stress at the midpoint of the specimen can be estimated:

\[
L = (ktE \sigma)^{-1} (H/ktE)
\]

where \( L \) is the specimen length, \( \sigma \) is the maximum stress, \( E \) is the elastic modulus, \( H \) is the length of holder, \( t \) is the specimen thickness, and \( k \) is the empirical constant, 1.280.

Three-point bend specimen tests are commonly chosen because of the ease of load application and the ability to load the same rig for different stresses. The load is applied by turning a bolt in the rig, deflecting the specimen. The elastic stress at the midpoint of the specimen is then calculated:

\[
\sigma = 6Ety/H^2
\]

where \( \sigma \) is the maximum tensile stress, \( E \) is the elastic modulus, \( t \) is the specimen thickness, \( y \) is the maximum deflection, and \( H \) is the length of the holder.

However, this test has a number of disadvantages. For example, dissimilar metal corrosion and/or crevice corrosion can develop under the bolt. Once the crack has formed, the stress conditions change such that the outer layer of the specimen is not subject to a tensile stress alone, but to a complex combination of tensile and bending stresses. The propagating crack will then deviate from the centerline. Thus, the three-point bend test should be considered only as a qualitative test to determine the susceptibility to stress-corrosion cracking.

- **Four-point bend specimens** provide a uniform tensile stress over a relatively large area of the specimen. With the four-point bend test, tensile stresses can be maintained during the growth of the crack. The elastic stress in the outer layer of the specimen between the two inner supports can be calculated:

\[
\sigma = 12Ety/(3H^2 - 4A^2)
\]

where \( s \) is the maximum tensile stress, \( E \) is the elastic modulus, \( t \) is the specimen thickness, \( y \) is the maximum deflection, \( H \) is the distance between outer supports, and \( A \) is the distance between outer and inner supports.

- **U-bend specimens** are prepared by bending a strip 180 degrees around a mandrel with a predetermined radius. Figure 4 shows that specimens may also be bent less than 180 degrees.
The circumferential elastic stresses \( \sigma_c \) and transverse strain \( \epsilon_t \) to the stressed surface. \( Z \) is the wall thickness, \( E \) is the elastic modulus, and \( \mu \) is Poisson’s ratio, \( \epsilon_c \) is the circumferential strain, and \( \epsilon_t \) is the transverse strain.

**Tensile specimens**

For specific purposes such as alloy development, a large number of stress-corrosion specimens need to be evaluated. Tensile specimens may be suitable for this purpose if those for measuring tensile properties in air are adapted to SCC, as discussed in ASTM G 49. When uniaxially loaded in tension, the stress pattern is simple and uniform, and the magnitude of the applied stress can be accurately measured. Specimens can be quantitatively stressed by equipment that applies either a constant load, a constant strain, or an increasing load or strain.

This type of test is one of the most versatile methods of SCC testing, because of the flexibility permitted in the type and size of the test specimen, stressing procedures, and the range of stress levels. It allows the simultaneous exposure of unstressed specimens (no applied load) with stressed specimens, and permits subsequent tension testing to distinguish between the effects of true SCC and mechanical overload.

A wide range of specimen sizes would be appropriate, depending primarily on the dimensions of the product. Note that stress-corrosion test results can be significantly influenced by the cross section of the test specimen. Although large specimens may be more representative of most structures, they often cannot be prepared from the available product forms being evaluated. They also present more difficulties in stressing and handling in laboratory testing.

Therefore, smaller cross-sectional specimens are also frequently selected. They have a greater sensitivity to SCC initiation, usually yield test results rapidly, and permit greater convenience in testing. However, the smaller specimens are more difficult to machine, and results are more likely to be influenced by extraneous stress concentrations as a consequence of nonaxial loading, corrosion pits, and so on. Consequently, specimens less than about 10 mm (0.4 in.) in gage length and 3 mm (0.12 in.) in diameter are not recommended, except when testing wire specimens.

Tension specimens including machined notches are suitable for studying SCC and hydrogen embrittlement. The presence of a notch induces a triaxial stress state at the root of the notch, in which the actual stress will be greater by a concentration factor that is dependent on the notch geometry. The advantages of such specimens include the localization of cracking to the notch region and acceleration of failure. However, unless directly related to practical service conditions, the results may not be relevant.

Tension specimens can be subjected to a wide range of stress levels associated with either elastic or plastic strain. Because the stress system is intended to be essentially uniaxial (except in the cast of notched specimens), great care must be exercised in the construction of stressing frames to prevent or minimize bending or torsional stresses.

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For more information: The information in this article was extracted from the “Corrosion Testing” section of the ASM Metals Handbook, Desk Edition. It is available in both book and CD ROM. See the table of contents on the ASM Web site, www.asminternational.org. Click on “Shop ASM,” then click on the picture of the book, then click on the blue underlined title to view the table of contents. You can also order online.