Designation: G 30 – 97

Standard Practice for Making and Using U-Bend Stress-Corrosion Test Specimens[1]

This standard is issued under the fixed designation G 30; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

1. Scope

1.1 This practice describes procedures for making and using U-bend specimens for the evaluation of stress-corrosion cracking in metals. The U-bend specimen is generally a rectangular strip which is bent 180° around a predetermined radius and maintained in this constant strain condition during the stress-corrosion test. Bends slightly less than or greater than 180° are sometimes used. Typical U-bend configurations showing several different methods of maintaining the applied stress are shown in Fig. 1.

1.2 U-bend specimens usually contain both elastic and plastic strain. In some cases (for example, very thin sheet or small diameter wire) it is possible to form a U-bend and produce only elastic strain. However, bent-beam (Practice G 39 or direct tension (Practice G 49)) specimens are normally used to study stress-corrosion cracking of strip or sheet under elastic strain only.

1.3 This practice is concerned only with the test specimen and not the environmental aspects of stress-corrosion testing which are discussed elsewhere **(1)**,[2] in Practices G 35, G 36, G 37, G 41, G 44, G 103 and Test Method G 123.

1.4 The values stated in SI units are to be regarded as standard. The inch-pound units in parentheses are provided for information.

1.5 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.* (For more specific safety hazard information see Section 10.)

2. Referenced Documents

2.1 *ASTM Standards:*

E 3 Methods of Preparation of Metallographic Specimens[3]

G 1 Practice for Preparing, Cleaning, and Evaluating Corrosion Test Specimens[3]

G 15 Terminology Relating to Corrosion and Corrosion Testing[4]

G 35 Practice for Determining the Susceptibility of Stainless Steels and Related Nickel-Chromium-Iron Alloys to Stress Corrosion Cracking in Polythionic Acids[3]

G 36 Practice for Evaluating Stress-Corrosion Cracking Resistance of Metals and Alloys in a Boiling Magnesium Chloride Solution[3]

G 37 Practice for Use of Mattsson's Solution of pH 7.2 to Evaluate the Stress-Corrosion Cracking Susceptibility of Copper-Zinc Alloys[3]

G 39 Practice for Preparation and Use of Bent-Beam Stress-Corrosion Specimens[3]

G 41 Practice for Determining Cracking Susceptibility of Metals Exposed Under Stress to a Hot Salt Environment[3]

G 44 Practice for Evaluating Stress Corrosion Cracking Resistance of Metals and Alloys by Alternate Immersion in 3.5 % Sodium Chloride Solution[3]

G 49 Practice for Preparation and Use of Direct Tension Stress-Corrosion Test Specimens[3]

G 103 Practice for Performing a Stress-Corrosion Cracking Test of Low Copper Containing Al-Zn-Mg Alloys in Boiling 6 % Sodium Chloride Solution[4]

G 123 Test Method for Evaluating Stress-Corrosion Cracking of Stainless Alloys with Different Nickel Content in a Boiling Acidified Sodium Chloride Solution

3. Terminology

3.1 For definitions of corrosion-related terms used in this practice see Terminology G 15.

4. Summary of Practice

4.1 This practice involves the stressing of a specimen bent to a U shape. The applied strain is estimated from the bend conditions. The stressed specimens are then exposed to the test environment and the time required for cracks to develop is determined. This cracking time is used as an estimate of the stress corrosion resistance of the material in the test environment.

5. Significance and Use

5.1 The U-bend specimen may be used for any metal alloy

[1] This practice is under the jurisdiction of ASTM Committee G-1 on Corrosion of Metals and is the direct responsibility of Subcommittee G01.06on Stress-Corrosion Cracking and Corrosion Fatigue.

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[2] The boldface numbers in parentheses refer to the list of references at the end of this practice.

[3] *Annual Book of ASTM Standards*, Vol 03.01.

[4] *Annual Book of ASTM Standards*, Vol 03.02.

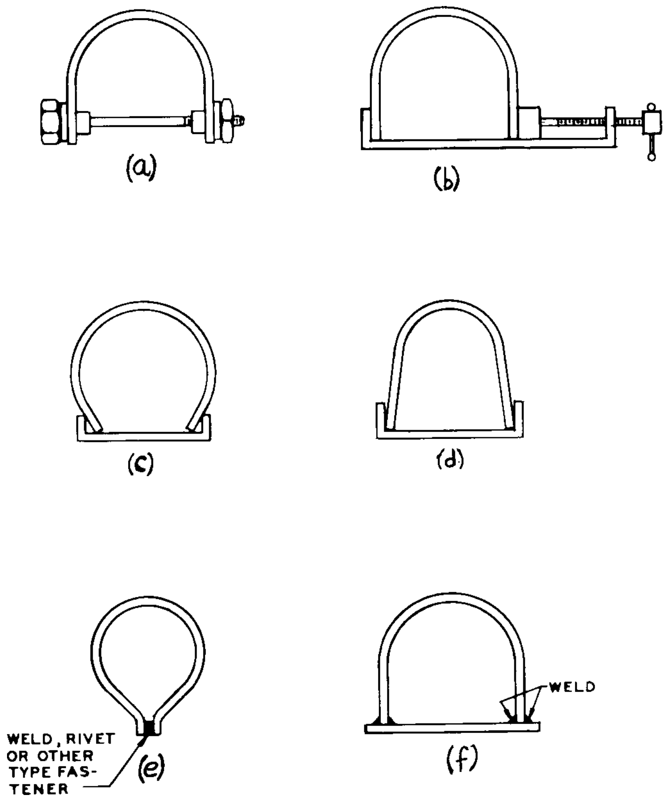


FIG. 1 Typical Stressed U-bends

sufficiently ductile to be formed into the U-shape without mechanically cracking. The specimen is most easily made from strip or sheet but can be machined from plate, bar, castings, or weldments; wire specimens may be used also.

5.2 Since the U-bend usually contains large amounts of elastic and plastic strain, it provides one of the most severe tests available for smooth (as opposed to notched or precracked) stress-corrosion test specimens. The stress conditions are not usually known and a wide range of stresses exist in a single stressed specimen. The specimen is therefore unsuitable for studying the effects of different applied stresses on stress-corrosion cracking or for studying variables which have only a minor effect on cracking. The advantage of the U-bend specimen is that it is simple and economical to make and use. It is most useful for detecting *large differences* between the stress-corrosion cracking resistance of (*a*) different metals in the same environment, (*b*) one metal in different metallurgical conditions in the same environment, or (*c*) one metal in several environments.

6. Hazards

6.1 U-bends made from high strength material may be susceptible to high rates of crack propagation and a specimen containing more than one crack may splinter into two or more pieces. Due to the highly stressed condition in a U-bend specimen, these pieces may leave the specimen at high velocity and can be dangerous.

7. Sampling

7.1 Specimens shall be taken from a location in the bulk sample so that they are representative of the material to be tested; however, the bulk sampling of mill products is outside the scope of this standard.

7.2 In performing tests to simulate a service condition it is essential that the thickness of the test specimen, its orientation with respect to the direction of metal working and the surface finish, etc., be relevant to the anticipated application.

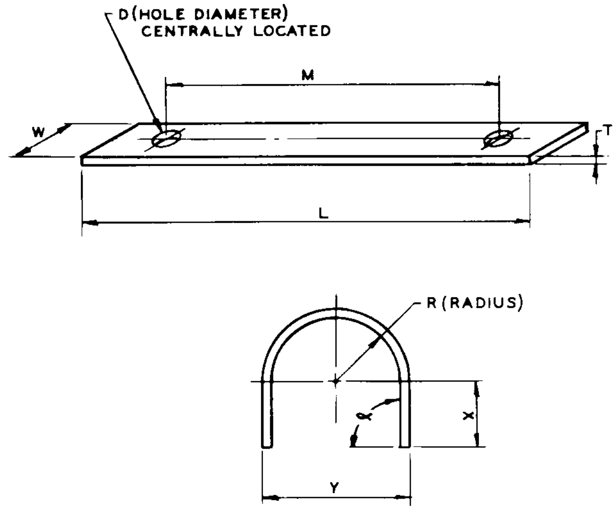
8. Test Specimen

8.1 *Specimen Orientation*—When specimens are cut from sheet or plate and in some cases strip or bar, it is possible to cut them transverse or longitudinal to the direction of rolling. In many cases the stress-corrosion cracking resistance in these two directions is quite different so it is important to define the orientation of the test specimen.

8.2 *Specimen Dimensions*—Fig. 2 shows a typical test specimen and lists, by way of example, several dimension combinations that have been used successfully to test a wide range of materials. Other dimensional characteristics may be used as necessary. For example, some special types of U-bend configuration have been used for simulating exposure conditions encountered in high temperature water environments relative to the nuclear power industry. These include double U-bend **(2)** and split tube U-bend (or reverse U-bend) **(3)** specimens.

8.2.1 Whether or not the specimen contains holes is dependent upon the method of maintaining the applied stress (see Fig. 1).

8.2.2 The length (*L*) and width (*W*) of the specimen are determined by the amount and form of the material available, the stressing method used, and the size of the test environment container.



Examples of Typical Dimensions (SI Units)

Example	L, mm	M, mm	W, mm	T, mm	D, mm	X, mm	Y, mm	R, mm	α, rad
a	80	50	20	2.5	10	32	14	5	1.57
b	100	90	9	3.0	7	25	38	16	1.57
c	120	90	20	1.5	8	35	35	16	1.57
d	130	100	15	3.0	6	45	32	13	1.57
e	150	140	15	0.8	3	61	20	9	1.57
f	310	250	25	13.0	13	105	90	32	1.57
g	510	460	25	6.5	13	136	165	76	1.57
h	102	83	19	3.2	9.6	40	16	4.8	1.57

FIG. 2 Typical U-Bend Specimen Dimensions (Examples only, not for specification.)

8.2.3 The thickness (*T*) is usually dependent upon the form of the material, its strength and ductility, and the means available to perform the bending. For example, it is difficult to manually form U-bends of thickness greater than approximately 3 mm (0.125 in.) if the yield strength exceeds about 1400 MPa (200 ksi).

8.2.4 For comparison purposes, it is desirable to keep the specimen dimensions, especially the ratio of thickness to bend radius, constant. This produces approximately the same maximum strain in the materials being compared (see 9.3). However, it does not necessarily provide tests of equal severity if the mechanical properties of the materials being compared are widely different.

8.2.5 When wire is to be evaluated, the specimen is simply a wire of a length suitable for the restraining jig. It may be desirable to loop the wire rather than use just a simple U-shape **(4)**.

8.3 *Surface Finish*:

8.3.1 Any necessary heat treatment should be performed before the final surface preparation.

8.3.2 Surface preparation is generally a mechanical process but in some cases it may be more convenient and acceptable to chemically finish (see 8.3.4).

8.3.3 Grinding or machining should be done in stages so that the final cut leaves the surface with a finish of 0.76 µm (30 µin.) or better. Care must be taken to avoid excessive heating during preparation because this may induce undesirable residual stresses and in some cases cause metallurgical or chemical changes, or both, at the surface. The edges of the specimen should receive the same finish as the faces.

8.3.4 When the final surface preparation involves chemical dissolution, care must be taken to ensure that the solution used does not induce hydrogen embrittlement, selectively attack constituents in the metal, or leave undesirable residues on the surface.

8.3.5 It may be desirable to test a surface (for example, cold rolled or cold rolled, annealed, and pickled) without surface metal removal. In such cases the edges of the specimen should be milled. Sheared edges should be avoided in all cases.

8.3.6 The final stage of surface preparation is degreasing. Depending upon the method of stressing, this may be done before or after stressing.

8.4 *Identification* of the specimen is best achieved by stamping or scribing near one of the ends of the test specimen, well away from the area to be stressed. Alternatively, nonmetallic tags may be attached to the bolt or fixture used to maintain the specimen in a stressed condition during the test.

9. Stress Considerations

9.1 The stress of principal interest in the U-bend specimen is circumferential. It is nonuniform because (*a*) there is a stress gradient through the thickness varying from a maximum tension on the outer surface to a maximum compression on the inner surface, (*b*) the stress varies from zero at the ends of the specimen to a maximum at the center of the bend, and (*c*) the stress may vary across the width of the bend. The stress distribution has been studied **(5)**.

9.2 When a U-bend specimen is stressed, the material in the outer fibers of the bend is strained into the plastic portion of the true stress-true strain curve; for example, into Section *AB* in Fig. 3(*a*). Fig. 3(*b*–e) show several stress-strain relationships that can exist in the outer fibers of the U-bend test specimen;

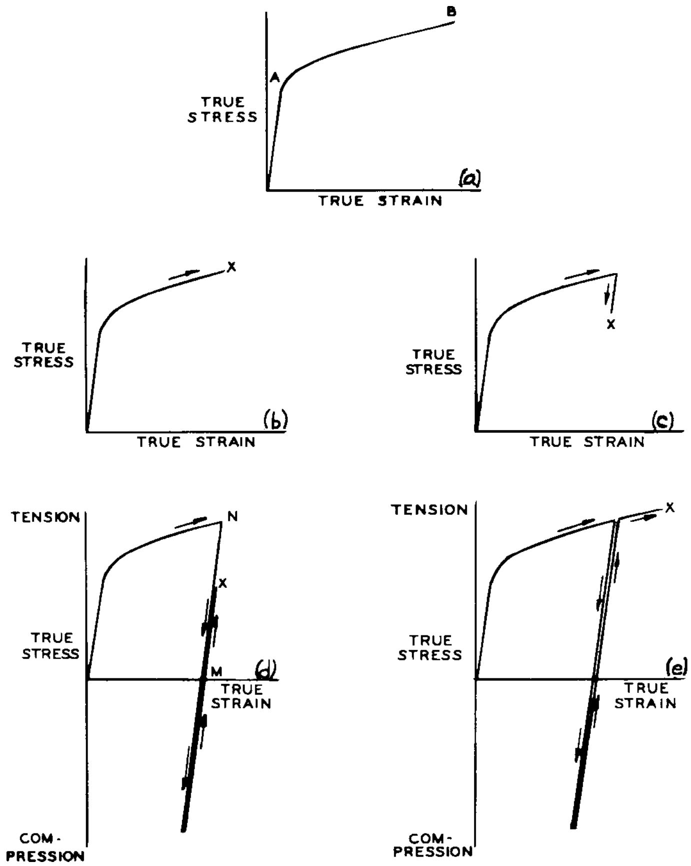


FIG. 3 True Stress-True Strain Relationships for Stressed U-Bends

the actual relationship obtained will depend upon the method of stressing (see Section 10). For the conditions shown in Fig.

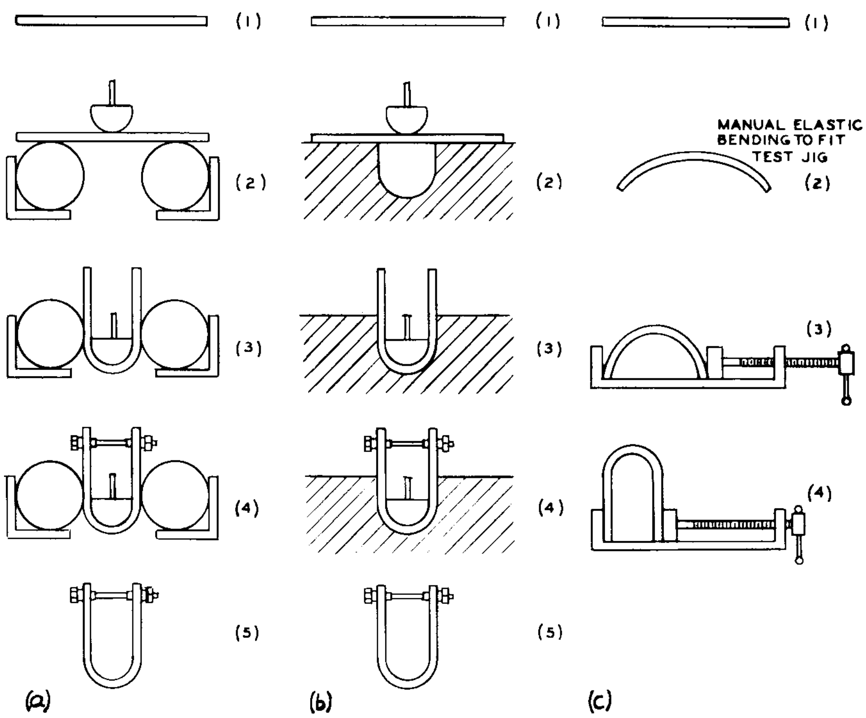


FIG. 4 Methods of Stressing U-Bend Specimens—Single-Stage Stressing

3(*d*), a quantitative measure of the maximum test stress can be made **(6)**.

9.3 The total strain (ϵ) on the outside of the bend can be closely approximated to the equation:

$$\epsilon = T/2R \text{ when } T << R$$

where:
T = specimen thickness, and
R = radius of bend curvature.

10. Stressing the Specimen

10.1 Stressing is usually achieved by either a one- or a two-stage operation.

10.2 Single-stage stressing is accomplished by bending the specimen into shape and maintaining it in that shape without allowing relaxation of the tensile elastic strain. Typical stressing sequences are shown in Fig. 4. The method shown in Fig. 4(*a*) may be performed in a tension testing machine and is often the most suitable method for stressing U-bends that are difficult to form manually due to large thickness or high-strength material or both. The techniques shown in Fig. 4(*b* and *c*) may be suitable for thin or low-strength material, or both, but are generally inferior to the method shown in Fig. 4(*a*). The method shown in Fig. 4(*b*) results in a more complex strain system in the outer surface and may cause scratching. The technique shown in Fig. 4(*c*) suffers from greater lack of control of the bend radius. The two types of stress conditions that can be obtained by the single-stage stressing method are defined by point *X* in Fig. 3(*b* and *c*). In the latter case, some elastic strain relaxation has occurred as a result of allowing the U-bend legs to spring back slightly at the end of the stressing sequence.

10.3 Two-stage stressing involves first forming the approximate U-shape, then allowing the elastic strain to relax completely before the second stage of applying the test stress. A typical sequence of operations is shown in Fig. 5. The type of equipment shown in Fig. 4(*a* and *b*) can also be used to preform the U-shape. The test strain applied may be a percentage of the tensile elastic strain that occurred during preforming (Fig. 3(*d*)) or may involve additional plastic strain (Fig. 3(*e*)).

10.4 The slope, *MN*, of the curve shown in Fig. 3(*d*) is steep (equal to Young's modulus). Therefore, it is often difficult to reproducibly apply a constant percentage of the total elastic prestrain and there is a danger of leaving the specimen surface under compressive stress. For this reason and also because it results in a more severe test (that is, higher applied stress), *it is recommended that the stress conditions shown in Fig. 3(b or e) be achieved.* Hence, the final applied strain prior to testing consists of plastic and elastic strain. To achieve the conditions shown in Fig. 3(*b* and *e*), it is necessary (*a*) to avoid prestraining a greater amount than the final test strain and (*b*) to avoid "springback" of the U-bend legs after achieving the final plastic strain.

10.5 The bolt or restraining jig used to maintain the stress should be insulated from the test specimen to avoid galvanic corrosion effects. The insulators should have mechanical strength adequate to stand the stressing pressure, should not creep significantly during the test, and should be inert to the

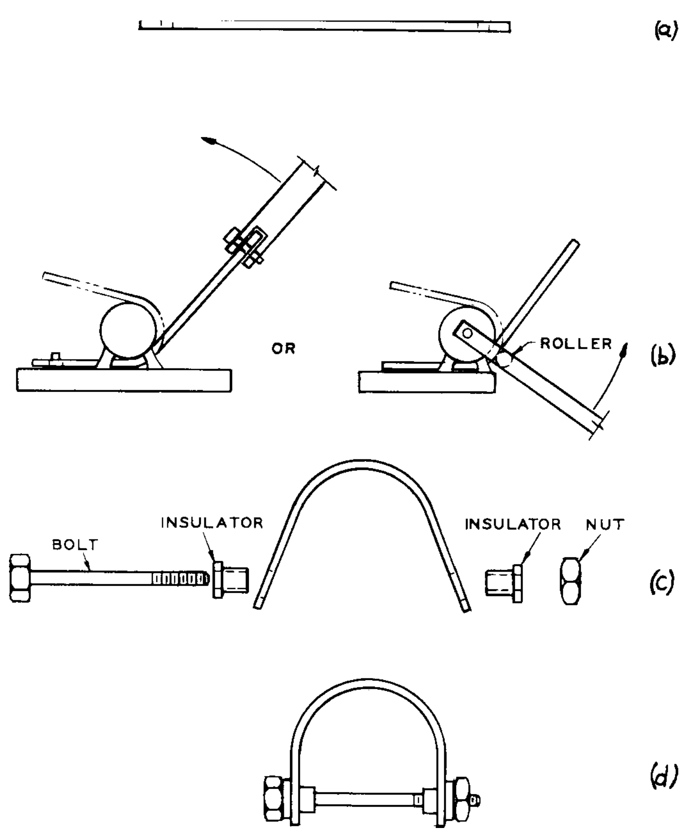


FIG. 5 Method of Stressing U-Bend—Two-Stage Method

test environment. Insulators (Fig. 4 and Fig. 5) made of zirconia or other non-compressible non-conducting materials have proven satisfactory for this purpose. It is advisible to use flat metal washers (not shown) between the insulators and the bolt and nut to extend the life of the insulators. In some cases the use of insulators can be avoided by using a restraining jig made from a metal similar or the same as that being tested, provided it does not fail by stress-corrosion cracking in the test environment. The bolt, nut and flat washers must resist corrosion in the test environment. UNS N10276 has been satisfactory in many environments, although other materials may be superior in highly oxidizing environments.

10.6 Some tests require that the U-bend specimen fit through a 45/50 ground glass joint for exposure in an Erlenmeyer flask. Examples a, e and perhaps d from Fig. 2 will accomplish this, assuming any insulator between the specimen and fastener is not too large. Larger insulators can be desirable so that a ceramic material (does not allow stress relaxation by compression during the test) can be used without breaking. Example h in Fig. 2 provides a U-bend which can be bent around a 9.6 mm (0.375 in.) diameter mandrel as in Fig. 4a. This specimen can then be stressed using substantial ceramic insulators (which fit into 9.6 mm (0.375 in.) diameter holes) and inserted through a 45/50 ground glass joint. This specimen is fabricated to provide plastic and elastic strain (position of X as shown in Fig. 3b or Fig. 3e) as follows.

10.6.1 Set the gap in the die at the mandrel diameter (9.6 mm or 0.375 in.) plus two times the metal thickness. Mark the centerline on the specimen to aid in aligning.

10.6.2 First depress the mandrel (hydraulic) until the apex of the U-bend is approximately level with the bottom of the die. Continue stressing until the legs of the U-bend are nearly parallel. Final stressing is preferably done with the fastener. The specimen may be stressed in the die or it may be removed and re-stressed outside the die.

10.6.3 Stress the U-bend so that the legs are parallel, that is, the U-bend is more severely bent than it was due to the die pressure.

11. Exposure of the Test Specimen

11.1 Prior to exposure the stressed specimen should be degreased in a solution known to be chemically inert to the metal being tested. In some cases, it may be more convenient and satisfactory to degrease prior to stressing. After degreasing, the specimens should be handled with clean gloves or tongs.

11.2 The stressed specimen should be examined for mechanical cracking prior to testing. A similar or more stringent inspection technique to that which will be used in the subsequent test should be applied. For example, if test specimens will be examined at 20× during the test, then they should be inspected at 20× or higher magnification prior to testing, to confirm the absence of cracks.

11.3 As soon as possible after degreasing, stressing, and inspecting, the specimen should be put in test. Periodic checks should be made to ensure that the stress is not grossly relieved during the test. The latter most commonly occurs as a result of poor material selection in the restraining jig, insulators, etc., and can be corrected by redesign.

12. Inspection

12.1 Determination of cracking time is a subjective procedure involving visual examination that under some conditions can be very difficult, as noted in 12.4-12.6, and depends on the skill and experience of the inspector.

12.2 Examination procedures will depend upon convenience and the purpose of the test. In most laboratory tests, it is convenient and satisfactory to remove specimens from the environment (with clean gloves or tongs) and examine with the naked eye or at low magnification, for example, 20× (see 11.2). After inspection for cracks, the specimens can then be returned to the test. When working with a new system, it is advisable to confirm that this removal during the test does not influence the stress-corrosion cracking susceptibility. If the aim of the test is solely to determine whether the specimen can be made to crack, it is quite common practice to draw the legs of the U-bend together after a predetermined time in test and then return it to the test media.

12.3 Alternative methods are to view the specimen through the test chamber or to remove specimens at intervals during the test but not return them to the test chamber. The latter is suitable if one wishes to detect cracking on a microscopic scale.

12.4 Corrosion products may obscure cracking. Techniques for cleaning specimens are discussed in Practice G 1. Cleaned specimens should not be returned to test unless it is the intention of the test to evaluate this variable. If chemical cleaning techniques are used, then a stressed, clean, crack-free specimen should be given the same cleaning cycle to confirm that the cleaning agent does not itself cause cracking.

12.5 If specimens inspected at low magnification on completion of the test show no cracking, it is advisable to examine metallographically at higher magnifications, for example, 500× (see Method E 3). Overstressing the bend to open up any cracks may aid inspection provided a control specimen, which has not been stress-corrosion tested, can be overstressed without cracking.

12.6 Removal of the applied stress and comparison of the amount of relaxation in the tested versus an unexposed specimen can also be used to detect and measure the progress of cracking **(7)**. If this method is used, then the specimen should be inspected to ensure that the loss of relaxation is due to crack propagation and not to general corrosion or pitting.

12.7 Fracture of specimens of relatively notch-sensitive materials can occur as a result of pitting corrosion and consequent mechanical fracture. Careful examination or fractography, or both, should be used to eliminate from evaluation any failures that did not result from stress-corrosion cracking.

NOTE 1—Any cracking at the specimen ends where the applied stress is considered to be zero (see Section 9.1) may reveal inherent problems in specimen preparation or material performance, or both, and should be investigated. Such cracks could result from unknown residual stresses or localized crevice corrosion or both. If crevices are expected in service, a U-bend specimen employing a crevice on the bend or a double U-bend (Section 8.2) may be useful.

13. Reporting

13.1 The time at which cracks are visible at a stated magnification should be reported. The specimens may remain in test after cracks have initiated and crack depths can be measured metallographically after a predetermined time in test.

13.2 When several specimens are tested it may be more meaningful to report the percentage cracked.

13.3 The orientation of the specimen (for example, transverse or longitudinal to the rolling direction), the dimensions of the stressed U-bend, its surface finish method of cleaning, and the method of stressing should be reported in addition to complete details concerning the material and test environment.

14. Keywords

14.1 plastic strain; stress—corrosion cracking; stress-corrosion test specimen; U-bends

REFERENCES

(**1**) Romans, H. B., "Stress Corrosion Test Environments and Test Durations," *Symposium on Stress Corrosion Testing, ASTM STP 425*, ASTM, 1967, pp. 182–208.

(**2**) Copson, H. R., and Dean, S. W., "Effect of Contaminants on Resistance to Stress Corrosion Cracking of Ni-Cr Alloy 600 in Pressurized Water", *Corrosion*, Vol. 21, No. 1, January 1965, pp. 1–8.

(**3**) Totsuka, N., Lunarska, E., Cragnolino, G., and Szklarska-Smialowska, Z., "Effect of Hydrogen on the Intergranular Stress Corrosion Cracking of Alloy 600 in High Temperature Aqueous Environments" *Corrosion*, Vol. 43, No. 8, August 1987, pp. 505–514.

(**4**) Loginow, A. W., "Stress Corrosion Testing of Alloys," *Materials Protection*, Vol 5, No. 5, May 1966, pp. 33–39.

(**5**) Nathorst, H., "Stress Corrosion Cracking in Stainless Steels Part II. An Investigation of the Suitability of the U-Bend Specimen," *Welding Research Council Bulletin Series*, No. 6, October 1950.

(**6**) Dana, A. W. Jr., "Stress Corrosion Cracking of Insulated Austenitic Stainless Steel," *ASTM Bulletin No. 225*, ASTM, October 1957.

(**7**) Thompson, D. H., "A Simple Stress-Corrosion-Cracking Test for Copper Alloys," *Materials Research and Standards*, Vol 1, February 1961, pp. 108–111.