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WELDMENT EVALUATION METHODS

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WELDMENT EVALUATION METHODS

by

J. J. Vagi, R. P. Meister,
and M. D. Randall

to

OFFICE OF THE DIRECTOR OF DEFENSE
RESEARCH AND ENGINEERING

DEFENSE METALS INFORMATION CENTER
Battelle Memorial Institute
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WELDMENT EVALUATION METHODS

J. J. Vagi, R. P. Meister, and M. D. Randall*

SUMMARY

The most important criterion for judging the performance of a weldment is whether or not it performs the functions required for its intended service. A service performance test, therefore, is really the final test. However, the need for weldment evaluation exists long before the final structure is complete and actual service begins. Some type of test which will give the best information on how the product will perform during fabrication and service must be used prior to fabrication to provide indications of the efficiency of design, welding procedures, expected mechanical properties, and behavior during service.

Weldment evaluation is very complex. There are many methods for evaluating welded joints. There are many kinds of test specimens, and often there are several ways of evaluating these specimens. Even in only one aspect of weldment evaluation, such as cracking, there are many variables involved; for cracking, they include temperature (subzero to elevated temperatures), the types of test specimens, and the welding conditions. In some instances, more than one type of specimen must be used to obtain reliable information on the expected service performance of the welded joints.

Numerous reports are available on weldment evaluation but these are usually limited to a specific test method for a limited application. When considering evaluation methods for weldments, one may find it difficult to obtain information on the wide variety of test specimens or evaluation methods that are available and that will fulfill the designer's or fabricator's requirements. This comprehensive report reviews the broad range of test specimens and evaluation methods that are available or of special current interest for evaluating welds.

Tension, shear, bend, toughness, fatigue, creep, stress rupture, and cracking tests are widely used for fusion-welded, spot-welded, and brazed joints. Descriptions of many of these tests with drawings of specimens used for the tests are included to provide a needed reference for selecting or designing suitable test specimens for the weldment being considered. The drawings also serve to show that many special test specimens, in addition to the standard specimens, have been and can be developed for special applications. Publications and specifications are cited to provide the reader with references to additional details of the testing procedures.

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TABLE OF CONTENTS

ILLUSTRATIONS

ILLUSTRATIONS (CON'D)

INTRODUCTION

Welding is a desirable and highly efficient method for constructing a great variety of products ranging from miniature electronic components to bridges, ship hulls, and large rocket-motor cases. Since information is needed during design stages to aid in predicting a structure's behavior during fabrication or in service, the need for evaluating the performance of welds exists long before service begins.

A great variety of testing methods and specimens exist for evaluating performance of welds. Only a limited number of these, however, are considered to be "standard"-type specimens because fabricated structures and the service environments are difficult to reproduce in detail under laboratory conditions. Attempts are often made, therefore, to develop special test specimens that are designed to be more representative of the actual structure.

In DMIC Report 165, "Methods of Evaluating Welded Joints", Randall, Monroe, and Rieppel reviewed the industrial use of various test specimens for evaluating fusion welds.(1)* The principal weld evaluation methods included weldability, tension, shear, bend, fatigue, and impact tests, and, to a limited extent, stress-rupture and creep tests. In general, these tests are applicable to a variety of fusion-welded structures, but their use for joints made by other processes, such as resistance welding and brazing, is limited.

Since publication of the earlier report, continued progress has been made in weld evaluation techniques. New test specimens have been developed for toughness tests for fusion-welded joints, fatigue tests for fillet-welded joints, and shear tests for brazed joints. Specimens and tests for evaluating toughness and brittle fracture are receiving much greater consideration than are the details of tests for other performance characteristics. This probably is due to a recognition of frequently catastrophic nature of brittle fractures, the lack of warning before fractures occur, and the need to avoid or predict their occurrence. Also, a number of new tests such as the variable-restraint (Varestraint) test have been introduced for evaluating weld metal cracking susceptibility.

Experience in research, development, and production shows the need for information concerning tests and test specimens that are used for weldment evaluation. Published literature usually is concerned with a limited scope of weldment evaluation and, consequently, considerable effort often is required to search the literature for needed information concerning other types of welds or evaluation methods. This report describes new test specimens and evaluation methods developed since the time of the earlier report. Because of the importance of joining processes such as spot welding and brazing, test specimens designed specifically for evaluating joints made by these processes also are described. For the reader's convenience, test specimens that have been used in the past are included, in order to provide a comprehensive review within one document.

* References are listed at the end of this report.

It has been stated that the faithful execution of the testing procedure should provide a rational basis for the establishment of materials, procedures, and techniques, and, hopefully a reasonable evaluation of expected service performance.(1) A number of factors are important not only in the evaluation of the testing procedure, but also in reporting on the information obtained. These include: the purpose of the test, intended service conditions, allowables, specimen design, specimen-preparation method and finish, the source of the specimen (part and location), ambient conditions (atmosphere, temperature, humidity, pressure, geographical location, etc), rates of loading (crosshead speed), test materials, material condition, testing equipment, methods for making measurements or observations, scales involved, failure characteristics (type, location, size, geometry, etc.), interpretation of results and bases for these interpretations, and conclusions. Often, in published reports, meaningful details of the testing procedure are omitted, and thus the reported data may have limited usefulness. Therefore adequate details of all tests should be furnished when reporting test results.

TENSION TESTS

Uniaxial tension tests comprise the most commonly used destructive test methods for evaluating the mechanical properties of welds.(1) They provide valuable information on load-bearing capacities, strain-hardening properties, stress levels at which necking and final failure occur, and ductility. Data obtained from tension tests can be reported in many ways, but the information usually reported includes:

(1) Ultimate strength
(2) Yield strength
(3) Stress-strain curves
(4) Modulus of elasticity
(5) Elongation
(6) Reduction of area.

The tests provide numerical values which can be compared or otherwise analyzed and used for design and analysis of engineering structures. Fracture surfaces of tension-test specimens that fail through the weld also can provide useful information on the presence and effects of defects such as porosity, hot cracks, slag inclusions, and fracture characteristics.

A wide variety of tension-test specimens are available for evaluating weldments. The type of specimen that is selected depends on the design of the part, the intended service and the type of information desired. Occasionally, standard tests or specimens are unsuitable and modifications are made or specimens designed to suit a particular design or structure. The most widely used types of tension specimens for evaluating strength properties of welded joints are:

(1) Transverse-weld specimens
(2) Longitudinal-weld specimens
(3) All-weld-metal specimens
(4) Spot-weld tension and tension-shear specimens
(5) Brazed tension and tension-shear specimens.

Fusion welds that are evaluated by standard strength tests include butt welds and fillet welds. Resistance welds are generally evaluated by cross-tension or tension-shear tests, and brazed joints are evaluated by straight tension or tension-shear tests. In addition, many modifications of the listed test specimens have been used to measure special properties or to evaluate simulated or actual structural joints. Typical tension-test specimens are illustrated in Figures 1 through 9, and are discussed in the following sections.

Transverse-Weld Tension Specimens

Transverse butt-weld tension tests provide limited information on the mechanical properties of fusion welds. Test results must be interpreted with great care because of the variations in properties resulting from inhomogeneous structures along the gage length. These tests are used chiefly to obtain strength data from which joint efficiency may be calculated and to obtain information on fracture characteristics. The specimens are prepared by butt welding two plates and then machining the specimens from the weldments, with the weld joint bisecting the gage length.

Transverse-weld tension specimens are widely used in industrial welding-procedure and personnel qualification tests. Typical transverse-weld specimen designs are shown in Figures 1 and 2. The round specimen generally is used only for testing plate; the 0.505- and 0.0357-inch-diameter sizes are most popular. The rectangular radiused-section specimen, shown in Figure 3, is used when it is desirable to force failure to occur in the weld metal.

A subsize transverse-weld tension-test specimen has been recommended by the Materials Advisory Board, particularly for preliminary evaluations of small pilot lots of new alloys at room and elevated temperatures.[5] The subsize specimen has the advantages of requiring less material and lower gripping loads. The smaller specimen is also useful for elevated-temperature tests because it allows more rapid heating and improves temperature uniformity along the specimen gage length. This specimen is acceptable for production-lot testing only if the laboratory performing the tests can demonstrate that the specimen size does not affect test results. The specimen is the rectangular reduced-section specimen, with the smallest dimensions shown in Figure 2. Grip-section design is optional but should avoid eccentric loading. Testing in accordance with the applicable MAB procedure is required.

Specimen designs that vary from the standard specimen designs are in common use. For example, a 1/4-inch-wide reduced section was used by Rudy and co-workers for strength tests to compare properties of weld joints with those of the low-alloy high-strength-steel parent metal.[7] In these evaluations, joint efficiency was based on yield-strength values.

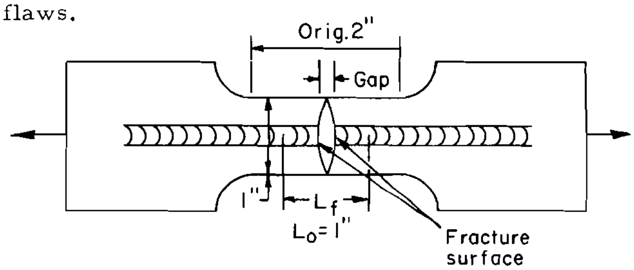
Because the structures found in weldments are heterogeneous, the transverse-weld tension test does not provide a quantitative measure of weld-joint ductility. In this test, each zone of the composite specimen is loaded to the same stress (assuming a uniform specimen cross section). The stress-strain behavior in the weld, in the heat-affected-zones and in the base plate is likely to be different, however. When the weld-metal strength significantly exceeds the strength of the base plate (overmatching), nearly all of the plastic strain and fracture occurs outside the weld in the heat-affected zone or unaffected base metal. The ultimate strength, yield strength, reduction of area, and elongation will be equivalent to that of the base plate and give little or no indication of weld-metal properties. Small defects in the weld metal may have no effect since the specimens usually fail outside the weld metal. When the weld-metal strength is significantly lower than that of the heat-affected zone or parent metal (undermatching), plastic strain and failure occur chiefly in the weld metal. The test, therefore, may fail to disclose undesirable features in the heat-affected zone or parent metal. In addition, for undermatching, elongation occurs almost entirely in the weld metal. Therefore, percent elongation based on the entire gage length is erroneous and meaningless.

Longitudinal-Weld Tension Specimens

The purpose of the longitudinal-weld tension specimen is to provide a quantitative measure of the properties of a weld joint and adjacent metal areas and to evaluate stress-strain behavior of the various weld zones. The specimen is prepared with the weld along the longitudinal axis of the specimen and bisecting the width of the specimen as illustrated in Figure 4. The reduced section is made wide enough to include base metal on each side of the weld; however, there are no standards for the relative amounts of parent metal and heat-affected zones to be included.

During testing, the longitudinal-weld tension specimen is loaded in a direction parallel to the weld. The weld metal, heat-affected zones, and base metal are strained equally and simultaneously. When the load is applied, weld metal, regardless of strength, elongates with the base plate. Poor weld-metal ductility often forces fracture initiation to occur in the weld metal at a strength level considerably below that of the surrounding unwelded base plate. On the other hand, weld metals having good ductility and appreciably lower strength than the base plate may sustain uniaxial loads to strength levels of the base plate. Because of these effects, longitudinal-weld specimens should be considered for use in conjunction with transverse-weld specimens, particularly where weld-metal and base-plate strengths or transverse and longitudinal stresses differ.

The longitudinal-weld tension-test specimen shown below has been used in analyses of the elongation behavior of fusion welds in 300 M low-alloy, high-strength steel.[7] The specimen was made sufficiently wide to include all of the weld zones. After the weld was machined flush with the parent metal surfaces, grid markings were placed on the specimen to permit measurement of elongation. The specimen was then tested to failure in tension and the broken pieces were fitted together for measuring gap width and L_f (final gage length) in the weld metal and base metal. Elongations were calculated using the equations shown below. The analyses showed that with flow-free welds, weld-metal and base-metal elongations were about equal and uniform along the gage length. Fracture surfaces exhibited shear failure. With flaws present near the surface of the weld-metal, weld-metal elongations dropped off significantly and fracture surfaces exhibited a brittle texture in the regions of the flaws.



$$\text{Base-Metal Elongation, percent} = \frac{L_f - L_o}{L_o} \times 100$$

$$\text{Weld-Metal Elongation, percent} = \frac{L_f - \text{Gap} - L_o}{L_o} \times 100$$

Where L_o = initial gage length
L_f = final gage length

All-Weld-Metal Tension Specimens

The round all-weld-metal tension specimen is one of the simplest and most valuable of all specimens available for evaluating properties of fusion weld deposits. It is used to obtain values of tensile strength, yield strength, elongation, and reduction of area for the weld-metal deposits only.[8] The all-weld-metal tension specimen has been used to determine variations in weld-metal tensile properties due to changes in weld-metal composition, welding position, deposition techniques, and preheat and interpass temperatures.[9] The specimen is usually prepared by depositing filler metal in a grooved joint and machining to final size as illustrated in Figure 5. During deposition, dilution (alloying) of the filler metal with base metal can occur. When the properties of the deposited filler metal only are desired, care should be exercised to minimize dilution. Otherwise, the welding processes, techniques and procedures used for actual fabrication of the part containing the weld should be used for preparation of the weldment to be tested.[8]

Spot-Weld Cross-Tension Specimens

Cross-tension tests provide information on ultimate strength, spot-weld diameter, and manner of failure when spot welds are stressed in a direction normal to the surface of the material.[6] They are used also to provide a better measure of notch sensitivity than is obtained from the tension-shear test and to furnish data that, when combined with tension-shear strength data, will provide a measure of spot-weld ductility.

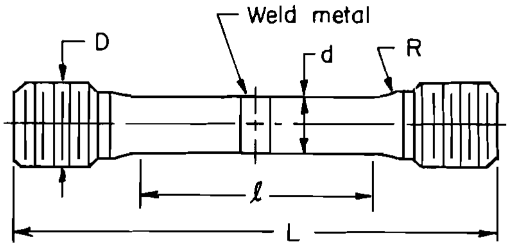
Two types of specimens are available--the cross-tension-test specimens shown in Figures 6 and 7 and the U-tension-test specimen shown in Figure 8. Special fixtures used for testing each type of specimen also are illustrated. The specimens are prepared from premachined or sheared and drilled coupons by joining the crossed coupons with a spot weld at the center of the intersection. The completed specimens are assembled into the testing fixtures as shown.

The cross-tension specimen shown in Figure 6 is tested by applying tensile loads directly to the holding fixture. This type of fixture utilizes a pinning system to prevent excessive bending of thin or soft materials. The cross-tension specimen shown in Figure 7 is tested by applying loading in a compressive direction to the fixture, which transfers tensile loads to the specimens. This test is generally used for thicker or stiffer materials that are less subject to bending. The U-tension specimens also are tested by applying tensile loads to the supporting blocks. The supporting blocks are necessary to confine loading to the spot-weld area. The U-tension test is limited to those materials that can be bent readily into a U-shape.

Brazed-Joint Tension Specimens

Tension tests for brazed joints are required by the ASME Boiler and Pressure Vessel Code, Section IX.[3] These tests are performed in order to qualify brazing procedures and to evaluate the performance of personnel. The tension-test specimens required for brazed butt and scarf joints in plate are shown in Figure 9. To meet the requirements of the Code, the specimen must break in the base metal or tensile strength of the specimen must be at least 95 percent of the specified tensile strength of (1) the base metal in the annealed condition or (2) the weaker of the two base metals in the annealed condition, if materials of different minimum tensile strengths are used.

FIGURE 1. TRANSVERSE WELD-METAL TENSION-TEST SPECIMEN (ROUND)



Dimensions, inches					Approx. area, sq in.
d	D	ℓ	L	R	
0.505	3/4	2-1/4	5-1/2	3/8	1/5
0.357	1/2	1-3/4	3-1/2	0.25	1/10
0.252	3/8	1-1/4	3	0.18	1/20
0.160	5/16	3/4	2	0.15	1/50
0.113	1/4	5/8	1-5/8	0.09	1/100

Dimensions shown are MIL-STD-418; usually tested at room temperature in air but has been used for elevated-temperature tests.

Purpose of Test- Developmental, production quality, strength, ductility, weldability, and design allowables.

Number of Specimens Tested - Usually 3, varying from 2 to 6.

Important Variables - Specimen geometry, weld quality, weld inspection, specimen positioning, strain-rate control, measurements, and data analysis.

Data Obtained - Tensile strength, yield strength, elongation, and reduction of area; for plain-carbon steels, both upper and lower yield strengths usually determined by drop-of-beam technique; otherwise, yield strength determined by offset-yield technique, usually 0.2 percent offset with occasional use of 0.1 percent offset; elongation in 2 inches most used, but elongation in 1 inch and between the weld edges used occasionally; location of failure.

Specifications - MIL-STD-00418B (SHIPS), ASTM E8-61T, ASME Sec. IX cover round, all-weld-metal tension specimens; however, same specimens generally used for transverse weld tests.

References - 2, 3, 4.

Remarks - Used extensively; should not be used as sole basis for weldment evaluation.

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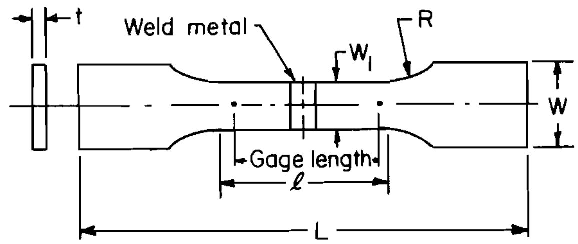
FIGURE 2. TRANSVERSE-WELD TENSION-TEST SPECIMEN--REDUCED SECTION (FLAT)



Dimensions, inches					
W	W_1	ℓ	L	R	G
--	0.250 ± 0.005	--		1/4 min	1
3/4	0.500 ± 0.010	2-1/4 min	8 min	1/2 min	2
2	1-1/2 ± 0.01	9 min	16 ±	1-3	8

Dimensions for smallest specimen are MAB; remainder, are ASTM standard for unwelded base plate; 1/2 inch wide specimen used for t from 0.005 to 5/8 inch; 1-1/2 inch specimens used for t of 3/16 inch and over; used for all temperatures and all atmospheres; tested with and without weld reinforcement, preferably without.

Purpose of Test - Developmental, production quality, strength, ductility, weldability, design allowables, and comparison of weld-joint properties with parent-metal properties.

Number of Specimens Tested - Usually 3, varying from 2 to 6.

Important Variables - Specimen geometry, weld quality, weld inspection, specimen positioning, strain-rate control, measurements, and data analysis.

Data Obtained - Tensile strength, yield strength, elongation, and reduction of area; for plain-carbon steels, both upper and lower yield strengths usually determined by drop-of-beam technique; otherwise, yield strength determined by offset-yield technique, usually 0.2 percent offset but some use of 0.1 percent offset; elongation in 2 inches most used, but elongation in 1 inch and in 1/2 inch used occasionally; elongation in 8 inches used for largest specimen; reduction of area rarely determined for ultrahigh-strength steels; location of failure.

Specifications - MIL-STD-00418B (SHIPS); has specification for welded specimen but differs from ASTM; ASTM E8-61T covers tension testing of base materials but same specimen generally used for welds; company specifications.

References - 2, 4, 5.

Remarks - Most widely used test specimen; should be used in conjunction with longitudinal-weld tension specimen to obtain accurate evaluation of weldment strength and ductility.

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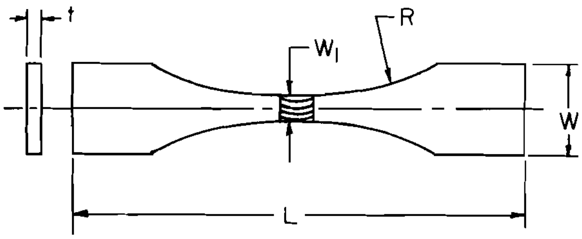
FIGURE 3. TRANSVERSE-WELD TENSION-TEST SPECIMEN - RADIUSED SECTION (FLAT)



Dimensions, inches				
t	W_1	W	L	R
0.050	0.20	1.50	9.34	3.00
1.00	1.00	1.50	10.00	2.00

Dimensions shown represent extremes, with major dimensions about the same for intermediate values of t; usually tested at room temperature in air without weld reinforcement.

Purpose of Test - Developmental, production quality, strength, ductility, weldability, and design allowables force fracture in weld.

Number of Specimens Tested - Usually 3.

Important Variables - Specimen geometry, weld quality, weld inspection, specimen positioning, strain-rate control, measurements, and data analysis.

Data Obtained - Tensile strength, yield strength, elongation, and reduction of area; for plain-carbon-steel, both upper and lower yield strengths usually determined by drop-of-beam technique; otherwise, yield strength strength determined by 0. 2 percent offset-yield technique; elongation in 1/2, 1, and 2 inches determined; location of failure.

Specifications - Usually company specifications.

Remarks - Should be used in conjunction with longitudinal-weld tension specimen to obtain accurate evaluation of weldment strength and ductility.

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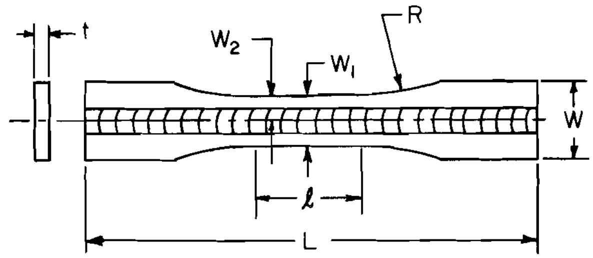
FIGURE 4. LONGITUDINAL-WELD TENSION-TEST SPECIMEN (FLAT)



Dimensions, inches						
W	W_1	W_2	ℓ	L	t	R
3/4	1/2	1/4	2-1/4	8	t	1
1-1/2	1	1/2	4	12	t	2

Smaller dimensions used for t up to 1/4 inch; larger dimensions used for t greater than 1/4 inch; usually tested in air at 70 F but limited use at elevated temperatures; usnally tested without weld reinforcement.

Purpose of Test - Developmental, strength, ductility, weldability, and design allowables; seldom used for production quality.

Number of Specimens Tested - Usually 3, varying from 2 to 4.

Important Variables - Specimen geometry, weld quality, weld inspection, specimen positioning, strain-rate control, measurements, and data analysis.

Data Obtained - Tensile strength, yield strength, elongation, and reduction of area; for plain-carbon steels, both upper and lower yield strengths usually determined by drop-of-beam technique; otherwise, yield strength determined by offset-yield technique, usually 0. 2 percent offset but some use of 0. 1 percent offset; elongation in 2 inches most used but elongation in 1 inch and 1/2 inch used occasionally; reduction of area rarely obtained for ultrahigh-strength steels; fracture characteristics; defects; fracture origin.

Specifications - ASTM E8-61T(base plate specimen but used for welds).

References - 4.

Remarks - Used much less than transverse-weld tension specimen but considered very important for evaluation of composite weldment (weld, HAZ, and base plate) strength; should be used in conjunction with transverse-weld tension specimen to obtain accurate evaluation of weldment strength and ductility (see text).

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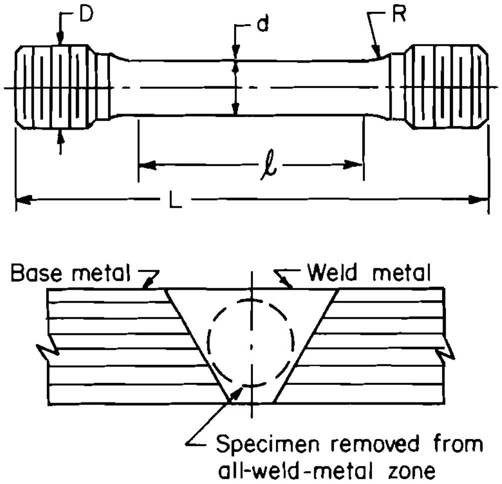
FIGURE 5. ALL-WELD-METAL TENSION-TEST SPECIMEN (ROUND)



Dimensions, inches					Approx. area, sq in.
d	D	ℓ	L	R	
0.505	3/4	2-1/4	5-1/2	3/8	1/5
0.357	1.2	1-3/4	3-1/2	0.25	1/10
0.252	3/8	1-1/4	3	0.18	1/20
0.160	5/16	3/4	2	0.15	1/50
0.113	1/4	5/8	1-5/8	0.09	1/100

Dimensions shown are MIL-STD-418; usually tested at room temperature in air.

Purpose of Test - Developmental, production quality, strength, ductility, weldability, and design allowables.

Number of Specimens Tested - Usually 3, varying from 2 to 6.

Important Variables - Specimen geometry, weld quality, weld inspection, specimen positioning, strain-rate control, measurements, and data analysis; weld-joint preparation such as type of backup bar used, root gap, and bevel are important variables as they influence the extent of dilution of the deposited filler metal with base metal.

Data Obtained - Tensile strength, yield strength, elongation, and reduction of area; for plain-carbon steels, both upper and lower yield strengths usually determined by drop-of-beam technique; otherwise, yield strength determined by offset-yield technique, usually 0.2 percent offset with occasional use of 0.1 percent offset; elongation in 2 inches most used, but elongation in 1 inch used occasionally.

Specifications - MIL-STD-00418B(SHIPS); ASTM E8-61T; ASME Sec. IX.

References - 2, 3, 4.

Remarks - Second most widely used specimen; good specimen for accurate evaluation of weld-metal strength and ductility but base-plate dilution must be minimized for the specimen to be truly representative of all weld metal. The reduced section is often tapered to a slightly smaller diameter at the center. MIL-STD 418 requires that the difference shall not exceed 1 percent of the diameter. Finishing marks should be in the direction of the gage length.

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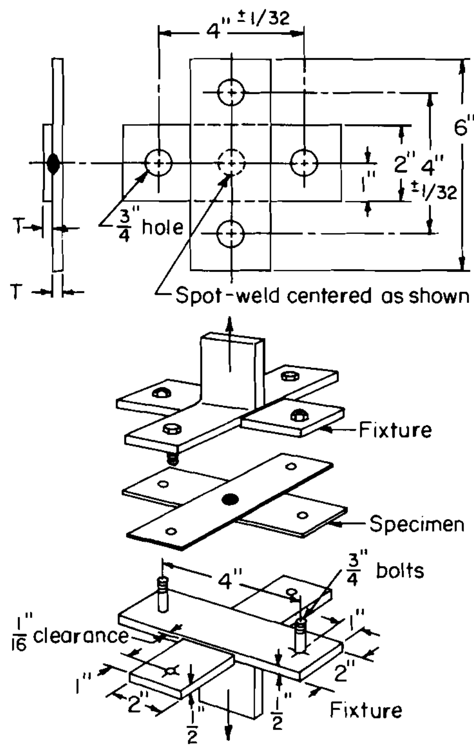
FIGURE 6. SPOT-WELD CROSS-TENSION-TEST SPECIMEN FOR THICKNESSES UP TO 0.191 INCH



Purpose of Test - Developmental, strength, design allowables, ductility ratio.

Number of Specimens Tested - Usually 3.

Important Variables - Weld size, metallurgical history of weld and base metal, chemical composition, concentricity of loading, welding variables.

Data Obtained - Ultimate strength, weld diameter, fracture characteristics.

Specifications - AWS C1.1.

References - 6.

Remarks - Used in conjunction with tension-shear-test results to obtain tension/shear ductility ratio.

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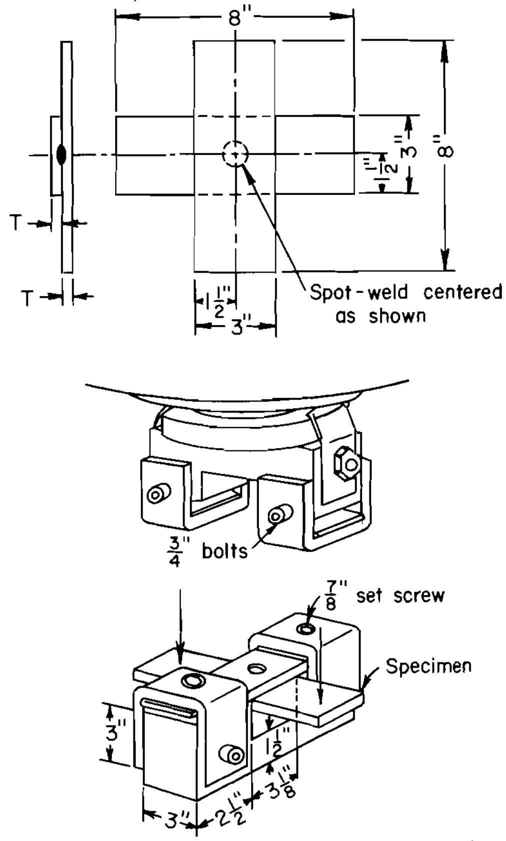
FIGURE 7. SPOT-WELD CROSS-TENSION-TEST SPECIMEN FOR THICKNESSES OVER 0.191 INCH



Purpose of Test - Developmental, strength, design allowables, ductility ratio.

Number of Specimens Tested - Usually 3.

Important Variables - Weld size, metallurgical history of weld and base metal, chemical composition, and concentricity of loading, welding variables.

Data Obtained - Ultimate strength, weld diameter, fracture characteristics.

Specifications - AWS C1.1-66

References - 6.

Remarks - Used in conjunction with tension-shear-test results to obtain tension/shear ductility ratio.

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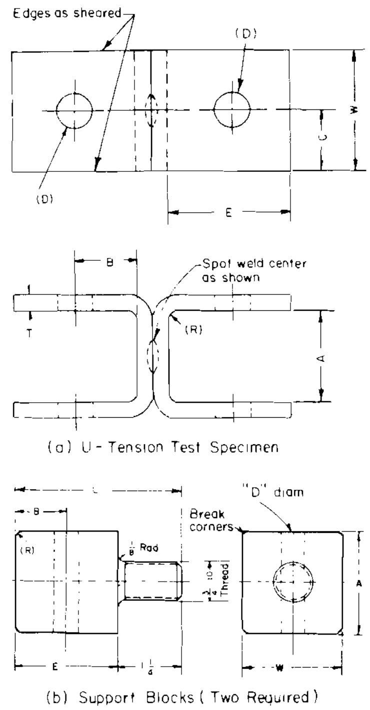
FIGURE 8. SPOT-WELD U-TENSION-TEST SPECIMEN



Dimensions, inches									
t, (thickness of specimen)	W	A	B	C	D_1	D_2	E	R*	L
Up to 0.100	1	1	1/2	1/2	21/64	11/32	1	5/32	E + 1-1/4
0.101 and over	2	2	1	1	9/16	17/32	2	1/4	E + 1-1/4

*For magnesium, high-strength aluminum alloys, and other alloys that cannot tolerate these radii, the radius must be increased to a suitable value within the limits of the capability of the particular material. It is desired to form these specimens without the necessity of heating as this will modify the results.

Purpose of Test - Developmental, strength, design allowables, ductility ratio.

Number of Specimens Tested - Usually 3.

Important Variables - Weld size, metallurgical history of the weld and base metal, chemical composition and concentricity of loading, welding variables.

Data Obtained - Ultimate strength, weld diameter, fracture characteristics.

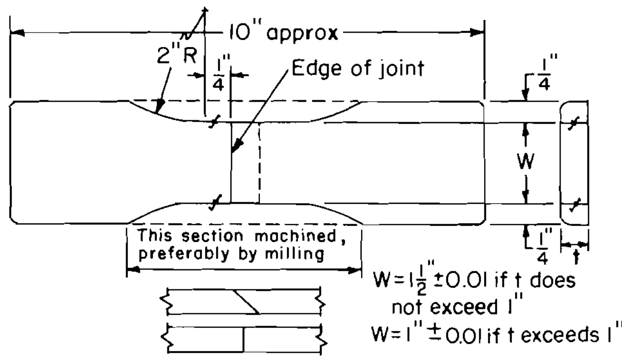
Specifications - AWS C1.1-66.

References - 6.

Remarks - Used in conjunction with tension-shear-test results to obtain tension/shear ductility ratio.

****

FIGURE 9. TRANSVERSE-BRAZED-JOINT TENSION-TEST SPECIMEN



Purpose of Test - Ultimate tensile strength.

Number of Specimens Tested - 2 minimum.

Important Variables - Base metal, brazing filler metal, brazing position.

Data Obtained - Ultimate load and strength, cross-sectional area, joint clearance, base-metal strength.

Specifications - ASME Sec. II.

References - 3.

Remarks - Specimen shown is for plate. Similar specimens are used for evaluating butt and scarf joints in pipe after machining to provide plane parallel faces across the gage section.

****

SHEAR TESTS

Tension-shear tests are used extensively for fillet-welded, spot-welded, and brazed joints. Fillet-weld tension-shear-test specimens normally represent completed joints in weldments and are prepared using similar procedures. Tension-shear-test specimens for evaluating spot welds or brazed joints also are easily prepared with equipment normally utilized in production. Numerous types of specimens have been used for evaluating brazed joints and strength values obtained vary widely, depending on the type of specimen used. Progress has been made recently by the American Welding Society toward establishing a standard tension-shear specimen for brazed joints. The specimens that are favored for determining tension-shear strength are shown in Figures 10 through 18.

Fillet-Weld Shear Specimens

For evaluating fusion-welded fillet joints, two basic types of specimens are available: the transverse fillet-weld-shear specimen and the longitudinal fillet-weld-shear specimen(Figures 10 to 13). All of these specimens are reasonably representative of fillet-welded joints being used for fabricating metals in industry.

Double-lap-shear specimens are more desirable than single-lap shear specimens because they are more symmetrical and hence the stress state when they are loaded better approaches pure shear. Pure shear loading in single-lap joint specimens requires special testing fixtures to align the specimen or to prevent bending of the specimen. The double-lap shear specimens are used for testing a broad range of fillet-welded plate sizes, whereas eccentric loading becomes excessive with thick-plate single-lap shear specimens. Gaps between the overlapped plates of single-lap specimens affect the stress concentration at the root of the welds and cause inconsistent test results. Consequently, these specimens are sensitive to preparation parameters. They are also sensitive to weld and heat-affected-zone defects, such as weld undercut, underbead cracking, and unfilled craters. The longitudinal-tension fillet-weld shear-test specimen, Figure 13, measures the strength of the fillet weld when the specimen is loaded parallel to the direction of the weld.

Spot-Weld-Shear Specimens

The tension-shear test is used extensively for evaluating resistance spot welds in sheet materials. The test is used mainly to determine ultimate shear strength when the specimen is tested in tension.[6] When used in combination with the cross-tension strength of spot welds, the cross-tension strength/tension-shear strength ratio is referred to as a measure of ductility. For uniform-size spot welds, the ductility ratio is computed from load values; however, for dissimilar size spot welds, ductility ratio is computed on the basis of strength.

A typical spot-weld tension-shear-test specimen that is widely used in industry is illustrated in Figure 14. One disadvantage of this type of specimen is its tendency to rotate when load is applied because of the offset in the lapped specimen; hence, pure-shear loading of the weld is prevented. This effect generally is disregarded, however.

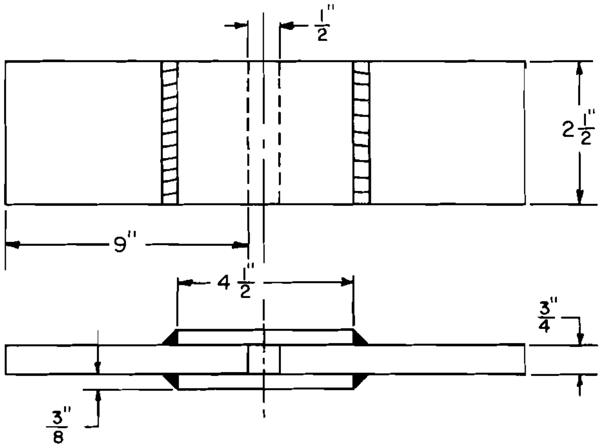
The spot-weld tension-shear test specimen illustrated in Figure 15 was recommended by the Materials Advisory Board.[5] With this specimen, as with other tension-shear test-specimen designs, eccentricity of loading must be minimized during fabrication and testing of the specimen. The joint efficiency of the spot weld is determined as the ratio of the shear load at failure of this spot-welded specimen to the product of the ultimate strength obtained for the same base metal, specimen width, and specimen thickness. The ultimate shear strength of the weld is the maximum shear load divided by the net shear area of the spot weld.

In aircraft and other applications where multiple rows of spot welds are used, test specimens containing a similar arrangement of spot welds are evaluated. In joint designs of this type, the effects of spot-weld spacing and arrangement on joint strength are evaluated.

Brazed-Joint Shear Specimens

Tension-shear-test specimens that conform to ASME Boiler and Pressure Vessel Code requirements are shown in Figure 16. These specimens are tested by standard procedures to obtain the maximum load sustained by the specimen. Acceptability of the strength-test results is based on comparison of joint strength and annealed-parent-metal strength. Many types of specimens have been used for evaluating the shear-strength of brazed joints.[14] With the same brazing alloy, base metal, and procedures, however, a wide range of shear-strength measurements can be obtained by varying the specimen. Because of the great variety of tension-shear specimens in use, efforts are being made toward standardization. Recently, the American Welding Society selected a lap-shear-test specimen as a standard for evaluating the strength of brazed joints.[12] The specimen is prepared by brazing overlapped portions of rectangular coupons (test-bar legs) followed by machining to form a reduced-section specimen. The specimen is illustrated in Figure 17. The Miller-Peaslee specimen also is widely used. This specimen is prepared from notched-rectangular coupons and is edge brazed. The specimen then is machined to the geometry shown in Figure 18 to provide nearly pure shear loading. An additional wide variety of specimens that have been used for evaluating brazed joints are illustrated in Figure 19.

FIGURE 10. DOUBLE-LAP TRANSVERSE-FILLET-WELD TENSION-SHEAR TEST SPECIMEN



Dimensions shown are MIL-STD-00418B (SHIPS); usually tested at room temperature in air.

Purpose of Test - Developmental, production quality, weldability, and design allowables; for comparative rather than absolute values.

Number of Specimens Tested - Usually 3, varying from 2 to 6.

Important Variables - Specimen geometry, weld quality, specimen positioning, strain-rate control, measurements, and data analysis.

Data Obtained - Weld shearing strength (reported as pounds per lineal inch of weld or psi based on throat).

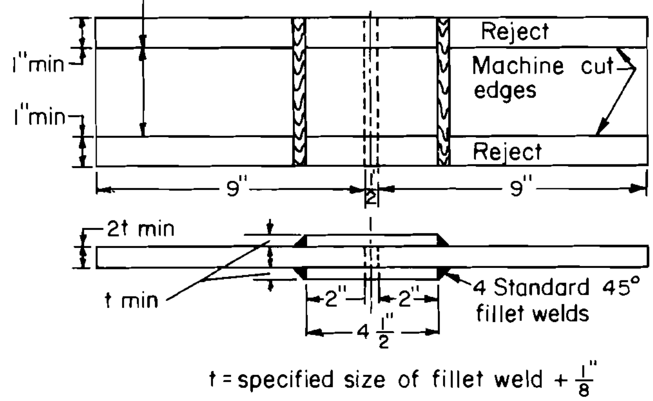
Specifications - MIL-STD-00418B(SHIPS); API-12C; AWS A4. 0.

References - 2, 10.

Remarks - Most widely used shear specimen and considered most desirable; although dimensions shown above are standard, because of the absence of eccentric loading this specimen can be used for a wide range of plate thicknesses without loss of sensitivity; it is recommended that the specimen edges be machined to eliminate the effects of weld craters at ends. This specimen is used when comparative values of strength per lineal inch of fillet weld are sufficient, and when because of cost or of time limitations it is desired to avoid machining of specimen shown in Figure 11.

****

FIGURE 11. DOUBLE-LAP TRANSVERSE-FILLET-WELD TENSION-SHEAR-TEST SPECIMEN



Purpose of Test - Tension shear strength, design allowables, production quality.

Number of Specimens Tested - 2 minimum.

Important Variables - Welding conditions, specimen preparation, alignment of specimen in testing fixture.

Data Obtained - Weld shearing strength, (reported as pounds per lineal inch of weld or psi based on throat).

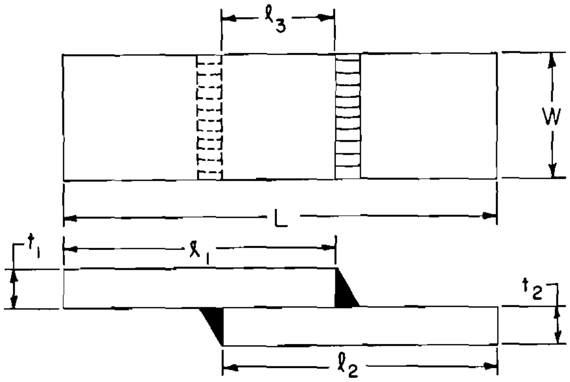
Specifications - MIL-STD-00418B(SHIPS); AWS A4. 0.

References - 2, 10.

Remarks - Specimen is sensitive to root notches, bend contour, and certain types of defects. This specimen is used when more nearly exact values of strength per lineal inch of fillet weld than those obtained with the specimen of Figure 10 are desired.

****

FIGURE 12. SINGLE-LAP TRANSVERSE-FILLET WELD TENSION-SHEAR TEST SPECIMEN



Dimensions, inches						
ℓ_1	ℓ_2	ℓ_3	L	t_1	t_2	W
6	6	1-1/2	10-1/2	<1/4	<1/4	1-1/2
9	9	1-1/2	16	>1/4	>1/4	2

Dimensions varied widely: usually tested at room temperature in air.

Purpose of Test - Developmental, strength, ductility, weldability, and design allowables.

Number of Specimens Tested - Usually 3.

Important Variables - Specimen geometry, weld quality, specimen positioning, strain-rate control, measurements, and data analysis.

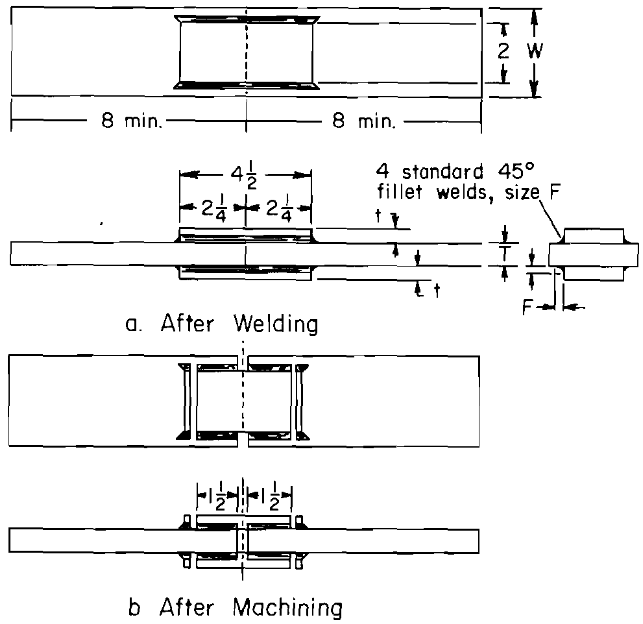
Data Obtained - Weld shearing strength (reported as pounds per lineal inch of weld or psi based on throat).

Specifications - Usually company specifications.

Remarks - Since load eccentricity increases with increasing plate thickness, this specimen not used for plates greatly exceeding 1/4-inch thickness; it is recommended that the specimen edges be machined to eliminate the effects of weld craters at ends.

****

FIGURE 13. LONGITUDINAL-FILLET-WELD TENSION-SHEAR-TEST SPECIMEN



Dimensions, inches					
Size of Weld	F	1/8	1/4	3/8	1/2
Thickness (min)	t	3/8	1/2	3/4	1
Thickness (min)	T	3/8	3/4	1	1-1/4
Width	W	3	3	3	3-1/2

Purpose of Test - Tension-shear strength, production quality, developmental.

Number of Specimens Tested - 2 minimum.

Important Variables - Welding conditions, specimen preparation, alignment of specimen in testing fixture.

Data Obtained - Weld shearing strength (reported as pounds per lineal inch of weld for welds which rupture.)

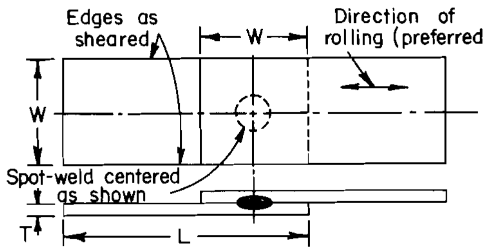
Specifications - MIL-STD-00418B (SHIPS), AWS A4.0.

References - 2, 10.

Remarks - Specimen is sensitive to root notches, bend contour, and certain types of defects.

****

FIGURE 14. SPOT-WELD TENSION-SHEAR-TEST SPECIMEN



Dimensions, inches		
T (Thickness of Thinner Sheet)	W (Specimen Width)	L (Recommended Length)
Up to 0.030	5/8	3
0.031 to 0.050	3/4	3
0.051 to 0.100	1	4
0.101 to 0.130	1-1/4	5
0.131 to 0.190	1-1/2	5
0.191 and over	2	6

Above data from AWS C1.1-66.

Purpose of Test - Weldability, design data, strength, ductility, weld size.

Number of Specimens Tested - 2 minimum.

Important Variables - Base-metal chemical composition, strength, ductility, thickness.

Data Obtained - Ultimate strength, weld diameter, fracture characteristics-- whether by shear of weld metal or by tear of the base metal, and whether the fracture is ductile or brittle.

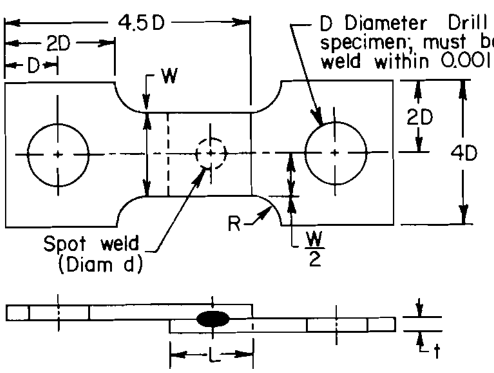
Specifications - MIL-W-6858; AWS C1. 1.

References - 6, 11.

Remarks - For materials 0.116 inch thick and greater. It is generally recommended that the tension-testing grips be offset to avoid bending at the grips.

****

FIGURE 15. SPOT-WELD REDUCED-SECTION TENSION-SHEAR-TEST SPECIMEN (MAB)



t	W
≤0.03	0.625
0.06	1.0
0.125	1.5
0.188	2.0
0.250	2.5
0.375	3.0
0.5	4.0

$d = 3t + 0.06$
$D \geq 2d \geq 6t + 0.12$
$L \geq 3d$

Purpose of Test - Developmental, ultimate load and strength, location of failure.

Number of Specimens Tested - 2 minimum.

Important Variables - Size, location and metallurgical history of weld and base metal, rolling direction, concentricity of loading, postweld heat treatment, specimen orientation relative to rolling direction, test temperature, loading rate, welding technique, material chemistry and metallurgical features, specimen thickness and width.

Data Obtained - Maximum shear load, weld area, irregularities disclosed on fracture surface.

Specifications - None.

References - 5.

Remarks - Surface indentations must not exceed 2 percent of sheet thickness. Pin loading of specimen allows for axiality at room and elevated temperatures.

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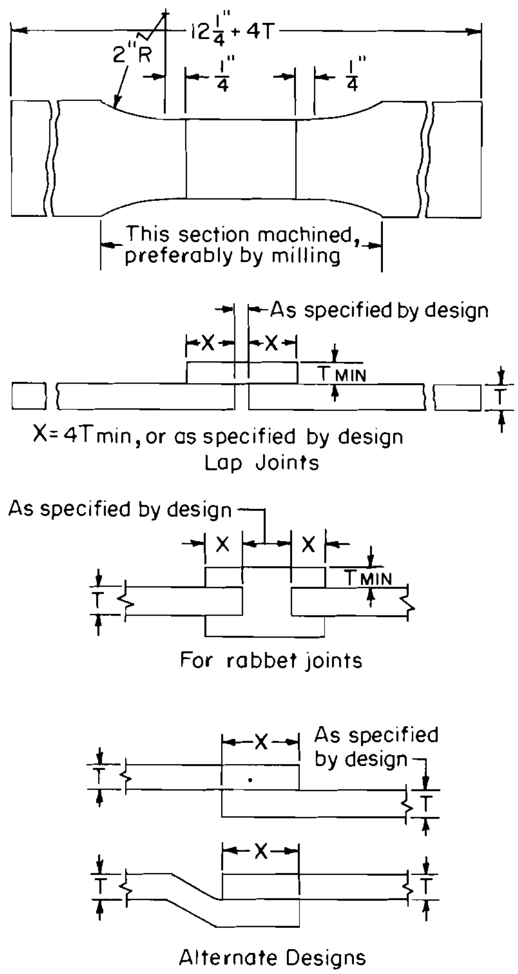
FIGURE 16. BRAZED-JOINT LAP-SHEAR-TEST SPECIMENS (ASME)



Purpose of Test - Ultimate strength, location of failure, ultimate strength of base metal, qualification.

Number of Specimens Tested - 2.

Important Variables - Base Metal, brazing filler metal, brazing position, joint clearance.

Data Obtained - Ultimate strength, cross-sectional area, joint clearance, base-metal strength.

Specifications - ASME Sec. IX.

References - 3.

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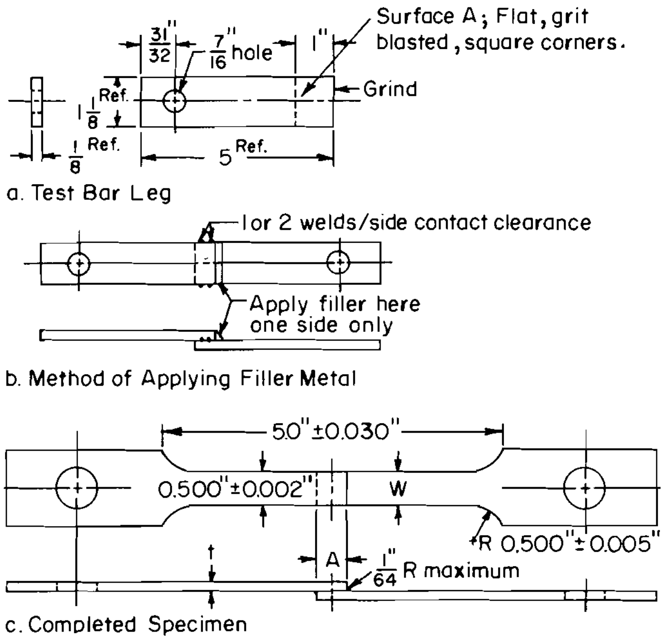
FIGURE 17. SINGLE-LAP BRAZED-JOINT SHEAR TEST SPECIMEN (AWS)



A	
Overlap as ratio of overlap to thickness	Actual overlap, inch
1/4	0.031
3/8	0.047
1/2	0.062
3/4	0.094
1	0.125
2	0.25
4	0.5
6	0.75

Purpose of Test - Strength of brazed joints, design, standardization, filler-metal development, process development.

Number of Specimens Tested - 10.

Important Variables - Base Metal, brazing alloy, fluxes, overlap, uniformity and accuracy of dimensions, surface preparation, joint clearance.

Data Obtained - Hardness, breaking load, location of failure, overlap (A), thickness (t) and width (W), average unit shear stress, average unit tensile stress.

Specifications - AWS C3.2

References - 12.

Remarks - Tack weld using GTAW process to maintain a constant and predetermined joint gap.

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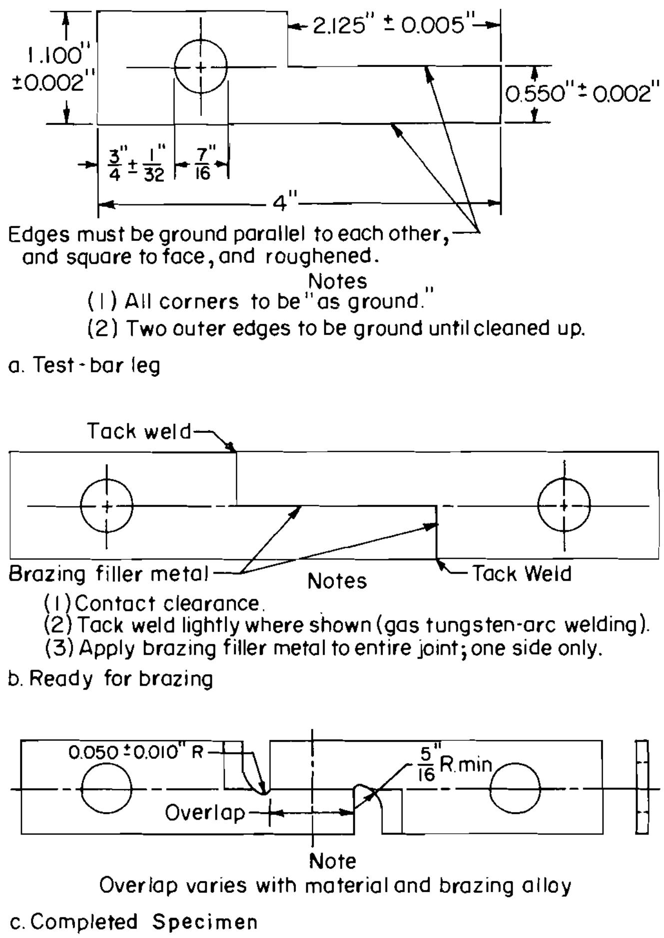
FIGURE 18. MILLER-PEASLEE SPECIMEN FOR BRAZED-JOINT SHEAR STRENGTH



Purpose of Test - Strength of brazed joints, filler metal, process and process-parameter development.

Number of Specimens Tested - 10.

Important Variables - Base metal, brazing alloy, fluxes, overlap, uniformity and accuracy of specimen dimensions, surface preparation, joint clearance.

Data Obtained - Breaking load, location of failure, overlap, thickness.

Specifications - Company.

References - 13.

Remarks - Tack weld using GTAW process not as reproducible as the single-lap shear test. Excess filler metal is removed after brazing.

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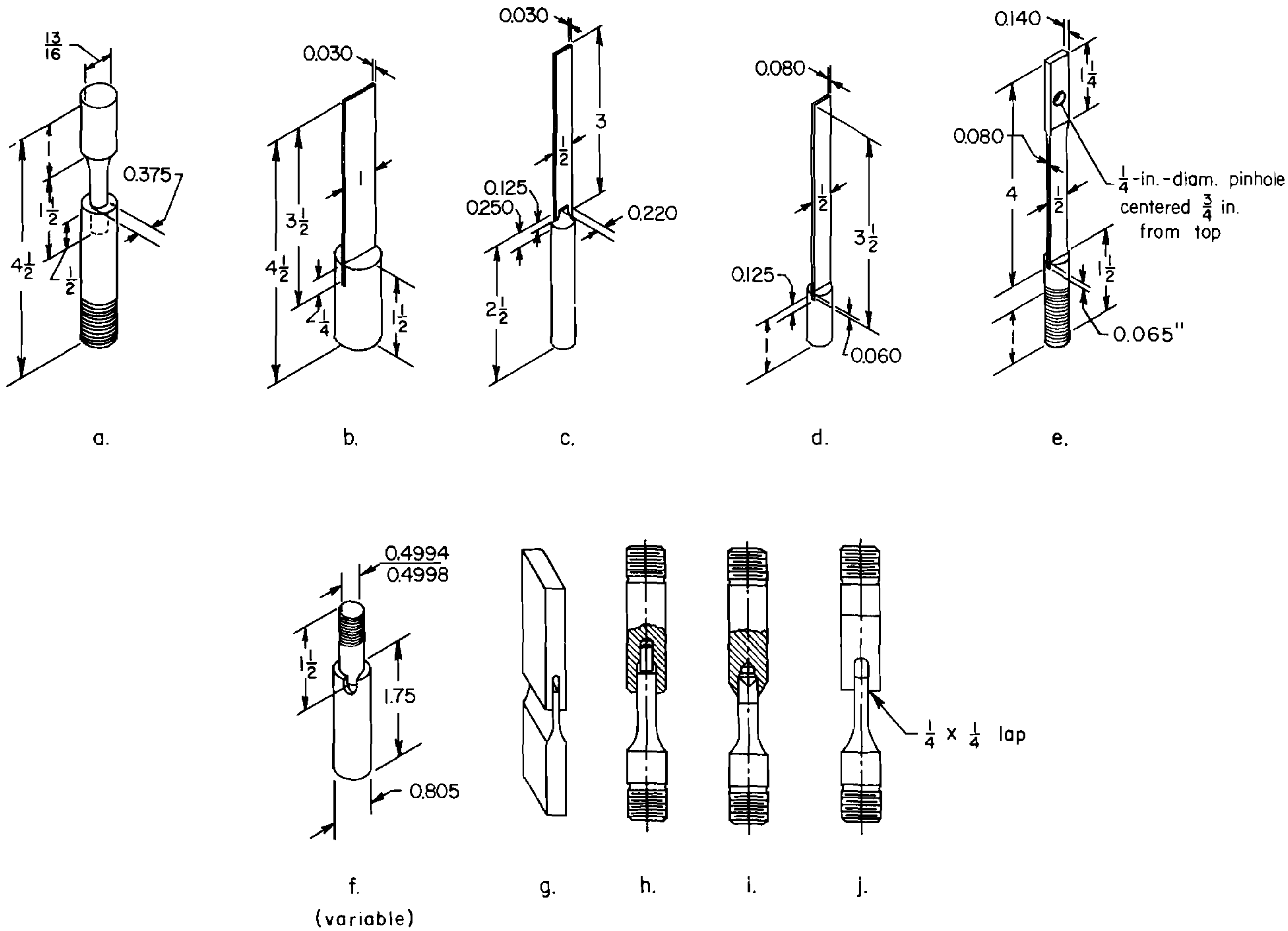
FIGURE 19. MISCELLANEOUS SPECIMENS FOR EVALUATING BRAZED-JOINT PROPERTIES(14,15)



BEND TESTS

Bend tests are used to evaluate ductility and soundness of welded or brazed joints. They are, next to tension tests, the most widely used group of tests for evaluating welds. Their popularity is justifiable on the basis of their simplicity and economy in materials and testing equipment and ease of specimen preparation. They provide reliable evaluations of ductility over a wide range of temperatures and useful information regarding weld soundness.

Specimens for bend tests may be used for evaluating the root, face, or side of the weld by placing the appropriate surface in tension. Corners and edges are usually filed or machined smooth so as to remove notches or machining marks that may otherwise influence the test results. Several specifications require such preparation. Specimens and equipment that are most generally used for bend tests are shown in Figures 21 through 32, and comprise the following types of tests:

(a) Longitudinal-weld, guided-bend tests;
(b) Transverse-weld, guided-bend tests;
(c) Longitudinal-weld, free-bend tests;
(d) Transverse-weld, free-bend tests;
(e) Fillet-weld, tee-bend tests.

Bend-test results are expressed in various terms: percent elongation of outer fibers, minimum bend radius prior to failure, go or no-go (passage or failure) for specific test conditions, and angle of bend prior to failure. Elongation is considered to provide the most reliable and reproducible data. Data also are obtained on weld soundness to characterize weld-metal flaws.

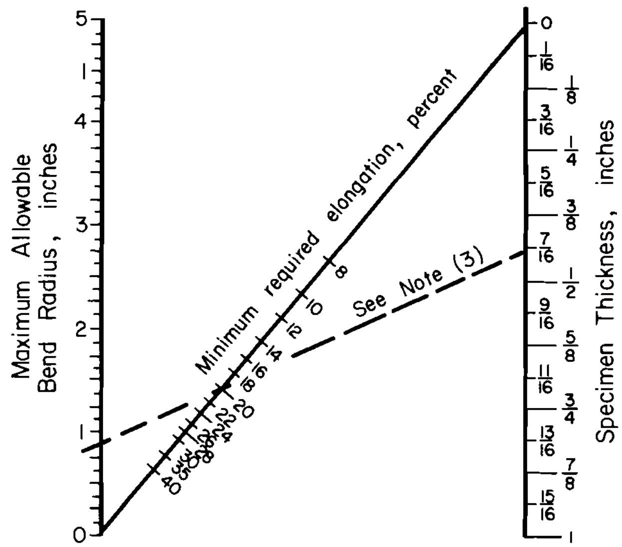
Elongation (e) occuring in the outer fibers, at the outer radius, is determined from gage marks that are scribed, inked, or photoetched on the specimens prior to testing or may be approximated from the radius of curvature (R) at the inside surface of the bend and the initial plate thickness (t):

$$e = t/(2R + t) \times 100.$$

In calculations of bend elongation, the bend radius obtained just before failure is recorded. When a minimum elongation is required for a particular specimen thickness, the maximum bend radius may be selected on a nomograph from MIL-STD-00418 (SHIPS). The nomograph is shown and its use explained in Figure 20. The nomograph also may be used to determine percent elongation from the specimen thickness and radius of the bend specimen.

For tests where bend specimens are progressively bent over a series of dies having decreasing radii, the radius of the last die passed before failure, is recorded as bend radius. In these tests, the specimen is forced to the bottom of a vee block by progressively smaller radii plungers in turn. Bend-ductility results also may be expressed in terms of the angle of bend just prior to failure. In the tee-bend test, the bend angle existing at the point of failure or the maxi-

FIGURE 20. NOMOGRAPH FOR SELECTING MAXIMUM BEND RADIUS(2)



Notes:

(1) It is recommended that the specimen thickness for the bend tests in general be approximately 3/8 inch. However, the specimen thickness may be any value within the range given above as dictated by the material thickness, available equipment, or the applicable specification.

(2) Required accuracy of measurement is as follows:

(a) Specimen thickness - ±1/64 inch.
(b) Elongation - ±1 percent.
(c) Bend radius - ±1/16 inch.

(3) Example - MIL-S-0000 requires a minimum elongation of 20 percent. Thus, if a 7/16-inch thick specimen is desired, a line is drawn between these two points and extended to determine the appropriate bend radius,which in this case would be 7/8 inch.

****

mum load indicated by drop-of-beam is recorded. In addition, load-deflection curves can be plotted from data in bend tests and provide measurements of yield load, elongation, and total energy-to-fracture (area under the load deflection curve). These results must be interpreted under the specific conditions of the test.

Although dimensions of guided-bend specimens vary over a wide range, two sizes are preferred. For materials from 0.010 to 1/4-inch thick, specimen length and width usually are 6-inches and 1-inch, respectively. For materials over 1/4-inch-thick, the length and width are 10 and 1-1/2 inches, respectively. Free-bend specimens usually are slightly longer (about 12 inches) but about the same width (1-1/2 inches).

The specimen width-to-thickness ratio is of considerable importance, since this ratio determines the extent of stress biaxiality produced during bending. This ratio varies from a low of 1.5 to a high of 18 but averages about 6. In general, a specimen width-to-thickness ratio of at least 4 should be maintained.

The ratio of span length to specimen thickness for single-point loading is also important. For ratios of span length to specimen depth (ℓ/t) of less than about 6 (depending on material), shearing stresses become significant and contribute substantially to deflection. When this ratio, ℓ/t, exceeds 6 by a considerable amount, bending stresses control. In general, an ℓ/t ratio of at least 10 should be maintained for single-point loading.

The two-point, symmetrical loading, "pure bending" system eliminates the effects of shear between the loading points so that fiber elongations are proportional to the distance from the neutral axis of the specimen in the elastic region and approximately so in the plastic region. For this reason, two-point loading is desirable, particularly for transverse weld-bend tests. In this instance, weld, heat-affected zone, and base plate are stressed equally in the constant-moment, central section of the specimen.

Strain-rate sensitivity is very important in tests of many refractory-metal alloys and of steels at very high strength levels. In general, however, results of bend tests on unnotched bend specimens of low- and medium-strength steels are not greatly affected by changes in strain rate up to rates approaching impact.

Longitudinal-Weld Bend Specimens

The longitudinal-weld guided-bend tests are considered more useful for ductility evaluations than transverse-weld guided bend tests because straining is the same in each of the various portions of weld-joint zones, i.e., in the weld, heat-affected zone, and base metal. A typical specimen for this type of test is shown in Figure 21. The ASME Boiler and Pressure-Vessel Code, Section IX, also requires guided bend tests on longitudinal brazed joints in dissimilar metal combinations. The brazed-joint specimen shown in Figure 22 is bend tested using the same fixture that is used for welded joints.

Transverse-Weld Bend Specimens

In transverse-weld, guided-bend specimens, Figures 23 and 24, mismatching of weld metal and base metal may result in unequal strains in the various zones, and the specimen may not conform to the bend die radius. Transverse-weld bend tests may contribute very little significant information on ductility of narrow welds, such as those made by electron-beam welding. Ductility of the specimen may be limited, not because the weld metal or heat-affected zone lacks ductility, but rather because of the limited width of the ductile areas.[19] The ASME Boiler and Pressure and Vessel Code, Section IX, also requires guided bend tests of transverse brazed-joint specimens, as shown in Figure 25. The testing fixture is the same as that for welded joints and the specimen must conform to within 1/8 inch of the die radius.

Free-Bend Specimens

Free-bend-specimens may be used for evaluating ductility of welds. Although quantitative data such as elongation, deflection, and angle of bend can be obtained, this specimen has limited use because it is difficult to confine bending to the desired area. Specimens used for this test are shown in Figures 26 and 27, which also illustrate initial and final bending methods used in tests of the specimens. Initial bending is performed with a two-point loading arrangement to confine the bend to the desired location. The specimen then is transferred to another fixture for final bending by compressing the ends of the specimen so that the specimen is bent into a U shape. Performance is rated on the basis of the number, size, and type of cracks or depressions which may appear during bending.

Fillet-Weld Tee-Bend Specimens

The fillet-weld tee-bend specimen, Figure 28, is used exclusively for evaluating fillet-weld performance. In this test, the specimen is bent until the angle of bending is 120 degrees or until fracture occurs. Performance is based on the maximum load, angle of bend, and fracture type shown in Figure 29.

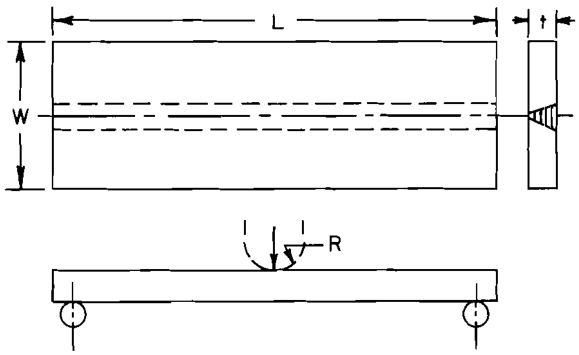
Notched-Bend Specimens

Current specifications that require bend tests for evaluating welds generally specify the use of unnotched specimens. A variety of notched-bend-test specimens are, however, used for evaluating notch toughness of weldments.[18, 20-22] These specimens are described later in the section on "Notch-Toughness and Fracture Toughness Tests". The nick-break specimen is an additional type of notched-bend test specimen. It is used chiefly for evaluating weld-metal soundness. This specimen is described in the section on "Soundness Tests".

Bend Test Fixtures

Fixtures have been reasonably standardized for the standard bend tests. A fixture for guided bend tests of transverse or longitudinal welded and brazed joints is illustrated in Figure 30. The specimen is bent to conform to the die so that a 1/32-inch wire (AWS) or a 1/8-inch wire (ASME) will not fit between the specimen and the die. The fixture for performing the fillet-weld tee-bend tests is illustrated in Figure 31; the plunger is advanced until the specimen has entirely fractured or the angle of bending has reached 120 degrees. A die set for bending specimens progressively through decreasing radii is illustrated in Figure 32.

FIGURE 21. LONGITUDINAL-WELD GUIDED-BEND TEST SPECIMEN (FACE AND ROOT BEND)



Dimensions, inches			
L	W	t	R
10	1-1/2	3/8	3/4
- 4	1-1/2	<1/4	Var.

Dimensions varied greatly; first dimensions shown are AWS standard. Second dimensions used for sheet with series of varying radii dies (see below); usually tested at room temperature in air with welds ground flush.

Purpose of Test - Developmental, production quality, ductility, weldability, design allowables, crack propagation.

Number of Specimens Tested - Usually 3, varying from 2 to 6.

Important Variables - Specimen geometry, weld quality, weld inspection, specimen positioning, measurements, and data analysis.

Data Obtained - Elongation in outer fibers (either measured or calculated), angle of bend, minimum bend die radius, load-deflection curves, location of first and subsequent fractures, fracture and defect features.

Specifications - MIL-STD-00418 B(SHIPS), AWS A4. 0, and ASME Sec. IX cover transverse-weld, guided-bend specimens but same dimensions are generally used for longitudinal weld test.

References - 2, 3, 10

Remarks - Considered one of most valuable of the bend tests; when used as a 180-degree guided-bend test, this is a go-no go test; however, if load-deflection, angle of bend, and minimum bend radius are determined, the test can be quantitative.

Testing Procedures:

Standard guided bend-- specimen bent about fixed radius until failure occurs or until specimen is bent 180 degrees. Surface defects on tension face must conform to allowable limits of pertinent specifications.

Single-point loading--load-deflection curve obtained for yield and ultimate strength and total energy-to-failure determinations. Also, angle of bend-to-failure can be reported but is not considered as significant as elongation estimates.

Varying radii dies --specimen is bent using a series of varying radii plungers until failure occurs. The specimen is "bottomed" in a die block by each plunger. The last radius passed before failure is recorded for elongation calculations.

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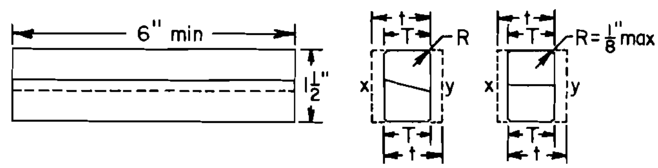
FIGURE 22. LONGITUDINAL BRAZED-JOINT GUIDED-BEND-TEST SPECIMEN



Note:

Machine x or y side as necessary to comply with requirements for longitudinal 1st surface and longitudinal 2nd surface bends. Thickness of machined specimens shall be as shown.

t, in.	T, in.
	All ferrous and nonferrous materials
1/16-3/8	t
>3/8	3/8

Purpose of Test - Soundness.

Number of Specimens Tested - 2 face and 2 root bend.

Important Variables - Base metal, brazing filler metal, brazing position, joint clearance.

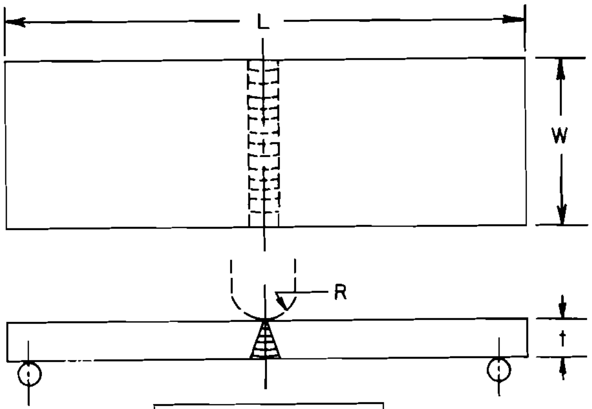
Data Obtained - Crack size and location, fracture and defect features.

Specifications - ASME Sec. IX.

.eferences - 3.

****

FIGURE 23. TRANSVERSE-WELD, GUIDED-BEND-TEST SPECIMEN (FACE AND ROOT BEND)



Dimensions, inches			
L	W	t	R
6*	1-1/2	3/8	3/4
4	1-1/2	<1/4	Var.

*minimum

Dimensions vary greatly. First set of dimensions shown are AWS standard. Second set of dimensions used for sheet with series of varying radii dies. Usually tested at room temperature in air with welds ground flush; corners are rounded to 1/16-inch max. radius.

Purpose of Test - Developmental, production quality, ductility, weldability, design allowables, crack propagation.

Number of Specimens Tested - Usually 3, varying from 1 to 6.

Important Variables - Specimen geometry, weld quality, weld inspection, specimen positioning, measurements, and data analysis.

Data Obtained - Elongation in outer fibers across weld (either measured or calculated), angle of bend, minimum plunger radius, load-deflection curves, and fracture and defect features.

Specifications - MIL-STD 00418B(SHIPS); AWS A 4. 0; ASME Sec. IX.

References - 2, 3, 10.

Remarks - Sensitive to weld-metal strength and ductility; if weld-metal strength is greater than that of the base plate and HAZ, almost all deformation will occur in base plate with the weld area remaining virtually straight; if weld metal has same or lower strength than base plate, the weld area will conform to die radius and elongation measurements across weld will be reliable. Corners are rounded and tool marks should be lengthwise of the specimen. Not acceptable for AWS if plate thickness is less than 3/8 inch.

Testing Procedures - Same as for longitudinal-weld guided-bend specimens.

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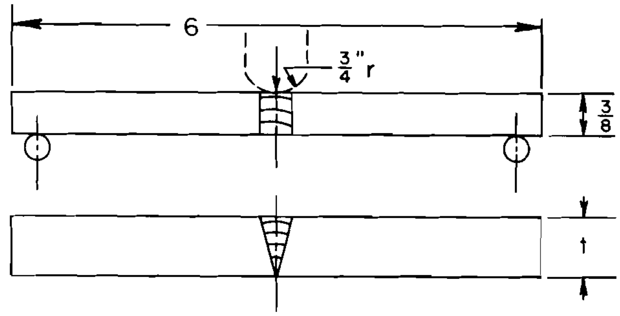
FIGURE 24. TRANSVERSE-WELD GUIDED-BEND-TEST SPECIMEN (SIDE BEND)



For plates 3/4 to 1-1/2 inches thick, specimen t equals actual plate t (less any surface grinding); for plates over 1-1/2 inches thick, cut specimen into about equal strips 3/4 to 1-1/2 inches wide and test each strip; test not applicable to plates less than 3/4 inch thick. Usually tested at room temperature in air. Root and face of weld should be machined to prevent premature edge failure.

Purpose of Test - Developmental, production quality, ductility, weldability, design allowables, crack-propagation and susceptibility, and weld soundness.

Number of Specimens Tested - Usually 3, varying from 1 to 6.

Important Variables - Specimen geometry, weld quality, weld inspection, specimen positioning, strain-rate control, measurements, and data analysis.

Data Obtained - Elongation in outer fibers across weld (either measured or calculated), angle of bend, minimum bend, die radius, load-deflection curves, and fracture and defect features.

Specifications - MIL-STD-00418B(SHIPS); AWS A4. 0; ASME Sec. IX.

References - 2, 3, 10.

Remarks - Side bending strains entire weld cross section, thus exposing defects near mid-thickness that might not contribute to failure in face-or root-bend test. Particularly useful in exposing lack of fusion defects and weld and HAZ cracks in multipass welds. This specimen often used to determine fissuring in stainless steel weldments.

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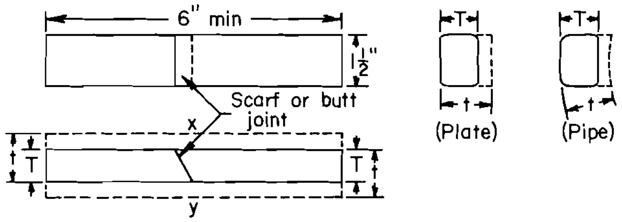
FIGURE 25. TRANSVERSE BRAZED-JOINT GUIDED-BEND-TEST SPECIMEN



t, in.	T, in.
	All ferrous and non-ferrous materials
1/16-3/8	t
>3/8	3/8
<3/8	3/8 or 4t (whichever is less)

Note:
Machine X or y side as necessary to comply with requirements for transverse 1st surface and transvetse 2nd surface bends. Thickness of machined specimen shall be as shown.

Purpose of Test - Soundness.

Number of Specimens Tested - 2 root and 2 face bends.

Important Variables - Base metal, brazing filler metal, brazing position, joint clearance.

Data Obtained - Crack size and location, fracture and defect features.

Specifications - ASME Sec. IX.

References - 3.

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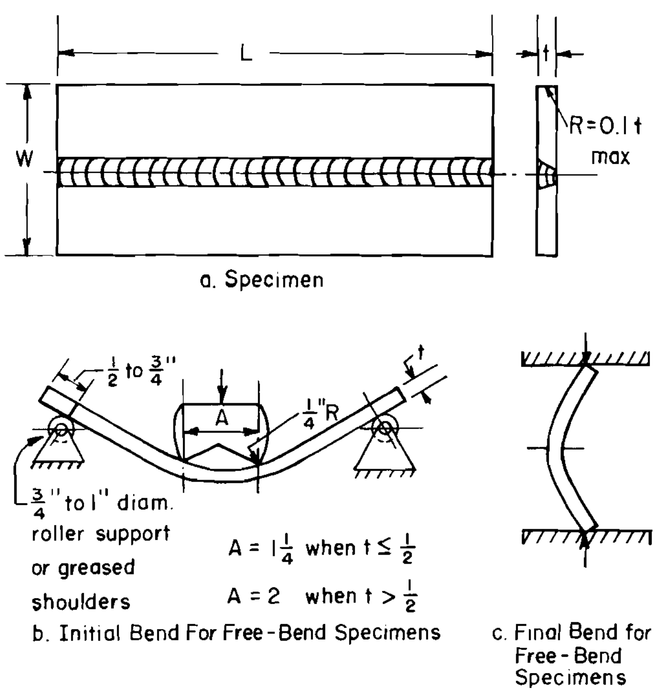
FIGURE 26. LONGITUDINAL-WELD FREE-BEND-TEST SPECIMEN



a. Specimen

b. Initial Bend For Free-Bend Specimens

c. Final Bend for Free-Bend Specimens

Dimensions, inches		
L	W	t
6	3/8	1/4
8	9/16	3/8
9	3/4	1/2
10	15/16	5/8
11	1-1/8	3/4
12	1-1/2	1
13-1/2	1-7/8	1-1/4
15	2-1/4	1-1/2
18	3	2
21	3-3/4	2-1/2

Dimensions shown are AWS A 4.0 specimen for transverse weld. Usually tested in air at room temperature. W = 1.5t.

Purpose of Test - Developmental, production quality, ductility, weldability, design allowables, crack propagation, and weld soundness.

Number of Specimens Tested - Usually 2, varying from 1 to 3.

Important Variables - Specimen geometry, weld quality, weld inspection, measurements, and data analysis.

Data Obtained - Elongation in outer fibers (either measured or calculated), angle of bend, minimum bend radius, and fracture location, fracture and defect features.

Specifications - None for longitudinal-weld specimen but specifications applying to transverse-weld specimen generally used.

References - 2, 3, 4, 10.

Remarks - Only limited use made of this specimen. Although quantitative data such as elongation and angle of bend can be obtained, this test is principally a go-no go test. Surface defects on tension face must conform to allowable limits of pertinent specifications. A guided-bend test using varying radii dies or a single-point bending system used to obtain load-deflection curves generally is preferred to the free-bend specimens for quantitative evaluation. Corners are rounded and tool marks should be lengthwise of the specimen.

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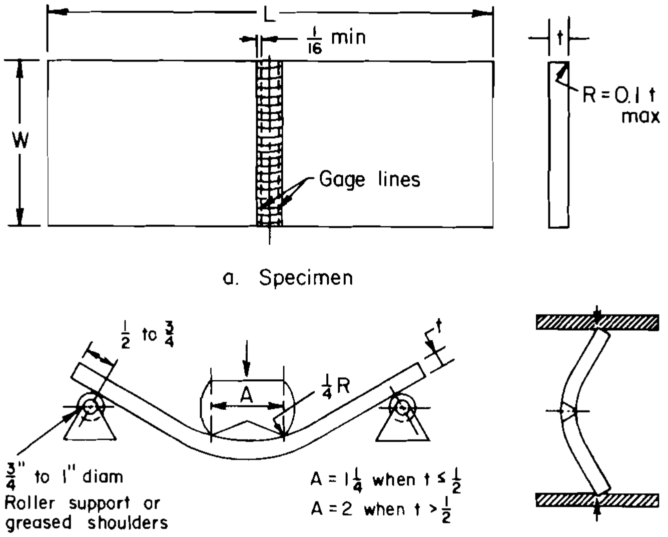
FIGURE 27. TRANSVERSE-WELD FREE-BEND-TEST SPECIMEN (FACE AND ROOT BEND



b. Initial Bend for Free-Bend Specimens

c. Final Bend for Free-Bend Specimens

Dimensions, inches		
L	W	t
6	3/8	1/4
8	9/16	3/8
9	3/4	1/2
10	15/16	5/8
11	1-1/8	3/4
12	1-1/2	1
13-1/2	1-7/8	1-1/4
15	2-1/4	1-1/2
18	3	2
21	3-3/4	2-1/2

Dimensions shown are AWS A 4.0. Usually tested in air at room temperature. W = 1.5 t.

Purpose of Test - Developmental, production quality, ductility, weldability, design allowables, crack propagation, and weld soundness.

Number of Specimens Tested - Usually 2, varying from 1 to 6.

Important Variables - Specimen geometry, weld quality, weld inspection, measurements, and data analysis.

Data Obtained - Initial and final gage length to nearest 0.01 inch, elongation in outer fibers (either measured or calculated), angle of bend, and minimum bend radius.

Specifications - MIL-STD-00418B(SHIPS), AWS A4.0, ASTM E16, ASME Sec. IX.

References - 2, 3, 4, 10.

Remarks - Only limited use made of this specimen. Although quantitative data such as elongation and angle of bend can be obtained, this test is principally a go-no go test. Surface defects on tension face must conform to allowable limits of pertinent specifications. A guided-bend test using varying radii dies or a single-point bending system used to obtain load-deflection curves generally is preferred to the free-bend specimens for quantitative evaluation. Corners are rounded and tool marks should be lengthwise of the specimen.

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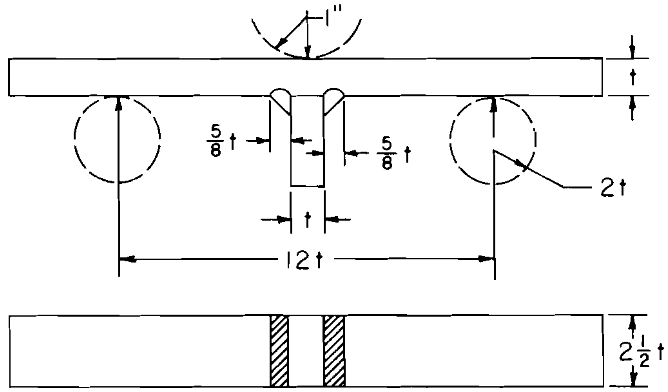
FIGURE 28. FILLET-WELD TEE-BEND TEST SPECIMEN



Usually used for t = 1/2 inch, but has been used for t = 1/4 to 1-1/2 inches; fillet weld deposited in a series of 18 increments, each about 2-11/16 inches long so as to form a joint 24 inches long containing 9 welded increments per side; after welding and aging a minimum of 21 days, bend specimens 2-1/2 t wide are cut from test specimens; usually tested at room temperature in air.

Purpose of Test - Developmental, production quality, strength, ductility, weldability, and design allowables.

Number of Specimens Tested - Usually 2.

Important Variables - Specimen geometry, weld quality, weld inspection, specimen positioning, and data analysis.

Data Obtained - Absorbed energy (from load-deflection curve), angle of bend, lateral contraction at a point 1/32 inch below toe of fillet nearest failure, and fracture location and type.

Specifications - MIL-STD-00418B(SHIPS), AWS A4.0.

References - 16, 17, 18.

Remarks - Because of restrictions on fillet-weld size, this test is limited to a specific energy input for a given electrode size; necessarily, this limits usefulness of test for studying effects of welding-procedure changes.

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FIGURE 29. CLASSIFICATIONS FOR FRACTURES DEVELOPED WITH THE FILLET-WELD TEE-BEND TEST

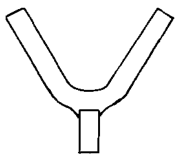
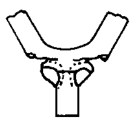
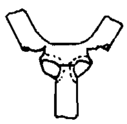
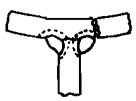
	Type "O" No Failure
	Type "1" Fracture A crack which starts at the toe of the fillet and follows the bond zone or the heat-affected zone under the weld but does not turn into the plate metal.
	Type "2" Fracture A slowly progressing crack which starts at the toe of the fillet and extends either directly into the plate material or follows the bond zone or heat-affected zone for a short distance and then turns into the plate metal.
	Type "3" Fracture A sudden or sharp crack which generally starts at the toe of the fillet and extends directly or perpendicular in the plate metal.

FIGURE 31. TEE-BEND-TEST FIXTURE

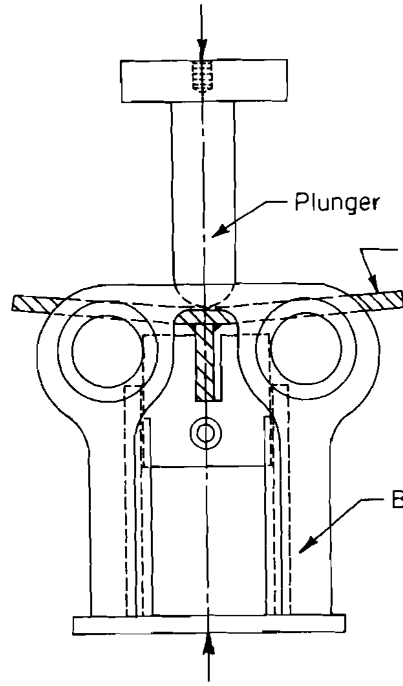


FIGURE 30. TYPICAL GUIDED-BEND-TEST FIXTURE

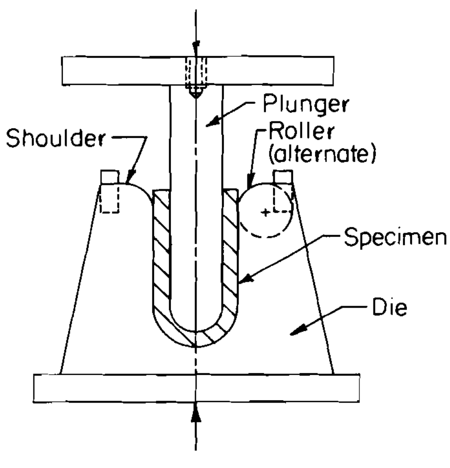
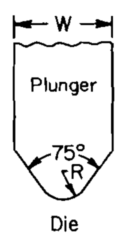
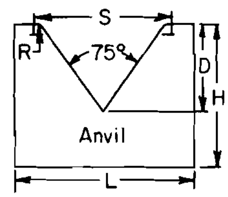


FIGURE 32. PROGRESSIVE-BEND-TEST DIE SET



Plunger Dimensions		
R	W	T*
1-1/2	3-1/2	1-3/4
3/4	2	1-3/4
1/2	1-3/4	1-5/8
1/4	1-1/4	1-1/4
3/16	1-1/4	1-1/4
3/32	1-1/4	1-1/4
1/8	1-1/4	1-1/4
1/16	1-1/4	1-1/4
3/64	1-1/4	1-1/4
1/32	1-1/4	1-1/4
1/64	1-1/4	1-1/4
Sharp	1-1/4	1-1/4

*T represents the thickness of the plunger.



Dimensions of Anvils		
Dimension	Anvil 1	Anvil 2
D	2	1-1/4
H	3-1/2	1-3/4
L	4-1/2	1-3/4
R	1/4	3/16
S	3-1/2	1-1/4
T*	1-3/4	1-3/4

*T represents the thickness of the anvil

Anvil 1 - minimum die - 1/2-inch radius
Anvil 2 - minimum die - 1/4-inch radius

All dimensions in inches

FATIGUE TESTS

The ability of a material or structure to withstand cyclic stresses is measured by fatigue tests. Structural assemblies are often subjected to variations in applied loads, which causes fluctuations of stresses in the various parts of the structure. When fluctuating stresses are of sufficient magnitude, failure may occur when the stress is repeated a sufficient number of times even though the maximum applied stress may be considerably less than the static strength of the material. Because of the extensive use of welding for fabricating structural assemblies, it is important to understand and evaluate the behavior of welded structures that are subjected to fatigue loading.

The process of welding, by its very nature, introduces local disturbances in the base-metal structure. The welding process, whether it involves using a brazing alloy or a fusion weld bead, introduces internal changes and possibly flaws within the heated zone. It also produces geometric notch effects at the junction between the added metal and the base metal. Welds affect the fatigue strength of a structure whether they are load-bearing or non-load-bearing welds. Whatever their origin, stress raisers such as changes in sections can profoundly affect the overall fatigue strength of the weldment.

In the choice of methods and specimens for fatigue testing, the type of loading experienced by the actual structure is important. Although large, built-up sections that simulate actual structures may be subjected to fatigue evaluation, fatigue testing of individual welded joints is performed in the laboratory with specimens that can be accommodated by the available equipment. Fatigue loading of these specimens generally is confined to one of the following:

(1) Axial
(2) Bending
(3) Rotational bending.

Axially loaded fatigue specimens are stressed in either tension, compression, or a combination of tension and compression. Fatigue in bending, is accomplished by flexing the specimen (generally made from plate material) while it is supported as a simple beam. In some cases, one end of the specimen is fixed and the fatigue load is applied at the free end. The rotating-beam-fatigue test is a special case of bend loading with a bending couple applied at each end of a round specimen while it is being rotated. One revolution constitutes one tension-compression fatigue cycle.

It is especially desirable that the preparation, machining, and stressing of fatigue specimens be done with care, particularly in the case of the coupon-type specimens, to insure accurate and reproducible loading conditions from specimen to specimen. The geometries of the grip ends (including the bolt holes) of fatigue specimens vary considerably, depending on the type and size (or capacity) of the fatigue-testing equipment that is available. Typical examples are shown in some of the figures. Geometric proportionality in gage sections is desirable for test specimens so that large specimens tested in high-capacity machines may be better related to smaller specimens tested on low-capacity machines.

Fatigue tests are much more complex than static tests and are subject to the influence of many variables that would have little or no influence on a static tension or bend test. In view of the wide variety of fatigue-specimen sizes and shapes possible, it is imperative that one be aware of all possible test variables when considering fatigue behavior of welded joints. Significant variables involved in fatigue testing weldments generally include the following:

(1) Stress concentrations, such as size, shape and roughness of weld beads (even the location of the start and stop position of the fusion weld bead can be significant)

(2) Number of cycles of repetitions of load (loading history)

(3) Magnitude, nature, and range of applied stress

(4) Properties of base metal and weld metal

(5) Weld joint design

(6) Heat treatment before, during and after welding

(7) Size effects

(8) Surface finish and surface treatments (shot peening around a weld can influence fatigue life)

(9) Rate of load application (low or high strain rate)

(10) Rest periods (if any) during fatigue test

(11) Temperature of test and environment

(12) Location and appearance of fracture, including point of origin of fatigue crack and presence or absence of defects

(13) Defects and nondestructive inspection methods

(14) Specimen geometry.

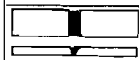
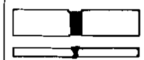
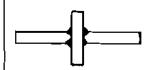
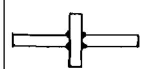
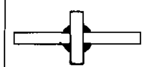
Fatigue-test specimens vary considerably in size and shape, depending upon such factors as the joining method, the kind of information needed, and the type and magnitude of the applied fatigue stresses. Many of the fatigue-test specimens that are used for evaluating fatigue properties of welds conform to previously established standards for specimens not containing welds, i.e., plate, sheet, bar, etc. These are small specimens that can be machined and tested conveniently with conventional equipment. A number of specimens, however, are complex and relatively large so as to be representative of actual structural weldments. These specimens are used where large, complex welded structures and thick plate material are involved, and high capacity equipment is required for fatigue testing them.

The complexity of some welded joints makes it impossible to generalize on the effects of welding on fatigue strength or to suggest a few "standard" weld-test specimens to evaluate fatigue behavior. However, it is of some value to consider relative fatigue strengths of a number of the more common joint configurations that have been used for test specimens, as well as for structural assemblies.

Figure 33 shows, in a general way, the effect of several weld-joint designs and weld-band geometries on fatigue strength.(23) For example, weld-bead geometry has a distinct influence on fatigue behavior of the cross joints. The effects of such variables as weld-bead contour and weld defects become even more important in their effects on the fatigue life of high strength steel weldments where brittle failure can occur. Attempts to increase the strength of a weldment by increasing the strength of the base metals are not always successful because the weld bead or fusion zone may become a limiting factor in fatigue behavior. The initiation and growth of fatigue cracks in welded joints also are affected by joint type and other factors, as shown in Figure 34.(24) The location of a fatigue failure may bear no relation to the location of a tensile failure in the same specimen.

Fatigue specimens for arc-welded, spot-welded, and brazed joints are shown in Figures 35 through 48. Fusion-welded fatigue-test specimens consist of butt, lap, and tee joints in which the loads are applied in directions that are normal (transverse weld) or parallel (longitudinal weld) to the major axis of the weld joint. Spot-welded fatigue-test specimens consist of lap joints and special types of butt joints. In the aircraft industry, specimens containing arrays of spot welds representative of actual assemblies are customarily tested in fatigue. Brazed fatigue-test specimens also consist of butt and lap joints that are stressed in a direction transverse to the joint. There are relatively few standard fatigue-test specimens designed specifically for evaluating welded joints; these often are not representative of actual joints or correlation of data obtained with actual joints is difficult. Consequently a variety of fatigue-test specimen designs have been developed and used in attempts to simulate actual weldments.

FIGURE 33. FATIGUE STRENGTH OF WELDED JOINTS IN MILD STEEL(23)

Type of Joint	Description	Maximum Stress Range, psi, for 2 x 10^6 Cycles: Alternating Push Pull	Maximum Stress Range, psi, for 2 x 10^6 Cycles: Repeating Tension
	V-butt, root sealed, machined flush	± 20,200	0 to 31,400
	V-butt, root sealed, as welded	± 15,700	0 to 12,300
	V-butt, root unsealed, as welded	± 13 400	0 to 7,850
	Cross joint, plates fully bevelled, complete fusion at root	± 11,200	0 to 9,000
	Cross joint, plates partially bevelled, incomplete fusion at root	± 3,300	0 to 15,700
	Cross joint, no preparation, plain fillets	± 5,050	0 to 8,950
	Lap joint, concave end fillets	± 7,600	0 to 14,600
	Lap joint, plain end fillets	± 6,270	0 to 11,600
	Lap joint, concave side fillets	± 8,300	0 to 15,700
	Lap joint, plain side fillets	± 5,800	0 to 11,200

Transverse-Weld Fatigue Specimens

Typical transverse-butt weld fatigue specimens are shown in Figures 35 through 39. When weld-metal fatigue properties are required, the side radius of the specimen is made small, as in the specimens shown in Figures 35 and 39, to help confine the failure in the weld metal. The R. R. Moore type rotating-beam specimen, which has been used for fatigue studies over many years, is shown in Figure 36. When a large side radius is used, as in the R. R. Moore specimen, failure is not necessarily restricted to the weld-metal location. Typical flat specimens for evaluating complete weld joints are shown in Figures 37 through 39.

Longitudinal-Weld Fatigue Specimens

Longitudinal-butt weld fatigue specimens are illustrated in Figures 40 through 42. These specimens contain all of the structures normally formed in a weld joint. With these specimens, all of the weld zones are subjected to approximately equal stress levels, so that the weakest zone will fail initially. As is the case with longitudinal-weld tension or bend tests, longitudinal-weld fatigue tests should be expected to discriminate the weakest zone in a welded joint. The bending-fatigue specimen shown in Figure 42 is considered to be an improvement over previous bending-fatigue specimens, because a constant stress is provided along the gage section of the specimen.

Fillet-Weld Fatigue Specimens

Fillet-weld fatigue behavior also can be evaluated using either transverse- or longitudinal-weld fatigue-test specimens, as illustrated in Figures 43, 44, and 45. The basic specimen can be adapted for evaluating transverse welds, longitudinal welds, or combinations of these two types. The complexity of some welded structures makes it very difficult to determine the fatigue strength of whole structures with simple test specimens. For example, actual beam sections are sometimes used to study continuous longitudinal fillet welds in structural steels, such as T or H-section beams. Figure 45 illustrates a relatively new type of axially loaded specimen for evaluating the fatigue behavior of longitudinal fillet weldments under axial stress. This specimen is relatively simple and inexpensive and is reported to provide fatigue data representative of actual beam specimens in bending fatigue.(26)

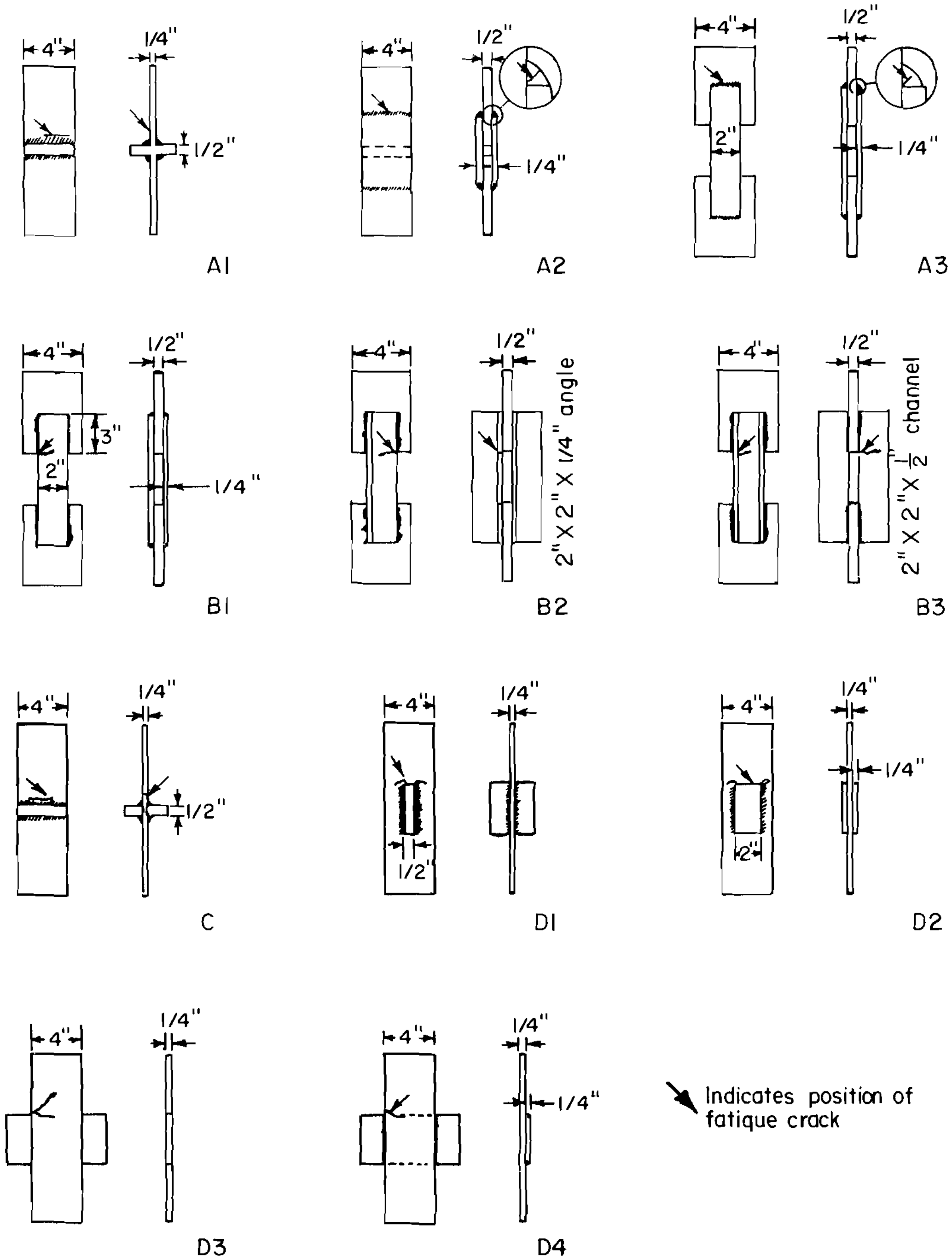
Spot-Weld Fatigue Specimens

Spot welds usually are subjected to fatigue tests, particularly when aircraft applications are involved. Figure 46 shows a single spot-weld axial-fatigue test specimen recommended by the American Welding Society.(6) This specimen is essentially a duplicate of the spot-weld tension-shear test specimen except for the grip end preparation. The gripping method must provide for good alignment of the axial load with the center of the weld nugget. The complex nature of spot-weld fatigue-test specimens utilized by some aircraft companies is illustrated in Figure 47. As shown, an array of multiple spot welds is tested in a single specimen. These specimens usually are representative of the spot-welded structures in aircraft.

Brazed-Joint Fatigue Specimens

Brazed-joint fatigue properties have been determined with both lap- and butt-joint specimens, as shown in Figures 36 and 48. Published figures are scarce, however, on fatigue strength of brazed joints. In general, the lap joint is the most common type of brazed joint. Butt joints, generally considered poor design, are used only when absolutely necessary.

FIGURE 34. FATIGUE FAILURE SITES IN VARIOUS WELD JOINTS IN ALUMINUM ALLOYS(24)



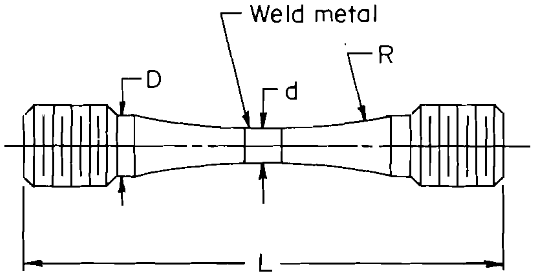
A = Load-carrying transverse fillet welds

B = Load-carrying longitudinal fillet welds

C = Non-load-carrying transverse fillet welds

D = Non-load-carrying longitudinal fillet welds

FIGURE 35. TRANSVERSE-WELD, AXIAL-FATIGUE-TEST SPECIMEN (ROUND)



Dimensions, inches			
d	D	L	R
0.25	1.0	6	2.5
0.25	0.435	3-3/16	10

Test temperatures range from +70 to 1800 F; normally tested in air.

Purpose of Test - Developmental, fatigue strength, weldability, and design allowables.

Number of Specimens Tested - Average 12, varying from 3 to 25.

Important Variables - Specimen geometry, weld quality, weld inspection, testing equipment, specimen preparation, specimen positioning, measurements, and data analysis.

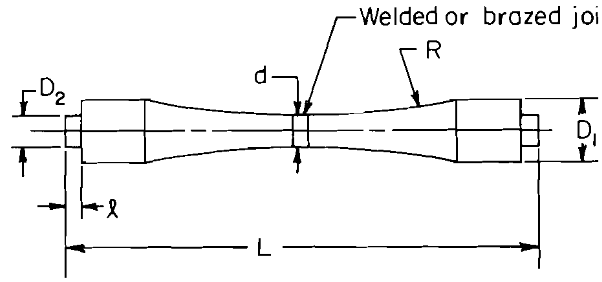
Data Obtained - Fatigue strength, cycles to failure, and endurance limit.

Specifications - Company specifications only.

Remarks - Specimen designed to force failure in weld (in the absence of gross base-plate flaws); necessarily considered a weld evaluation and not a composite weldment (weld, HAZ, and base-plate) test; should be used in conjunction with longitudinal-weld specimen.

****

FIGURE 36. TRANSVERSE-WELD AND TRANSVERSE-BRAZE ROTATING-BEAM-BENDING-FATIGUE-TEST SPECIMEN (ROUND)



Dimensions, inches					
ℓ	L	d	D_1	D_2	R
0.50	10.21	1.00	1.50	0.640	9.00
--	3-7/16	0.300 $\pm$0.003	0.480	--	9-7/8

Second set of dimensions are for standard R. R. Moore specimen with drilled and tapped specimen ends; specimens usually tested at room temperature in air.

Purpose of Test - Developmental, production quality, fatigue strength, weldability, and design allowables.

Number of Specimens - Usually 10, varying from 3 to 12.

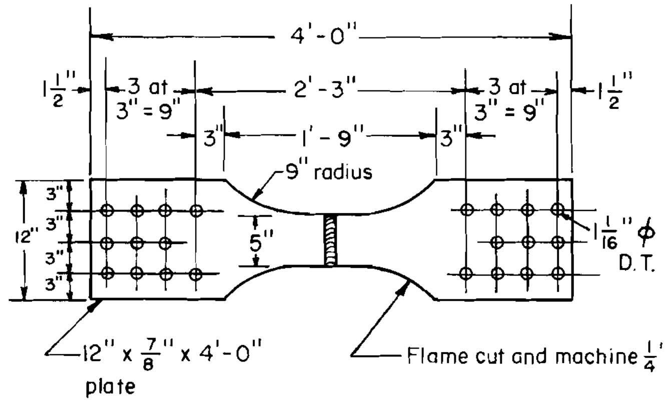
Important Variables - Specimen geometry, welded or brazed-joint quality, weld inspection, testing equipment, specimen preparation, specimen positioning, measurements, and data analysis.

Data Obtained - Fatigue strength, cycles to failure, and endurance limit.

Remarks - Because of generous radius, failure is not limited to weld location, and may occur in weld, HAZ, or base plate.

****

FIGURE 37. TRANSVERSE-WELD AXIAL-FATIGUE-TEST SPECIMEN FOR THICK-PLATE WELDMENTS



Dimensions shown are for a relatively large specimen. They can be scaled down without noticeable size effects.

Purpose of Test - Developmental, production quality, fatigue strength, weldability, and design allowables.

Number of Specimens Tested - Average about 10.

Important Variables - Specimen geometry (with or without weld reinforcement), weld quality, weld inspection, test equipment and test cycle, specimen preparation and positioning, measurement, data analysis, heat treatment.

Data Obtained - Fatigue strength, cycles to failure, endurance limit, effects of defects on fatigue properties.

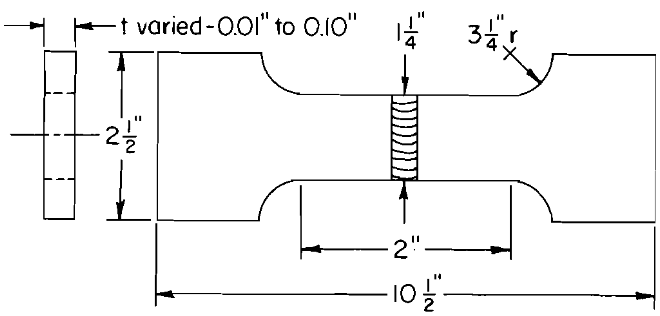
Specifications - Generally company specifications following shop practice. Specimen can be used for tests of either full or partial penetration butt welds.

References - 25.

Remarks - No apparent specimen-size effects evident within a width range of 1-3/8 to 6 inches, and thickness range of 1/2 to 1-1/2 inch. When tested with weld reinforcement, specimen sensitive to bead shape, weld undercut, and weld-metal strength.

****

FIGURE 38. TRANSVERSE-WELD AXIAL-FATIGUE-TEST SPECIMEN (FLAT)



Dimensions varied greatly; tested over wide range of temperature from -100 to +1600 F, usually in air; tested with and without weld reinforcement, depending on service conditions.

Purpose of Test - Developmental, production quality, fatigue strength, weldability, and design allowables.

Number of Specimens Tested - Average 10, varying from 3 to 25.

Important Variables - Specimen geometry (with or without weld reinforcement), weld quality, weld inspection, testing equipment, specimen preparation, specimen positioning, measurements, and data analysis.

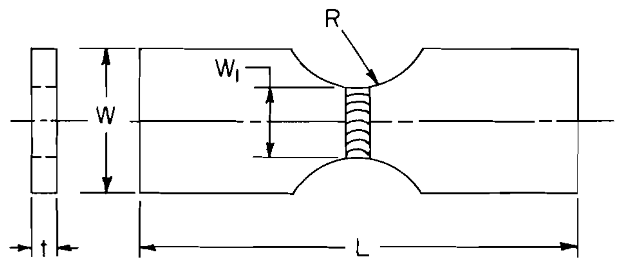
Data Obtained - Fatigue strength, cycles to failure, and endurance limit.

Specifications - Company specifications only.

Remarks - Specimen, when tested with weld reinforcement, is sensitive to bead shape, weld undercut, weld-metal strength (overmatching or undermatching).

****

FIGURE 39. TRANSVERSE-WELD BENDING-FATIGUE-TEST SPECIMEN (FLAT)



Dimensions, inches				
L	W	W_1	R	t
4	1-1/4	3/4	1/2	1/8
9-1/4	2	1-1/2	3	1/8

Dimensions varied greatly; usually tested at room temperature in air; tested with and without weld reinforcement, depending on service conditions.

Purpose of Test - Developmental, production quality, fatigue strength, weldability, and design allowables.

Number of Specimens Tested - Usually 10.

Important Variables - Specimen geometry (with or without weld reinforcement), weld quality, weld inspection, testing equipment, specimen preparation, specimen positioning, measurements, and data analysis.

Data Obtained - Fatigue strength, cycles to failure, and endurance limit.

Specifications - Company specifications only.

Remarks - Specimen designed to force failure in weld or HAZ, consequently, not a composite-weldment test specimen.

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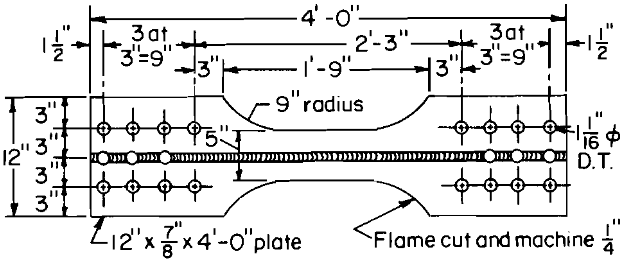
FIGURE 40. LONGITUDINAL-WELD AXIAL-FATIGUE-TEST SPECIMEN FOR THICK-PLATE WELDMENTS



Purpose of Test - Developmental, determination of fatigue strength, effects of welding parameters on fatigue strength and design allowables.

Number of Specimens Tested - For an S-N curve, at least 10 specimens.

Important Variables - Specimen geometry (with or without weld reinforcement), weld quality, weld inspection testing equipment, specimen preparation, positioning and measurements, data analysis, and heat treatment.

Data Obtained - Fatigue strength, cycles to failure, and endurance limit.

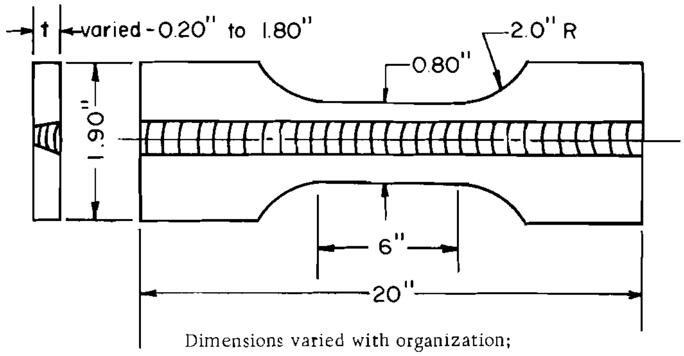
Specifications - Company specification.

References - 25.

Remarks - Specimen when tested with weld bead intact is sensitive to bead shape, roughness, and weld undercut. No important specimen-size effects appear to be evident within a width variation of 1-1/2 to 11-1/2 inches and thickness variations of 1/2 to 1-1/2 inches.

****

FIGURE 41. LONGITUDINAL-WELD AXIAL-FATIGUE-TEST SPECIMEN



Dimensions varied with organization; usually tested in air at room temperature; tested with and without weld reinforcement, depending on service conditions.

Purpose of Test - Developmental, fatigue strength, weldability, and design allowables.

Number of Specimens Tested - Usually 5, varying from 3 to 6; however at least 10 should be used to establish S-N curve.

Important Variables - Specimen geometry (with or without weld reinforcement), weld quality, weld inspection, testing equipment, specimen preparation, specimen positioning, measurements, and data analysis.

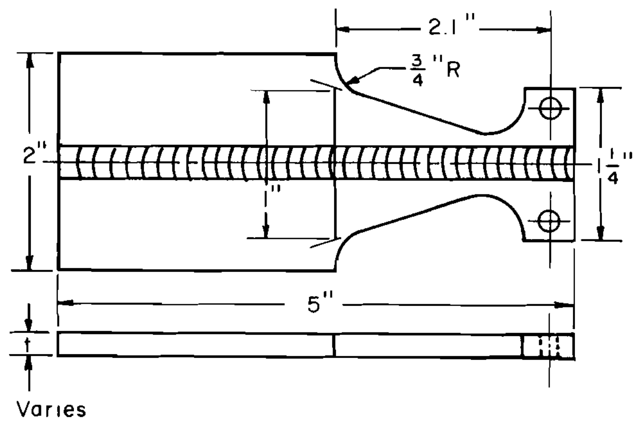
Data Obtained - Fatigue strength, cycles to failure, and endurance limit.

Specifications - Company specifications only.

Remarks - Specimen evaluates composite weldment; the effects of weld-metal "mismatching" are the same for this specimen as for static tension specimen (see section on tension tests).

****

FIGURE 42. LONGITUDINAL-WELD CONSTANT-MOMENT BENDING-FATIGUE-TEST SPECIMEN



Dimensions varied greatly; usually tested at room temperature in air; tested with and without weld reinforcement depending on service conditions.

Purpose of Test - Developmental, production quality, fatigue strength, weldability, and design allowables.

Number of Specimens Tested - 10.

Important Variables - Specimen geometry, weld quality, weld inspection, testing equipment, specimen preparation, specimen positioning, measurements, and data analysis.

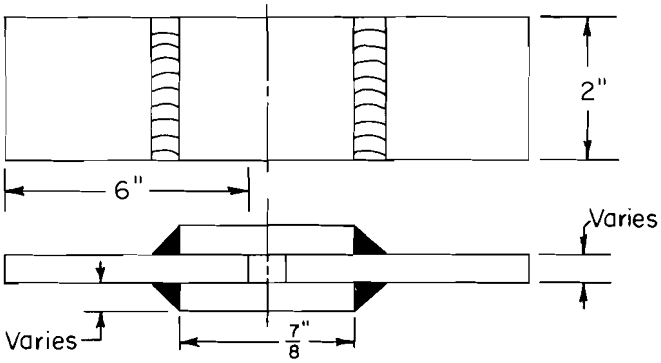
Data Obtained - Fatigue strength, cycles to failure, and endurance limit.

Specifications - Company specifications only.

Remarks - Considered good weldment evaluation; because of constant stress over a considerable portion of specimen, failure will occur at weakest point such as a weld defect.

****

FIGURE 43. TRANSVERSE-FILLET-WELD AXIAL-FATIGUE-TEST SPECIMEN



Thickness dimensions not reported but probably can be used on plates up to 1/2 inch thick without difficulty.

Purpose of Test - Developmental, fatigue strength, weldability, and design allowables.

Number of Specimens Tested - 3 reported but at least 10 should be used to establish S-N curve.

Important Variables - Specimen geometry (for symmetry), weld quality, weld inspection, testing equipment, specimen preparation, specimen positioning, measurements, and data analysis.

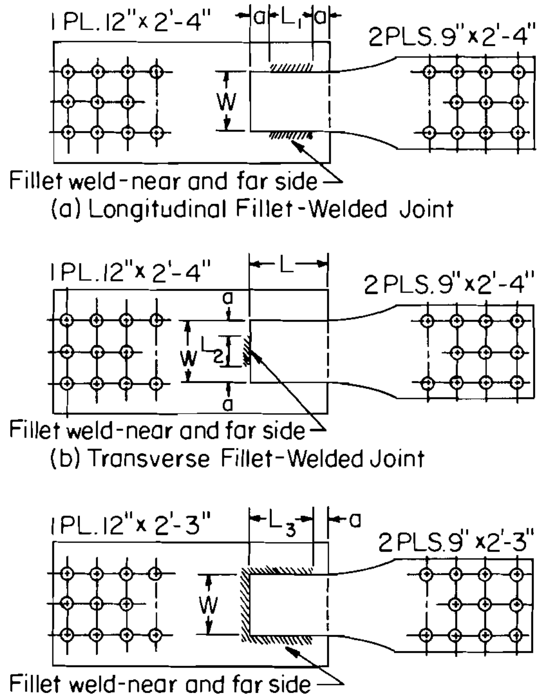
Data Obtained - Fatigue strength, cycles to failure, and endurance limit.

Specifications - Company specifications only.

Remarks - Very limited use but considered good test specimen; it is recommended that the specimen edges be machined to eliminate the effects of weld craters at ends.

****

FIGURE 44. TRANSVERSE- AND LONGITUDINAL-FILLET-WELD AXIAL-FATIGUE-TEST SPECIMENS



(a) Longitudinal Fillet-Welded Joint

(b) Transverse Fillet-Welded Joint

(c) Combined Longitudinal and Transverse Fillet-Welded Joint

Purpose of Test - Fatigue properties of fillet-welded joints.

Number of Specimens Tested - Average about 10.

Important Variables - Specimen geometry, weld quality and weld inspection, test equipment and test cycles, specimen preparation.

Data Obtained - Fatigue strength, cycles to failure, endurance limit, effects of defects on fatigue properties.

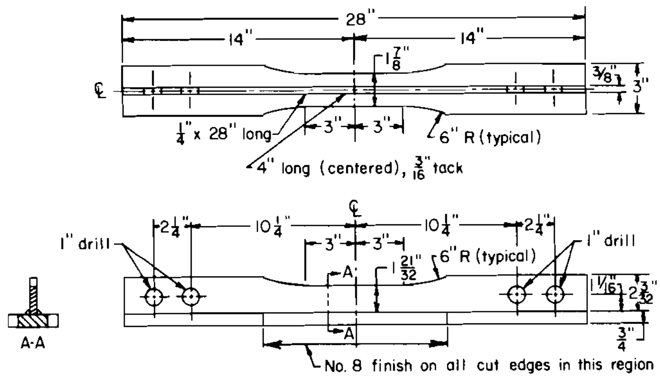
Specifications - Company specifications.

References - 25.

Remarks - Note that two plates exactly matched are attached to both sides of rectangular end by matching fillet welds.

****

FIGURE 45. LONGITUDINAL-FILLET-WELDED-TEE, AXIAL-FATIGUE-TEST SPECIMEN



Purpose of Test - Fatigue properties of longitudinal fillet weldments under axial stress.

Number of Specimens Tested - At least 10 specimens for S-N curve.

Important Variables - Specimen geometry, weld quality, weld inspection, test equipment, specimen preparation and positioning, measurements, and data analysis.

Data Obtained - Fatigue data for flange-to-web fillet welds under axial stresses such as those in the pure-moment region in beams or in tension members of a truss.

Specifications - None.

References - 26.

Remarks - Fillet welds terminate outside the gage section. Correlation of welded tee specimen with welded beams reported to be good. Special grips are used in axial stressing of this specimen.

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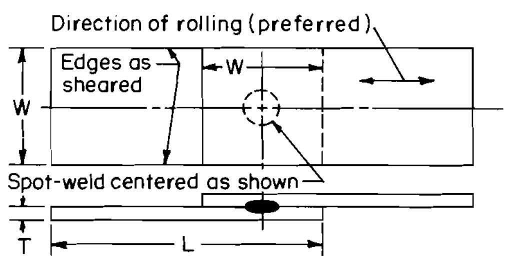
FIGURE 46. SPOT-WELD AXIAL-FATIGUE-TEST SPECIMEN



Dimensions, inches

T Thickness of Thinner Sheet)	W (Specimen Width)	L (Recommended Length)
Up to 0.030	5/8	3
0.031 to 0.050	3/4	3
0.051 to 0.100	1	4
0.101 to 0.130	1-1/4	5
0.131 to 0.190	1-1/2	5
0.191 and over	2	6

Purpose of Test - Fatigue properties of spot welds.

Number of Specimens Tested - Generally 3.

Important Variables - Alignment of load with weld, specimen geometry, weld quality.

Data Obtained - fatigue strength, cycles to failure.

Specifications - AWS C1.1-66.

References - 6.

Remarks - Grip end should be designed and carefully prepared to ensure loading along the spot weld centerline.

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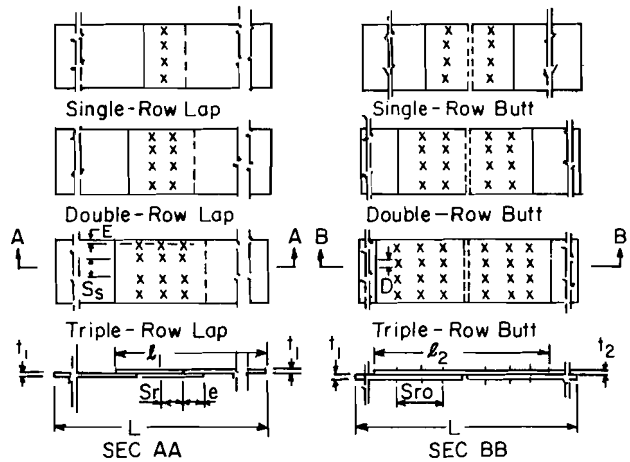
FIGURE 47. MULTIPLE-SPOT-WELD AXIAL-FATIGUE-TEST SPECIMENS



L - Panel length
W - Panel width
E - End distance
D - Weld or rivet diameter
ℓ_1 - Plate length
ℓ_2 - Strap length
S_s - Pitch
Sr - Row spacing
Sro - Row spacing (overall)
t_1 - Plate thickness
t_2 - Strap thickness
e - Edge distance

Purpose of Test - Determine fatigue strength of spot-weld construction.

Number of Specimens Tested - At least 10 for an S-N curve.

Important Variables - Joint type, geometry (including spacing of spots, number of rows, etc.), fatigue cycle, and stress.

Data Obtained - Fatigue strength, cycles to failure, and endurance limit, effects of variables on fatigue life.

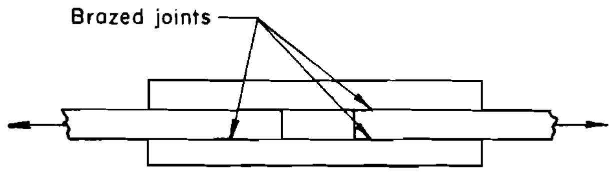
Specifications - Company specifications.

References - 27.

Remarks - Geometric parameters will be by far the most important variables operating in these specimens and results obtained may be expected to apply to other materials in a qualitative way.

****

FIGURE 48. DOUBLE-LAP BRAZED-JOINT AXIAL-FATIGUE-TEST SPECIMEN



Purpose of Test - Fatigue properties of brazed lap joints.

Number of Specimens Tested - Minimum of 10 specimens for an S-N curve.

Important Variables - Brazing cycle and filler material, joint clearance, and geometry.

Data Obtained - Fatigue strength, cycles to failure, endurance limit, effects of brazing variables and of braze defects on fatigue life.

Specifications - None.

References - 28.

Remarks - Size of specimen will depend on fatigue equipment and type of structure being joined by brazing.

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CRACKING SUSCEPTIBILITY TESTS

Cracks may form as a result of the welding operation and can occur within the weld metal or outside the weld deposit in the weld-heat-affected zone. Occasionally, cracks will occur in both places in the same weld. Test methods and specimens to determine crack sensitivity or susceptibility are numerous. Most organizations using weld tests generally include cracking susceptibility tests among them. Cracking susceptibility tests vary in type from simple to complex but despite the large number available, only about one-half dozen are used to any great extent. The weld-cracking susceptibility-test specimens that are considered to be the most useful and of significant current interest are summarized in Table 1 and illustrated in Figures 49 through 67. These specimens may be used alone or in combination for evaluating the cracking tendencies of welds in various material combinations under the weld-fabricating conditions. Test results may include information on crack location, orientation and size, conditions existing during their formation such as temperature and conditions of restraint, and time after welding.

Generally speaking there are two types of cracks that are experienced in welding operations-hot cracks and cold cracks. Weld hot cracking (sometimes called supersolidus cracking) is believed to occur during solidification of the molten weld metal or base metal. There are several theories of hot cracking and they are discussed in a recent report by Kammer, et al.(32) One popular theory considers hot cracking to be caused by intergranular eutectic-type liquid films. Regardless of the acceptibility of any one theory, the hot cracks can occur in the weld-metal zone or in the heat-affected zone and are intergranular-type cracks. The mechanism of hot cracking in the heat-affected zone is believed to be the same as that which produces hot cracks in the weld-metal. That is, compounds such as Fe-Ni-S liquate in the high-temperature portions of the HAZ or weld metal and form cracks. The chemical compositions of both the filler metal and the base metal probably are of prime importance in hot cracking. Research has shown that tramp elements such as sulfur and phorphorus promote hot cracking. Mechanical restraint undoubtedly promotes hot cracking and is utilized in many of the test specimens for evaluating crack susceptibility.

Cold cracking, as the name implies, occurs at much lower temperatures than does hot cracking -- in steels at temperatures below the start of the austenite-martensite transformation (Ms). Some cold cracks form during the welding operations, while others form some time after the weld has cooled to room temperatures. These cracks are transgranular in nature.

One type of cold cracking is generally attributed to a combination of thermal and mechanical stresses and dissolved hydrogen that has diffused into the heat-affected zone. The role of hydrogen is relatively well-understood, and this type of cracking can be reduced through the use of low-hydrogen consumables and by using preheat, postheat, and control of heat input rates. Other important factors relating to cold cracking are chemical compositions of the base plate and filler wire and the degree of restraint. Chemical composition and welding conditions (e.g., heat input) determine the type of microstructure formed in the weld-metal and in the heat-affected zone. In steels, for example, the transformation on continuous cooling from the austenite region to a hardened microstructure is one of the factors involved in cold cracking. The application of preheating and postheating reduces the cooling rate through this critical temperature range and favors softer and more ductile transformation products in the microstructure. The slower cooling also aids in the escape of hydrogen from the weld and from the heat-affected zone.

Cracking susceptibility test specimens attempt to take into account as many of the variables that affect the cracking tendencies as possible. Specimens can be designed to provide such features as variable restraint or variable cooling rate along the length of the test weld. The wide variety of tests being used reflects the number of variables and the different attempts at finding optimum specimen sizes and geometries. The choice of a particular weld-cracking test depends on an understanding of the variables that influence the hot- or cold-cracking tendencies and the information that is desired.

In the finger test, for which Figure 49 shows a test specimen, the stress and strain conditions imposed on a weld deposit solidifying in the presence of a transverse base-metal crack are simulated. This test consists of depositing a weld bead across tightly compressed bars. Transverse-base metal cracks are simulated by the gaps between the bars. Different degrees of severity of weld straining may be developed by varying the width of the fingers. Performance is based on the percentage of the bead width that contains cracks.

The Houldcraft and Battelle hot-crack susceptibility specimens, Figures 50 and 51, each provide a wide range of restraint in a single specimen. The Houldcraft specimen was developed to evaluate the cracking tendency of sheet material welded by the tungsten-arc process, with or without filler metal. The Battelle specimen was developed to evaluate the cracking tendencies of welding filler metals deposited under conditions of high restraint. The tests are made

TABLE 1. SUMMARY OF WELD-CRACKING TESTS

Test	Figure	Material Normally Evaluated	Welding Process	Remarks
Finger	49	High-alloy steels and superalloys	Metal-arc, MIG	Designed to simulate notch extension cracking encountered in welding buckets to gas turbine discs
Houldcroft	50	Aluminum and steels	TIG with or without filler wire	Probably could be used for other materials and MIG process if smaller diameter filler wires were used
Battelle Design	51	Plain-carbon, low-alloy, high-strength and ultrahigh-strength steels	MIG	Semiquantitative test for relative cracking susceptibility
Lehigh restraint	52	Steels	Metal arc	Measures restraint necessary to produce weld-metal cracking
Varestraint	53	Low- and high-alloy steels	Machine welded with TIG arc bead-on-plate	No filler metal used - argon gas shielding
Murex hot crack	54	Steels	Metal arc	Used for evaluating filler metals
Root pass	55	Filler-metal electrode steels	Gas metal arc	Evaluation of root-pass cracking in armor welds
Submerged-arc welding	56	Steels	Submerged arc	- -
Keyhole slotted-plate	57	Steels	Metal arc	Semiquantitative test for weld and heat-affected zone cracking
Naval Circular Filler-Weldability (NCFW)	58	Low-alloy medium-strength steels, such as HY-80 and HY-130/150	Gas metal arc	Self-restraint specimen simulating restraint found in large construction
Controlled thermal severity (C. T. S.)	59	Steels	Metal arc	Test evaluates the HAZ cooling rate and not external restraint
Circular groove	60	Steels	Metal arc	Weld metal and heat-affected zone hot and cold cracking
Segmented groove	61	Steels	Metal arc	A modification of the circular-groove test
Circular Patch	62	All	Metal arc	Heat-affected zone, hot and cold cracking

TABLE 1. CONTINUED

Test	Figure	Material Normally Evaluated	Welding Process	Remarks
Restrained patch	63	High-temperature sheet alloys	Manual or automatic TIG	Also used to study strain gage cracking in René 41
U. S. Navy circular patch	64	Steels	Metal arc	Electrode qualification test for hot and cold cracking
Cruciform	65	Armor steels	Metal arc	Sensitive to testing conditions
BWRA	66	Cr-Ni austenitic steels	Metal arc	Designed to simulate pipe and header joints
Wedge	67	Medium-carbon low-alloy steels	Metal arc	Weldability versus transformation characteristics - variable cooling rate

by depositing a weld bead along the length of the specimen. Complete penetration is required for welds on the Houldcroft specimen, while only partial penetration is required for the Battelle specimen. Performance is based on crack length in the Houldcroft specimen and on the point of crack initiation in the Battelle specimen.

The Lehigh restraint-test specimen, Figure 52, provides a quantitative measure of the degree of restraint necessary to produce weld-metal cracking.(32,36) The degree of restraint is varied by changing the length of slots extending inward from the edges of the plate toward the weld groove. Each level of restraint requires a separate specimen and, consequently, several specimens are required to bracket the range of restraint within which cracking occurs. Cracking is detected by examination of weld cross sections. Performance is based on the minimum distance between the ends of opposing slots that just results in cracking.

The variable-restraint (Varestraint) test is a relatively new method for evaluating the hot-cracking tendencies of weldments.(2,37) The test is conducted by depositing a weld on a cantilevered specimen beginning at the left, as shown in Figure 53, and continuing until the arc reaches Point A. The cantilevered section is then bent to conform to a variable curved die, and the arc continues to Point C where the arc is interrupted. After cooling, the as-welded face surface of the specimen is examined at 60X magnification, and the length of each crack is measured and recorded. To facilitate the more accurate evaluation of the lengths of cracks and detection of minute cracks, a cross section containing the test weld may be removed, and the face surface polished. Performance is based on the following:

(1) Cracking threshold. This is the minimum augmented strain that is required to produce cracking which provides a quantitative value for comparing welding procedures.

(2) Maximum crack length. This is used for identifying materials with low hot-cracking sensitivity and provides a qualitative index for preliminary rapid screening of materials.

(3) Total combined crack length in the weld deposit and heat-affected zone. This value is used as a quantitative index of the hot-cracking sensitivity of the weld metal and heat-affected zone for a specific welding procedure.

The Murex hot-crack test specimen, Figure 54, is used for obtaining comparative information on similar welding filler metals. The test is performed by depositing a fillet weld in a vee groove formed between two 1/2-inch-thick plates. Five seconds after welding is started, one of the plates is rotated about the point of the vee by a predetermined amount, usually about 30 degrees. The speed of rotation is adjusted to control straining of the weld metal. Measured performance is based on lengths of cracks appearing as a result of straining.

The joining of thick plates, such as in armor fabrication, requires the welding of high-strength quenched and tempered steels without hot cracking of root-pass weld metal. A specimen for evaluating root-pass crack susceptibility of weld metal deposited from either shielded-metal-arc or submerged-arc welding electrodes is shown in Figure 55. A specimen developed primarily for evaluating hot-cracking tendencies of submerged-arc weld deposits is shown in Figure 56. After deposition of the weld metal, slag removal, and cooling to 100 F, the specimen chosen is examined by visual, dye-penetrant, or radiographic techniques. Performace is based on the extent of weld-metal cracking.

The NASL (U. S. Naval Applied Science Laboratory) Weldability Test System represents a new approach to the prediction of crack susceptibility.(45) The systems consists of several tests because no single test was found suitable for studies of all of the types of cracking. This system includes the keyhole-slotted-plate, the NASL circular-fillet-weldability (NCFW) and the modified-controlled-thermal-severity (CTS), tests. Specimens for these tests are shown in Figures 57, 58, and 59.

The keyhole-slotted-plate specimen is used to evaluate susceptibility of a mixture of weld metal and base metal to hot and cold cracking under restrained conditions. Since a notch is present in the bottom of the weld groove, the specimen is representative of a root pass in a restrained weld. In this specimen, which is self-restrained, restraint is varied along the length of weld by varying specimen dimensions as shown in Figure 57. The test is performed by depositing the weld metal to 1/4 inch from the hole in the specimen, and inspecting for cracking. Inspections are made at various time intervals after welding, using magnetic particles or other NDT methods. Performance is based on the length of cracks, time of cracking, and location of cracks.

The NASL-circular-fillet-weldability (NCFW) test specimen is another self-restrained specimen. Stress increases with the number of weld layers deposited. This test is used to evaluate the crack susceptibility in the weld metal and heat-affected zone. The layer at which cracking first occurs and the type, quantity and size of cracks are considered in the evaluation. Performance is based on comparison with results obtained from other material combinations for which fabrication experience exists.

The controlled-thermal-severity (CTS) test is used to evaluate the effect of heat-affected-zone cooling rate (not restraint) on cold-cracking. The CTS test is performed by depositing fillet welds on a specimen in which all dimensions except thickness are fixed. This test is based on the assumption that the cracking is related to the cooling rate at about 572 F in the heat-affected zone adjacent to the fusion line. The specimen consists of two plates that are surface ground on the interface surfaces to provide good contact for heat flow. These plates are clamped together with a bolt and held firmly with two anchor welds. After the specimen is cooled to room temperature, the bithermal test weld is deposited and allowed to cool to room temperature. Then the trithermal test weld is deposited. The bithermal and trithermal test welds are welds in which heat can flow away from the welds through two plate sections and three plate sections, respectively. Thermal-severity numbers are calculated on the basis of the cross-sectional areas of the paths through which heat can flow away from the weld. Performance is based on crack lengths observed on transverse-weld cross sections as a function of thermal-severity number.

The circular-groove test is basically a go - no go test designed to evaluate weld-metal and heat-affected-zone hot and cold cracking in various base metal/filler metal combinations. The specimen consists of a circular groove machined in a square plate (Figure 60). Weld metal is deposited in the groove and the extent of cracking expressed as a percent of total weld length. The test can be made semiquantitative by varying the diameter of the groove or the plate dimensions. The segmented-groove specimen, (Figure 61) is a modification of the circular groove specimen designed to simulate the notch extension cracking encountered in welding buckets to gas-turbine discs. The specimen consists of four segments, usually with the abutting faces finish machined. The segments are tacked together and then the test weld is deposited in one pass. The extent of cracking is determined by breaking apart the segments and noting the cracked (oxidized) area.

The circular-patch test (Figure 62), is used to investigate weld-metal cracking, but it has been used to evaluate both hot and cold heat-affected-zone cracking. The specimen consists essentially of welding a circular disc back into a square plate from which it was cut.

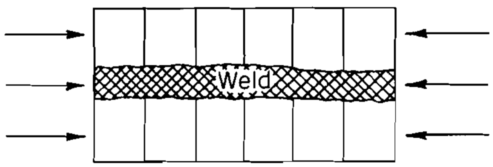
A full penetration, circular, bead-weld cracking specimen (Figure 63), has been used for evaluating sheet materials. The test is suitable for use with all welded materials. Although the test is essentially a go - no go test, it can be made semiquantitative by varying the patch diameter. Performance is evaluated on the basis of the crack length expressed as a percentage of total weld length.

The U. S. Navy circular-patch test differs from the other two circular-patch tests discussed mainly in the welding procedure used. The test is used principally in the qualification of electrodes and is considered a severe test for hot and cold cracking. Each quadrant of the specimen (Figure 64), is completely welded in the sequence shown using a 2-1/2-inch-diameter full- or split-weave buildup sequence determined by the electrode diameter. After welding,the specimen is allowed to stand for 24 hours. If no cracks are visible, a concentric disc 2 inches larger in diameter than the weld is flame cut from the plate. The disc is machined on each side and radiographed. If the weld is sound, sections for metallographic examination, hardness tests, and impact specimens are cut from each quadrant.

Several test specimens are used almost exclusively for evaluating cracking in weld heat-affected zones. The cruciform test specimen shown in Figure 65 is used to differentiate between the cracking tendencies of various heats of armor steel. The test is designed to evaluate heat-affected-zone cracking, but has been criticized on the ground that it was more sensitive to testing conditions than to differences in cracking susceptibility. The possibility that hydrogen will diffuse from one fillet to another has also been pointed out. Before the fillet welds are deposited, the assembly is tack welded using a jig to obtain accurate fit-up. Each fillet is deposited , in the numbered sequence shown, at a constant predetermined starting temperature. After welding, the specimen is aged 48 hours at room temperature, then stress relieved at 1150 F for 2 hours (heating to and cooling from 1150 F at the rate of 100 F per hour). The specimen is then inspected for cracking and sectioned for metallographic examination.

The specimens shown in Figures 66 and 67 were developed to investigate heat-affected-zone cracking. The specimen for the BWRA test for Cr-Ni austenitic steels consists of a pipe section welded into a hole in a heavy base-metal block. Each pass is deposited manually in two 180-degree segments. The specimen is allowed to cool to room temperature between passes. To evaluate single-pass applications, the pipe is welded to a flat prepared surface. After welding, the heat-affected zone is examined at 20X and any suspected regions are removed and sectioned for further examination. The entire assembly can also be heat treated and then reexamined for further cracking. This test is an excellent example of one designed to investigate a particular fabrication and service problem. The wedge-test specimen (Figure 67), provides range of cooling rates similar to those found in a set of CTS assemblies, owing to varying cooling rates along the tapered section. After preparation of the test block, thermocouples are attached along the wedge to record thermal cycles during welding. The welded specimen is sectioned longitudinally, polished, etched, and examined for cracks. The location of the last crack is related to the cooling rate at that position. The wedge test has been found useful for comparative determinations of critical cooling conditions for a series of steels, but this test cannot be substituted for the CTS tests for fillet welds. The cooling rates for fillet welds are more severe in the CTS tests and critical cooling rates for cracking are lower.

FIGURE 49. FINGER-TEST CRACK-SUSCEPTIBILITY SPECIMEN



Purpose of Test - Hot cracking tendencies of high-alloys steels.

Number of Specimens Tested - 2 minimum.

Important Variables - Welding conditions; severity of straining of the weld depends on the width of the fingers.

Data Obtained - Effect of notch on hot-cracking tendencies; percentage of bead width that is cracked.

Specifications - None

References - 29, 30, 31.

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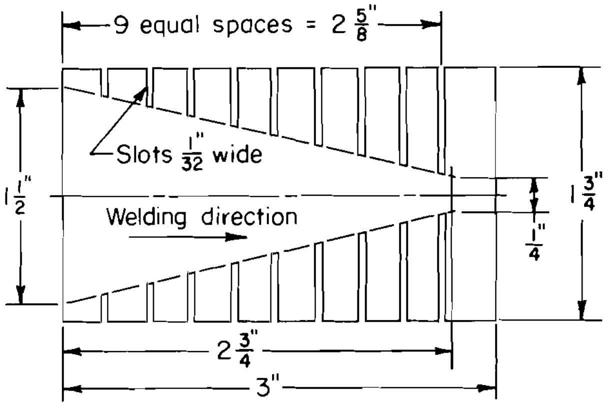
FIGURE 50. HOULDCROFT CRACK-SUSCEPTIBILITY SPECIMEN



Dimensions shown are recommended for 1/16-inch-thick sheet; dimensions are increased 50 percent for 1/8-inch-thick sheet. Arc is initiated at edge of plate to initiate a weld crack and then welded in direction shown; crack will propagate (if hot-crack sensitive) until the degree of restraint is insufficient to continue crack; the length of crack is a measure of hot-cracking sensitivity; complete weld penetration must be obtained and a constant weld width maintained; specimens should not be rigidly clamped down during welding; usually welded at room temperature in air.

Purpose of Test - Developmental, weldability, and crack susceptibility.

Number of Specimens Tested - Usually 6 (mean crack length computed).

Important Variables - Specimen geometry, weld quality, complete weld penetration, crack-length determination, and data analysis.

Data Obtained - Hot-crack susceptibility index in terms of crack length.

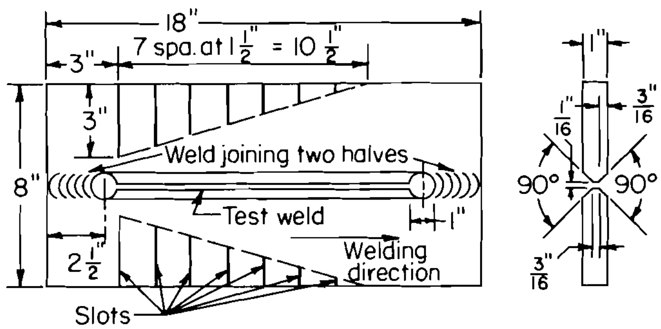
Specification - None.

References - 32, 33, 34, 35.

Remarks - Useful for evaluating relative cracking sensitivity of various materials; this is a hot-cracking test for inert-gas tungsten-arc welds in thin sheet; it is believed that the test could be extended to consumable-electrode welding providing wire diameter is sufficiently small; specimen is sensitive to welding speed.

****

FIGURE 51. BATTELLE CRACK-SUSCEPTIBILITY SPECIMEN



Test weld deposited in groove in direction shown; welded with or without preheat in air.

Purpose of Test - Developmental, weldability, and crack susceptibility.

Number of Specimens Tested - Usually 3.

Important Variables - Specimen geometry, weld inspection, crack-length determination, and data analysis.

Data Obtained - Unslotted width of specimen at point where hot cracks initiate; this is considered the cracking index of the test weld.

Specifications - None.

References - 36.

Remarks - Considered a good semiquantitative test for evaluating relative cracking susceptibility; has advantage of limited testing to determine a cracking index as compared with other go - no go tests. The surface of the test weld should be concave for optimum results.

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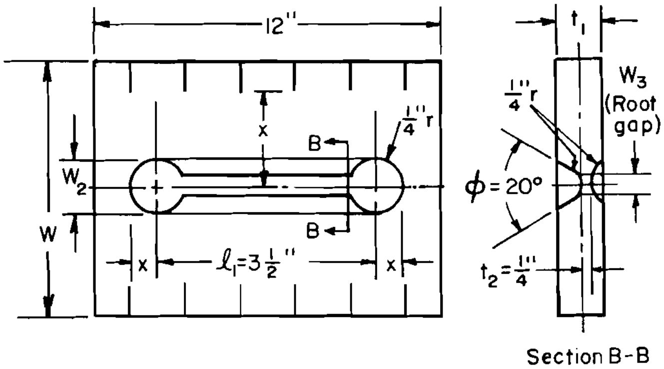
FIGURE 52. LEHIGH RESTRAINT-CRACKING SPECIMENS



Dimensions, inches									
ℓ_1	L	W	X	W_2	W_3	t_1	t_2	ϕ(a)	R
3-1/2	12	8	Var.	1/2	1/16	<1	1/4	20°	1/4
5-1/2	12	8	Var.	1/2	1/16	>1	1/4	20°	1/4

Dimension X usually varied in 1/2-inch increments. Temperature of base plate at time of depositing test weld varied depending on condition studied, i.e., preheat, ambient temperature, etc. Small specimen illustrated.

Purpose of Test - Crack susceptibility, developmental

Nondestructive Inspection (in order of decreasing use) - Visual, penetrant, magnetic and radiographic.

Important Variables - Specimen geometry, weld quality, weld inspection, and data analysis, base plate of filler metal, welding conditions.

Data Obtained - Degree of restraint necessary to cause hot cracking.

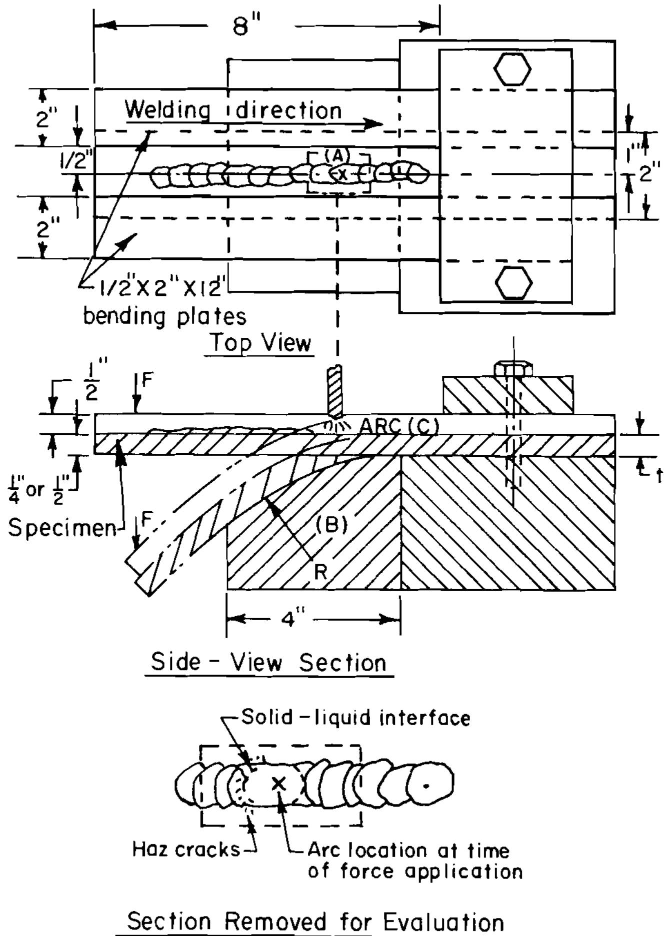
Specifications - None.

References - 18, 35.

Remarks - This test was designed to obtain, quantitatively, the degree of restraint necessary to cause weld-metal cracking during cooling. It is a go - no go test and requires several specimens to estimate cracking susceptibility. Variables that can be studied include base plate, filler metal, preheat, heat input, and effects of multipass welding. Generally, the first specimen welded will be under full restraint (no saw cuts). If this specimen cracks, another specimen is welded that contains less restraint (saw cuts). Sufficient specimens are welded until a restraint level is reached at which no further cracking occurs.

****

FIGURE 53. VARESTRAINT CRACK-SUSCEPTIBILITY SPECIMEN



augmented strain, $e_t = \frac{t}{2R}$

A = Point of tangency

B = Replaceable die block

C = Run-off area

Purpose of Test - Hot-cracking susceptibility, relative crack sensitivity.

Number of Specimens Tested - 3 minimum.

Important Variables - Materials, base metal thickness, metallurgical and surface conditions, welding variables.

Data Obtained - Length of each crack in weld, maximum crack length, location of each crack (weld or heat-affected zone), number of cracks, total crack length, including HAZ, corresponding augmented strain.

Specifications - MIL-STD-00418B (SHIPS)

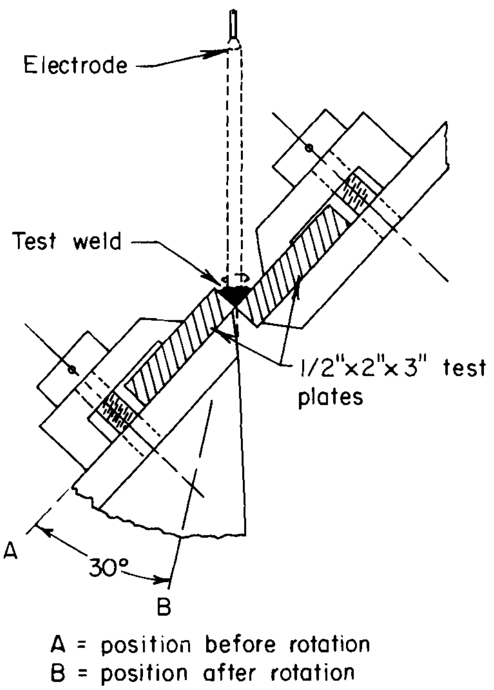
References - 2, 37.

Remarks - When required, the tested surface of the specimen is machined in the longitudinal direction to a finish no rougher than 125 RHR;

specimen face surface is examined at 60X, as-welded or welded and polished. Weld-puddle geometry is maintained constant for rapid screening of materials when using the maximum crack-length criterion.

****

FIGURE 54. MUREX HOT-CRACK SPECIMEN



Purpose of Test - Hot-cracking tendencies of welding filler metals, experimental.

Number of Specimens Tested - 1 to 4.

Important Variables - Materials and welding variables, speed of rotation.

Data Obtained - Crack length.

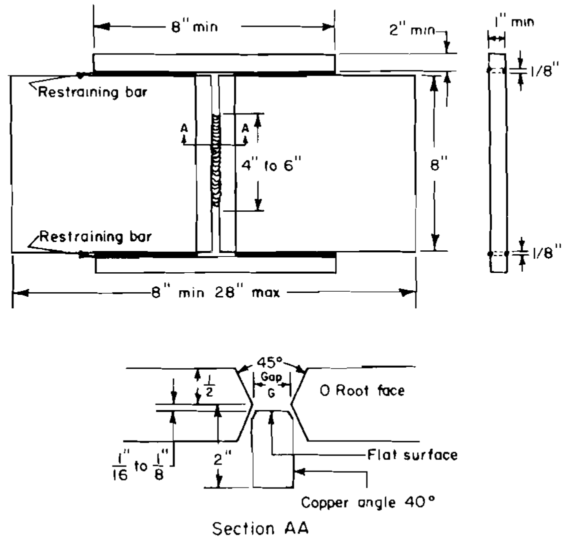
Specifications - Company.

References - 38, 39.

Remarks - Performance based on crack length.

****

FIGURE 55. ROOT-PASS CRACK SUSCEPTIBILITY SPECIMEN



Electrode Diameter, in.	Root Gap (G), in.	Root-Bead Thickness, in.
5/32	3/16	0.160 - 0.200
3/16	1/4	0.185 - 0.240
1/4	5/16	0.250 - 0.330
5/16	3/8	0.280 - 0.360

Purpose of Test - Susceptibility of root-pass weld metal to longitudinal cracking, optimize joint design; heat input rate to produce crack-free root pass.

Number of Specimens Tested - 1 for each condition.

Important Variables - Materials, joint design, welding variables.

Data Obtained - Longitudinal crack length.

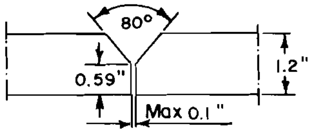
Specifications - MIL-E-986; MIL-E-13080A.

References - 40, 41.

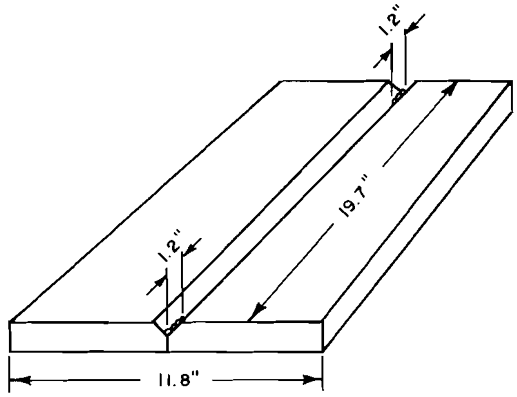
Remarks - Longitudinal-weld crack length in excess of 20 percent of the total weld length is cause for rejection.

****

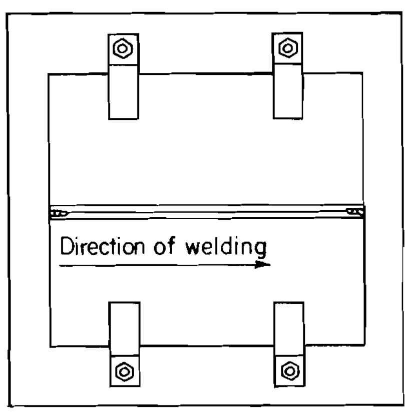
FIGURE 56. SUBMERGED-ARC-WELD CRACK-SUSCEPTIBILITY SPECIMEN



a. Edge Preparation



b. Test Plate 1.2" X 12" X 20"



c. Setup, for Welding Test-Plate (restraint by clamping)

Purpose of Test - Evaluations of hot-cracking tendencies.

Number of Specimens Tested - 1 for each condition.

Important Variables - Material and welding variables.

Data Obtained - Presence or absence of cracks; length of cracks.

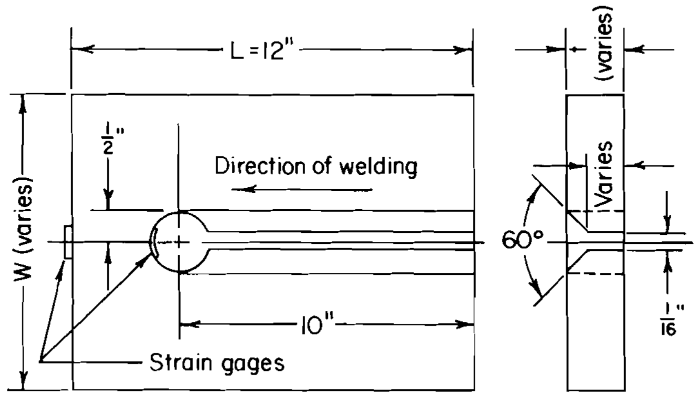
Specifications - None.

References - 42.

Remarks - Test can be used with other welding processes. The specimen is tack welded at each end. The test weld is then deposited starting on one tack weld and terminating at the other.

****

FIGURE 57. KEYHOLE-SLOTTED-PLATE RESTRAINT-TEST SPECIMEN



Restraint varied by varying L, W, and t; normally L held constant; example - for t = 1/2 inch, W varied from 6 to 10 inches.

Purpose of Test - Developmental, weldability, and crack susceptibility.

Number of Specimens Tested - Usually 3.

Important Variables - Filler metal, base metal, specimen geometry, weld quality, welding conditions, weld inspection, instrumentation, measurements, and data analysis.

Data Obtained - Extent and type of hot and cold cracking, length of cracks, time of cracking.

Specifications - None.

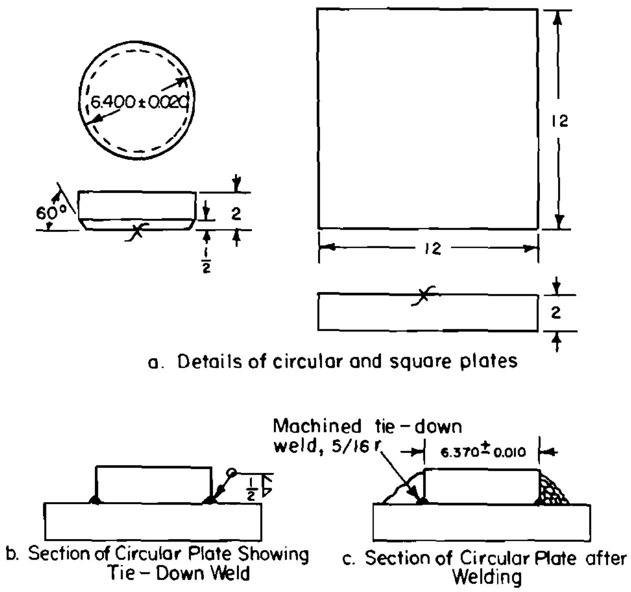
References - 35, 43

Test Procedure - Weld deposited in groove beginning at edge of plate and proceeding toward hole; strains from two gages recorded continuously during welding and as weld cools to room temperature; gross cracking indicated from strain measurement.

Remarks - A semiquantitative test to determine where and when cracking occurs; cracking usually occurs along weld and occasionally in HAZ; simultaneous monitoring of strain, time, and temperature of weld can provide useful information regarding crack formation, particularly delayed cracking (hydrogen-induced).

****

FIGURE 58. NAVY CIRCULAR-FILLET-WELDABILITY (NCFW)-TEST SPECIMEN



a. Details of circular and square plates

b. Section of Circular Plate Showing Tie-Down Weld

c. Section of Circular Plate after Welding

Purpose of Test - Prediction of hot- and cold-cracking susceptibility.

Number of Specimens Tested - 1.

Important Variables - Materials, welding sequence, bead sequence, interpass temperature, interlayer time, inspection interval.

Data Obtained - Layer in which cracking first appears; type, size and number of cracks, time of cracking.

Specifications - None.

References - 44

Remarks - Four macrosections examined at 50X for cracks, 5 layers for covered electrode welds, 6 layers for gas metal-arc welds.

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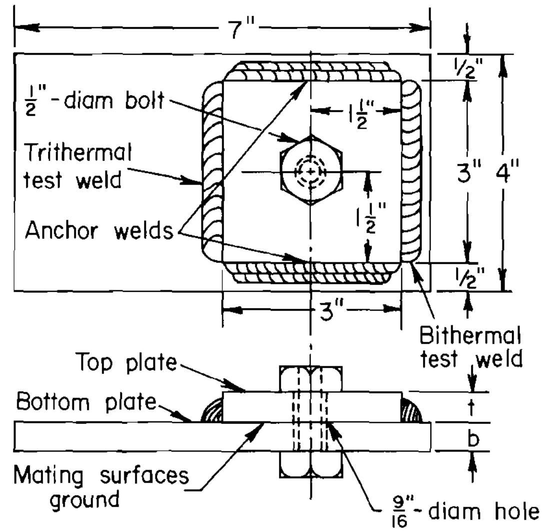
FIGURE 59. CONTROLLED THERMAL-SEVERITY (CTS) CRACK-SUSCEPTIBILITY SPECIMEN



Dimensions t and b varied to change thermal severity; the thermal severity number is obtained from the following formula:

TSN = 4(t+b) for bithermal welds

TSN = 4(t+2b) for trithermal welds.

After specimen assembled and anchor welds deposited, assembly allowed to cool to room temperature for depositing bithermal test weld; similarly, specimen cooled to room temperature before trithermal weld deposited; severity of cracking determined by measurements of crack length on metallographic sections.

Purpose of Test - Developmental, weldability, and crack susceptibility.

Number of Specimens Tested - Usually 3.

Important Variables - Specimen geometry, weld quality, crack detection, and data analysis.

Data Obtained - Extent of cracking.

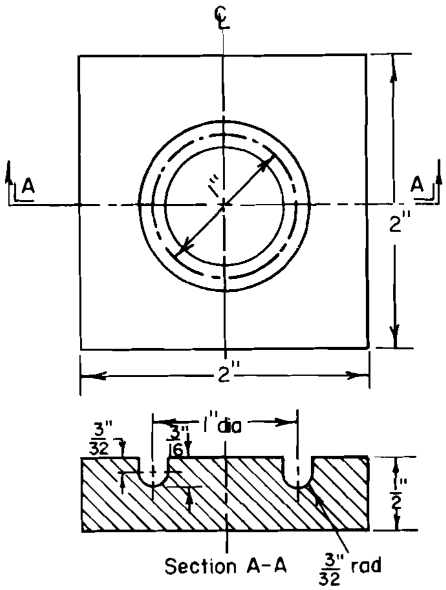
Specifications - None.

References - 35, 44, 45.

Remarks - Test based on assumption that extent of hard-zone cracking is mainly dependent on cooling rate at about 572 F (300 C), as measured in HAZ adjacent to fusion line; when a critical rate of cooling for a given electrode-steel combination is exceeded, cracking is supposed to occur irrespective of external restraint applied; test evaluates effects of weld and HAZ cooling rates and not external restraint.

****

FIGURE 60. CIRCULAR-GROOVE CRACKING TEST SPECIMEN



Purpose of Test - Cracking susceptibility and comparison of base-metal filler-metal combinations.

Number of Specimens Tested - 1.

Important Variables - Specimen geometry (groove diameter), materials, welding procedure, weld quality.

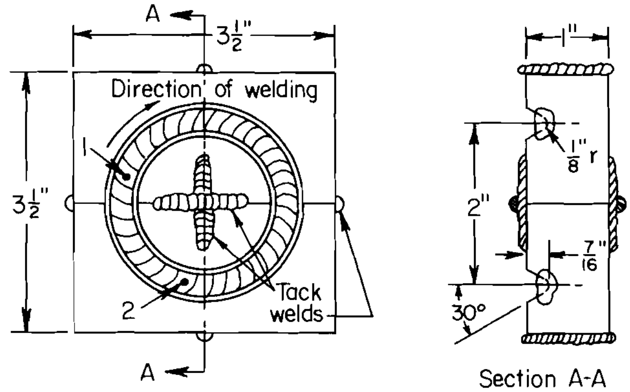
Data Obtained - Type, size, location and orientation of cracks.

Specifications - None.

References - 32, 46.

Remarks - Performance and comparisons based on crack length.
****

FIGURE 61. SEGMENTED-GROOVE CRACKING TEST SPECIMEN (MODIFIED CIRCULAR RESTRAINT)



Dimensions varied; tests made at room temperature in air.

Purpose of Test - Developmental, weldability, and crack susceptibility.

Number of Specimens Tested - 1.

Important Variables - Specimen geometry, materials, welding procedures, weld quality.

Data Obtained - Extent and type of cracking; cracking usually expressed as percent of total length of weld.

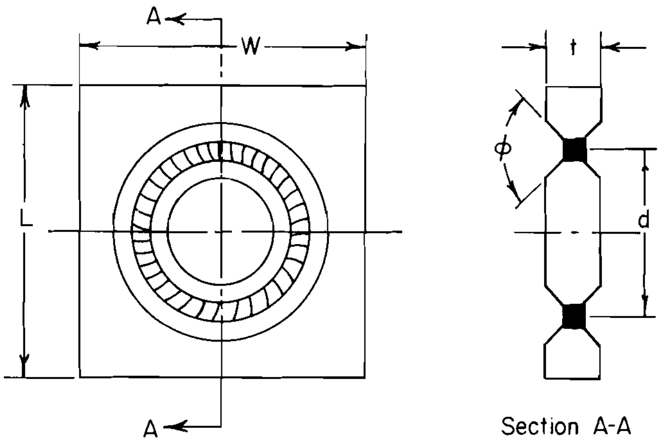
Specifications - Company specifications only.

Reference - 35, 47.

Test Procedure - The four blocks are surface ground on their mating edges, clamped together, and tack welded; groove in assembly is machined; weld is initiated at Point 1 (in figure) and proceeds in clockwise direction to Point 2; after specimen has cooled to below 200 F, the remaining 120 degrees is welded with another test electrode; specimen examined for weld cracks.

Remarks - Test for hot and cold cracking of welds and HAZ's; essentially a go-no go test but could be made quantitative by varying diameter of groove; expensive tests.
****

FIGURE 62. CIRCULAR-PATCH CRACK-SUSCEPTIBILITY SPECIMEN



Dimensions, inches				
L	W	ϕ	d	t
12 5	12 5	90° 0°	Var. 2	Var. 0.076

Dimensions varied greatly but dimensions shown are recommended for plates (1/4 inch and thicker) and sheets; the variable dimensions are discussed in Remarks below. Tested in air at room or preheat temperature.

Purpose of Test - Developmental, crack susceptibility, study effects of welding procedures and restraint.

Number of Specimens Tested - Usually 1 per patch diameter, d, to establish restraint level necessary to cause cracks.

Important Variables - Specimen geometry, weld quality, weld inspection, welding procedures, and data analysis.

Data Obtained - Extent and type of cracking.

Specifications - Company specifications only.

References - 32, 35, 48.

Remarks - This test evaluates both hot- and cold-cracking tendencies of welds and HAZ's; although this basically is a go-no go type of test, a quantitative evaluation of cracking susceptibility can be obtained by varying the patch diameter, d; decreasing "d" increases restraint; it has been shown that residual stresses of the order of the base-plate yield strength can be obtained by maintaining the patch-diameter/plate-width ratio, d/L, between 0.2 and 0.3. On the basis of this criterion, it was concluded that a 12-inch-square plate was optimum size.

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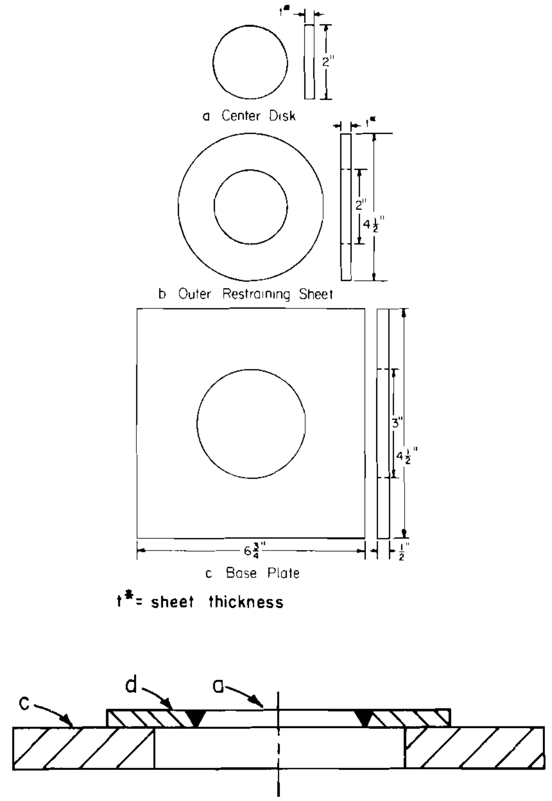
FIGURE 63. RESTRAINED-PATCH-CRACK SUSCEPTIBILITY SPECIMEN FOR SHEET METAL



d. Cross Section

Purpose of Test - Hot and cold cracking tendencies, comparisons of weldability of various sheet materials.

Number of Specimens Tested - 1.

Important Variables - Materials, welding conditions, joint gap, weld quality, postweld heat treatment.

Data Obtained - Crack length, type.

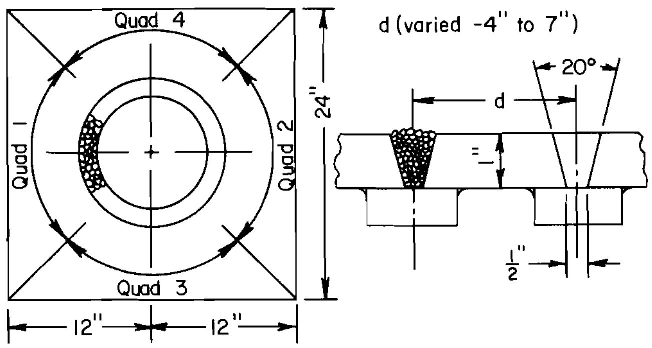
Specifications - Company

References - 49, 50.

Remarks - This test was developed to evaluate the weldability of aircraft gas-turbine engine sheet materials. Size of the center disk is representative of many applications where component pieces are welded into jet-engine assemblies. Outer restraining sheet if first welded to the base plate. The center disk is then welded to the outer restraining sheet. The center disk is machined 0.003 to 0.005 inch larger than the original diameter of the hole in the outer restraining sheet to provide a slip fit after the first weld is made. Inspections for cracks are made using visual, fluorescent penetrant, microscopic, and radiographic methods.

****

FIGURE 64. U. S. NAVY CIRCULAR-PATCH CRACK-SUSCEPTIBILITY SPECIMEN



Dimensions shown are MIL-E-986C; d varies with coated-electrode diameter, increasing from 4 to 7 inches as electrode diameter increases from 5/32 to 5/16 inch; for Grade HT steel, preheat and interpass temperature is 0 F; for Grade STS, it is 75 F (+25 F tolerance).

Purpose of Test - Developmental, crack susceptibility, and weldability.

Number of Specimens Tested - Surveyed organizations used 2 specimens per each size of electrode, but specifications require 1.

Important Variables - Specimen geometry, weld quality, weld inspection, and test-temperature control.

Data Obtained - Extent of cracking; crack size and location; and weld-metal hardness.

Specifications - MIL-E-22200 and MIL-E-986.

References - 18, 35, 51.

Test Procedure - Each quadrant completely welded in numerical sequence shown in sketch; the number of layers using a weave buildup sequence depends on electrode diameter; completed weld allowed to stand 24 hours; if no cracks are visible, a concentric disk 2 inches larger in diameter than weld is flame cut from plate, surface machined on each side, and radiographed; if weld is sound, then sections for metallographic examination and hardness tests are cut from each quadrant.

Remarks - An acceptability test for electrode qualification; considered a severe test for hot and cold cracking.

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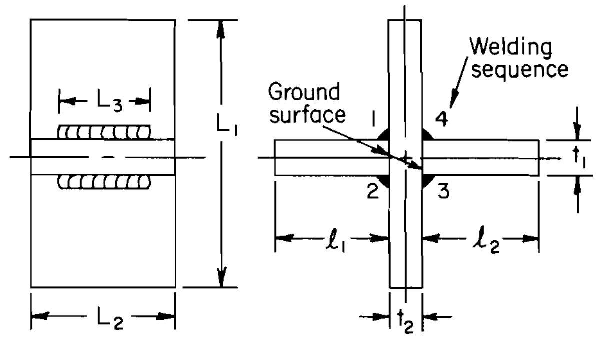
FIGURE 65. CRUCIFORM CRACK-SUSCEPTIBILITY SPECIMEN



Dimensions, inches						
ℓ_1	ℓ_2	L_1	L_2	t_1	t_2	L_3
6	6	12	12	Var.	Var.	6
4	4	8	12	1/4-2	1/4-2	6
3-t	3-t	3	3	0.04	0.04	3

Dimensions varied greatly; the first set of dimensions is preferred; the other sets of dimensions are given to show the range of dimension variation reported; tests usually made at room temperature in air.

Purpose of Test - Developmental, crack susceptibility, and weldability.

Number of Specimens Tested - Usually 1, varying from 1 to 5.

Important Variables - Specimen geometry, weld quality, weld inspection, specimen positioning, measurements, and data analysis.

Data Obtained - Extent of cracking.

Specifications - "Procedure : Armor Plate Crack Sensitivity Test", Research Group, Ordnance Advisory Committee on Welding of Armor.

References - 35, 40, 52, 53.

Test Procedure - Fillet welds are deposited in sequence shown; temperature at start of each fillet is the same (either room temperature or predetermined pre-heat temperature); after welding, specimen is aged at room temperature for 48 hours, then stress relieved at 1150 F for 2 hours (heating and cooling from 1150 F at the rate of 100 F per hour); specimen is inspected for cracking and cross sections are cut for metallographic examination.

Remarks - Considerable uncertainty regarding usefulness of specimen; Poteat and Warner(53) concluded that the test was more sensitive to testing conditions (temperature fit-up, plate size, etc) than to differences in crack susceptibility of the base metal used; they concluded that the cruciform test in its present form, under test conditions in a production ship, was unsuitable as a crack-susceptibility test for armor steel; its usefulness for other materials appears equally uncertain.

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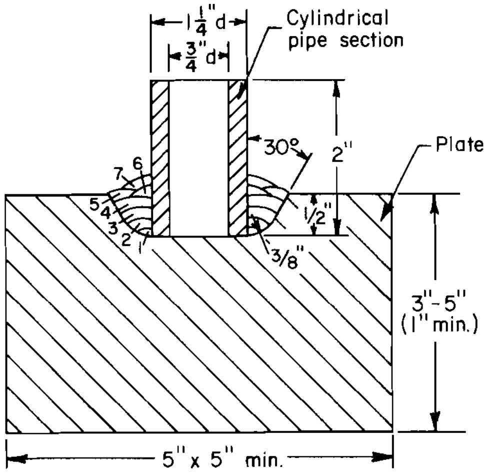
FIGURE 66. BWRA CRACKING TEST SPECIMEN



Purpose of Test - Cracking in weld-heat affected zones, experimental.

Number of Specimens Tested - 1 or more.

Important Variables - Material and welding variables, welding procedures, weld quality.

Data Obtained - Crack location and size.

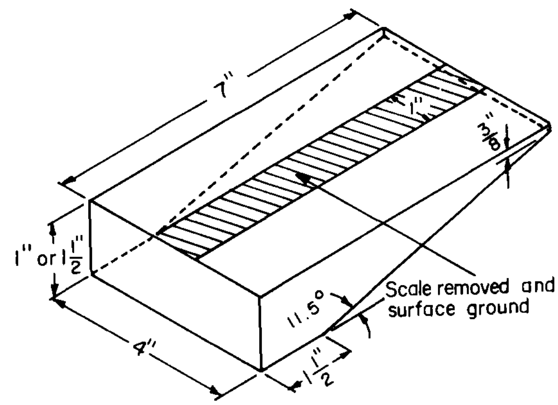
Specifications - BWRA.

References - 54.

Remarks - For single-pass welds the groove is eliminated. After removing slag, the weld heat-affected zones are examined at low magnifications for cracks. Suspect regions are sectioned transverse to the direction of welding and examined using metallographic techniques.

****

FIGURE 67. WEDGE-TEST CRACK SUSCEPTIBILITY SPECIMEN



Purpose of Test - Relation between weldability and transformation characteristics; hydrogen content and internal cooling rate for cracking.

Number of Specimens Tested - 1 to 3.

Important Variables - Heat input per unit length, size of electrode, hydrogen content of weld and base metal, weld-bead size, geometry of weld bead and heat-affected zone.

Data Obtained - Cracking related to cooling rate; critical cooling rate for cracking (position of last crack related to cooling rate at that position).

Specifications - None.

References - 55.

Remarks - The weld is sectioned longitudinally on its centerline to reveal heat-affected zones. Section then examined for cracking after polishing and etching. Essentially a cold-cracking test.

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NOTCH-TOUGHNESS AND FRACTURE-TOUGHNESS TESTS

Tests that have been proposed and used for evaluating toughness of welded joints may be divided into two broad categories: notch-toughness tests and fracture-toughness tests based on fracture mechanics. In this report, notch-toughness tests are considered to be those tests that are used to measure the ability of a material to absorb energy and deform plastically in the presence of a stress raiser and which are often used to determine the ductile-to-brittle transition temperature of a material. The Charpy impact tests, NRL's drop-weight test and notched-tension tests are typical examples of tests that are used for these purposes. With the exception of the NRL drop-weight specimen, specimens for these tests are small in size and can be tested with the types of impact- or tension-testing equipment in general use throughout the country. Some of these specimens are standardized and are in wide industrial and laboratory use. Dynamic tests in which loading is applied by explosive detonations are used for toughness evaluations of armor and ship-plate weldments. Occasionally, notch-toughness tests are utilized to supplement information obtained from other tests in studies of fracture mechanisms.

Several notch-toughness test specimens have been designed to aid in the studies of the mechanisms of brittle fracture. These specimens usually are rather large and contain specially designed notches. Evaluations are made by tension testing or bending the specimens in high-capacity equipment.

Fracture toughness tests based on fracture mechanics generally are concerned with determination of critical crack size, i. e. , the maximum size crack that a material can tolerate without fracture when loaded to a specific stress level. (56) Critical fracture-toughness values are determined by applying linear elastic fracture-mechanics theory. The aim of sharp-crack fracture tests is to obtain the critical stress intensity factor for fracture toughness, which is used to describe the fracture behavior of a material. (57)

Table 2 lists some of the many specimens that have been proposed and used to evaluate notch-toughness, fracture mechanisms, and fracture toughness. Some of these specimens and their uses are described below. The classifications are arbitrary and other individuals may find different classifications to be useful.

Notch-Toughness-Test Specimens

Specimens for notch-toughness tests may be divided on the basis of loading techniques into three general categories:

TABLE 2. TEST SPECIMENS THAT HAVE BEEN PROPOSED AND USED FOR EVALUATION OF NOTCH-TOUGHNESS AND FRACTURE TOUGHNESS OF WELDMENTS[a]

Impact-Test Specimens
Charpy V-notch
Charpy keyhole notch
Charpy U-notch
Sheet Charpy V-notch
Pressed Charpy V-notch
Low-blow V-notch Charpy
Schnadt
NRL drop weight
NRL drop-weight bulge test
NRL drop-weight tear
Drop impact for spot welds
Tension- and Tear-Type Test Specimens
Tipper
Noren nominal cleavage (N-C) strength
Navy tear test
Bend-Test Specimens
Allison instrumented bend
Lehigh
Kinzel
Kommerell
Van der Veen
Precracked bend
Dynamic Test Specimens
Explosion bulge
Crack-starter explosion bulge
Army Ordnance (H-plate) ballistic impact
Specimens for Studies of Fracture
Notched bend specimen
Robertson
Esso
Double tension
Welded wide-plate tension
Delta
Greene-wells
Fracture-Toughness Test Specimens
Dougle-edge notch tension
Center-notch tension
Part-through crack tension
Single-edge-notch tension
Precracked bend
Compact K_{Ic} specimen

(a) Arranged on the basis of loading method and specimen complexity and usage.

(1) Small specimens for impact loading

(2) Small specimens for static loading

(3) Large specimens for dynamic loading.

These specimens are described in the following.

Small Specimens for Impact Loading

Small specimens for impact tests of welded joints include the Charpy V-, U-, and keyhole and other modified Charpy specimens, the NRL drop-weight specimen, and the Schnadt test specimen. Specimens that are representative of this group are shown in Figures 68 through 73. Of the many specimens used for evaluating notch toughness, the standard Charpy V-notch specimen is, by far, the most widely used; the Charpy-U and keyhole-notched specimens are used to a lesser degree. Modified Charpy specimens, including oversize, subsize, double-width and sheet Charpy modifications (Figures 69-72), also are in use. Correlation of Charpy V-notch-impact test results for standard-and nonstandard-size specimens can be made, although behavior in the notch is strongly dependent on the width across the notch.[65]

In these tests, the specimen is struck a blow with a hammer suspended in a pendulum-like arrangement in the impact testing machine. The energy absorbed in fracturing the specimen, percentage cleavage and shear fracture, reduction or increase of specimen width at the fracture are measured for a specific testing temperature. Energy absorbed, fracture appearance, and deformation near the notch are often obtained at several temperatures to determine the temperature range over which the material's fracture behavior changes from ductile to brittle.

The Charpy specimen has been used most extensively because it can be cut from various locations in the weld area and the notch orientation can be varied as desired. In recent years, a precracked-Charpy specimen also has been used.[56] In this specimen, a small fagitue crack is produced at the root of the notch before testing. The specimen is tested either with a pendulum-type impact-testing machine or in slow-bending. The resulting data are usually indicated as energy per unit area of fracture, e.g., foot-pounds/square inch. There is no overall correlation of data from these specimens with data obtained for other types of specimens of the same material.

Several drop-weight tests have been used in conjunction with notch-toughness evaluations. The Navy drop-weight test, Figure 71, is used to determine nil-ductility temperature (NDT) for base plate. It also has been used for determining NDT for the weld metal and the heat-affected zone. The NRL drop-weight tear test also has been used to determine NDT. A modification of the NRL drop-weight-tear-test specimen is shown in Figure 72. The specimen is tested in essentially the same manner as the Charpy V-notch specimen, but the specimen is considerably larger and requires larger testing equipment.[64] The specimens are full thickness of the plate. Instead of being machined, the notch is made by pressing a chisel-point tool into the edge of the specimen. The NRL and modified drop-weight tear-test specimens, like the Charpy V-notch specimen have been used to measure the fracturing characteristics of the parent metal at a specific temperature. Each has been adapted for evaluation of weld joints.

Four types of impact tests for spot welds are described by the American Welding Society[6]:

(1) Shear-impact test

(2) Drop-impact test

(3) Shear-impact loading test

(4) Tension-impact loading test.

The drop-impact test specimen in Figure 73 is used to evaluate the ability of spot welds to withstand shock loads in a direction normal to the plate, the most critical direction for shock loading of spot welds. When performing this test, slippage of the specimen in the clamps and bending of the plate or sheet are to be avoided. This test is conducted using a dropping weight, whereas the other spot-weld specimens are tested using pendulum-type machines. Performance is based on load-to-cause failure and on comparison with other materials.

Small Specimens for Static Loading

Small specimens for static tests include notched-bend-test specimens, notched-tension test specimens, and tear test (e.g. Navy tear-test) specimens. Typical specimens that have been proposed and used in static tests for evaluating notch toughness of welded joints are shown in Figures 74 and 75.

In bend tests conducted with the Kinzel specimen, Figure 74, and the Lehigh specimen, (not shown) fracture usually initiates from the heat-affected zone (in steel) and propagates into the base metal. Each of these specimens has been used for establishing ductile to brittle transition temperatures for steel weldments.

Notched-tension-test specimens are used for evaluating notch-strength ratio and notch toughness of weldments. When evaluating notch-strength ratio of sheet or plate material, notches are placed in the edges of the specimen as shown in Figure 81. The Navy tear-test specimen, Figure 75, developed for base-plate evaluations and used to study the susceptibility of the ship-plate steels to cleavage-type fractures has also been applied to weldments.[66,67] The specimen is loaded in tension and load-deflection curves obtained. The area under a curve from initial load application to ultimate load represents the energy required to induce initial cracking; the remaining area represents the energy required to propagate the tear or crack from initiation to completion.

Large Specimens for Dynamic Loading

Some toughness tests have utilized specimens that are subjected to dynamic loading from explosives or projectiles. These tests are used to study the behavior of large weldments when subjected to impact loading and to study the role of weld-metal toughness on the overall behavior of weldments. Selected specimens of the type used for these tests are shown in Figures 76 and 77.

The NRL explosion-bulge-test specimen consists of two large rectangular plates that are butt welded to form a square specimen. The specimen is tested by explosively loading the plates so that they are deformed into a circular die cavity, using successive shots to the point of weldment failure or until the bulge conforms to a specified hemispherical shape. The test has been used for evaluations of various base metal-filler metal combinations. The appearance of fracture surfaces is used to ascertain the material that is least resistant to brittle fracture. In the NRL crack-starter explosion-bulge test, a similar, but smaller, specimen is used to determine the highest temperature at which a specimen fractures with no evidence of ductility (a "flat break" in many pieces). The specimen is prepared by depositing a short bead of brittle weld metal that is then notched with an abrasive wheel. In the Army Ordnance ballistic-impact test, high-velocity impact loading is provided by a high-velocity projectile. The specimen is shown in Figure 78. Performance in this test is based on impact energy, number of fractures, and fracture appearance.

The drop-weight bulge-test specimen, Figure 78, was evolved from the NRL explosion-bulge test to provide a more feasible, less complex, and less costly shop-type test. In this test, the specimen, which is supported on an anvil having a 15-inch-diameter opening, is subjected to impact by a falling massive weight (about 6 tons). The impact is transmitted to the specimen through a soft, malleable-aluminum tup. Performance is based on strain or bulge at failure, energy to cause failure, and source and path of fractures.

Specimens for Studies of Fracture Mechanisms

A variety of large-plate specimens have been used for studies of crack initiation, crack propagation, and toughness, especially for welded steel structures.[66] The Robertson, Esso double-tension and delta-test specimens have been used for evaluating crack-propagation characteristics of base plates and weldments. The delta-test specimen, Figure 79, was developed to meet the need for a procedure which allows low-speed loading using a specimen that is large enough to represent prototype conditions.[74] The specimen is assembled as a 24-inch equilateral triangular plate, and is supported at three corners and loaded compressively to produce bending and dishing. Fracture initiates at a brittle-crack starter, located at the triple-weld junction in the center of the specimen, and is free to follow a natural path independent of preferential loading.

Extensive use has been made of large tension-test and bend-test specimens in studies of fracture of weldments that are subjected to low applied stresses.[66] Low-applied-stress fractures have been produced experimentally using a notch placed in an area of high residual stress. In practice, the notches are placed in the various weld zones to evaluate structures of special interest. Examples of large-plate notched specimens are shown in Figure 80.

Fracture-Toughness-Test Specimens

Widespread concern over brittle failure in materials, especially in high-strength metals, has led to the development of techniques and test specimens to measure fracture toughness based on fracture mechanics. Although most effort on development of fracture-toughness tests has concerned itself with base-metal properties, increasing attention is being given to fracture toughness of weldments. The presence of cracks in any structure is undesirable, but unfortunately it is not always avoidable, particularly in welded structures. Even the most careful inspection may not disclose all cracks. In high to very high strength materials used in aerospace applications, such as rocket-motor cases, the problem of fracture toughness becomes critical. For steels having above about 220,000 psi yield strength, the critical flaw size (the largest size crack a structure may tolerate without failing by catastrophic propagation of the crack under applied stress) becomes very small, and therefore, very difficult to detect. This can be illustrated by citing numerous examples of failures of high-strength rocket-motor cases which failed catastrophically while being hydrotested.

In view of the catastrophic failures experienced in high-strength materials, fracture toughness has been the subject of extensive investigations during recent years. During 1959, the American Society for Testing and Materials Committee on Fracture Testing of High Strength Sheet Materials reviewed testing methods for evaluating high-strength sheet materials with respect to their resistance to brittle fracture.[78]

The emphasis was placed on evaluating fracture toughness of materials having a strength-to-density ratio of 700,000 (psi: $lb/in.^3$). The first test method developed by the Committee was "Recommended Practice for Sharp Notch Tension Testing of High-Strength Sheet Materials", ASTM Designation E 338-67. This recommended practice covered the determination of a comparative measure of the resistance of high-strength sheet material (yield strength to density ratio of over 700,000, psi: $lb/in.^3$) to fracture originating from a very sharp crack or crack-like stress concentrator.

The quantities determined from the test were the sharp-notch strength and the ratio of sharp-notch strength to yield strength. Sharp-notch strength was defined as a value determined by dividing the maximum load sustained in a slow tension test of a notched specimen by the initial area of supporting cross section in the plane of the notches or cracks. The recommended practice for sharp-notch-tension testing was not intended to provide an absolute measure of resistance to crack propagation that could be used in calculations of the strengths of structures. However, the tests provided useful information on effects of composition and processing variables on materials, on relative crack-propagation resistance of materials, and on requirements for specifications of acceptance and manufacturing quality.

Dimensions of specimens for determining sharp-notch strength in accordance with ASTM E 338-67 are shown in Figures 81 and 82. The specimens are restricted to one width (3. 00 inches), and 60-degree vee notches having a 0. 0007-inch radius (maximum) are required. ASTM recommends that the central-through-notch tension specimen contain a centrally drilled 0. 025-inch hole from which crack-starter slots are extended by means of saw cuts. Fatigue-crack extensions from the slots may then be produced prior to fracture-toughness-testing by cyclic tension-tension stressing and pin loading in the same manner as in tension testing.

Recently, the ASTM Committee E-24 on Fracture Testing of Metals proposed a recommended practice for plane-strain fracture-toughness testing of high-strength metallic materials using a fatigue-cracked bend specimen.(4) The specimen and dimensions are shown in Figure 83; the size of the specimen increases with toughness of the material. In general, the procedure involves three-point bend testing of notched specimens that have been previously cracked in fatigue. During testing a record is obtained for load versus displacement across the notch. The load that corresponds to a prescribed increment of crack extension is used to calculate a value for K_{Ic}, the plane-strain fracture toughness.

This K_{Ic} value is a property that characterizes the susceptibility of a material in a neutral environment to unstable crack extension under conditions of high restraint from plastic deformation; a condition corresponding to a plane-strain state of stress near the crack front. It is believed to represent a lower limiting value of fracture toughness. It is a function of strain rate and temperature. In the presence of corrosive environments or cyclic stressing, significant crack extension can occur at K_I values less than K_{Ic}. When using K_{Ic} values in the design of service components, therefore, differences that may exist between laboratory tests and field conditions should be recognized and taken into account. The ASTM proposed recommended practice is expected to serve a number of useful purposes:

(1) In research or development, to establish the effects of metallurgical variables such as composition or heat treatment, or of fabricating operations such as welding or forming on the fracture toughness of new or improved materials in quantitative terms.

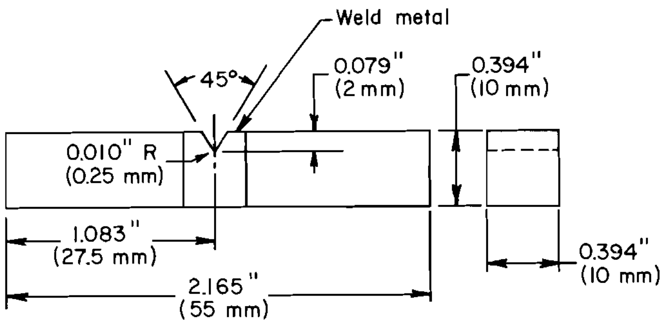
(2) In service evaluation, to establish the suitability of a material for a specific application for which the stress conditions are prescribed and for which maximum flaw sizes can be established with confidence.

(3) For information and for specifications of acceptance and manufacturing quality control, when there is a sound basis for specifying minimum plane-strain fracture values.

Another type of specimen used in fracture-toughness testing is the compact K_{Ic} specimen illustrated in Figure 84.(80) Before testing, the notch depth is extended at least 0. 050 inch by fatigue cracking. The specimen then is loaded in tension to cause fracture and determine K_{Ic} values. Recommended testing procedures for the compact K_{Ic} specimen are being prepared by ASTM Committee E-24 on Fracture Testing of Metals for possible adoption in the future.

Additional edge-notched and centrally notched specimens which have been suggested by other investigators are shown in Figures 85 and 86.(79,81)

FIGURE 68. CHARPY V-NOTCH IMPACT SPECIMEN



Dimensions shown are ASTM standard; used for wide range of temperatures; usually tested in air.

Purpose of Test - Developmental, production quality, notch toughness, ductility, weldability, and design allowables.

Number of Specimens Tested - Usually 3 if tested at only a single temperature; usually 2 per temperature for determination of transition temperature.

Important Variables - Specimen geometry, weld quality, weld inspection, testing equipment, specimen positioning, test-temperature control, measurements, and data analysis.

Data Obtained - Impact energy, lateral expansion and contraction, and fracture appearance.

Specifications - ASTM E-23; MIL-E-22200; Fed. Test Method Std. No. 151.

References - 4, 58, 59

Remarks - Most widely used impact specimen. For base-plate evaluation, this specimen appears to be the best, partly because of the tremendous amount of data that are available from previous tests that used this specimen.

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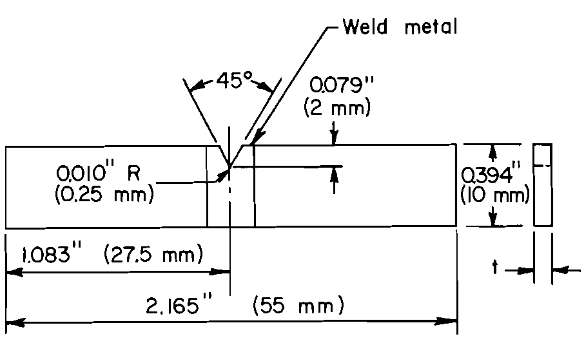
FIGURE 69. CHARPY V-NOTCH IMPACT SPECIMEN--SHEET



Standard Charpy vee-notched specimen except specimen thickness, t, is equal to thickness of test sheet, t; used for wide range of temperatures; usually tested in air.

Purpose of Test - Developmental, production quality, notch toughness, ductility, weldability, and design allowables.

Number of Specimens Tested - Usually 3 if tested at only a single temperature; usually 2 per temperature for determination of transition temperature.

Important Variables - Specimen geometry, weld quality, weld inspection, testing equipment, specimen positioning, test-temperature control, measurements, and data analysis.

Data Obtained - Impact energy, lateral contraction, and fracture appearance.

Specifications - ASTM-E-23 pertaining to full-size Charpy specimens would seem applicable.

References - 4, 59, 60.

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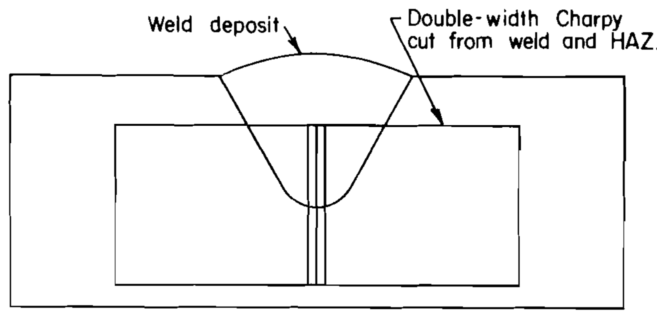
FIGURE 70. DOUBLE-WIDTH CHARPY V-NOTCH IMPACT SPECIMEN



Purpose of Test - Indication of fracture toughness of weld and heat-affected base metal simultaneously.

Number of Specimens Tested - 15 or 20 may be required for determining brittle transition temperature.

Important Variables - Weld-metal and base-metal chemistry, test-temperature, welding parameters.

Data Obtained - Relative toughness of weld metal and HAZ, crack propagation energy, transition energy-temperature curves.

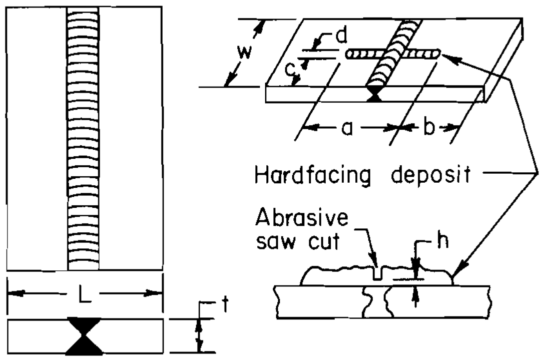
Specifications - Same as for standard Charpy specimens.

References - 8.

Remarks - For composite weld structures. The test weldment consists of a bead-on-plate weld or in heavy-plate thickness, a multipass weld deposited in a V-groove cut halfway through the plate. For fracture-toughness data, the Charpy should be precracked.

****

FIGURE 71. NRL DROP-WEIGHT-TEST SPECIMEN



Dimensions, inches							
L	W	t	a	b	c	d	h
14	3-1/2	1/2 to 1-1/4	2-1/2	5-3/4	1-1/2	1/2	1/16
5	2	1/2	2	1-1/2	3/4	1/2	1/16

NRL reference standard specimen is 14 by 3-1/2 by 1 inch with a 12-inch span and a 0.3-inch anvil stop device used to limit deflection. Smaller specimens used for materials thinner than 3/4 inch but at least 1/2 inch. Testing done over wide range of temperature in air.

Purpose of Test - Developmental, ductility, crack susceptibility, crack propagation, impact energy, and weldability, notch toughness of weld metal.

Number of Specimens Tested - 6.

Important Variables - Specimen geometry, weld quality, weld inspection, testing equipment, specimen positioning, test-temperature control, measurements, data processing, and data analysis.

Data Obtained - Impact energy and fracture appearance, NDT temperatures of weld metal.

Specifications - See references.

References - 61, 62

Remarks - Very useful specimen for determining NDT (nil-ductility temperature) or the temperature at which a running cleavage crack will not be arrested. Basically, it is a base-plate test but is used effectively as a screening test for subsequent explosion-bulge testing. Crack-starter electrode recommended is 3/16-inch-diameter Murex Hardex N.

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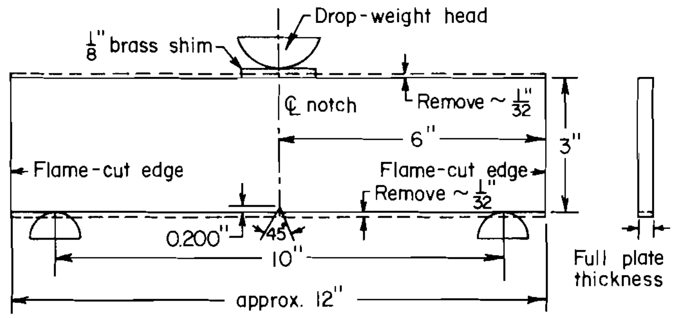
FIGURE 72. DROP-WEIGHT-TEAR-TEST SPECIMEN



Purpose of Test - Base-metal and weld-metal toughness.

Number of Specimens Tested - At least 3 per condition.

Important Variables - Base-metal and weld-metal properties, test temperature.

Data Obtained - Energy absorption required to fracture specimen under dynamic loading, fracture-propagation transition temperature, fracture appearance.

Specifications - None.

References - 63, 64.

Remarks - Sharp notch is pressed in with a chisel-like tool. This specimen has been used at Battelle Memorial Institute.

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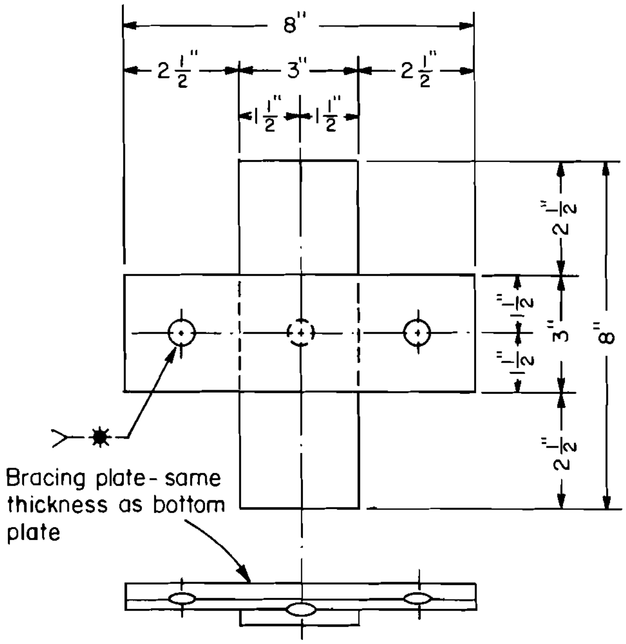
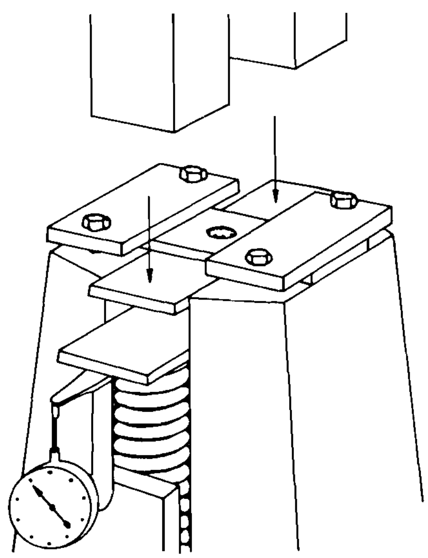
FIGURE 73. DROP-IMPACT TEST-SPECIMEN FOR SPOT WELDS



a. Drop-Impact-Test Specimen



b Drop-Impact Testing Arrangement

Purpose of Test - Notch-Toughness

Number of Specimens Tested - Two for each condition.

Important Variables - Materials, welding variables, weld size, sheet thickness, gripping method.

Data Obtained - Impact load to break welds.

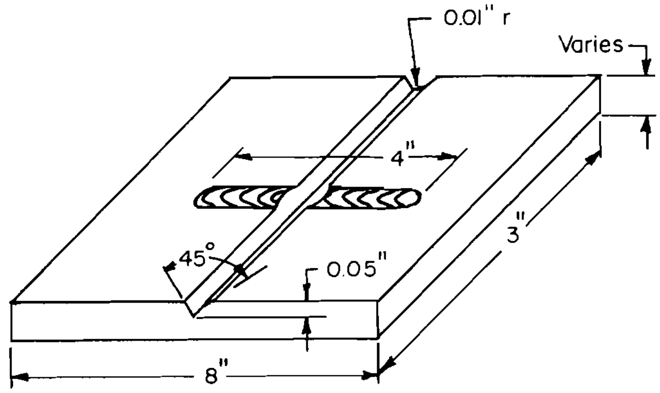
Specifications - AWS C1. 1-66.

References - 6.

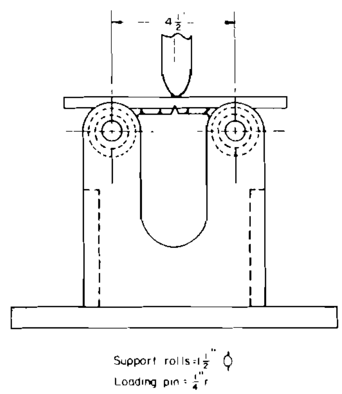
Remarks - Bracing plate and damping arrangement are used to reduce bending.

****

FIGURE 74. LONGITUDINAL-BEAD-WELD, NOTCH-BEND SPECIMEN (KINZEL)



Dimensions as proposed by Kinzel; however, other dimensions have been used; span length and specimen length often varied; specimens usually welded without preheat and tested over range of temperature to establish transition temperature.



Purpose of Test - Notch toughness.

Number of Specimens Tested - Usually 2 to 3 specimens if tests are made at a single temperature; otherwise, sufficient specimens to test over a range of temperature to establish transition behavior.

Important Variables - Specimen geometry, notch geometry, weld quality, specimen positioning, test-temperature control, measurements, and data analysis.

Data Obtained - Lateral contraction and fracture characteristics usually determined; however bend angle at maximum load and load-deflection curves have been used as performance criteria.

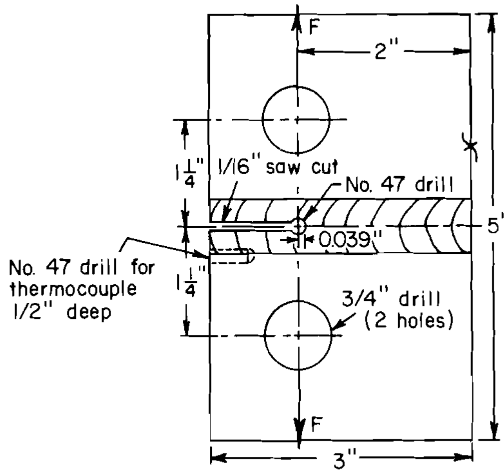
Specifications - None.

References - 18, 20.

Remarks - Specimen very useful for evaluating relative merits of steel compositions, heat treatment (before and after welding), and welding procedures; test is sensitive to HAZ and weld-metal changes as a result of heat input.

****

FIGURE 75. NAVY TEAR-TEST SPECIMEN



1/16-inch is machined from edge marked ✗ to remove heat-affected metal.

Purpose of Test - Notch toughness of weld metal and unwelded base plate.

Number of Specimens Tested - 1 to 5.

Important Variables - Materials, welding conditions, test temperature, loading rate, constraint.

Data Obtained - Load-deflection curves, energy to initiate fracture, energy to propagate fracture, transition temperature range, fracture type.

Specifications - None.

References - 66, 67, 68.

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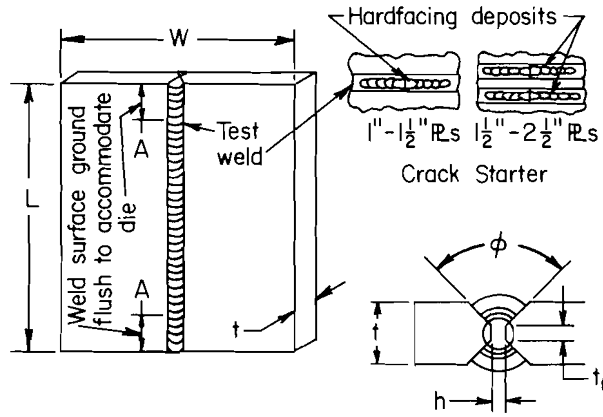
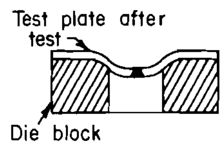
FIGURE 76. EXPLOSION-BULGE- AND CRACK-STARTER EXPLOSION-BULGE-TEST SPECIMENS





Dimensions, inches						
L	W	t	t_1	h	Φ	A
20	20	1 to 1-1/2	1/16	3/32	60°	5
30	30	1-1/2 to 2-1/2	1/16	3/32	60°	7

Dimensions shown are NRL standard; the overall dimensions generally are adhered to; weld-joint dimensions varied; tested over wide range of temperature.

Purpose of Test - Developmental, ductility, crack susceptibility, crack propagation, and weldability.

Number of Specimens Tested - NRL requires 5 to 6 samples; others use 3.

Important Variables - Specimen geometry, weld quality, weld inspection, testing equipment, specimen positioning, test-temperature control, and data analysis.

Data Obtained - Impact energy, fracture appearance, reduction in plate thickness, and extent of cracking after testing, NDT temperature.

Specifications - NRL Standard Evaluation Procedures for Explosion-Bulge Testing, 15 March 1961.

References - 69, 70.

Remarks - This is a good test specimen for composite weldment evaluation. Without the crack-starter deposit, it permits evaluation of weldment performance in the presence of any natural defects. With crack starter, it provides a good evaluation of the fracture-propagation characteristics of weld HAZ and unaffected base plate. This specimen is used by U. S. Navy as acceptance test. NRL developed a modification of this test called the explosion-tear test (ETT).

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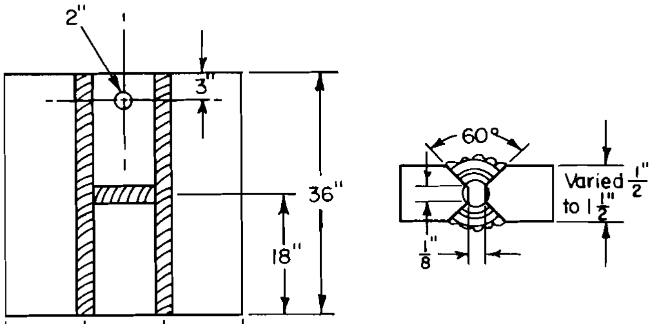
FIGURE 77. ARMY ORDNANCE BALLISTIC-IMPACT SPECIMEN (H-PLATE)



Generally tested at 70 F in air. Some testing over a range of temperature for development purposes.

Purpose of Test - Developmental, production quality, ductility, crack susceptibility, crack propagation, ballistic shock, and weldability.

Number of Specimens Tested - 1.

Important Variables - Weld quality, weld inspection, measurements, data analysis, filler metal, joint geometry, welding procedure, and material.

Data Obtained - Impact energy, fracture appearance, and extent of cracking.

Specifications - MIL-A-46027 (ORD), MIL-W-46086.

References - 71, 72.

Remarks - Army Ordnance acceptance test based on arbitrary limits of acceptable ballistic-shock performance; not considered to have a direct relationship to actual performance of that joint in the hull of an armored vehicle; considerable effort has been made to find a cheaper and better evaluation test for Army Ordnance qualification of armor and armor weldments. Explosion-bulge (Fig. 76) and notched-longitudinal-bend (Fig. 74) specimens appear to be reasonable substitutes for H-plate.

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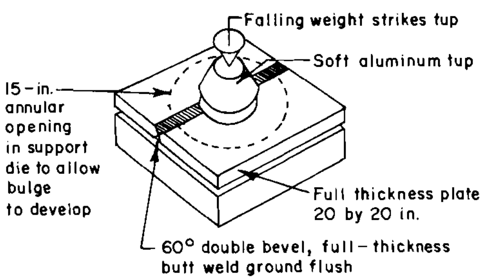
FIGURE 78. DROP-WEIGHT-BULGE-TEST SPECIMEN (NRL)



Support die on concrete pad

Purpose of Test - Fracture-propagation behavior.

Number of Specimens Tested - 1 or more, depending on circumstances - more if temperature effects are being studied.

Important Variables - Welding variables, weld quality and inspection, energy per blow, specimen positioning, test temperature.

Data Obtained - Fracture-toughness behavior, energy absorption to failure, strain or bulge at failure, source and path of failure.

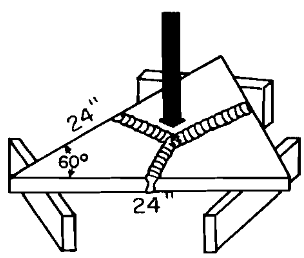
Specifications - None.

References - 63.

Remarks - Test evolved at NRL from explosion-bulge test. This test is less complex and less costly than the explosion-bulge test. Weld reinforcement ground flush and smooth on both sides before testing; test has been used for 1-inch plate weldments.

****

FIGURE 79. DELTA-TEST SPECIMEN



Load applied through 4" ball

Purpose of Test - Effects of welding variables on brittle behavior of steels.

Number of Specimens Tested - At least 3 per variable.

Important Variables - Plate material, welding variables, rolling direction as a variable in crack-propagation direction.

Data Obtained - Transition temperature for ductile to brittle behavior; anisotropy effects in plate, effects of thermal treatment on fracture, weldability, load-deflection record.

Specifications - None.

References - 73, 74.

Remarks - Tests using this specimen indicate that the fractures are comparable to those reported in service failures. Good feature is that the fracture can seek its own path whether in HAZ, base plate, or weld metal.

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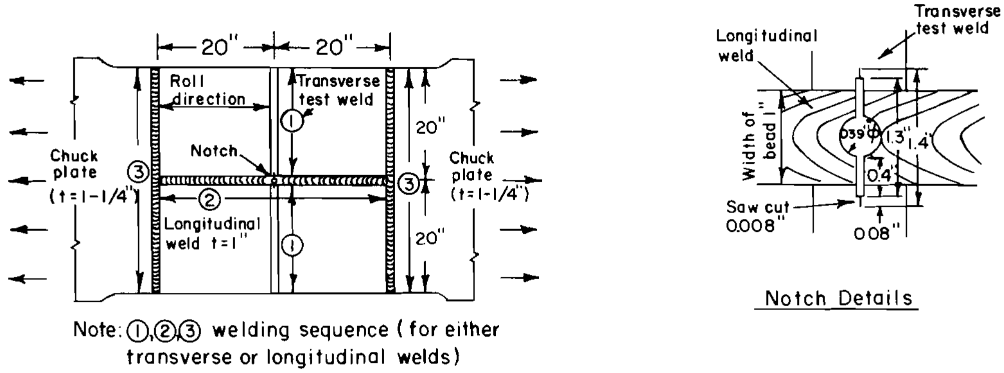
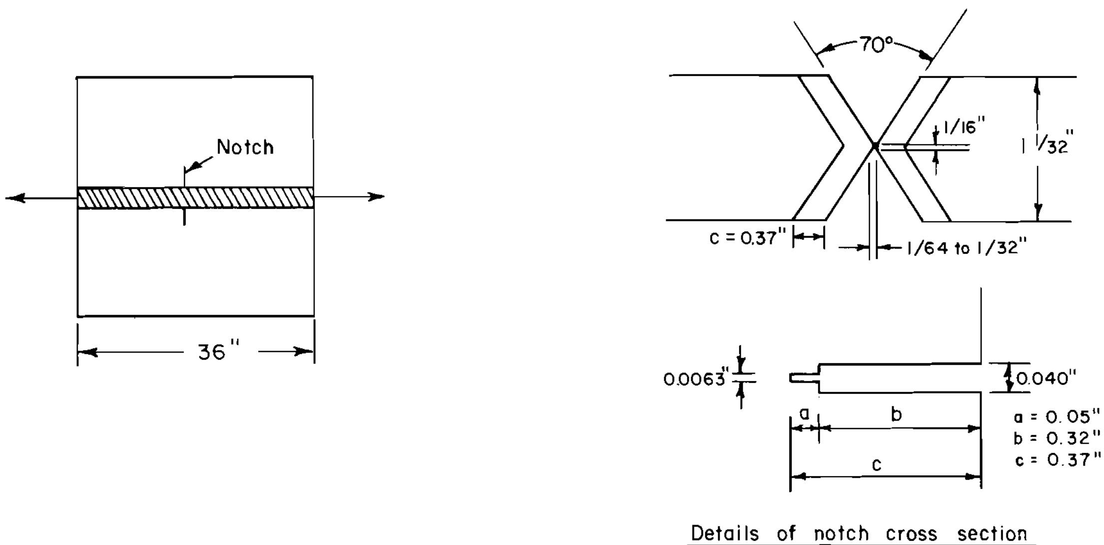
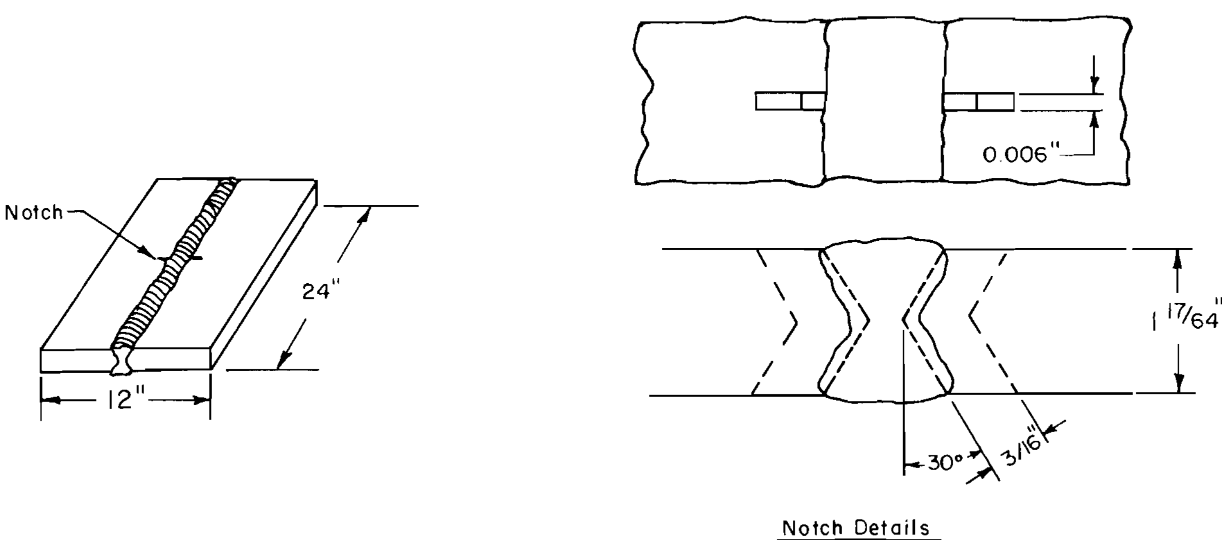
FIGURE 80. LARGE-NOTCHED-TENSION- AND BEND-TEST SPECIMENS



a. Wide – Plate Tension Specimen (75)

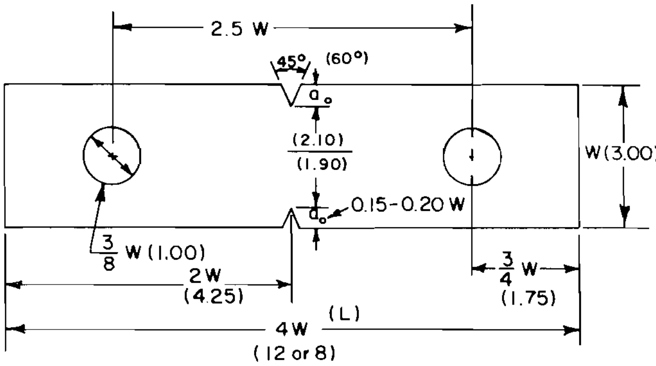


b. Greene – Wells Type Tension Specimen (76)



c. Notched – Bend Specimen (77)

FIGURE 81. DOUBLE-EDGE-NOTCH TENSION SPECIMEN



Width (W) to thickness (B) ratio is 16B< W<45B. Pinhole diameter is W/3 to W/2. Notch-root radius is to be less than 0.001 inch. Notch-root position is to be symmetrical about line connecring centers of loading pinholes within 0.001 W (inch). Dimensions in parentheses are those required for ASTME 338-67.

Dimensions, inches			
W	Thickness[a]	L	Pin Diam.
1	.022 .063	4	3/8
2	.044 - .125	8	3/4
3	.067 - .188	12	1-1/8
4	.088 - .250	16	1-1/2

[a]Maximum thickness for ASTME 338-67 is 0.025 inch.

Purpose of Test - Notch strength.

Number of Specimens Tested - Generally 1 for each condition to be investigated.

Important Variables - Notch characteristics, materials, concentricity of loading, specimen design.

Data Obtained - Maximum load at instability, maximum crack length at instability, percentage of shear lip on the running crack fracture surface, estimate of crack extension prior to instability.

Specifications - ASTM E 338-67.

References - 78, 79.

Remarks - Usually W is chosen to suit an existing set of loading pins or conditions tabulated above.

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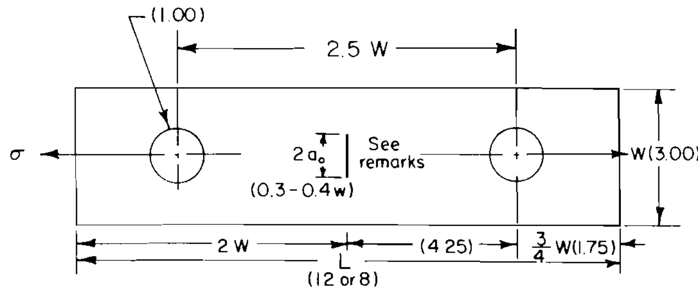
FIGURE 82. CENTRAL-THROUGH-NOTCH TENSION SPECIMEN



Width (W) to thickness (B) ratio is 16B<W<45B. Pinhole diameter is W/3 to W/2. Notch-root radius is to be less than 0.001 inch. Notch-root position is to be symmetrical about line connecting centers of loading pinholes within 0.001 W (inch). Dimensions in parentheses are those required for ASTM E 338-67.

Dimensions, inches			
W	Thickness[a]	L	Pin Diam.
1	.022 - .063	4	3/8
2	.044 - .125	8	3/4
3	.067 - .188	12	1-1/8
4	.088 - .250	16	1-1/2

[a]Maximum thickness for ASTM E 338-67 is 0.025 inch.

Purpose of Test - Notch strength.

Number of Specimens Tested - Generally 1 for each condition to be investigated.

Important Variables - Notch characteristics, materials, concentricity of loading, specimen design.

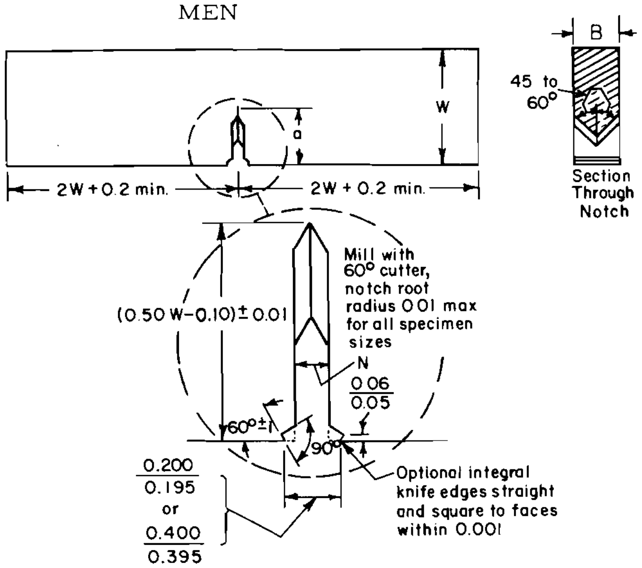
Data Obtained - Maximum load at instability, maximum crack length at instability, percentage of shear lip on the running-crack surface, estimate of crack extension prior to instability.

Specifications - ASTM E 338-67.

References - 78, 79.

Remarks - Usually, W is chosen to suit an existing set of loading pins or conditions tabulated above. ASTM E 338-67 suggests a central-notch crack starter consisting of a 0.025-inch center hole extended by saw cuts terminated in narrow slots having a maximum width of 0.008 inch. Narrow slots can be produced with a jewelers saw. Narrower slots can be produced by electrical-dischargemachining methods. Other crack-starter designs may be used, but must lie within the envelope defined by ASTM E 338-67. Slots usually extended by fatigue cracking prior to fracture-toughness testing.

FIGURE 83. PRECRACKED BEND-TEST SPECIMEN



Thickness	B	±0.01B
Depth	W = 2B	±0.01W
Crack Length	a = 0.5W	0.45 to 0.55W
Support Span	S = 4W	
Notch Width	N = 0.125	For B ≦ 1 inch
(Maximum)	N = 0.25	For B ≧ 1 inch

Note:

(1) Integral knife edges are omitted when attachable knife edges are used.

(2) Tolerances given are for 1-inch thickness. Tolerances are proportioned for smaller sizes.

(3) Chevron notch required.

Purpose of Test - Fracture-toughness of weld, adjacent metal (HAZ), or base plate.

Number of Specimens Tested - 1 to 3.

Important Variables - Notch location with respect to weld, plate surface and rolling direction; effective crack depth, type of weld, material toughness, strain rate, temperature.

Data Obtained - K_{Ic} fracture-toughness numbers, fracture appearance, load displacement record and associated calculations, number of cycles to generate last 0.05 inch of fatigue-crack extension, specimen and testing conditions.

Specifications - ASTM Part 31 (proposed).

References - 4, 79.

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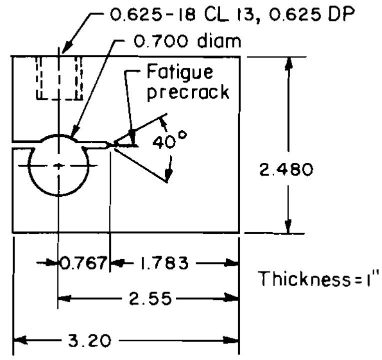
FIGURE 84. COMPACT K_{Ic} TYPE FRACTURE-TOUGHNESS SPECIMEN



Purpose of Test - Fracture toughness.

Number of Specimens Tested - 1 to 3.

Important Variables - Materials, notch location relative to weld, material toughness, temperature.

Data Obtained - K_{Ic}, fracture appearance, load-displacement record and related calculations.

Specifications - Company specifications.

References - 80.

Remarks - Used to evaluate steels.

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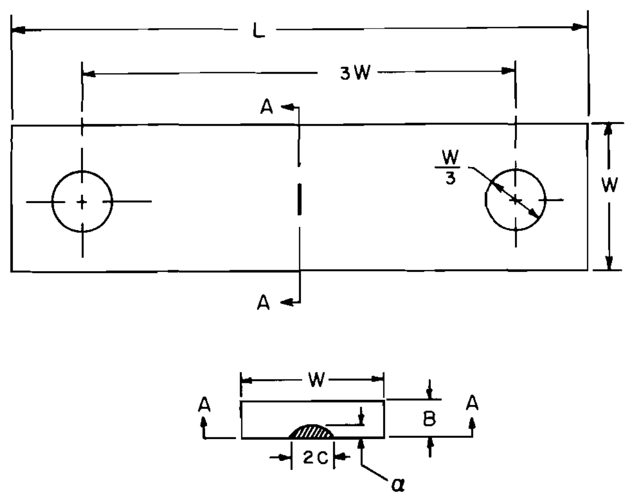
FIGURE 85. SURFACE-NOTCH TENSION SPECIMEN



Purpose of Test - Crack-toughness value, K_{Ic}, effect of crack size or gross stress or fracture.

Number of Specimens Tested - Varies with range of crack sizes to be investigated.

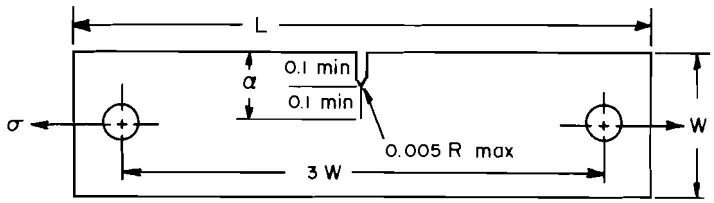
Important Variables - Notch characteristics, materials, specimen design, general yielding characteristics of materials tested.

Data Obtained - Crack size, stress-strain curves.

References - 79, 81.

Remarks - Surface crack simulates a defect type commonly observed as a source of failure in weldments or plate. Specimen size must be selected for the largest crack to be tested.

FIGURE 86. SINGLE-EDGE-NOTCH TENSION SPECIMEN



Purpose of Test - Crack-toughness value, K_{Ic}.

Number of Specimens Tested - generally 1 for each condition to be investigated.

Important Variables - Notch characteristics, materials, specimen size, general yielding characteristics.

Data Obtained - Initial crack size, critical load (load for abrupt plane-strain crack motion, stress-strain curves.

References - 79, 81.

Remarks - This specimen allows measurement of high toughness values with limited-capacity machines.

****

STRESS-RUPTURE AND CREEP TESTS

Stress-rupture tests determine the time required for rupture, whereas creep tests measure time-dependent strain; both tests are run under conditions of constant load and temperature. In a practical sense, a stress-rupture test is one of relatively short duration (e.g., stress to rupture in 10, 100, or 1,000 hours) but stress-rupture time may be extrapolated to periods of as long as 100,000 hours with limited actual tests in the range of 2,000 to 10,000 hours or longer. Creep tests, on the other hand, are generally conducted for a prolonged time period. These tests are usually conducted under stresses that will give true minimum creep rates ranging between 0.001 and 0.00001 percent per hour (0.1 and 0.01 percent per 1000 hours). A creep rate of 0.00001 percent per hour or 1 percent in 100,000 hours (about 11 years) is used in designing rapidly rotating and highly stressed parts, such as steam turbine blades, where the allowable creep must be very small over a long period of time.

Many types of welded engineering structures are subjected to stress at elevated temperatures; these include high-pressure boilers, petroleum cracking equipment and piping used in the petroleum industries, and wing sections of supersonic aerospace vehicles.

In order that various laboratories have some common basis for conducting creep tests and comparing data, the Joint ASTM-ASME Research Committee on Effect of Temperature on Properties of Metal and the Materials Advisory Board have recommended standard test procedures.[4,5] An adequate description of prior processing of the material being investigated should be available before testing, because stress-rupture and creep properties are influenced significantly by material condition. Consequently, specimens for these tests should be taken from material in the form and condition that represent those in which the material is used.

Although stress-rupture and creep tests are used extensively for evaluating the performance of unwelded base metal, the use of these tests for evaluation of weldments appears to be limited. Considerable latitude is found in the choice of test-specimen design. Specimens of the type, size, and shape used for standard tension tests are generally suitable; however, design of the grip ends usually is optional to allow for adaptation of the specimen to the testing equipment.

A specimen that has been used extensively for stress-rupture and creep tests of transverse- and longitudinal-weld specimens is shown in Figure 87. This specimen has been used only for material in sheet thicknesses. Somewhat smaller specimens also can be used for these tests in order to economize on materials, achieve more rapid heating, reduce grip loads, and improve temperature uniformity along the gage length. Such subsize specimens are recommended for evaluating small lots of refractory metals.[5]

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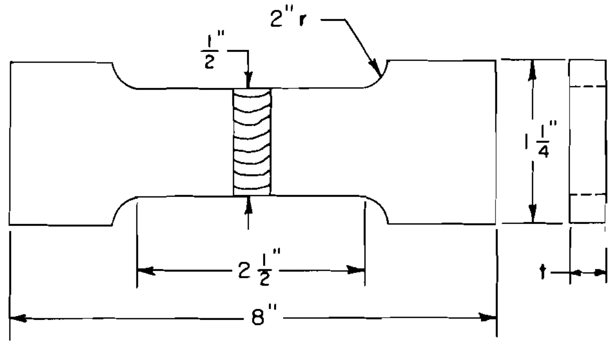
FIGURE 87. TRANSVERSE- AND LONGITUDINAL-WELD STRESS-RUPTURE AND CREEP-TEST SPECIMEN



Dimensions and test temperature varied greatly; tested with and without weld reinforcement, depending on service conditions. Same dimensions used for longitudinal-weld specimen. t varies 0.040" to 0.125".

Purpose of Test - Developmental, strength, ductility, weldability, and design allowables.

Number of Specimens Tested - Usually 3, varying from 2 to 10.

Important Variables - Specimen geometry, weld quality, weld inspection, specimen positioning, test-temperature control, measurements, and data analysis.

Data Obtained- Time to failure, stress to rupture in 100, or 1000 hours, elongation in 1/2 inch and in 2 inches, and reduction of area.

Specifications - Company specifications.

References - 4, 5.

Remarks - The same general remarks concerning the effects of weld-metal strength that were made of tension specimens apply (see section on tension tests).

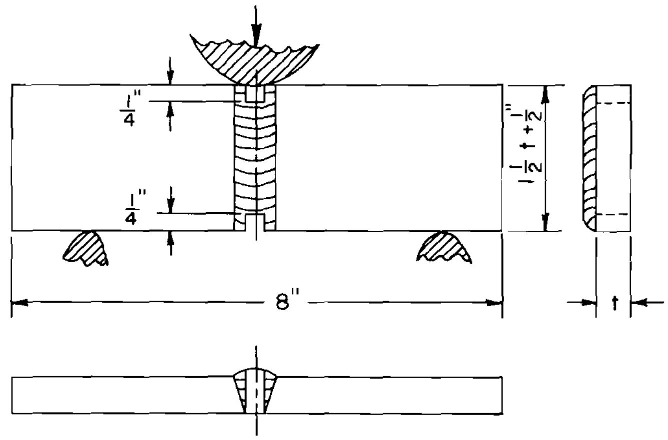
****

SOUNDNESS TESTS

In accordance with the American Welding Society's "Standard Methods for Mechanical Testing of Welds", the term "soundness" means the degree of freedom of a weld from defects discernible by visual inspection of any exposed surface of the weld.[10] Specimens that are used extensively to determine weld soundness include the nick-break test specimen (Figure 88), the fillet weld break-test specimen (Figure 89), and the bead-on-plate weldability test specimen (Figure 90). However, valuable information on weld soundness also is obtained from examination of weld-metal failures obtained with other kinds of test specimens.

The nick-break and the fillet-weld-break test specimens are designed so that fracture is forced to take place in weld metal under either slow or rapid applications of force (press or hammer blows). The bead-on-plate weldability specimen is used to evaluate weld soundness by fracturing or sectioning the specimen to expose sections of the weld for visual examinations. Weld-metal soundness then is evaluated by examining the fracture surfaces for flaws to ascertain characteristics such as flaw type, size, orientation, and location. The main types of flaws include porosity, slag and other types of inclusions, cracks, lack of fusion, and unsatisfactory penetration. Performance is based on number and size of inclusions, pores and cracks, and degree of penetration. Acceptance limits are in accordance with specifications or as agreed upon between the fabricator and the customer.

FIGURE 88. NICK-BREAK SOUNDNESS SPECIMEN



Other dimensions used occasionally. Dimensions not critical; tested at room temperature in air.

Purpose of Test - Weld soundness and ductility.

Number of Specimens Tested - 2.

Important Variables - Weld quality, weld inspection, and data analysis.

Data Obtained - Fracture appearance, extent of porosity, cracking, and inclusions.

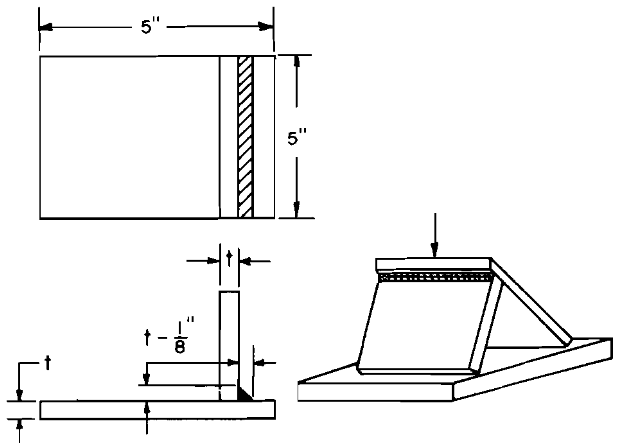
Specifications - API Std. 1104; AWS A4.0.

References - 10, 82.

Remarks - Used principally as acceptance test for porosity and inclusion limitations. Specimen bent transversely at nicked cross section. Rate of loading not important. Loading method shown is in accordance with AWS. API 1104 permits fracturing the specimen by tension test techniques or by gripping one end and striking the free end with a hammer blow.

*************** ****************

FIGURE 89. FILLET-WELD-BREAK SOUNDNESS SPECIMEN



Other dimensions used occasionally. Dimensions not critical; tested at room temperature in air.

Purpose of Test - Weld soundness, root penetration, and ductility.

Number of Specimens Tested - 2.

Important Variables - Specimen geometry, weld quality, welding conditions, weld inspection, and data analysis.

Data Obtained - Extent of porosity, cracking, inclusions, and penetration.

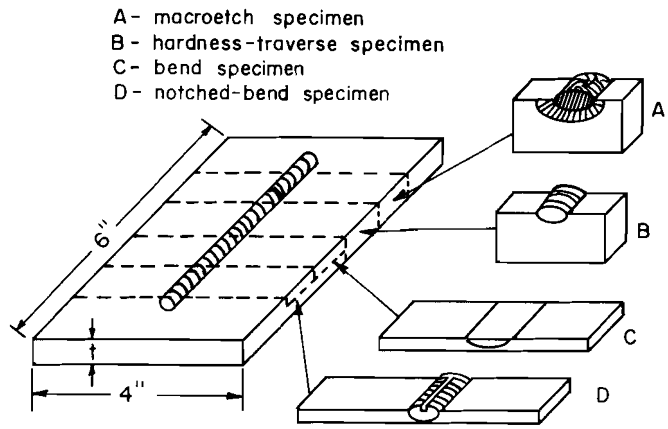
Specifications - MIL-E-8697, MIL-E-13080A, ASME Sec. IX, AWS A4.0.

Reference - 10, 82.

Remarks - Specimen broken apart by press or hammer blows. Fracture surfaces examined for porosity, inclusions, cracks, penetration, etc.

****

FIGURE 90. BEAD-ON-PLATE WELDABILITY TEST SPECIMEN



Dimensions often changed to vary cooling rate.

Purpose of Test - Crack susceptibility, crack propagation; weld and HAZ hardness, bend ductility; study effects of welding conditions such as heat input, preheat, etc.; occasionally used for quality control.

Number of Specimens Tested - Usually 1.

Important Variables - Specimen geometry (only as it affects weld cooling rate), weld quality, weld conditions, weld inspection, and data analysis.

Data Obtained - Hardness, soundness, microstructure, and elongation (in the case of bend specimens).

Specifications - None.

References - 46.

Remarks - Simple but extremely useful test.

****

HARDNESS TESTS

Hardness-testing methods often are used in routine weld evaluations, either alone or in combination with other testing methods, to provide information on weld properties in addition to that obtained from strength tests, described in previous sections of this report. Although methods for measuring hardness of metals are rather well standardized, no standards have been established for hardness measurements relative to weld joints. It was considered useful, therefore, to describe briefly some of the ways in which hardness measurements have been used for evaluating welds.

Hardness of the various zones of a weldment is influenced by many factors. In a broad sense these factors include the chemical composition of the weld metal and parent metal, the condition of the parent metal prior to welding, the welding process and procedure, and the processing to which the weldment may be subjected after welding.

The information gained from hardness measurements of welded joints is broad in scope. These measurements provide indications of metallurgical changes caused by welding, metallurgical variations and abrupt microstructural discontinuities in weld joints, brittleness, and relative machineability and workability.

Transformation processes may occur in the heat-affected zone as a result of the heating and cooling cycles imposed by the welding process. The thermal cycle may be one that results in an austenite-to-martensite transformation with a marked increase in hardness. On the other hand, in an area where the temperature rise is moderate, a tempering effect can occur, with a corresponding lowering of hardness. Since the cooling rates in weld zones differ considerably, hardness differences would be expected in the various zones. Similarly, oxidation or contamination of various metals like titanium and molybdenum during welding can cause metallurgical changes that can be discerned by hardness measurements. Welding of cold-worked austenitic stainless steels produces softened heat-affected zones that can be identified from hardness measurements. Abrupt changes in hardness indicate abrupt changes in microstructure, which can produce notch effects. By utilizing proper thermal or mechanical treatments, these effects may be reduced or counteracted to lower stress levels that are more compatible with service requirements.

Hardness measurements also are used in studying the effects of various welding parameters on the properties of the weld metal and the heat-affected zone. For example, in multiple-pass welds in steel, high hardness in welds and heat-affected zones may be detrimental to the weldment properties. After the initial weld pass, subsequent weld passes can temper or lower the hardness in the weldment. The hardness test is useful in determining the effectiveness of such heat treatments.

Hardness tests have been used for evaluating joints made by all of the conventional joining processes. All of the hardness-testing techniques for metals have been used. Specimens for hardness testing include as-welded partial or complete assemblies, weldments from which the reinforcement has been removed, and weld-joint cross sections.

For hardness tests involving completed assemblies, the weld reinforcement may or may not be removed. When it is not removed, a local area of the reinforcement is ground smooth before testing. For large assemblies, several portable hardness testers are available that can be readily transported for use at the assembly site.

Hardness testing of welds is usually performed on machined, ground, polished, or polished-and-etched transverse-weld-joint cross sections. Generally, hardness indentations are made at selected locations of interest in the various weld zones or a traverse is made along a line crossing the weld joint. Indentations at the selected locations often are made in groups of three but the number of indentations may range from one to as high as seven in thick-plate weldments. In fusion welds, the regions that are selected for hardness measurements typically include the center, face, and root regions of the weld metal, fusion-line regions, heat-affected zone, and parent metal. Hardness traverses typically include a traverse along the center and one near the surface of the sheet or plate thickness, and then one midway between these traverses. Figure 91 illustrates the cluster-type and traverse type hardness evaluations discussed in the foregoing. These illustrate a limited variety of the hardness-testing procedures for fusion-weld evaluations. Similar procedures are employed for evaluating hardness in resistance spot welds. A typical spot-weld hardness-traverse procedure is illustrated in Figure 92. The hardness traverse is made on a mounted, polished, and etched specimen taken across the diameter of a spot weld. The traverse begins at the center of the nugget and progresses outward into the parent metal. A similar procedure has been suggested by the International Institute of Welding for spot-weld evaluations.[83] The required distances between indentations and method for presenting the data in graphical form are as shown in Figure 92. A minimum of three indentations in the heat-affected zone is recommended.

Hardness-testing methods that are used in conjunction with welded joints generally include one or more of the following:

(1) Brinell
(2) Rockwell
(3) Vickers
(4) Knoop

The Brinell and Rockwell tests produce relatively large indentations and, consequently, are used for evaluating large welds or weld-joint areas. Typical applications include hardness measurements of fusion-welded joints in plate and sheet. The Vickers and Knoop hardness tests, which produce relatively small indentations, are widely used for hardness measurements in cross sections of small welds and extremely localized weld areas. Typical uses of these tests include hardness measurements of fusion or bond-line regions in diffusion-bonds, roll welds, electron-beam welds, and brazed joints.

The usual precautions suggested for general hardness testing also apply to the testing of welds. The specimen should be flat in order that it may seat firmly on the anvil and that symmetrical impressions may be obtained. It should be thick enough to prevent erroneous results due to the effects of the supporting anvil or backing material. The impressions should not be within two diameters or diagonals of the edge of the specimen. Penetrators should be calibrated periodically to ensure against improper readings.

FIGURE 91. TYPICAL ARRANGEMENTS OF INDENTATIONS FOR MEASURING HARDNESS IN VARIOUS ZONES ACROSS A DOUBLE-VEE-GROOVE WELD JOINT

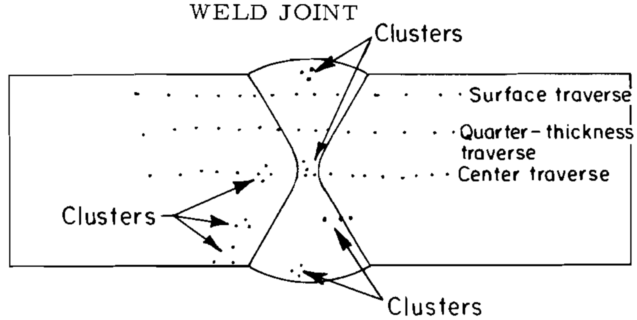
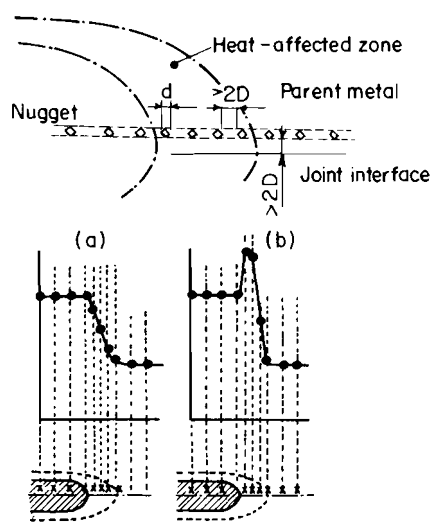


FIGURE 92. ILLUSTRATION OF HARDNESS TRAVERSES FOR SPOT WELDS



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13. ABSTRACT

This Report describes the specimens and test methods used for the evaluation of weldments by destructive means. Tests described include tension, shear, bend, fatigue, cracking susceptibility, notch toughness, fracture toughness, stress rupture, creep, soundness, and hardness tests. The Report essentially updates DMIC Report 165 on the same subject, and also includes information on testing of brazed and resistance welded structures as well as on other types of tests not included in the earlier report. Specimens and test methods are described through the use of 92 illustrations plus standard information applying to each illustration as follows: Purpose of test, number of specimens tested, important variables, data obtained, specifications, references, and remarks.

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	ROLE	WT	ROLE	WT	ROLE	WT
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Braze Welding						
Creep (Materials)						
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Creep Tests						
Fatigue Tests						
Fillets						
Fracture Testing						
Hardness Tests						
Mechanical Properties						
Mechanical Tests						
Notch Toughness						
Shear Tests						
Spot Welding						
Static Tests						
Tension Tests						
Toughness						
Welded Joints						
Welding						
Weldments						