

Test Methods for Evaluating the Resistance Spot Welding Behavior of Automotive Sheet Steel Materials



American Welding Society®



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Test Methods for Evaluating the Resistance Spot Welding Behavior of Automotive Sheet Steel Materials

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Prepared by the
American Welding Society (AWS) D8 Committee on Automotive Welding

Under the Direction of the
AWS Technical Activities Committee

Approved by the
AWS Board of Directors

Abstract

This document presents standard test methods for evaluating the resistance spot welding behavior of automotive sheet steels. The document contains a number of tests and test methods useful in determining the resistance spot welding performance of coated and uncoated automotive sheet steels of all strength levels and compositions. The test methods are designed to assess current range, electrode endurance, and weld properties of automotive sheet steels. The weld property tests include tests for hold time sensitivity, weld hardness, shear tension strength, and cross tension strength.



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W. F. Qualls	<i>Consultant</i>

Advisor to the AWS D8 Committee on Automotive Welding

J. F. Hinrichs	<i>Friction Stir Link, Incorporated</i>
----------------	---

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M. Hebert	<i>General Motors (Retired)</i>

Foreword

This foreword is not part of AWS D8.9M:2012, *Test Methods for Evaluating the Resistance Spot Welding Behavior of Automotive Sheet Steel Materials*, but is included for informational purposes only.

Since its publication in 1997, the AWS D8.9 standard has been widely used by steel companies and automotive companies alike to test the weldability of sheet steels for various automotive applications. This document evolved from the Auto/Steel Partnership of the American Iron and Steel Institute's publication, Weld Quality Test Methods Manual. The AWS D8D Subcommittee, which includes members of the Auto/Steel Partnership's Standardized Welding Test Method Task Force, acknowledges the important contributions made by the Auto/Steel Partnership's staff and members in the development and revision of this document.

With the introduction of new advanced high strength steels into automotive production there is a strong need to test these new steels. Therefore, a set of weld schedules has been added in this revision to address this need. Further, a new Design of Experiments (DoE) test method has been included to examine the robustness of advanced high strength steels to variations in welding parameters that typically occur under shop-floor conditions. The procedure outlined in the DoE testing method has been validated at four independent testing laboratories.

This document not only contains test methods for evaluating the welding behavior of sheet steels, but also covers areas essential to using these test methods in obtaining an accurate assessment of the material and its welding attributes.

Listed below are the key test methods described in this document:

- Sampling and characterization of test material
- Equipment setup and electrode installation
- Electrode conditioning and weld size stabilization
- Endurance (electrode life) testing
- Current level/current range testing
- Weld property testing
- Current break-through testing
- Design of Experiments testing

The sampling and material characterization procedures, equipment setup and electrode installation procedures, and electrode conditioning/weld size stabilization procedures are common to all test methods. In the endurance test, the "endurance limit" (defined as the number of acceptable welds made during the test) is the key welding performance measure that is determined by this test. Other welding behavior measures determined in this test are current levels and current range. Weld button characteristics are assessed by destructive peel testing of weld samples.

The weld property tests are designed to determine hold-time sensitivity, weld button fracture mode, shear tension strength, cross tension strength, metallurgical properties, and hardness of welds made with the test material. The weld property testing is now required at two different weld sizes. Proper judgment should be exercised when interpreting the results of the weld property tests on higher strength steels (such as those with ultimate tensile strength greater than 500 MPa), especially with tests run at the minimum weld size. Welds in such higher strength steels may show interfacial fractures even at short hold times, especially at thicker gauges. The requirement to conduct the tests at the minimum weld size is included to generate more complete information on the behavior of such steels. A fracture classification chart has been added as an Annex D.

Current levels and current range are also determined during the weld property tests. The current break-through test is designed to evaluate the effects that sheet lubricants, conductive paints, or other surface treatments have on the initiation of spot welding current and nugget formation. The types of tests to use shall be specified by the party for whom the testing is to be performed. For some steels, all tests may be specified, while for others, only one test may be specified.

It should be noted that not all of the above tests are required to establish the resistance spot welding behavior of a given grade of steel. The current level/current range testing and weld property testing together generally provide a good indication of the resistance spot welding behavior, whereas the DoE testing is intended to examine the robustness of a given grade of high strength steel to variations in key process variables. The specific tests required to establish the resistance spot welding behavior of a given grade of steel should be agreed upon by the steel supplier (or test laboratory) and the automotive company (or buyer of the steel).

Users of this document have requested that subsequent updates to the document include provisions for the incorporation of other types of welding equipment, electrode caps, and weld schedules than those provided in the document. The inclusion of these alternative methods may permit the testing to be more customer-focused and allow for the determination of specific material and welding performance issues as they relate to a particular manufacturing situation. A commentary and discussion are provided in Annex E and are intended to serve as guidelines should the users of this document desire to utilize alternative test methods for the weld characterization of sheet steels.

It should be noted that, as the weldability evaluation procedures in alternative methods deviate from the procedure described in this document, they may add to the complexity and cost of the material evaluation. The type of evaluations required, and any deviations required to perform them, should be agreed upon between the party for whom the testing is to be performed and the testing laboratory.

Comments and suggestions for the improvement of this standard are welcome. They should be sent to the Secretary, AWS D8 Committee on Automotive Welding, American Welding Society, 550 N.W. LeJeune Road, Miami, FL 33126.

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Test Methods for Evaluating the Resistance Spot Welding Behavior of Automotive Sheet Steel Materials

1. Scope and Applicability

1.1 Scope. This document contains several standardized test methods that are designed to evaluate the resistance spot welding behavior of coated and uncoated sheet steels in a laboratory environment. The test methods allow for uniform testing of automotive sheet steels to determine the following:

- (1) The effect of the interaction between a sheet steel's coating (metallic, nonmetallic, or both) and the welding electrodes on electrode deterioration and weld size/quality behavior over an extended number of welds
- (2) Current levels and current range
- (3) Mechanical properties of welds at different weld sizes and hold times
- (4) Metallurgical and hardness properties of welds
- (5) The effects of sheet lubricants, conductive paints, or other surface treatment on current break-through
- (6) The robustness of a grade of steel to variations in key welding process variables

The test methods are intended for application in a laboratory environment to characterize certain aspects of the welding behavior of sheet steel products under controlled experimental conditions. **They are not intended to simulate production welding practices or to predict welding performance of a given grade of steel in production operations.** The test methods and parameters are designed to be used for sheet steels ranging in thickness from 0.6 mm to 3.0 mm. The tests may be used for sheet steel materials of all yield strengths typically used in automotive applications. In the endurance test, a minimum of two tests per material is recommended to obtain an accurate assessment. The endurance test was developed for low strength (tensile strength less than or equal to 300 MPa) coated steels of lighter gauges. This test is normally used for coated steels with tensile strength less than or equal to 500 MPa and gauges less than 1.2 mm. The weld property tests are designed primarily for gauges of 1.2 mm and heavier.

The specific type and number of tests that are required shall be at the discretion of the specifying party. While the test methods were developed to compare the welding behavior of different steel grades, they can be judiciously applied to evaluate other aspects of welding behavior. Not all of the above mentioned tests are required to establish the resistance spot welding behavior of a given grade of steel. The current level/current range testing and weld property testing together generally provide a good indication of the resistance spot welding behavior, whereas the DoE testing is intended to examine the robustness of a given grade of high strength steel to variations in key process variables.

The specific tests required to establish the resistance spot welding behavior of a given grade of steel should be agreed upon by the steel supplier (or test laboratory) and the automotive company (or buyer of the steel).

A commentary is provided in Annex D on alternative test methods and is intended to serve as a guide should the users of this document desire to utilize alternative test methods for the weld characterization of sheet steels. Because the weldability evaluation procedures in alternative methods deviate from the procedure described in this document, the use of the alternative test methods may add to the complexity and cost of the material evaluation. The type of evaluations required, and any deviations required to perform them, should be agreed upon between the party for whom the testing is to be performed and the testing laboratory.

Resistance spot welding behavior is dependent upon a wide variety of interacting material and weld process factors. To obtain repeatable and reproducible performance data, it is imperative that all experimental variables and the way a test is conducted be closely controlled. Therefore, the instructions for the various sampling and testing procedures in this manual are stated in mandatory language and should be followed as closely as possible. Deviations from the prescribed

procedures or test methods, permissible with the consent of the party for whom the testing is performed, have to be noted and reported.

For the purpose of determining appropriate welding parameters and tests required, steel grades have been classified into four groups based on their minimum tensile strength. These groups are listed in Table 1. Also provided in Table 1 are examples of typical steel grades that fall into each of these four groups.

1.2 Standard Units of Measurement. This standard makes sole use of the International System of Units (SI).

1.3 Safety Precautions. Safety issues and concerns are addressed in this standard, although health issues and concerns are beyond the scope of this standard. Safety and health information is available from the following sources:

American Welding Society¹:

- (1) ANSI Z49.1, *Safety in Welding, Cutting, and Allied Processes*
- (2) AWS Safety and Health Fact Sheets
- (3) Other safety and health information on the AWS website

Material or Equipment Manufacturers:

- (1) Material Safety Data Sheets supplied by materials manufacturers
- (2) Operating Manuals supplied by equipment manufacturers

Applicable Regulatory Agencies

Work performed in accordance with this standard may involve the use of materials that have been deemed hazardous, and may involve operations or equipment that may cause injury or death. This standard does not purport to address all safety and health risks that may be encountered. The user of this standard should establish an appropriate safety program to address such risks as well as to meet applicable regulatory requirements. ANSI Z49.1 should be considered when developing the safety program.

¹ AWS standards are published by the American Welding Society, 550 N.W. LeJeune Road. Miami, FL 33126.

Table 1
Classification of Steels for Resistance Spot Welding and Testing Purposes^a

Group	Min. Tensile Strength	Typical Products (YS/TS)
1	<350 MPa	Mild 140YS/270TS, BH 180YS/300TS BH 210YS/320TS, BH 240YS/340TS
2	350 MPa–500 MPa	BH 260YS/370TS, HSLA 280YS/350TS HSLA 350YS/450TS, DP 300YS/500TS
3	>500 MPa–800 MPa	DP 350YS/600TS, TRIP 350YS/600TS DP 500YS/800TS, TRIP 500YS/800TS CP 700YS/800TS
4	>800 MPa	DP 700YS/1000TS, Mart 950YS/1200TS Mart 1150YS/1400TS, Mart 1250YS/1520TS

^a BH: Bake Hardenable; HSLA: High Strength Low Alloy; DP: Dual Phase; TRIP: Transformation-Induced Plasticity; CP: Complex Phase; YS: Yield Strength; TS: Tensile Strength

Note: Steels with a minimum tensile strength above 500 MPa (Groups 3 and 4) are generally considered Advanced High Strength Steels (AHSS).

Source: Adapted from AWS D8.1M:2007, *Specification for Automotive Weld Quality-Resistance Spot Welding of Steel*, Table 1, American Welding Society from World Steel Association, *Advanced High Strength Steel (AHSS) Application Guidelines*, September 2006.

2. Normative References

The standard listed below contains provisions, which, through reference in this text, constitute mandatory provisions of this AWS standard. For undated references, the latest edition of the referenced standard shall apply. For dated references, subsequent amendments to, or revisions of, any of these publications do not apply.

AWS A3.0M/A3.0, *Standard Welding Terms and Definitions, Including Terms for Adhesive Bonding, Brazing, Soldering, Thermal Cutting, and Thermal Spraying*.

3. Terms and Definitions

AWS A3.0M/A3.0, *Standard Welding Terms and Definitions, Including Terms for Adhesive Bonding, Brazing, Soldering, Thermal Cutting, and Thermal Spraying*, provides the basis for terms and definitions used herein. However, the following terms and definitions are included below to accommodate usage specific to this document:

anchor weld. The first of two welds made on a peel-test sample.

average weld size. The mean of all weld sizes (peel sample test welds) determined at a given checkpoint.

button. See **weld button**.

checkpoint. The location in the test sequence where specific weld-size or weld-size/fracture mode criteria are determined.

composite tip imprint. A carbon-paper impression produced on a piece of white paper showing the combined contact pattern of the top and bottom electrode faces when the electrodes are brought into direct (without the presence of any test coupon) contact with each other under full welding force.

coupon. A single, small piece of test material with specified dimensions used to make up test samples.

cross tension test. A destructive test to measure spot weld strength and weld size with the test weld in the plane perpendicular (direct tension) to the applied load.

cross tension test coupon. A coupon, cut from a coupon strip (see Figure 3A) in accordance with Table 3 with its length parallel to the direction of rolling, used to make up a cross tension test sample.

cross tension test sample. A lap joint test sample, composed of two cross tension test coupons having a specified overlap and standard size, used to determine the direct tension strength of the test weld and its fracture mode.

current. The effective (RMS) welding current of a spot weld measured at the secondary side of the welding transformer and is calculated by an integrating current meter.

current break-through test. A test to determine the time, in number of half cycles of input frequency, required to achieve 90% of the mean, effective welding current for overcoming any surface condition.

current break-through time (CBTT). The total number of half-cycles (at 60 Hz) of a weld not achieving or exceeding 90% of the mean (effective) welding current.

current level. The current required to produce a specific weld size or expulsion criteria in one or more spot welds.

current range. The difference in welding current between the I_{MIN} and I_{MAX} currents.

current setting. The programmed welding current (in kA) of an electronic spot weld controller capable of constant current control or the % heat or % current setting used to set the welding current on some constant-voltage-type welding controllers.

dressed electrode face diameter. The mean diameter of the electrode surface (the portion which contacts the sheet surface) after the electrode faces are paralleled and adjusted (dressed) to size. This dimension is measured directly or is calculated by subtracting the tip-imprint correction factor (CF) from the individual tip imprint diameters.

effective (RMS) welding current. The integrated current (amperage) of a weld is equivalent in its heating or power capability to pure DC (direct current).

electrode face diameter. The mean diameter of the electrode surface (which contacts the sheet surface) before the electrode is dressed. This dimension is the as-ordered or as-machined diameter measured prior to electrode installation and dressing.

electrode face diameter weld size (FDWS). The mean diameter of a weld button is equal to the *specified* dressed electrode face diameter (see Tables 4a, 4b, and 4c) of the electrodes being used.

electrode sticking criterion. The condition at which severe sticking between the electrode and the peel-test sample is noted and when applying pressure with a finger at the farthest end of the stuck sample results in permanent deformation (bending) of the peel-test sample before breaking free from the electrode.

endurance limit. The total number of acceptable welds made during the endurance test. This number does not include welds made during the weld-size stabilization procedure or welds made as part of the initial I_{MIN} and I_{MAX} determinations.

endurance limit criteria. The conditions being met to establish the endurance limit of endurance tests. These criteria may be set by the client for whom the testing is performed and may be more stringent than the endurance test termination criterion of this document.

endurance test. A test procedure for determining initial current levels and range (before endurance/electrode life testing), the endurance limit or electrode life, and final current levels and range (after endurance/electrode life testing) of the test material.

expulsion. The ejection of molten metal from the faying interface (interface between the two test coupons) of the sample. Expulsion may be verified by destructive peel testing of the sample and observing whether metal “whiskers” or “fingers” are evident at the interface.

four-coupon stack-up. A peel-test sample composed of four peel-test coupons. This stack-up applies only to single-weld peel-test samples in the current break-through test.

fracture or pullout mode. The appearance of the weld after peel testing. See Annex D.

fused region. The area of the nugget at the faying surface. The fused region may result in button pull, partial thickness fracture, interfacial fracture, or combinations thereof. See Annex D.

fused region diameter (FD). The diameter of the nugget fused region. See Figure 13.

hold-time sensitivity (HTS) panel coupon. A coupon, cut in accordance with Table 3, used to make up a HTS panel sample. The rolling direction is as noted in Table 3.

hold-time sensitivity (HTS) panel sample. A stack-up of two HTS panel coupons used for making test welds in the HTS test.

hold-time sensitivity (HTS) test. A test which determines the behavior or properties of spot welds made to test samples under different rates of weld cooling.

I_{CBT} current. The current producing a weld size on a single-weld peel-test sample that is closest to (but does not exceed) the electrode-face diameter without causing expulsion.

I_{EFF} current. The same as **current**.

I_{FDWS} current. The lowest current producing weld sizes which meet the electrode face diameter (FDWS) weld size criterion and the fracture mode criterion.

I_{MAX} current. The lowest current (from a peel sample’s test weld) meeting either the I_{MAX} expulsion criterion or the I_{MAX} electrode sticking criterion. The current measured for the second weld (test weld) of the appropriate peel-test sample is the I_{MAX} current.

I_{MAX} electrode sticking criterion. The presence of severe electrode sticking on both anchor and test welds.

I_{MAX} expulsion criterion. The presence of interfacial expulsion on both anchor and test welds.

I_{MIN} current. The lowest current producing weld sizes which meet the minimum weld size (MWS) criterion and the fracture mode criterion. The current measured for the test weld of any sample is used when determining the I_{MIN} current. The I_{MIN} current is the mean of the test weld currents for the three peel samples that meet the I_{MIN} criteria.

I_{MWS} current. The lowest current producing weld sizes which meet the minimum weld size diameter (MWS) and the fracture mode criterion. This term only applies to 11.5.

I_{OP} current. The fixed welding current (which is set as close as possible to 200 A below $I_{MAX.}$) at which the endurance test is run.

individual tip imprint. A carbon-paper impression produced under full welding force on a piece of white paper showing the individual contact pattern of each electrode face (top and bottom electrodes) separately.

microhardness/metallographic sample. A test sample (taken from one of the HTS panels) which is sectioned across the centerline of the weld (perpendicular or parallel to the length of the sample from which it is extracted), mounted, polished, and etched for metallographic examination and microhardness testing.

material characterization panel (MCP). A steel panel (see Figure 4 for dimension and marking details) used in determining sheet thickness, coating weight, coating composition, and substrate composition. Mechanical properties and surface roughness may also be determined from this panel if so desired.

minimum weld size (MWS). The smallest allowable weld size.

panel sample. A stack-up of two panel coupons used for making rows of welds during the endurance test.

peel test. A destructive test for determining a spot weld's pullout mode and weld and/or button size. The test involves mechanically separating the lap joint by peeling.

peel-test coupon. A coupon, cut from a coupon strip (see Figure 3A) in accordance with Table 2 with its length parallel to the direction of rolling, used to make up a peel-test sample.

peel-test sample. A lap-joint test sample composed of two peel-test coupons having a specified overlap and standard size, which is used to determine the weld button size and fracture mode of a resistance spot weld. See Table 5 and Figure 5 for details.

percent (%) current. The designation for the weld control used to set the welding current on some constant-voltage welding controllers by means of controlling the output RMS voltage of the weld control.

percent (%) heat. The designation for the weld control used to set the welding current on some constant-voltage welding controllers by means of controlling the output RMS voltage of the weld control.

rolling direction (RD) mark. A mark made prior to coil-edge removal along the coil edge of a steel sheet, as shown in Figure 1, which identifies the rolling direction. See also **transferred rolling direction (RD) mark**.

secondary edge. The edge of peel coupon strips or the material characterization panel perpendicular to the rolling direction. See Figure 2.

shear tension test. A destructive test to measure spot weld strength and button size with the test weld in the same plane (shear orientation) as the applied load.

shear tension test coupon. A coupon, cut from a coupon strip (see Figure 3A) in accordance with Table 3 with its length parallel to the direction of rolling, used to make up a shear tension test sample.

shear tension test sample. A lap-joint test sample composed of two shear-test coupons having a specified overlap and standard size, which is used to determine the shear strength of the test weld and its fracture mode.

single-weld peel-test sample. A peel-test sample (two- and four-coupon stack-up). With a single weld used for the current break-through test.

stabilization weld size (SWS). The stabilization weld size, used during the electrode-face and weld-size stabilization procedure, is calculated by using the following formula:

$$SWS = 0.9 \times \text{target dressed face diameter (listed in Table 4). SWS is rounded to the closest 0.1 mm.}$$

tensile strength. In this document, tensile strength means ultimate tensile strength.

test weld. A weld made on any sample used to determine weld size, weld strength, button fracture mode, or in combination.

tip imprint correction factor (CF). The average difference between the individual tip imprint diameters from the paper imprints and the actual electrode face diameters of the top and bottom electrodes before dressing.

tip imprint diameter. The mean of the maximum and minimum diameters of composite or individual tip imprints.

top surface. For sheets with nominally equal coating weight on both sides, the top surface is the surface facing up (toward the viewer) in a stack of sheets. For differentially coated sheets this is the side having the heavier coating weight. *NOTE: If the heavier side of differentially coated sheets is not known or coded, preliminary coating weight analyses shall be performed as per 5.3 before proceeding with any marking and shearing operations.*

top surface identification (ID) mark. A mark, used to indicate the top surface of an untrimmed sheet, which is sufficiently long to be visible on the trimmed sheet.

transferred rolling direction (RD) mark. An RD mark transferred to all coupon strips and the material characterization panel in subsequent shearing operations. Individual coupons do not need to be marked with an RD mark.

transferred top surface identification (ID) mark. A mark placed along the secondary edge of the top surface of peel coupon strips (Figure 3A), panel coupon strips (Figure 3B), or the material characterization panel (Figure 4).

two-coupon stack-up. A test sample composed of two test coupons. The stack-up applies to both standard and single-weld peel-test samples; HTS panel samples, endurance test panel samples, shear tension samples, and cross tension samples.

weld button. The part of a spot weld which tears out during destructive testing of welded samples. It may include all or part of the nugget, the heat-affected zone (HAZ) and base metal. A hole is left in the mating sheet(s).

weld button size. The average of the minor and major dimensions of the weld button.

weld property test. A test procedure which determines current levels and current range, hold time sensitivity, mechanical weld properties (shear tension strength, cross tension strength, and microhardness), and weld nugget structure of the test material.

welding rate. The frequency, expressed in welds per minute, at which welds are made on the panel samples.

weld size. The average of the maximum and minimum dimensions of the fused region in destructive inspection or the nugget width in metallographic inspection.

4. Sample Preparation

4.1 Coupon Sizes

4.1.1 Peel-Test And Endurance Test Panel Coupons. See Table 2.

4.1.2 Hold-Time Sensitivity (HTS) Panels, Shear Tension Coupons, and Cross Tension Coupons. See Table 3.

4.1.3 Material Characterization Panel (MCP). The material characterization panel shall be 250 mm in the rolling direction by full coil width minus 100 mm from each edge.

4.2 Total Sheet Quantity Requirements. Total sheet quantity requirements for the endurance test and weld property tests are as follows:

4.2.1 Endurance Test. The required estimated area for each test replication of the Endurance Test (EA/R) shall be calculated using the following formula and the areas given in Table 2 or Table C.1:

$$\text{EA/R} = \text{Area 1} + \text{Area 2} + (\text{Area 3} \times \text{the expected number of endurance welds})$$

The total area required shall be calculated by multiplying the EA/R by the number of replicates (minimum of two) times a scrap loss factor (estimate includes MCP and trimmed edges) as shown by the following formula:

$$\text{Total Area For Endurance Tests} = \text{Number of Replicates} \times \text{EA/R} \times 1.3$$

Table 2
Coupon Dimensions and Estimated Material Requirements (Endurance Test)

Sheet Thickness (mm)	Peel-Test Coupons		Endurance Test Panel Coupons		Estimated Area Requirements/Replication ^g		
	Length ^{a,b} (mm)	Width ^b (mm)	Length ^c (mm)	Minimum Width ^d (mm)	Area 1 Stabilization Procedure (m ²) ^f	Area 2 I _{MIN} /I _{MAX} Tests (m ²) ^f	Area 3 ^{d,e} Endurance Test (m ² /weld) ^f
0.60–0.69	100	30	320	52	0.633	0.600	0.000982
0.70–0.89	100	30	340	55	0.674	0.600	0.001085
0.90–1.29	120	40	400	64	0.992	0.960	0.001520
1.30–1.69	140	50	460	73	1.372	1.400	0.002029
1.70–2.09	140	50	520	82	1.553	1.400	0.002482
2.10–3.00	140	50	580	91	1.756	1.400	0.002989

^a Rolling direction is parallel to this dimension.

^b Tolerance: ±1 mm.

^c Tolerance: ±5 mm; any rolling direction is acceptable.

^d Width may be increased to ease handling. If panel width is increased, a new m²/weld coefficient (Area 3) has to be calculated for the new width.

^e Coefficient for dimensions shown. Area 3 multiplier for the optional panels is listed in Table C.1 of Annex C.

^f 1 m² = 10.764 ft².

^g Total estimated material requirements (area) per replication = 1.3 × [Area 1 + Area 2 + (Area 3 × Expected No. of Endurance Welds)]. For example, for a 0.8 mm thick sheet with an expected endurance limit of 5000 welds:

Total Required Area Per Replication = 1.3 [0.674 m² + 0.600 m² + (0.001085 m²/weld × 5000 welds)] = 8.71 m² or ~94 square feet. See 4.2 for complete instructions.

Table 3
Coupon Dimensions and Estimated Material Requirements (Weld Property Tests)

Sheet Thickness (mm)	Hold-Time Sensitivity (HTS) Panel Coupons		Shear Tension Coupons		Cross Tension Coupons		Estimated Required Area 4/ Replication (m ²) ^{g,h}
	Length ^{a,b} (mm)	Width ^b (mm)	Length ^{a,c} (mm)	Width ^d (mm)	Length ^{a,e} (mm)	Width ^f (mm)	
0.60–1.29	140	350	105	45	150	50	3.0
1.30–3.00	140	350	138	60	150	50	3.5

^a Rolling direction is parallel to this dimension.

^b Tolerance: ±2 mm.

^c May be increased to accommodate gripping fixtures.

^d Tolerance: ±1.0 mm.

^e Tolerance: +0, –0.5 mm.

^f Tolerance: +0, –1.0 mm.

^g Total material requirement (area) for weld property tests per replication. Area 4 includes estimated requirements for electrode stabilization procedure, I_{MIN}/I_{MAX} tests, and all other weld property tests.

^h 1 m² = 10.764 ft².

Approximately 100 peel-test coupons and 6 to 20 standard panel coupons are required for the weld size stabilization procedure. Approximately 200 peel-test coupons are required for the I_{MIN} and I_{MAX} current determinations in the endurance procedure. Approximately 50 peel-test coupons and 50 standard panel coupons are required for every 1000 welds made during the endurance test. When using the optional panels, approximately 20 optional panel coupons (see Annex C) are required per 1200 welds.

4.2.2 Weld Property Tests. The required estimated area for each test replication of the Weld Property Tests (WPA/R) shall be determined using the appropriate Area 4 given in Table 3.

WPA/R = Estimated Area 4 (from Table 3)

The total area required shall be calculated by multiplying the WPA/R by the number of replicates times a scrap loss factor (estimate includes MCP and trimmed edges) as shown by the following formula:

Total Area For Weld Property Tests = Number of Replicates $\times$ WPA/R $\times$ 1.3

Approximately 100 peel-test coupons and 6 to 20 conditioning panel coupons are required for the weld size stabilization procedure. Approximately 100 peel-test coupons are required for the I_{MIN} and I_{MAX} current determinations.

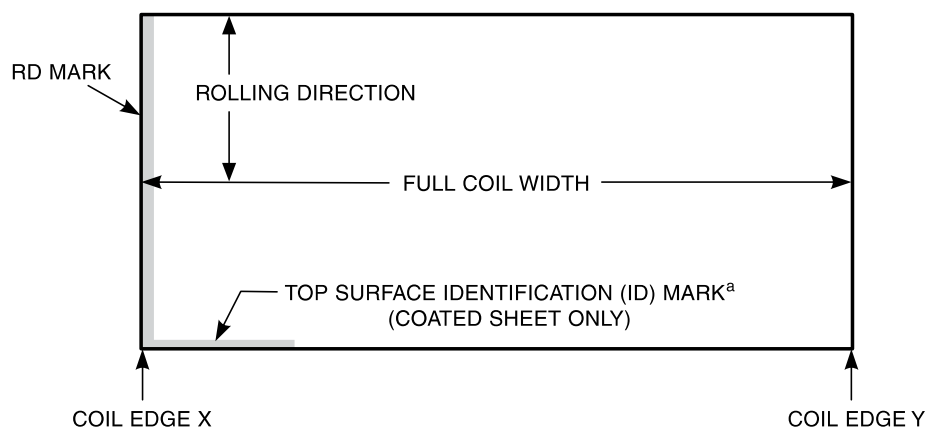
4.3 Rolling Direction (RD) Orientation. The rolling direction is shown in Tables 2 and 3.

4.4 Shearing Details. The test material shall be sheared so that the transferred top surface identification (ID) mark appears *on all strips, panels, and coupons of coated sheet steels*. Uncoated materials do not require this surface ID mark. The transferred rolling direction mark is only required on all coupon strips prior to coupon shearing and on the material characterization panel. Individual test or panel coupons do not require an RD mark.

4.4.1 Sheet Surface and Rolling Direction Identification. All sheets shall be labeled with marks that identify the top surface (see Clause 3 for definition) and the rolling direction (RD) prior to performing any shearing (see Figure 1). These marks shall be transferred to strips and coupons (as required) in subsequent shearing operations.

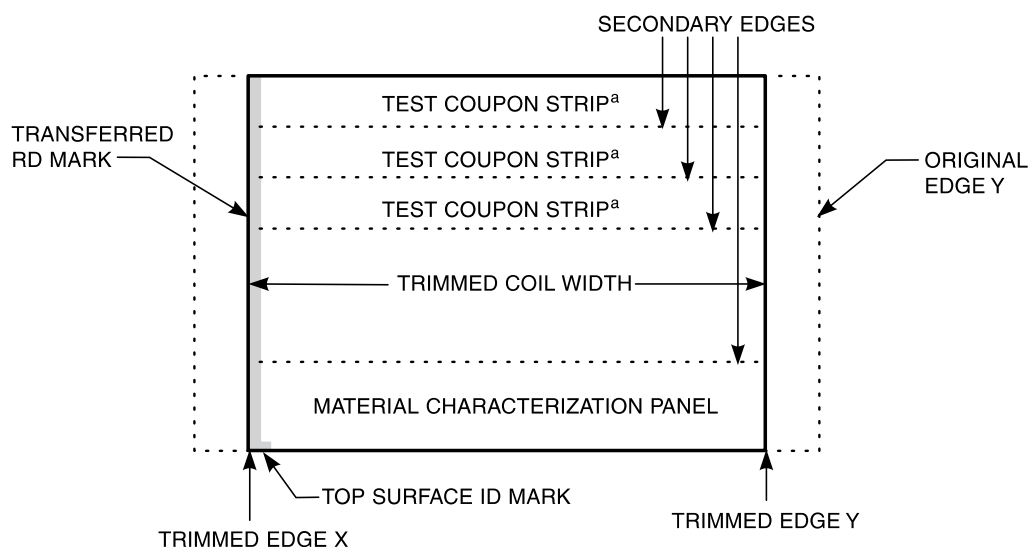
4.4.2 Coil Edge Removal. To eliminate any potential effects of edge coating weight and sheet thickness variations on test results, 100 mm $\pm$ 5 mm from each sheet's coil edges (X and Y) shall be sheared off and scrapped. After trimming Edge X, the RD mark shall be transferred as shown in Figure 2. Figure 2 also shows a typical layout for extracting peel coupon strips and the material characterization panel.

4.4.3 Test and Panel Coupon Shearing. The desired test coupon strips, panel coupon strips, or both shall be sheared from the trimmed sheet. The transferred RD mark shall appear on all such strips to serve as a reference for transferring



^aMake this mark long enough so that it is not lost after coil edge trimming.

Figure 1—Surface and Rolling Direction Marking of Sheet



^aFor HTS panel, peel, shear tension, and cross tension coupons.

Figure 2—Trimmed Coil Width with Transferred RD Mark on Sheet

the top surface ID mark to the secondary edge of test coupon strips of coated sheet. Using the RD mark as a reference, the top surface ID mark shall be transferred to the secondary edge of each coupon strip of coated sheet, as shown in Figures 3A and 3B. Unmarked coupons (test or panel) of coated sheet shall be discarded. All test coupons, except panel coupons for the endurance test, shall be sheared so that they have the proper rolling direction orientation (see Tables 2 and 3). Because panel coupons for the endurance test are not required to have a specific rolling direction orientation, their top surface ID mark may be located on either their short edges (width) or long edges (length) as shown in Figure 3B.

4.4.4 Material Characterization Panel Shearing. One Material Characterization Panel (MCP) shall be sheared from any trimmed sheet as illustrated in the Figure 2 example. If sheared correctly, the transferred RD mark will appear on the trimmed X edge. On coated sheet, the transferred top surface ID mark shall be marked on the secondary edge of the panel. The transferred RD mark should be used as a reference, as shown in Figure 4. Marks shall also be made at the 1/4, 3/8, center, 5/8, and 3/4 points of the panel width (trimmed coil width). Samples to be extracted from this panel require these location markings for sampling at the specified locations. Unmarked samples shall be discarded.

4.5 Surface Preparation. Samples shall be wiped with a clean rag to evenly distribute any mill oils present and to remove surface contaminants such as dirt, grease, etc. Cleaning with a solvent of any kind shall be prohibited. The purpose of wiping is not intended to remove mill oils but to redistribute them evenly. Any oil or dirt picked up during shearing operations shall be removed by lightly wiping the samples before using them. Samples with surface deposits, contamination, etc. that cannot be removed by light wiping shall be discarded.

5. Material Characterization

All samples for material characterization shall be cut from the Material Characterization Panel (MCP), being certain to keep surface, rolling direction, and location marks or codes on all samples and scrap pieces (for possible retests). For tests other than official material qualification tests, all of the material characteristics listed in Clause 5 should be determined and recorded. For official material qualification tests, all items in Clause 5 that are specified by the party for whom the tests are to be performed shall be determined and recorded on the Test Material Data Sheet (Form B-3) or a similar form.

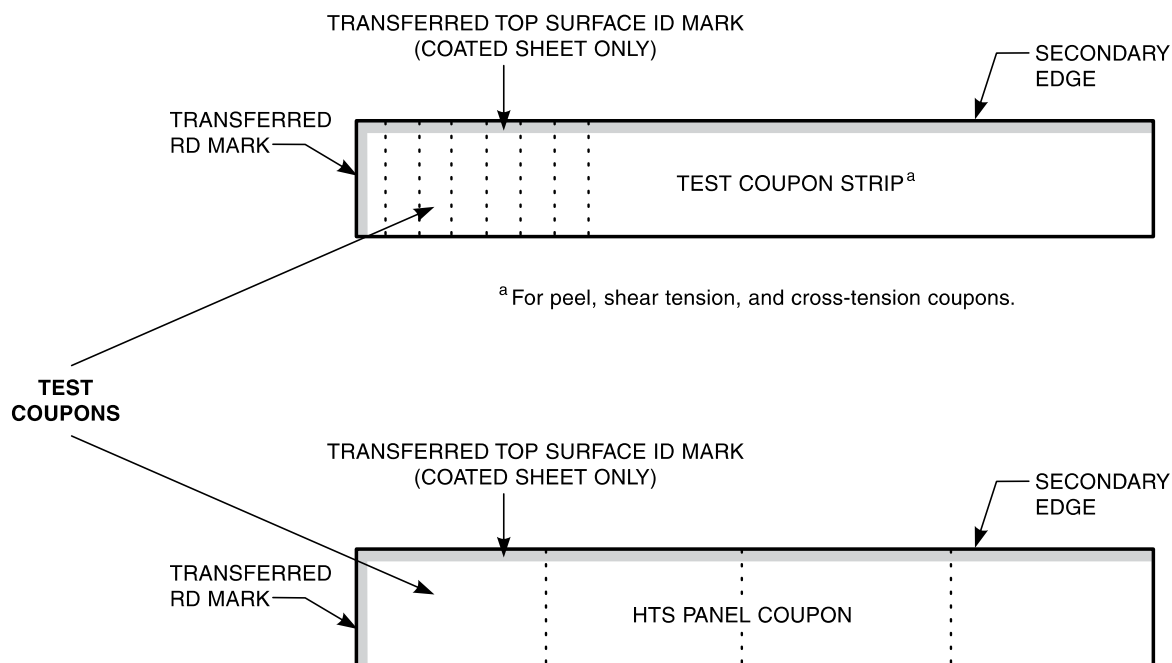


Figure 3A—Test Coupon Strips with Transferred Marks

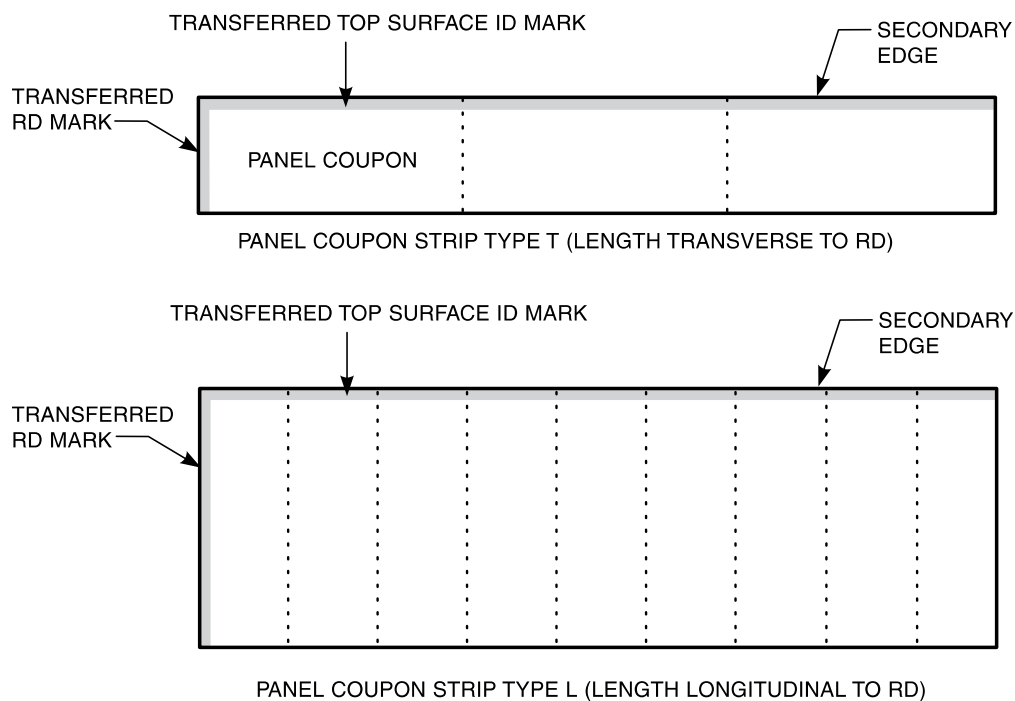


Figure 3B—Endurance Test Panel Coupon Strips with Transferred Marks

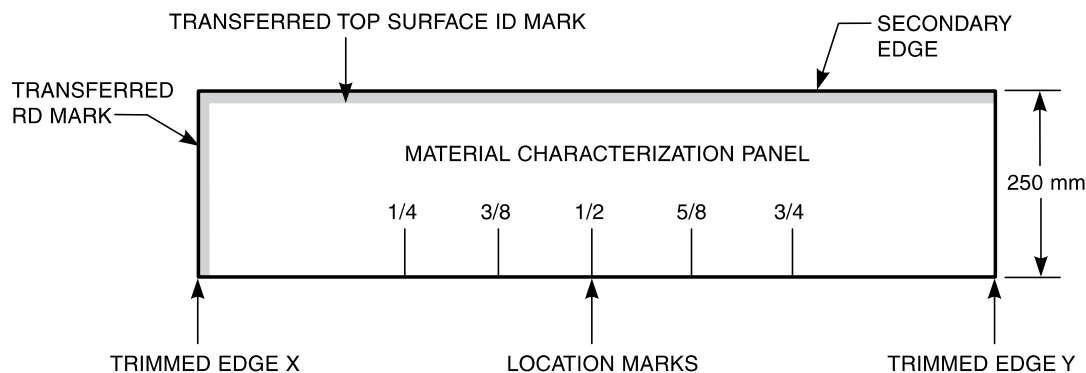


Figure 4—Material Characterization Panel with Transferred Marks

5.1 Sheet Identification. The following information or data about the test material shall be obtained and recorded.

- (1) Coil identification number or code
- (2) Substrate grade and material specification (if applicable)
- (3) Coating type and weight grade (nominal weight designation)
- (4) Surface lubricants, post-coating treatments, or both
- (5) Measured full sheet width before edge trimming and trimmed sheet width

5.2 Sheet Thickness. Before extracting any samples from the MCP, the sheet thickness shall be measured at five positions of the panel width (trimmed edge X, 1/4 point, center, 3/4 point, and trimmed edge Y) to the nearest 0.01 mm. The average of the five readings shall be calculated and rounded to the closest 0.01 mm. All data shall be recorded on the Test Material Data Sheet (Form B-3) or a similar form. The mean thickness shall also be recorded on the Welding Data Sheet (Form B-1) or a similar form.

5.3 Coating Weight. Coating weight shall be determined at the locations of the MCP listed below for each surface (top [marked side] and bottom) of the sheet by means of any accepted standard method [such as ASTM A 90 (weigh, strip, weigh), ASTM A 754 (X-ray fluorescence), etc.]. The test method that is used shall be recorded on the Test Material Data Sheet (Form B-3) or a similar form.

- (1) Trimmed edge “X” (Duplicate measurements from each surface)
- (2) Trimmed edge “Y” (Duplicate measurements from each surface)
- (3) Center of coil width (Duplicate measurements from each surface)

5.4 Coating Composition. Coating composition shall be determined for each surface (top [marked side] and bottom) of the MCP. Samples are to be taken between the 1/4 and 3/4 points of the coil width.

(1) Hot Dip Zn (Galvanized) and Hot Dip ZnFe (Galvannealed)

Elements: Zn, Al, Fe, Pb, Sb Location: between 1/4 and 3/4 points

(2) Electrolytic Zn (Electrogalvanized)

Elements: Zn, Fe Location: between 1/4 and 3/4 points

(3) Electrolytic ZnNi

Elements: Zn, Ni, Fe Location: between 1/4 and 3/4 points

(4) Electrolytic ZnFe

Elements: Zn, Fe Location: between 1/4 and 3/4 points

5.5 Substrate Composition. Substrate composition samples may be taken from any location on the Material Characterization Panel. Analysis shall include all elements relevant to the grade of steels being tested. This should include (but is not to be limited to) elements such as C, S, P, B, Al, Si, Mn, Cb, Ti, V, etc., that influence hardness, hardenability, and carbide stability at high temperatures.

5.6 Mechanical Properties (if required). Longitudinal tensile samples shall be taken at the center point of the Material Characterization Panel. Properties typically determined are yield strength, ultimate tensile strength, percent elongation, N value, and R value. All testing shall be performed per ASTM standards, and the ASTM number of the standard shall be reported on the Test Material Data Sheet (Form B-3) or a similar form.

5.7 Surface Roughness (if required). Surface roughness of each sheet surface (top and bottom) shall be determined per standard procedures such as ANSI B46.1, SAE J911, etc.

6. Welding Parameters

6.1 Electrode Specifications and Dimensions. See Annex A.

6.2 Welding Variables

6.2.1 Electrode Size and Dressed Face Diameter. The electrodes specified in Tables 4a, 4b, and 4c for the thickness of sheet being welded shall be used. A tolerance of ± 0.1 mm from the specified dressed face diameter shall be maintained.

6.2.2 Squeeze Time. The squeeze time shall be adjusted as needed to ensure that the force is at $\geq 98\%$ of static force value at initiation of welding current (target is 100% of static force). *NOTE: The squeeze time setting required to achieve this will vary with machines; 45 cycles–90 cycles are typical.*

6.2.3 Electrode Force. The force shall be adjusted to the specified values in Tables 4a, 4b, and 4c for the thickness of sheet being welded. Electrode force tolerance is $\pm 2\%$ of the value listed in Tables 4a, 4b, and 4c.

6.2.4 Weld Time. Weld time shall be adjusted to the specified values in Tables 4a, 4b, and 4c for the thickness of sheet being welded. Weld time (and other programmed times) is in number of cycles at a line frequency of 60 Hz.

Table 4a
Welding Parameters for Groups 1 and 2 Steels^a

Sheet Thickness (mm)	Electrode				Weld Time ^d (cy)	Short Hold Time ^e (cy)	Long Hold Time ^e (cy)	Welding Rate ^f (w/min.)
	Type No. ^b	Dressed Face Diameter (mm)	Force (kN) ^c	Cooling (l/min.)				
0.60–0.69	1	4.5	1.6	4	10	5	90	25
0.70–0.79	2	5	2.0	4	11	5	90	25
0.80–0.89	2	5	2.2	4	12	5	90	25
0.90–1.09	3	6	2.8	4	13	5	90	20
1.10–1.29	3	6	3.1	4	14	5	90	20
1.30–1.49	4	7	3.8	6	16	10	90	15
1.50–1.69	4	7	4.2	6	18	10	90	15
1.70–1.89	5	8	5.0	6	20	10	90	15
1.90–2.09	5	8	5.5	6	22	10	90	15
2.10–2.49	6	9	6.4	6	15-2-15	10	90	15
2.50–3.00	6	9	7.0	6	20-2-20	10	90	15

^a For tolerances and other details, see 6.2.1 through 6.3.

^b See Annex A for electrode details.

^c 1 kN = 224.8 lbf.

^d A weld time of x-y-x, x-y-x-y-x, and x-y-x-y-x-y-x refer to x cycles of weld time separated by y cycles of cool time.

^e See 6.2.6.

^f Applies to conditioning panel welds of all tests and panel welds of the Endurance Test.

Table 4b
Welding Parameters for Group 3 Steels^a

Sheet Thickness (mm)	Electrode				Weld Time ^d (cy)	Short Hold Time ^e (cy)	Long Hold Time ^e (cy)	Welding Rate ^f (w/min.)
	Type No. ^b	Dressed Face Diameter (mm)	Force (kN) ^c	Cooling (l/min.)				
0.60–0.69	1	4.5	1.8	4	12	5	90	25
0.70–0.79	2	5	2.3	4	13	5	90	25
0.80–0.89	2	5	2.5	4	14	5	90	25
0.90–1.09	3	6	3.2	4	15	5	90	20
1.10–1.29	3	6	3.6	4	16	5	90	20
1.30–1.49	4	7	4.4	6	10-2-10	10	90	15
1.50–1.69	4	7	4.8	6	12-2-12	10	90	15
1.70–1.89	5	8	5.8	6	9-2-9-2-9	10	90	15
1.90–2.09	5	8	6.3	6	10-2-10-2-10	10	90	15
2.10–2.49	6	9	7.4	6	9-2-9-2-9-2-9	10	90	15
2.50–3.00	6	9	8.1	6	10-2-10-2-10-2-10	10	90	15

^a For tolerances and other details, see 6.2.1 through 6.3.^b See Annex A for electrode details.^c 1 kN = 224.8 lbf.^d A weld time of x-y-x, x-y-x-y-x, and x-y-x-y-x-y-x refer to x cycles of weld time separated by y cycles of cool time.^e See 6.2.6.^f Applies to conditioning panel welds of all tests and panel welds of the Endurance Test.

Table 4c
Welding Parameters for Group 4 Steels^a

Sheet Thickness (mm)	Electrode				Weld Time ^d (cy)	Short Hold Time ^e (cy)	Long Hold Time ^e (cy)	Welding Rate ^f (w/min.)
	Type No. ^b	Dressed Face Diameter (mm)	Force (kN) ^c	Cooling (l/min.)				
0.60–0.69	1	4.5	2.1	4	12	5	90	25
0.70–0.79	2	5	2.6	4	13	5	90	25
0.80–0.89	2	5	2.9	4	14	5	90	25
0.90–1.09	3	6	3.6	4	15	5	90	20
1.10–1.29	3	6	4.0	4	16	5	90	20
1.30–1.49	4	7	4.9	6	10-2-10	10	90	15
1.50–1.69	4	7	5.5	6	12-2-12	10	90	15
1.70–1.89	5	8	6.5	6	9-2-9-2-9	10	90	15
1.90–2.09	5	8	7.2	6	10-2-10-2-10	10	90	15
2.10–2.49	6	9	8.3	6	9-2-9-2-9-2-9	10	90	15
2.50–3.00	6	9	9.1	6	10-2-10-2-10-2-10	10	90	15

^a For tolerances and other details, see 6.2.1 through 6.3.^b See Annex A for electrode details.^c 1 kN = 224.8 lbf.^d A weld time of x-y-x, x-y-x-y-x, and x-y-x-y-x-y-x refer to x cycles of weld time separated by y cycles of cool time.^e See 6.2.6.^f Applies to conditioning panel welds of all tests and panel welds of the Endurance Test.

6.2.5 Welding Current. Welding current is to be adjusted as needed or as specified. Allowable percent heat or percent current settings on the welding control shall be $\geq 60\%$ and $\leq 92\%$ (change tap settings as needed to stay within this range). See 7.1.3 for details.

6.2.6 Hold Time. Hold time shall be adjusted to the “short” hold time for the endurance test (see Tables 4a, 4b, and 4c) and to the specified hold time (short or long) in the weld property tests. All hold times are programmed times and do not reflect actual contact time.

6.2.7 Off Time. Off time shall be adjusted as needed to meet the specified welding rate.

6.2.8 Welding Rate. The welding rate shall be adjusted to that specified in Tables 4a, 4b, and 4c when making panel welds for electrode conditioning and all panel welds made during the endurance test. The tolerance for the welding rate is ± 1 w/min. The welding rate shall be checked with a stopwatch and weld counter or some other suitable means. Adjustment of the “off time” or other “noncritical” parameters may be made to achieve the proper welding rate.

6.3 Electrode Cooling

6.3.1 Coolant Flow Rate. Coolant flow shall be adjusted to meet the rate specified in Tables 4a, 4b, and 4c at a tolerance of $\pm 5\%$.

6.3.2 Coolant Temperature. Coolant temperature shall be $20^{\circ}\text{C} \pm 5^{\circ}\text{C}$.

6.3.3 Cooling Tubes. Ends are to be cut at a 45° angle and positioned so that the tip contacts the electrode cooling hole face (see 7.11 for additional details).

6.4 Weld Spacing and Overlap. Weld spacing and overlap for all peel-test samples shall be kept at the specified distances listed in Table 5 and Figure 5. Weld spacing for all electrode conditioning welds and the endurance test panel

Table 5
Weld Locations, Spacing, and Overlap Dimensions for Peel-Test Samples

Sheet Thickness (mm)	L ^a (mm)	W ^a (mm)	WS ^b (mm)	A ^b (mm)	B ^b (mm)
0.60–0.89	100	30	30	15	27.5
0.90–1.29	120	40	40	20	30
1.30–3.00	140	50	50	25	32.5

^a Tolerance: ± 1 mm.

^b Tolerance: ± 3 mm.

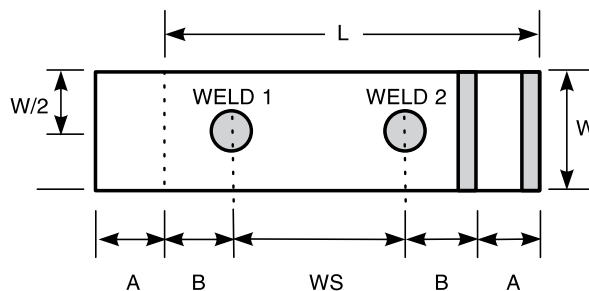


Figure 5—Weld Location, Spacing, and Coupon Overlap for Peel-Test Samples

welds shall be kept as listed in Table 6 and shown in Figure 6. Weld spacing and overlap for the weld property test samples are listed and shown in Clause 10. Spacing is measured from weld center to weld center for all welds.

6.4.1 Peel-Test Samples. The specified weld spacing (WS), listed in Table 5, shall be maintained between the anchor weld (1st weld) and the test weld (2nd weld) on all peel samples (shown in Figure 5).

6.4.2 Endurance Test and Electrode Conditioning Panel Samples. The specified weld spacing and edge distances (listed in Table 6) for the standard panel (shown in Figure 6) shall be maintained on all panel welds. The specified weld spacing and edge distances for the optional panel are listed in Annex C, Table C.1. The panel type used shall be recorded on the Welding Data Sheet using code “S” for the standard panel and “O” for the optional type. If panel welding is performed manually, spacing marks may be **lightly** scribed on the top panel coupon or ink marks may be made at the coupon edges (not at the weld location) to act as weld position locators. Maintaining weld spacing within the allowed tolerances may be difficult without such locators. No ink marks, pencil marks, etc. are allowed where the weld will be made. *NOTE: The only allowable marks over which welds can be made are **light** scribe marks produced with a metallic scribe.*

Table 6
Weld Spacing and Edge Distances for
Endurance Test and Electrode Conditioning Panel Samples

Sheet Thickness (mm)	L ^a (mm)	Minimum W ^b (mm)	WS ^c (mm)	A ^d (mm)	B ^e (mm)
0.60–0.69	320	52	14	19	19
0.70–0.89	340	55	15	20	20
0.90–1.29	400	64	18	23	23
1.30–1.69	460	73	21	26	26
1.70–2.09	520	82	24	29	29
2.10–3.00	580	91	27	32	32

^a $L = (18 \times WS) + 2A + 30$; Tolerance: ± 5 mm.

^b W may be increased to ease handling.

^c $WS = 3 \times$ Dressed electrode-face diameter; Tolerance: ± 3 mm.

^d A = the minimum edge distance; No specific tolerance.

^e Tolerance: ± 3 mm.

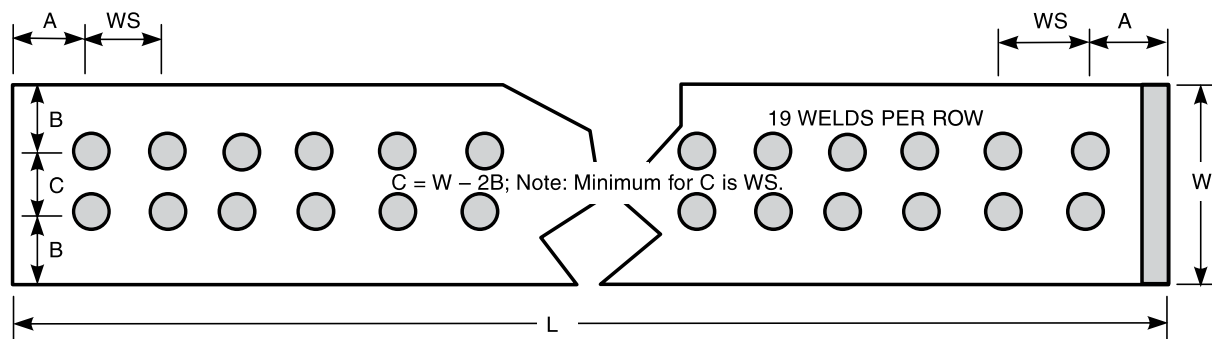


Figure 6—Weld Spacing and Edge Distances for
Endurance Test and Electrode Conditioning Panel Samples

6.5 Sample Orientation and Sequencing

6.5.1 Peel-Test Samples. Peel-test samples are welded in three different orientations (with respect to the throat of the welder) during various segments of the test procedures. These orientations, designated C, L, and R, are shown in Figure 7.

6.5.2 Endurance Test and Electrode Conditioning Panel Samples. The first row of 19 welds on these panel samples shall be made with the panels oriented (with respect to the welding machine) as illustrated in Figure 8A. To make the second row of 19 welds, the panel samples are to be rotated 180° in the horizontal plane to the orientation shown in Figure 8B.

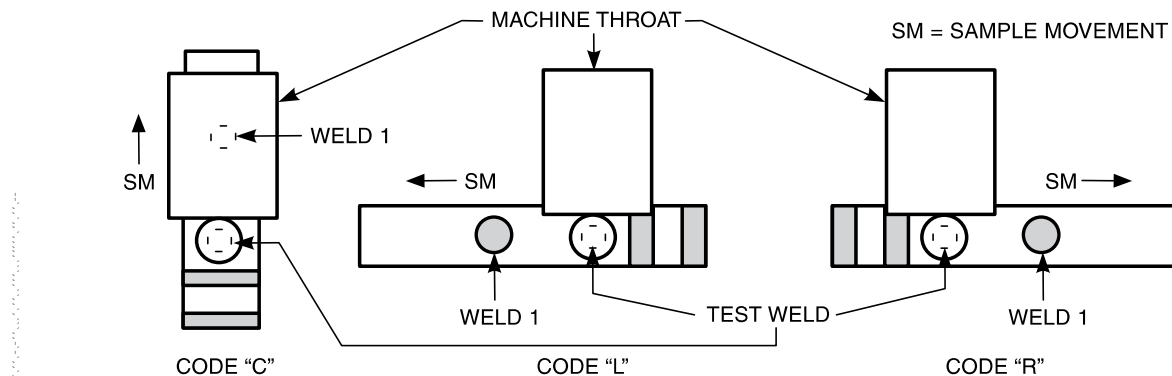


Figure 7—Top View of Peel Sample Orientations with Respect to Welding Machine Throat

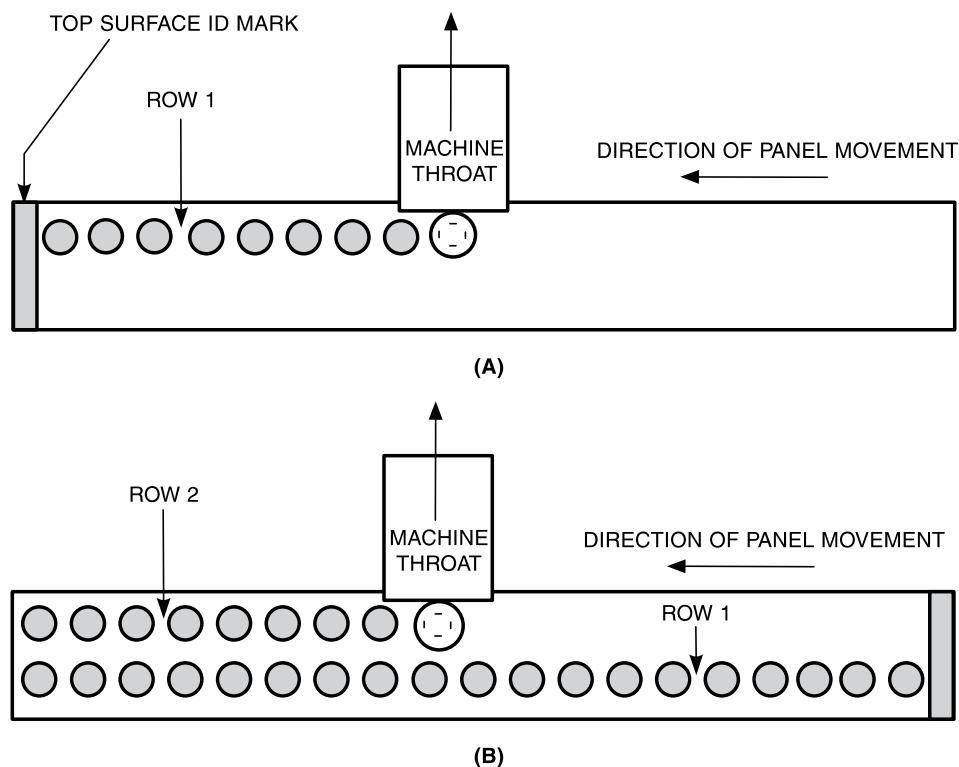


Figure 8—Panel Sample Orientations (A and B) with Respect to the Welding Machine Throat

6.5.3 Endurance Test Panel Sequencing. Panel welds shall be made one row at a time on different, consecutive panels (with a minimum delay time of 10 minutes between rows to prevent panel overheating) until the required number of panel welds (190) per checkpoint interval are completed. These instructions apply to both the standard panel and the optional panel. The 190 panel-weld total allows for a total of 200 welds per endurance test interval when the five peel samples (ten welds) are included.

6.6 Surface Orientation (Coated Sheet Steels Only)

6.6.1 Peel-Test Samples. All peel-test samples shall be configured with the **marked side facing up**, as shown in Figure 9, and nesting the coupons as best as possible to prevent shear burrs on the coupon edges from contacting each other or the coupon surface.

6.6.2 Endurance Test Panel Samples

6.6.2.1 For sheet with nominally equal coating weight per side (e.g., 60G/60G), panel samples shall be welded using the four surface-orientation combinations in the order specified in 1 through 4 below. This sequence shall be repeated on all subsequent panel sets (each group of four panels).

- (1) Top and bottom panel coupons both with the top surface ID mark facing up
- (2) Top and bottom panel coupons both with ID mark facing down
- (3) Top panel coupon with the ID mark facing up, bottom panel coupon with the ID mark facing down
- (4) Top panel coupon with the ID mark facing down, bottom panel coupon with the ID mark facing up

6.6.2.2 For differentially coated sheet (e.g., 60G/20G), panel samples shall be welded by alternating the surface-orientation combinations listed below. The marked side is the side with the heavier coating.

- (1) Top and bottom panel coupons both with the top surface ID mark facing up
- (2) Top and bottom panel coupons both with the top surface ID mark facing down

6.6.3 Weld Property Test Samples. All test samples (HTS panel, shear tension, and cross tension samples) shall be oriented with the marked side facing up, as shown in Figure 10. Overlap and weld spacings (HTS panel samples) are discussed and shown in the appropriate sections of the weld property test (Clause 11).

6.7 Weld Size

6.7.1 Minimum Weld Size (MWS). The minimum weld size is calculated by using the following formula:

$MWS = 4\sqrt{t}$, where t = average sheet thickness in mm, rounded to the closest 0.01 mm, and where MWS is rounded to the closest 0.1 mm. Weld size other than that specified earlier may be acceptable with the consent of the party for whom the testing is performed.

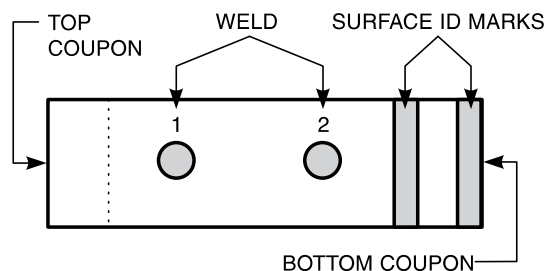


Figure 9—Surface Orientation of Peel-Test Samples

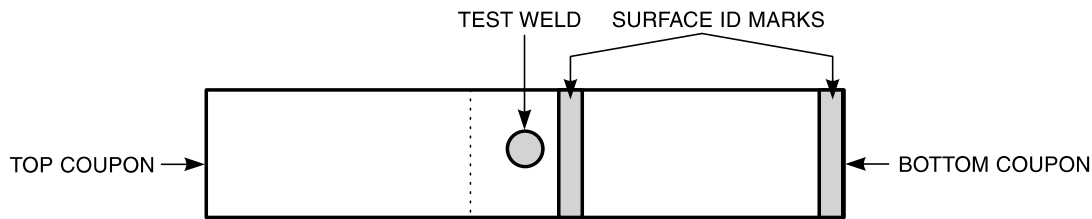


Figure 10—Surface Orientation of Weld Property Test Samples (Shear Tension Shown)

6.7.2 Stabilization Weld Size (SWS). The stabilization weld size is derived by the following formula:

$$\text{SWS} = 0.9 \times \text{specified electrode-face diameter (dressed, listed in Table 4)}$$

SWS is rounded to the closest 0.1 mm and has a target tolerance of ± 0.2 mm.

6.7.3 Face Diameter Weld Size (FDWS). The face diameter weld size is derived by the following formula:

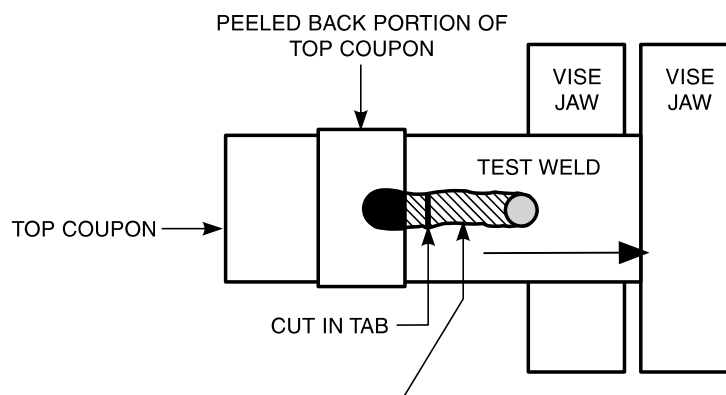
$$\text{FDWS} = \text{the specified electrode-face diameter (dressed, listed in Table 4)}$$

FDWS is rounded to the closest 0.1 mm.

The allowable tolerance for FDWS for sheet thicknesses less than 1.30 mm is ± 0.2 and for sheet thickness greater than or equal to 1.3 mm is ± 0.3 .

6.7.4 Weld Size Measurements. All welds shall be measured across their minimum and maximum axes. In most instances this means measuring only button and partial thickness fractures (i.e., material protruding from one of the previously welded sheets). Interfacial fractures can be included in the measurement only when determined to be part of the nugget. When measuring the dimensions of the fused region (partial or full interfacial fractures), an optical magnification glass or some other suitable instrument may be required to precisely determine the dimensions of the fused region.

6.7.4.1 To make proper measurements on peel-test samples, the tab that is usually pulled out of the base metal connecting the test and anchor welds is to be peeled back at 180° to the original peeling direction. Sometimes this tab remains intact, requiring sawing or shearing to grip it (see Figure 11).



Note: This portion of the tab shall be pried up and peeled back in the direction of the large arrow.

Figure 11—Example of Tab Removal to Allow for Proper Measurement of Weld Buttons

6.7.4.2 For crescent, oval, or other irregularly shaped buttons, button size shall be measured by rotating the knife caliper until $D_{MIN.}$ and $D_{MAX.}$ are located. *NOTE: $D_{MIN.}$ and $D_{MAX.}$ are not necessarily perpendicular to each other. Care has to be taken to ensure that button lips (generally found perpendicular to the direction of peeling) are not included in the measurements.* All measurements shall be as close as possible to the actual button perimeter (see Figure 12A).

6.7.5 Weld Fracture Mode. The fracture mode of each test weld shall be determined per Annex D, Fracture Classification Charts, and recorded for each test sample.

6.7.6 Acceptable Weld Criteria. Both criteria (listed in 6.7.6.1 and 6.7.6.2) shall be met for welds at $I_{MIN.}$ current. Welds at $I_{MAX.}$ current do not have specific acceptance criteria and are characterized only. Welds at I_{MWS} and I_{FDWS} currents are characterized and evaluated against the acceptance criteria of Clause 11.

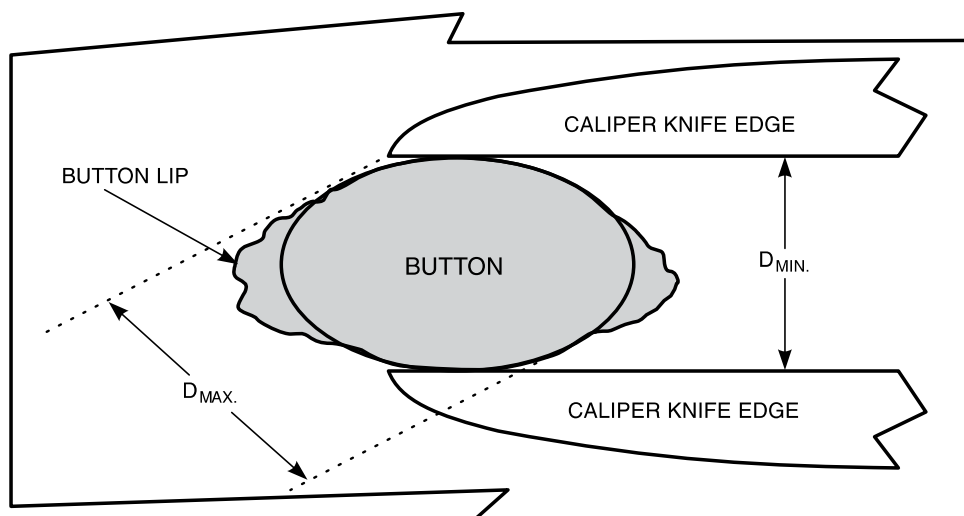


Figure 12A—Technique for Measuring Oval Weld Buttons

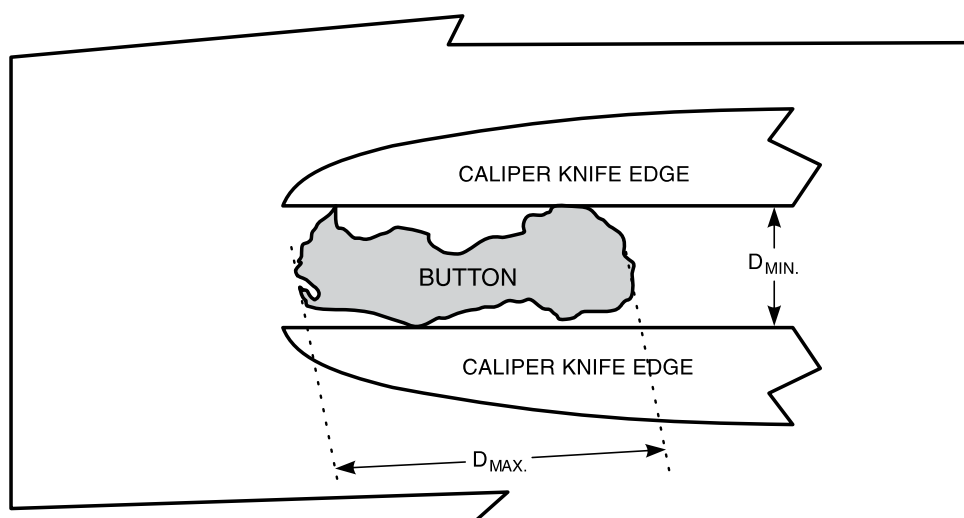


Figure 12B—Technique for Measuring Irregular Weld Buttons

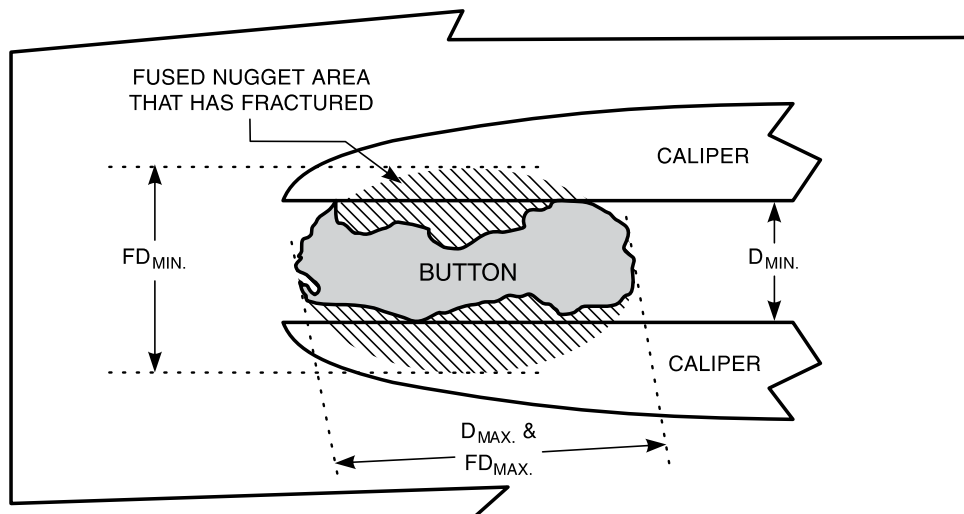


Figure 13—Technique for Measuring the Weld Button and Fused Diameters of Partial Interfacial Fractures

6.7.6.1 Minimum Weld Size. The test weld from the peel-test sample shall meet the minimum size criterion described in 6.7.1 to pass. A minimum acceptable weld size other than that specified in this document may be acceptable with consent of the party for whom the testing is performed.

6.7.6.2 Weld Fracture Mode. Fracture modes 1–6 are acceptable. Fracture mode 7 is only acceptable with customer concurrence and supporting metallographic cross-section evaluation showing fusion. The fused diameter of the test weld from the peel-test sample shall be round or oval.

7. Preferred Test Equipment

This clause lists the preferred test equipment to be used for all welding and testing. If equipment other than the preferred test equipment is used, specific note of this variance shall be made on the Welding Data Sheet and the appropriate test report. Recording of all pertinent test equipment is to be made on the appropriate data sheets or test reports.

7.1 Welding Machine

7.1.1 Type. A single point, single phase, 50/60 Hz, AC, 480/575 VAC (nominal), resistance spot welder with in-line loading and a pneumatic force application system is commonly employed. Notation shall be made on the Welding Data Sheet and all test reports of the type of welder (pedestal, press, or gun) used for the test.

7.1.2 Capacities. The transformer shall be capable of producing the necessary secondary currents at percent heat/percent current settings of 60%–92%, and which produces about a 100 A secondary current increment per each 1% heat/current setting increment. The force system shall be capable of providing the necessary welding forces without excessively harsh electrode impact (head velocity no greater than 80 mm/sec for a 50 kg head weight).

7.1.3 Controls. An AC welding power source equipped with an SCR controller or a medium frequency direct current (MFDC) power source with a microprocessor based controller shall be used. The controller may be setup to be operated in either “constant voltage” (percent heat or current phase shift control) or “constant current” (current programmed in amperes or kA) mode. If using a constant voltage control mode, automatic voltage compensation (AVC) must be used. For the current break-through test only the “constant voltage” mode is permitted. The type of controller operating mode to be used for tests other than current break-through test, is determined by agreement of the parties involved in the tests.

The controller operating mode shall be recorded on the welding data sheet and all test reports. *NOTE: Potentiometer (dial) type controllers shall not be used unless specific agreement of the parties involved in the testing is obtained.*

7.2 Current/Weld-Time Meter. An integrating-type current analyzer that measures effective (RMS) welding current and weld time shall be used. If possible, the current meter shall be calibrated periodically to a traceable standard by the manufacturer or a competent calibration laboratory. The first two half cycles of the weld time should be blanked (not measured).

7.3 Force Gauge. A strain gauge or piezo-electric type force gauge with flat contact faces is required. The instrument shall be calibrated and have a minimum accuracy of $\pm 2\%$ at the specific electrode force to be used.

7.4 Electrode Cooling. Appropriate flow meters, flow control devices, and temperature monitoring or control devices are needed to control/monitor electrode coolant. The machine cooling circuit shall be such that the coolant flowing to the electrodes shall not first flow through any other heat generating sources (e.g., SCRs or transformers). It is preferred that the electrodes are cooled in parallel, rather than in series, with respect to each other.

7.5 Weld Counter. Any electronic or mechanical device capable of sensing and counting each weld is acceptable. However, an electronic counter that senses welding current or some other signal that indicates a weld is made (current is passed) is highly recommended. *NOTE: When a mechanical counter is used, a lockout mechanism shall be used to prevent counting of nonwelds when tip imprints are taken or when the welder is cycled without making a weld.*

7.6 Calipers. A knife-edge caliper calibrated and capable of measuring to 0.01 mm is required for measuring weld button dimensions.

7.7 Tip Dressing File. A parallel, 150 mm long, extra smooth machinists file having a Swiss pattern, #2 cut is required for dressing and paralleling of the electrode faces.

7.8 Tip Dressing Emery Paper. A 400 grit, silicon-carbide, A-weight emery paper may be used for final dressing of the electrode faces.

7.9 Carbon Paper. Premium quality carbon paper that produces sharp, dark electrode imprints shall be used to make all tip imprints.

7.10 Tip Imprint Paper. High quality, smooth, white paper, such as used with laser printers or copiers, shall be used for all tip imprints.

7.11 Electrode Cooling Tubes

7.11.1 Dimensions. All cooling tubes shall have a pointed discharge end with a 45° angle. It is recommended that: (1) for electrode types 1 through 3, nominal cooling tube dimensions of 4.6 mm OD/3.8 mm ID are preferred; and (2) for electrode types 4 and 5, nominal cooling tube dimensions of 6.4 mm OD/4.8 mm ID are preferred. The type (see Annex A) used shall be recorded on the Welding Data Sheet.

7.11.2 Position. It is preferred that the pointed end of the tube be in contact with the back-face (termination of the cooling hole) of the electrode (spring loaded or friction-fit sliding tubes are needed) as shown in Figure 14.

8. Electrode Installation and Dressing Procedure

This electrode installation and dressing procedure, combined with components in Clause 9, Electrode Face and Weld Size Stabilization Procedure, were developed in the early 1990s. The purpose of these combined procedures was to promote repeatability and reproducibility in endurance (electrode life) testing of low strength, light gauge galvanized steels, when employing flat face truncated cone electrodes. Extensive testing revealed that utilization of these detailed procedures significantly reduced test to test variability in endurance test results.

8.1 Electrode Measurements Before Installation and Electrode Installation. The appropriate electrodes shall be selected for the material being tested by consulting Table 4a, 4b, or 4c.

8.1.1 Electrode Measurements Before Installation. Before any measurements during the testing or installation of the welding electrodes (new or remachined/redressed), the electrodes are to be coded T for top and B for bottom in accordance with the information presented in Annex A.

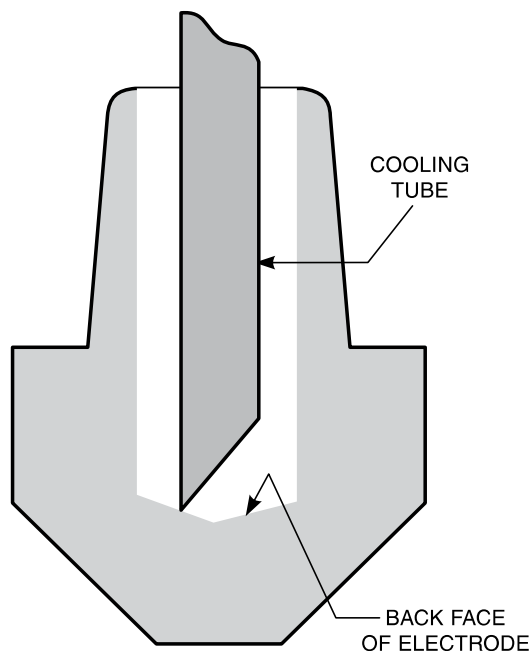


Figure 14—Preferred Position of Cooling Tubes in Electrodes

8.1.1.1 Face Thickness. Both electrodes' face thicknesses shall be measured (see Figure A.1 of Annex A) by any appropriate instrument. All electrodes have to be within ± 0.5 mm of the specified 9.7 mm face thickness otherwise they are to be discarded. The face thicknesses for both electrodes (T and B) are to be recorded on the Welding Data Sheet.

8.1.1.2 Face Diameters. The electrodes' face diameters shall be measured using any appropriate means that will provide accuracy to 0.05 mm and the measurements are to be recorded as instructed in (1) or (2) below. *NOTE: If the edges of the electrode faces are damaged or rounded so as to make accurate initial measurements (before dressing) impossible, option (1) below and 8.3 (not 8.4) must be used because the correction factor cannot be accurately determined.*

(1) If direct measurements of the electrodes are made after dressing(s) or custom-machined electrodes are used, measurements of the face-diameters are recorded in the "Undressed (As machined)" section of Tip Imprint Data Sheet B-2-DOPT1 or similar form.

(2) If electrode face measurements after dressing(s) will be determined by tip imprints, these measurements are coded **T** (for top diameter) and **B** (for bottom diameter), and are recorded in Tip Imprint Data Sheet B-2-DOPT2 or similar form.

8.1.2 Installation Instructions. After the required measurements in 8.1.1 are complete, installation of the electrodes may proceed. Before inserting the electrodes into the adapters/holders, the cooling tubes are to be adjusted to their proper position (see 6.3.3 or 7.11.2). The electrodes are then installed by inserting the electrodes into their adapters and applying adequate force (significantly lower than the target welding force) to seat them temporarily. This action is required to assure that the electrodes are in reasonably good alignment before final seating. When seated, the electrodes shall be checked for alignment.

8.1.2.1 If the electrodes are grossly misaligned, adjustments shall be made to achieve adequate alignment. When alignment has been achieved, the electrodes are to be fully seated by applying a welding force that is slightly greater (5% to 10% greater) than the force specified for the test.

8.1.2.2 If the electrodes are adequately aligned, the electrodes are to be fully seated by applying a welding force that is slightly greater (5% to 10% greater) than the force specified for the test. Final welding force adjustments shall be made later in 8.1.5.

8.1.3 Gap Adjustment. The electrode holders shall be adjusted to provide the appropriate gap between the electrodes (as required by the welding machine being used) or the proper airlock collapse distance (if the welder is so equipped).

8.1.4 Final Electrode Alignment. Final alignment of the electrodes shall be verified by bringing the electrodes together (with low or “tip dressing” force) and checking their alignment with a magnifying glass or some other suitable means. Adjustments are to be made to the electrode holders or other components, as needed, to achieve visual concentricity of the electrode faces.

8.1.5 Setting of the Welding Force. The welding force shall be set to its proper value using an appropriate, calibrated force gauge (see 7.3). If any adjustments to the air pressure are necessary to achieve the desired force, the machine should be cycled several times after each adjustment. The force shall be rechecked after each adjustment. *NOTE: It has to be ascertained that the force being measured is the force just prior to the onset of current flow (weld time initiation) and that this force is not on a steep portion of the force buildup curve (applies to nonairlock systems only). Calibration of the force buildup curve is required for nonairlock systems to determine the amount of squeeze time necessary to reach force stability (near 98% of full static force).* After the final force adjustments are complete, the regulated air pressure setting for the cylinder applying the welding force is to be recorded.

8.2 Custom Machined Electrodes. If the electrode faces have been custom machined to the specified face diameter (within the proper tolerance) and it is known that the faces will be parallel when mounted in the electrode holders, no electrode dressing is required and 8.3.3 follows directly.

8.3 Electrode Dressing Option 1—Using Direct Electrode-Face Measurements. This option applies when electrode faces are directly measured in place or are removed, measured, and reinserted in the exact location in the electrode holder from which they were removed. *NOTE: No tip imprints (individual or composite) are required until successful completion of the final dressing.*

8.3.1 Electrode-Face Paralleling and First Dressing (Sizing)

8.3.1.1 After insertion of the specified dressing file (see 7.7) between the tips, the electrodes are to be brought together with a **very low force** [<20 kgF (55 lbF) to prevent excessive material removal and gouging] so that both electrodes contact the file. *NOTE: An adjustable spacer may be used between the electrode arms to achieve the low force required for dressing.* The file is then rotated approximately 180° in the horizontal plane, then back. After one back and forth rotation, the electrodes are retracted and the file cleaned of filings. This procedure should be repeated several times (typically two to four times) to achieve parallelism and the required face diameter. *NOTE: If one face is much larger than the other, a steel coupon should be placed on the side of the file contacting the larger electrode for one or more of the file rotations so that both electrodes can eventually achieve the ± 0.1 mm tolerance.*

8.3.1.2 To smooth the electrode faces after filing, a piece of emery cloth or emery paper may be folded over one piece of flat, uncoated steel. The electrodes are then brought together with low force/tip dressing force (<50 kgF) so that both electrodes contact the emery cloth. The emery cloth should be rotated 180° in the horizontal plane, then back. If necessary, this step may be repeated one time to smooth the electrode faces. *NOTE: If performed more than twice, face-edge rounding may occur which can result in erroneous tip measurements.*

8.3.1.3 If the electrode faces can be accurately measured with the electrodes in place, the face diameters of both top and bottom electrodes shall be measured using a suitable instrument that has an accuracy to 0.05 mm or better. If the electrodes must be removed to measure their faces, an alignment mark shall be scribed on both the electrode holders and the body of the electrodes so that the electrodes can be reinserted at the exact location from which they were removed. The electrodes may be removed by any suitable means and measurements of the face diameters of both top and bottom electrodes shall be made with any appropriate instrument that will provide accuracy to 0.05 mm or better. The measurements are recorded in the B-2-DOPT1 Tip Imprint Data Sheet (or similar form) in the “After First Dressing” row. It should then be determined which category—(1), (2), or (3)—the measurements fit and which instructions to follow.

(1) If the one or both of electrode face diameters are below the -0.2 mm lower tolerance, 8.3.2 (Second and Subsequent Dressings) follows.

(2) If both electrode faces are within the ± 0.2 mm tolerance, 8.3.3 follows.

(3) If one or both electrodes exceeds the $+0.2$ mm tolerance, the electrodes are discarded. New electrodes are then to be installed, using the installation procedure described in 8.1 and the dressing procedure in 8.3.

8.3.2 Second and Subsequent Dressings (if required). Steps 8.3.1.1, 8.3.1.2, and 8.3.1.3 are to be repeated until the electrode face diameters meet the tolerance. Typically no more than two dressings should be required but are allowed in this procedure because direct electrode face measurements are made. The actual face diameter measurements for the last dressing are to be recorded in the “After Last Dressing” row of DOPT1. *NOTE: If one or both electrodes exceed the +0.2 mm tolerance, the electrodes shall be discarded. New electrodes are then to be installed using the installation procedure described in 8.1 and the dressing procedure in 8.3.*

8.3.3 Electrode Tip Imprints. After the final dressing has been successfully completed or after installation of custom machined electrodes (see 8.2), individual and composite tip imprints are to be made as shown in Figures 15A and 15B. The imprints shall be measured and recorded in the B-2-DOPT1 Tip Imprint Data Sheet row whose “Tip Print Code” is “After Last Dressing.” The CF, the Tip Print Correction Factor (needed to correct tip print measurement taken during the test), should be calculated as shown on the DOPT1 Tip Imprint Data Sheet. Once suitable tip imprints have been taken after completion of the direct measurement dressing option or after custom machined electrodes (not requiring dressing) are installed, 8.4 is skipped and 8.5 follows.

8.4 Electrode Dressing Option 2—Using Tip Imprints for Electrode-Face Measurements. This option is to be used when electrodes cannot be removed for direct measurements and electrode-face diameters must be determined using carbon paper tip imprints.

NOTE: This procedure only provides accurate measurements if the as-received or machined electrode faces are accurately measurable and do not have any discontinuities that will impair production of clean, clear tip imprints before dressing. Otherwise the inaccuracy of the correction factor, required to calculate the actual face diameters, will cause inaccurate face-diameter calculations, possibly resulting in out-of-tolerance actual face diameters.

8.4.1 Tip Imprints of Undressed Electrodes (Before First Dressing). Before any electrode dressing may be performed, duplicate sets of individual imprints (top and bottom electrodes) and of the composite imprint of the electrode faces shall be made in the boxes provided on the B-2-DOPT2 Tip Imprint Data Sheet, on a similar form, or on a separate piece of paper using full electrode force. Figures 15A and 15B show the proper paper and electrode configurations for both types of imprints (individual and composite). These duplicate imprints are coded **UD-1** and **UD-2** (UD = undressed electrode).

NOTE: The individual imprints must be examined for clarity and measurability. If these imprints are satisfactory in clarity and one can confidently say that the imprints accurately reflect tip topographies and diameters, the maximum and minimum diameters for all UD tip imprints shall be measured and their averages calculated. All UD tip imprint data is recorded on the DOP2 Tip Imprint Data Sheet.

8.4.2 Calculating the Tip Imprint Correction Factor (CF). CF is required when determining actual tip diameters via tip imprints because the carbon imprint diameter is usually larger than the actual face diameter. This effect is caused by the papers’ compaction and transference of carbon from the tip-face radius or the electrode bevel area. To determine CF, the following are calculated:

8.4.2.1 Mean tip imprint diameter of the undressed top electrode (TU):

$$TU = (TUD-1 + TUD-2)/2$$

(TUD-1 and TUD-2 are the duplicate UD tip imprint diameters for the **top** electrode from 8.4.1.)

8.4.2.2 Mean tip imprint diameter of the undressed bottom electrode (BU):

$$BU = (BUD-1 + BUD-2)/2$$

(BUD-1 and BUD-2 are the duplicate UD tip imprint diameters for the **bottom** electrode from 8.4.1.)

8.4.2.3 Tip imprint correction factor for the top electrode (TCF):

$$TCF = TU - T \quad (T \text{ was determined in 8.1.1.2})$$

8.4.2.4 Tip imprint correction factor for the bottom electrode (BCF):

$$BCF = BU - B \quad (B \text{ was determined in 8.1.1.2})$$

8.4.2.5 Mean tip imprint correction factor (CF):

$$CF = (TCF + BCF)/2$$

8.4.3 Electrode-Face Paralleling and Dressing (Sizing). This step may not begin until CF has been successfully determined in 8.4.2.

8.4.3.1 After insertion of the specified dressing file (see 7.7) between the tips, the electrodes are to be brought together with a very low force [<20 kgF (55 lbF) to prevent excessive material removal and gouging] so that both electrodes contact the file. *NOTE: An adjustable spacer may be used between the electrode arms to achieve the low force required for dressing.* The file is then rotated approximately 180° in the horizontal plane, then back. After one back and forth rotation, the electrodes are retracted and the file cleaned of filings. This procedure should be repeated several times (typically two to four times) to achieve parallelism and the required face diameter. *NOTE: If one face is much larger than the other, a steel coupon should be placed on the side of the file contacting the larger electrode for one or more of the file rotations so that both electrodes can eventually achieve the ± 0.2 mm tolerance.*

8.4.3.2 To smooth the electrode faces after filing, a piece of emery paper may be folded over one piece of flat, uncoated steel. The electrodes are then brought together with low force/tip dressing force (less than 50 kgF) so that both electrodes contact the emery paper. The emery paper should be rotated 180° in the horizontal plane, then back. If necessary, this step may be repeated to smooth the electrode faces. *NOTE: If performed more than twice, face-edge rounding may occur which can result in erroneous tip measurements.*

8.4.3.3 After completion of 8.4.3.1 and 8.4.3.2, two individual and composite carbon imprints of the electrode faces (using full electrode force) shall be made in the boxes provided on the B-2-DOPT2 Tip Imprint Data Sheet, on a similar form, or on a separate piece of paper. [See Figures 15A and 15B for paper and electrode configurations for both types of imprints (individual and composite)]. These duplicate imprints shall be coded **AD1-1** and **AD1-2** (AD1 = after dressing #1).

8.4.4 Calculating the Actual Electrode-Face Diameters After Dressings (1 or 2). The following formulas shall be used to calculate the corrected (actual) electrode-face diameter of the top (TD1) and bottom (BD1) electrodes after the first and second (if needed) dressing. *NOTE: The “x” in each code represents the dressing number (1 or 2).*

8.4.4.1 Mean tip imprint diameter calculation of the dressed top electrode (**TDx**):

$$TDx = (TADx-1 + TADx-2)/2$$

(TADx-1 and TADx-2 are the duplicate AD tip imprint diameters for the **top [T]** electrode after the first or second dressing.)

8.4.4.2 Mean tip imprint diameter calculation of the dressed bottom electrode (**BDx**):

$$BDx = (BADx-1 + BADx-2)/2$$

(BADx-1 and BADx-2 are the duplicate AD tip imprint diameters for the **bottom [B]** electrode after the first or second dressing.)

8.4.4.3 The top electrode's corrected electrode-face diameter calculation for dressing $\times$ (**TCDx**):

$$TCDx = TDx - CF \quad (CF \text{ was determined in 8.4.2.5})$$

8.4.4.4 The bottom electrode's corrected electrode-face diameter calculation for dressing $\times$ (**BCDx**):

$$BCDx = BDx - CF \quad (CF \text{ was determined in 8.4.2.5})$$

8.4.5 Determining the Status of the Electrode Faces After Dressings One or Two

8.4.5.1 If **TCDx** and/or **BCDx** are below the tolerance (< -0.2 mm) for the specified face diameter (e.g., 4.7 mm for a 5.0 mm face diameter), the electrode or electrodes are to be redressed by repeating steps 8.4.3, 8.4.4, and 8.4.5 if the electrodes have been dressed only once. *NOTE: If the electrodes have been dressed twice and this condition is still true, new electrodes shall be installed and the dressing procedure repeated.*

8.4.5.2 If **TCDx** and **BCDx** are within the tolerance (± 0.2 mm) for the specified face diameter, 8.5 follows.

8.4.5.3 If **TCDx** and/or **BCDx** are above the tolerance ($> +0.2$ mm) for the specified face diameter, the electrodes shall be discarded, new electrodes shall be installed and the dressing procedure repeated.

8.5 Verification of Electrode Concentricity and Parallelism. To verify electrode-face concentricity and parallelism, the minor and major diameters of the composite tip imprints (obtained after installation of custom machined electrodes or after the last dressing) shall be measured. If the difference between minor and major diameters is greater than 0.2 mm, several more composite imprints should be made to be sure that the carbon paper or white paper is not the cause of the apparent lack of concentricity. The new imprints should be closely examined. If the difference between the diameters is still >0.2 mm, the electrode-face alignment should be carefully rechecked with a magnifying glass when both electrodes are in contact with each other (head down). A backlight may help in this visual examination. After alignment has been checked at several locations approximately 90° apart, 8.5.1 or 8.5.2 follows.

8.5.1 If misalignment is evident, adjustments necessary to achieve alignment shall be made. After alignment has been achieved, several more composite tip imprints are to be made and measured (minor and major diameters). If the difference between the major and minor diameters is still >0.2 mm, 8.5.2 follows. If concentricity is within 0.2 mm, 8.5.3 follows.

8.5.2 If alignment is acceptable, the electrodes should be redressed lightly, using emery paper only, being certain that no rounding of the electrode face occurs. After redressing, additional composite tip imprints should be made and measured. If concentricity is within 0.2 mm, 8.5.3 follows. If concentricity is still not within 0.2 mm, new electrodes shall be installed, following the installation and applicable dressing instructions.

8.5.3 The latest set of composite tip imprints should be checked for uniformity of shading (indicating parallelism). If the imprints show uniform darkness from edge to edge, 8.5.4 follows. If the imprints do not show uniform darkness, it should be determined if this condition is caused by the carbon or imprint paper. If the papers do not appear to be the cause, the electrodes should be redressed once, lightly, using emery paper only. More imprints may be made and examined. If nonuniform shading still exists, 8.5.4 should be performed to determine if installation of new electrodes is required.

8.5.4 As a final alignment and parallelism check, several “heat-pattern welds” shall be made on one piece of clean, flat, uncoated, mild steel (~0.8 mm thick) using a low current (~6 kA–7 kA). *NOTE: Electrode coolant must be on for these “welds.”* Examination of the heat pattern around the “welds” should reveal it to be “relatively” circular and uniform. If these criteria are met, Clause 9 follows. If gross irregularities in the heat pattern are evident, the electrodes have to be redressed (if they have not been dressed twice, excluding the redressings in 8.5) using the dressing instructions in 8.3 or 8.4., or a second set of electrodes has to be installed if the first set of electrodes had been dressed twice. If the same results are obtained with the second set of electrodes, the instructions in 8.5.5 shall apply. See Figures 15A and 15B.

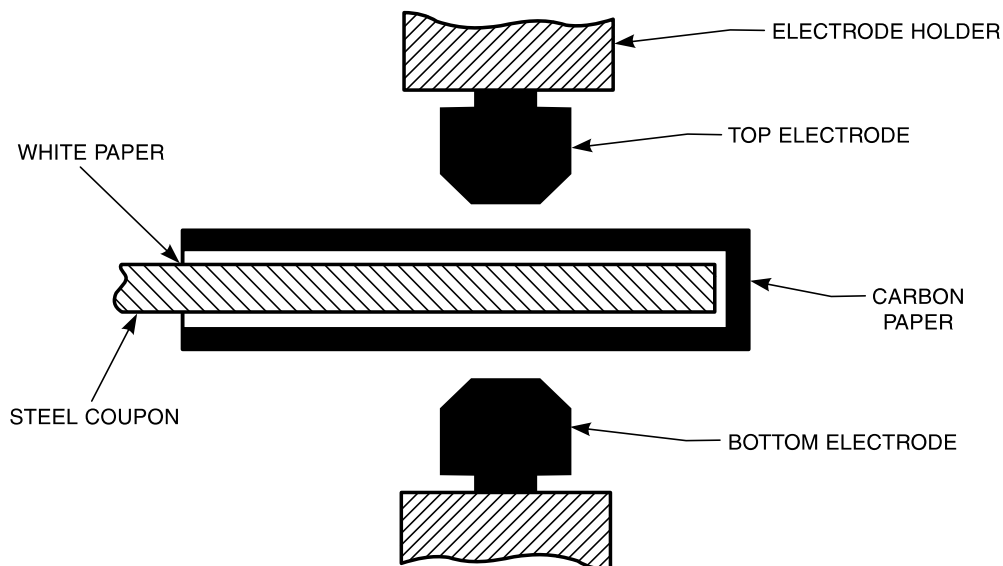


Figure 15A—Individual Tip Imprint Schematic

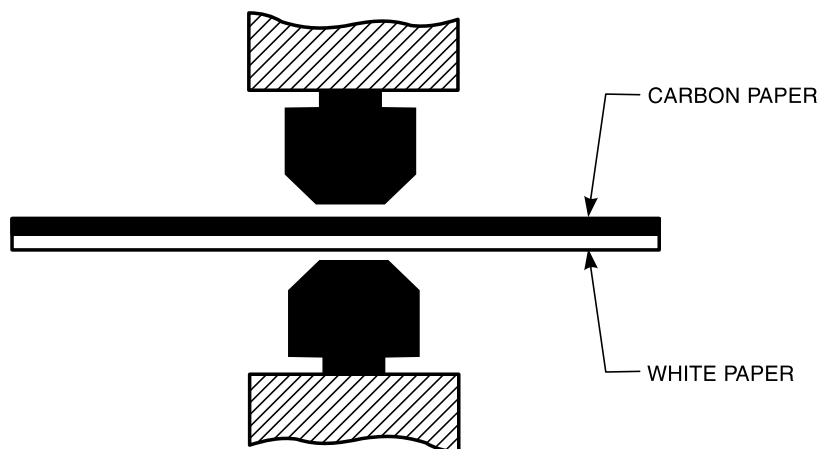


Figure 15B—Composite Tip Imprint Schematic

8.5.5 If the installation, second dressing, and other adjustments of a second set of electrodes still do not meet the stated tolerances or other criteria stipulated in the foregoing steps, **a third set of electrodes shall not be installed.** The second set of electrodes shall then be used even though the tolerances or criteria were not met. The specific tolerances or criteria that were not met shall be noted on the Tip Imprint Sheet (Forms B-2-DOPT1 or B-2-DOPT2), the Welding Data Sheet (Form B-1), and the Test Report (Forms B-4, B-5, or B-6).

9. Electrode-Face and Weld-Size Stabilization Procedure

9.1 Introduction and Overview. To compensate for the dynamic behavior of welding current versus weld size that occurs when making welds with new electrodes, especially when welding coated steels, a weld size stabilization procedure shall be performed at the start of any test. This stabilization procedure “conditions” the electrode faces, thus stabilizing the weld size behavior and promoting reproducibility of test results. In summary, this stabilization procedure consists of adjusting the welding current as needed to maintain a specified/fixed weld size. Figure 16 shows a graph that depicts typical steps of the stabilization procedure. Depending upon the test material, welding conditions, and weld size behavior, the stabilization procedure may require from approximately 80 to 200 (maximum allowed) welds. Except as specifically indicated, the welding conditions, parameters, materials, panel welding sequence, etc. used in this stabilization procedure shall be the same as those that will be used in the subsequent test procedure. In all cases, only the “test” weld (2nd weld) of the peel sample is used for establishing weld size and fracture mode. The target weld size during the stabilization procedure is termed the Stabilization Weld Size (SWS) and is defined as 90% of the dressed face diameter listed in Table 4a, 4b, or 4c (e.g., SWS = 4.5 mm for a 5.0 mm dressed face diameter). The SWS is rounded to the closest 0.1 mm.

9.2 Preparation

9.2.1 Before proceeding, an adequate quantity of peel-test and panel coupons required for this procedure shall be prepared, following the instructions in Clause 4. The appropriate welding parameters are determined by consulting Table 4a, 4b, or 4c for the material being tested. All welding parameters shall be set according to Clause 6 for the material being tested.

9.2.2 The following items shall be recorded on the Welding Data Sheet (Form B-1 or equivalent):

- (1) A test code
- (2) The type of test (Endurance Test, Weld Property Test, etc.)
- (3) All pertinent material data that is requested on the data sheet

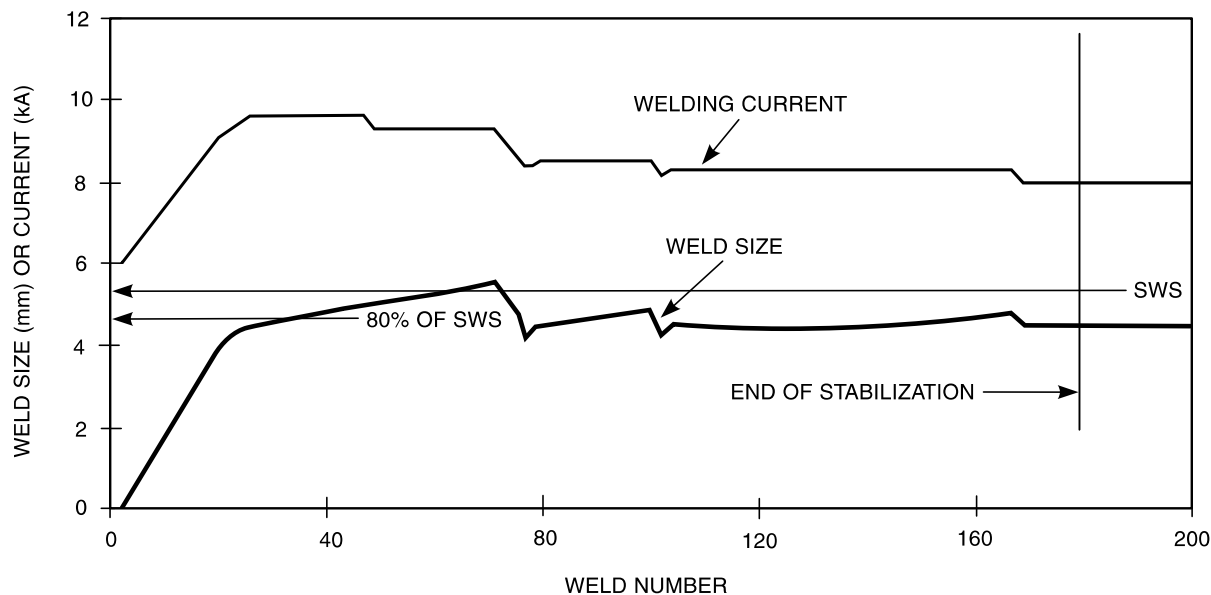


Figure 16—Graphical Example of a Typical Stabilization Procedure

- (4) The laboratory name and address
- (5) The date (or dates if run over one day) of the test
- (6) The name of the test operator
- (7) All welding parameters and electrode data

9.2.3 The following items shall be checked before proceeding:

- (1) That the electrodes have been properly dressed and that tip prints have been made, measured and recorded on the Tip Imprint Data Sheet.
- (2) That the electrode coolant flow is on and at the proper flow setting and temperature. (Actual flow and temperature shall be recorded on the Welding Data Sheet.)
- (3) That the weld counter is reset to zero.

9.2.4 For all test samples that are welded and tested, the following shall be recorded:

- (1) The tap and current setting (percent heat/percent current or programmed current) of each test weld
- (2) The measured welding current of each test weld (not anchor or panel welds)
- (3) The expulsion (E) or nonexpulsion (NE) of each weld (both welds in peel-test samples)
- (4) The peel-test sample orientation

(5) FD_{min} , FD_{max} , D_{MIN} , D_{MAX} . (see Figures 12A, 12B, 13, and Annex D, Fracture Classification Charts), the mean weld size, and the weld fracture mode of each test weld

9.3 Stabilization Procedure

9.3.1 Based on test data previously obtained for the type of material being evaluated, the welding current shall initially be set to a value that should result in fracture mode 8 (No Fusion condition), as included in Annex D, approximately 1000 A less than the current required to produce a minimum size weld. If previous data is unavailable, the appropriate default welding current presented in Table 7 may be used for the starting point.

Table 7
Default Initial Welding Currents

Sheet Thickness (mm)	Current (kA)		
	Uncoated	Zn Alloy Coated	Zn Coated
0.60–0.69	4 to 5	5	5 to 6
0.70–0.89	5 to 6	6	6 to 7
0.90–1.29	6 to 7	7 to 8	8 to 9
1.30–1.69	8 to 9	9	9 to 10
1.70–2.09	10 to 11	11 to 12	12 to 13

Note: Listed values are for low-strength Groups 1 and 2 steels.

9.3.2 One peel-test sample shall be welded and tested at this initial current setting. *NOTE: All peel-test samples used in the stabilization procedure shall be coded with the prefix S and their orientation kept constant, i.e., all type C, or all type L, or all type R (see Figure 7).*

9.3.2.1 If the test weld exhibits fracture mode 8, step 9.3.3 follows.

9.3.2.2 If a fused region of any size is obtained, the current setting is to be lowered in increments of 1000 A. One peel-test sample shall be welded and tested at each increment until a fracture mode 8 condition is obtained. After this condition is met, step 9.3.3 follows.

9.3.3 The current setting shall be increased in increments of approximately 300 A. One peel-test sample is to be welded and tested at each increment until the fused region size is approximately 70% to 80% of the SWS (for a 5.0 mm electrode face, SWS = 4.5 mm, and 80% of 4.5 mm = 3.6 mm.). After this condition is met, step 9.3.4 follows.

9.3.4 The current setting shall then be increased in smaller increments of approximately 100 A. Two peel-test samples shall be welded and tested at each increment until the average fused region size for the two samples meets the SWS (within ± 0.2 mm). *NOTE: If the last set of peel-test samples produces an average fused region that is greater than the 0.2 mm tolerance of the SWS (e.g., 4.8 mm for an SWS of 4.5 mm), the current setting **may not be reduced** in an attempt to reach the SWS.* Once the SWS has been reached or exceeded by one pair of peel-test samples in this initial determination of the SWS current, no reduction in current is allowed. After the conditions in this step are met, step 9.3.5 follows.

9.3.5 The current shall be adjusted to the setting (from step 9.3.4) that produced an average fused region size that meets or is closest to the SWS without exceeding the $+0.2$ mm tolerance (e.g., if SWS = 4.5 mm, and the 80% current setting = 4.2 mm and the 81% current setting = 4.8 mm, the current is to be set to 80%). Step 9.3.6 follows.

9.3.6 At the most recently determined current setting (from step 9.3.5 for the initial loop and from step 9.3.7.1 or 9.3.7.4 for subsequent loops), one row of 19 welds shall be made on a panel sample with the specified weld spacing and welding rate. The surface orientation(s) of the panel shall be as follows:

(1) *For equally coated sheet (e.g., 60G/60G):* The entire row shall be welded with the marked side of both the top and bottom coupons facing up (Surface Orientation 1).

(2) *For differentially coated sheet (e.g., 60G/20G):* Welding shall be performed with the marked side of both coupons facing up (Surface Orientation 1) for 10 welds, then flipping the panel upside down so that the marked sides are down (Surface Orientation 2) for the remaining 9 welds.

9.3.6.1 If any expulsion or severe electrode sticking occurs on these panel welds, welding shall be **halted immediately**. The current shall then be reduced in increments of approximately 300 A. Two peel-test samples shall be welded and tested at each increment until the weld size for the two samples is less than the average weld size determined for the most recent loop (step 9.3.5 or 9.3.7.4). After this current reduction sequence has been completed, step 9.3.7.3 follows directly.

9.3.6.2 If all 19 welds were successfully completed, step 9.3.7 follows.

9.3.7 Without adjusting the current setting, two peel-test samples shall be welded. If no expulsion occurs on any of the four welds, the samples shall be tested and their weld size measured. The condition that applies shall then be determined (9.3.7.1, 9.3.7.2, or 9.3.7.3), and instructions for that condition shall be followed.

*NOTE: If expulsion occurs on any of the four welds (anchor or test), welding is to be **halted immediately**. The current shall then be reduced in increments of approximately 300 A until a no-expulsion condition is achieved by all four welds of the two samples. Once this is achieved, the samples shall be tested and their weld size measured. The condition that applies shall then be determined (9.3.7.1, 9.3.7.2, or 9.3.7.3), and instructions for that condition shall be followed. (Any samples that contain expulsion welds do not need to be tested.)*

9.3.7.1 If the mean weld size is equal to or greater than the average weld size determined for the most recent loop (step 9.3.5 or 9.3.7.4) and is **not greater than SWS +0.2 mm**, the current setting shall not be adjusted. Step 9.3.8 shall be consulted to determine the status of the stabilization process.

9.3.7.2 If the mean weld size is **greater than SWS +0.2 mm**, the current shall be reduced in increments of approximately 300 A. Two peel-test samples shall be welded and tested at each increment until the average weld size for the two samples is less than the average weld size determined for the most recent loop (step 9.3.5 or 9.3.7.4). Once this condition is met, step 9.3.7.3 follows.

9.3.7.3 If the weld size is **less than the average weld size determined for the most recent loop** (step 9.3.5 or 9.3.7.4), the current setting shall be increased in increments of approximately 100 A. Two peel-test samples shall be welded at each increment until the average weld size for the two samples meets the SWS (within ± 0.2 mm) or slightly exceeds it. Once this condition is met, step 9.3.7.4 follows.

9.3.7.4 The welding current shall be adjusted to the setting from step 9.3.7.3 that produced an average weld size (of the two test welds) that meets or is closest to the SWS without exceeding the +0.2 mm tolerance (e.g., if SWS = 4.5 mm, and the 80% current setting = 4.2 mm and the 81% current setting = 4.8 mm, the current shall be set to 80%).
NOTE: If this current setting is the same as that used for the most recent loop (this is improbable but not impossible), the loop is to be considered successfully completed without a change in current settings. The status of the stabilization process is to be established at this point by proceeding to step 9.3.8 before further welding is performed.

9.3.8 If *one* of the conditions listed in 9.3.8.1 through 9.3.8.3 for ending the stabilization procedure has been met, the stabilization process is complete. If **none** are met, the process loops back to step 9.3.6, and steps 9.3.6 through 9.3.7 (with the latest current settings from either step 9.3.7.1 **or** 9.3.7.4) shall be repeated until **one** of the following conditions for ending the stabilization procedure are met.

9.3.8.1 It has been determined that the current setting required to meet the SWS has remained unchanged and remains stable (within about ± 100 A peel-test welds only) in three consecutive cycles or loops. Each loop consists of steps 9.3.6 through 9.3.8, ends at the conditional phrase at the start of step 9.3.8, and requires 23 welds (19 panel welds and 4 peel-test welds) all at the same current setting.

9.3.8.2 It has been determined that the current required to meet the SWS has increased by 300 A or more over the initial current required to achieve the SWS in step 9.3.5. *NOTE: This condition mainly applies when welding on highly aggressive coatings (regarding electrode wear).*

9.3.8.3 It has been determined that a total of 200 welds has been made during the stabilization procedure (total includes all welds made on peel and panel samples).

9.3.9 After any one of the conditions in 9.3.8 has been met, two sets of individual and two sets of composite carbon imprints of the electrode tips shall be made, and the number of welds made during the electrode stabilization process shall be recorded. Upon successful completion of the electrode stabilization procedure, the desired test(s) may begin.

10. Endurance Test

10.1 Introduction and Overview. The endurance test procedure is primarily designed to examine the electrode wear behavior when welding coated sheet steels using several criteria. However, it may also be suitable for evaluating other materials. As stated in 1.1, this test is intended for sheet thicknesses less than 1.2 mm. The criterion used in this test pro-

vides significant information about several aspects of spot welding behavior of sheet steels. The criteria include Initial $I_{MIN.}$ ($II_{MIN.}$) and Initial $I_{MAX.}$ ($II_{MAX.}$) welding currents and current range (immediately following the stabilization procedure), the endurance limit (number of welds until the test termination criterion is met), and Final $I_{MIN.}$ ($FI_{MIN.}$) and Final $I_{MAX.}$ ($FI_{MAX.}$) welding currents and current range (immediately following the endurance portion). Figure 17 is a graphical example of the results obtained with the endurance test.

10.2 Test Preparation. After the stabilization procedure (Clause 9) is completed, the weld counter is to be reset to zero, and it shall be confirmed that all welding parameters are still at their specified values. All pertinent information shall be entered on the Welding Data Sheet if this has not yet been done. As welds are made and tested, all required data (see 9.2.1 and 9.2.2) shall be recorded. All peel tests' surface orientation (see 6.6 and Figure 9) shall be kept constant throughout the test. Also, the minimum weld size (MWS) is to be calculated for the sheet thickness being tested using the formula found in 6.7.1, and shall be recorded.

10.3 Initial $I_{MIN.}$ Current Determination. *NOTE: All peel-test samples welded during the determination of the Initial $I_{MIN.}$ and $I_{MAX.}$ currents (10.3 and 10.4) of the test shall be coded with the prefix ICL.*

10.3.1 Based on weld size and welding current data from the weld stabilization procedure (Clause 9), the current setting shall be adjusted low enough to produce a weld that is at least 0.5 mm smaller than the MWS (ideally 0.5 mm to 1.0 mm smaller than the MWS). One peel-test sample shall be welded and tested at this current. If the resulting fused region is:

(1) Smaller than MWS–0.5 mm, step 10.3.2 follows.

(2) Larger than MWS–0.5 mm (e.g., larger than 3.1 mm for an MWS of 3.6), the current shall be reduced in increments of 300 A, and one peel-test sample shall be welded and tested at each increment until the weld size is smaller than MWS–0.5 mm. When this condition has been met, step 10.3.2 follows.

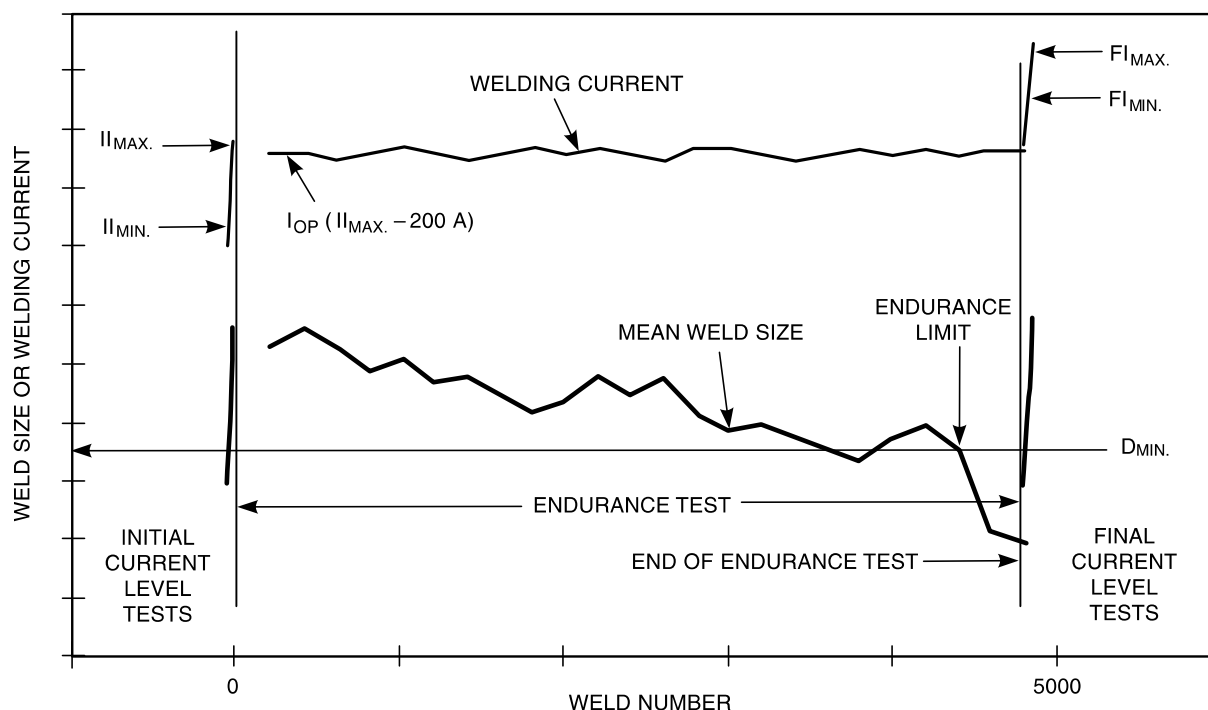


Figure 17—Graphical Example of the Endurance Test Procedure

10.3.2 The current setting shall be increased in increments of approximately 100 A. At each increment, one peel-test sample (any orientation type) shall be welded and tested until a weld size is obtained that satisfies both the MWS and the fracture mode requirements (see 6.7.6) for I_{MIN} . *NOTE: After both I_{MIN} criteria have been met by a peel-test sample, a reduction in current is **never** allowed even though the weld size may be greater than the minimum.* The orientation type [C, L, or R (see Figure 7)] of the first peel sample that meets both I_{MIN} criteria shall be recorded.

10.3.3 Using both of the other two sample orientation types not used in step 10.3.2 (i.e., if orientation C was used in step 10.3.2, L and R shall be used in this step), two peel-test samples shall be welded and tested at the same I_{MIN} current setting found in step 10.3.2.

10.3.3.1 If both of these samples meet the I_{MIN} criteria, step 10.3.4 follows.

10.3.3.2 If either of these samples does not satisfy the I_{MIN} criteria, the current setting shall be increased in increments of approximately 100 A, and peel-test samples shall be welded and tested until samples of all three orientations (all welded consecutively at the same current setting) meet the I_{MIN} criteria. After these criteria are met, step 10.3.4 follows.

10.3.4 The Initial I_{MIN} shall be calculated (in kA rounded to the nearest 0.1 kA) by averaging the current (recorded to 0.1 kA) measured for the test welds (second weld) from the final three peel-test samples in steps 10.3.2 and 10.3.3.1 or step 10.3.3.2. The average of the measured currents for these samples is the Initial I_{MIN} current. This current shall be coded II_{MIN} and be recorded on the Welding Data Sheet.

10.3.5 The average weld size shall be calculated (rounded to the closest 0.1 mm) for the three peel samples mentioned in 10.3.4. This mean weld size is the Initial I_{MIN} weld size. The mean shall be coded initial minimum fusion zone diameter (IFD_{MIN}) and be recorded on the Welding Data Sheet.

10.4 Initial I_{MAX} Current Determination

10.4.1 Starting from the Initial I_{MIN} current established in 10.3, the current setting shall be increased in increments of approximately 100 A. At each increment, one peel-test sample shall be welded and tested until either of the two I_{MAX} criteria [expulsion (interfacial) or severe electrode-to-sheet sticking for both welds of the peel sample] is met. *NOTE: At each increment, the peel sample orientation is to be changed so that the three types of peel samples are sequentially used (e.g., "C," then "L," then "R," then "C," etc.).* The orientation type [C, L, or R (see Figure 7)] of all peel-test samples shall be recorded. Once **one** sample meets either of the I_{MAX} criteria, welding shall cease immediately.

10.4.2 The current measured for the test weld (second weld) of the last sample (the one that meets either of the two I_{MAX} criteria) is the Initial I_{MAX} current. This current shall be coded II_{MAX} . The weld size of this weld shall be coded IFD_{MAX} . Both II_{MAX} and IFD_{MAX} shall be recorded on the Welding Data Sheet.

10.4.3 After II_{MAX} has been determined, duplicate individual and composite carbon tip imprints of the electrode faces shall be made on the Tip Imprint Data Sheet (Forms C-2-DOPT1, C-2-DOPT2, or equivalent).

10.4.4 The total number of welds (one peel sample = two welds) made in 10.3 and 10.4 shall be recorded on the Welding Data Sheet (Form C-1 or equivalent), being certain not to count any imprint strokes or other nonweld strokes as welds when a mechanical weld counter is used. The weld counter shall then be reset to zero.

10.5 Endurance Test. Figure 17 shows an example of typical results.

10.5.1 Based on the II_{MAX} current obtained in 10.4.2, the current setting shall be adjusted so that the expected welding current will be as close as possible to 200 A below the II_{MAX} current. This current is the operating current and is to be labeled I_{OP} . I_{OP} shall be kept constant throughout the endurance test.

10.5.2 Using a sufficient number of panel samples (see 6.6.2 for surface orientations and 6.5.3 for panel sequencing), 190 consecutive panel welds shall be made. The specified weld spacing (see Table 6) and panel welding rate (see Table 4a, 4b, or 4c) for the material being tested shall be used for all panel welds.

10.5.3 After completion of the 190 panel welds, five peel-test samples shall be welded and tested. All three peel-test sample orientations are to be used in this set of five samples, with no orientation being used for more than two samples. The order of welding the different peel-test sample orientations (C, L, and R) shall be randomized at each 200-weld checkpoint (e.g., at checkpoint 200, the sequence might be C, L, R, L, C; at checkpoint 400, the sequence might be L, C, R, R, C; etc.). Each set of peel samples is designated as the "200 welds" data set. *NOTE: All peel-test samples welded*

during this portion of the test shall be coded only with the test weld number (e.g., 192, 194, 196, etc.). The average weld size and average welding current shall be calculated for the five peel-test samples at each 200-weld checkpoint. The means shall be recorded on the Welding Data Sheet.

10.5.4 After completion of the peel-test welds at each checkpoint, duplicate individual and composite carbon tip imprints of the electrode face shall be made on the Tip Imprint Data Sheet being used. All tip imprints in this section are coded by using the weld number of the peel test most recently welded. When a mechanical weld counter is used, the counter is to be locked out for taking tip imprints so that no imprint strokes are counted as welds.

10.5.5 Steps 10.5.2 through 10.5.4 shall be repeated in sequential order until the test termination criterion is reached. The test termination point is reached when the weld size of all five peel-test samples is below the minimum weld size for two consecutive 200-weld checkpoints.

10.5.6 Endurance Limit Determination. As defined in the Clause 3, the endurance limit is the total number of acceptable welds made during the endurance test. The endurance limit criteria (the conditions that must be met to establish the endurance limit) may be the test termination criteria in 10.5.5 or may be defined by the client for whom the testing is performed. Determination of the endurance limit is therefore dependent upon the client's specifications.

10.6 Final I_{MIN} Current Determination. *NOTE: All peel-test samples welded during the determination of the Final I_{MIN} and I_{MAX} currents (10.6 and 10.7) shall be coded with the prefix FCL.*

10.6.1 Starting from the operating current (I_{OP} used in 10.5), the current setting shall be increased in increments of approximately 100 A. At each increment, one peel-test sample (any orientation type) shall be welded and tested until a fused region is obtained that satisfies both the MWS and the fracture mode requirements (see 6.7) for I_{MIN} . *NOTE: After both I_{MIN} criteria have been met by a peel-test sample, a reduction in current is **never** allowed even though the fused region diameter may be greater than the minimum.* The orientation type [C, L, or R (see Figure 7)] of the first peel-test sample that meets both I_{MIN} criteria shall be recorded.

10.6.2 Using both of the other two sample orientation types not used in step 10.6.1 (i.e., if orientation C was used in step 10.6.1, L and R shall be used in this step), two peel-test samples shall be welded and tested at the same I_{MIN} current setting found in step 10.6.1.

10.6.2.1 If both of these samples meet the I_{MIN} criteria, step 10.6.3 follows.

10.6.2.2 If either of these samples does not satisfy the I_{MIN} criteria, the current setting shall be increased in increments of approximately 100 A, and peel-test samples shall be welded and tested until samples of all three orientations (all welded consecutively at the same current setting) meet the I_{MIN} criteria. After these criteria are met, step 10.6.3 follows.

10.6.3 The Final I_{MIN} shall be calculated (in kA rounded to the nearest 0.1 kA) by averaging the current (recorded to 0.1 kA) measured for the test welds (second weld) from the final three peel-test samples in steps 10.6.1 and 10.6.2.1 or step 10.6.2.2. The average of the measured currents for these samples is the Final I_{MIN} current. This current shall be coded FiI_{MIN} and be recorded on the Welding Data Sheet.

10.6.4 The average weld button size shall be calculated (rounded to the closest 0.1 mm) for the three peel samples mentioned in 10.6.3. This mean weld size is the Final I_{MIN} button diameter. The mean shall be coded Final ID_{MIN} ($FiID_{MIN}$) to mean the D_{MIN} at the final minimum current and be recorded on the Welding Data Sheet.

10.7 Final I_{MAX} Current Determination

10.7.1 Starting from the Final I_{MIN} current established in 10.6, the current setting shall be increased in increments of approximately 100 A. At each increment, one peel-test sample shall be welded and tested until either of the two I_{MAX} criteria [expulsion (interfacial) or severe electrode-to-sheet sticking for both welds of the peel sample] is met. *NOTE: At each increment, the peel sample orientation is to be changed so that the three types of peel samples are sequentially used (e.g., C, then L, then R, then C, etc.).* The orientation type [C, L, or R (see Figure 7)] of all peel-test samples shall be recorded. Once one sample meets either of the I_{MAX} criteria, welding shall cease immediately.

10.7.2 The current measured for the test weld (second weld) of the last sample (the one that meets either of the two I_{MAX} criteria) is the Final I_{MAX} current. This current shall be coded FiI_{MAX} . The fused diameter of the fused region of this weld shall be coded Final ID_{MAX} ($FiID_{MAX}$). Both FiI_{MAX} and $FiID_{MAX}$ (final fusion zone diameter at I_{MAX}) shall be recorded on the Welding Data Sheet.

10.7.3 After FiI_{MAX} has been determined, duplicate individual and composite carbon tip imprints of the electrode faces shall be made on the Tip Imprint Data Sheet or some other suitable paper.

10.7.4 The total number of welds (one peel sample = two welds) made in 10.6 and 10.7 shall be recorded on the Welding Data Sheet, being certain not to count any imprint strokes or other nonweld strokes as welds when a mechanical weld counter is used.

10.8 Replication. The entire test shall be repeated at least once (for a total of 2 sets of test results) or for as many additional replications as desired. For each replication, returning to Clause 8 and completing Clauses 8 through 10 is required.

10.9 Calculations for Mean Current Levels and Current Ranges

10.9.1 Calculation of ICR. Calculation for the Initial Current Range (coded ICR) shall be performed for each replication using the following formula:

$$ICR = II_{MAX} - II_{MIN}$$

10.9.2 Calculation of Mean II_{MIN} , Mean II_{MAX} , and Mean ICR. Calculation for the means of all “Initial” current levels and current ranges for all replications (coded R1, R2, etc.) shall be performed using the following formulas:

(1) Mean $II_{MIN} = (R1II_{MIN} + R2II_{MIN} + RNII_{MIN})/N$, where N = the number of the last replication or the total number of replications

(2) Mean $II_{MAX} = (R1II_{MAX} + R2II_{MAX} + RNII_{MAX})/N$, where N = the number of the last replication or the total number of replications

$$(3) \text{ Mean ICR} = \text{Mean } II_{MAX} - \text{Mean } II_{MIN}$$

10.9.3 Calculation of FCR. Calculation for the Final Current Range (coded FCR) shall be performed for each replication using the following formula:

$$FCR = FiI_{MAX} - FiI_{MIN}$$

10.9.4 Calculation of Mean FiI_{MIN} , Mean FiI_{MAX} , and Mean FCR. Calculation for the means of all “Final” current levels and current ranges for all replications (coded R1, R2, etc.) shall be performed using the following formulas:

(1) Mean $FiI_{MIN} = (R1FiI_{MIN} + R2FiI_{MIN} + RNFiI_{MIN})/N$, where N = the number of the last replication or the total number of replications

(2) Mean $FiI_{MAX} = (R1FiI_{MAX} + R2FiI_{MAX} + RNFiI_{MAX})/N$, where N = the number of the last replication or the total number of replications

$$(3) \text{ Mean FCR} = \text{Mean } FiI_{MAX} - \text{Mean } FiI_{MIN}$$

10.9.5 Calculation of Mean Current Levels and Current Ranges for All Data (Initial and Final). Calculation for the means of all I_{MIN} and I_{MAX} current levels and all current ranges (Initial and Final) for all replications shall be performed using the following formulas:

$$(1) \text{ Mean All } I_{MIN} = (\text{Mean } II_{MIN} + \text{Mean } FiI_{MIN})/2$$

$$(2) \text{ Mean All } I_{MAX} = (\text{Mean } II_{MAX} + \text{Mean } FiI_{MAX})/2$$

$$(3) \text{ Mean All CR} = \text{Mean All } I_{MAX} - \text{Mean All } I_{MIN}$$

10.10 Endurance Test Report (Form B-4 [see Annex B] or equivalent)

10.10.1 All of the following informational items shall be reported on the Endurance Test Report.

- (1) Date(s) of test and the report date
- (2) Name and address of testing facility
- (3) Name of test operator and signature
- (4) List and description of all test equipment

- (5) Any variances to specified test equipment
- (6) All welding parameters (including electrodes)
- (7) Any variances to the test procedure
- (8) The test code for the test(s) (assigned by the operator or the party for whom the test is being conducted)

10.10.2 All of the following welding data shall be reported on the Endurance Test Report.

- (1) Initial currents (II_{MIN} and II_{MAX}) and current range (ICR) for each replication
- (2) Final currents (FiI_{MIN} and FiI_{MAX}) and current range (FCR) for each replication
- (3) Initial and Final I_{MIN} and I_{MAX} weld button sizes (ID_{MIN} , ID_{MAX} , $FiID_{MIN}$, and $FiID_{MAX}$) for each replication
- (4) Mean Initial currents (Mean II_{MIN} and Mean II_{MAX}) and current range (Mean ICR) for all replications
- (5) Mean Final currents (Mean FiI_{MIN} and Mean FiI_{MAX}) and current range (Mean FCR) for all replications
- (6) Mean of all currents (Mean All I_{MIN} and Mean All I_{MAX}) and current ranges (Mean All CR) for all replications
- (7) Electrode endurance (number of welds) to the specified termination point or an optional end point (decided by the party for whom the test is performed)

10.10.3 Data for the electrode face diameters shall be reported on the Endurance Test Report. The mean electrode face diameters [directly measured or the adjusted means (tip imprint—correction factor) from tip imprints] of both electrodes (top and bottom) and their composite (except for number one below) shall be reported for the following points in the test (other points optional):

- (1) In the as received or as-machined condition before installation (measured directly, not from tip imprints)
- (2) After the final electrode dressing
- (3) After completion of the electrode face stabilization procedure
- (4) After the Initial I_{MAX} has been determined
- (5) After the Endurance Limit has been reached
- (6) After the Final I_{MAX} has been determined

11. Weld Property Tests

11.1 Introduction and Overview. The Weld Property Test Procedure is designed to assess spot welding behavior and weld properties of uncoated and coated sheet steel using several criteria. These criteria include I_{MIN} and I_{MAX} currents and current range, hold time sensitivity tests, shear tension and cross tension tests, and metallographic/hardness tests. This test procedure may be performed independent of or in conjunction with the Endurance Test Procedure. The weld property tests are designed primarily for gauges greater than or equal to 1.2 mm.

The weld property testing is required at two different weld sizes, namely the minimum weld size (MWS) and the face diameter weld size (FDWS). Proper judgment should be exercised when interpreting the results of the weld property tests on higher strength steels (such as those with ultimate tensile strength greater than 500 MPa) in groups 3 and 4, especially with tests run at the minimum weld size. Welds in such higher strength steels may show interfacial fractures even at short hold times, especially at thicker gauges. The requirement to conduct the tests at the minimum weld size is included to generate more complete information on the behavior of such steels.

11.2 Test Preparation

11.2.1 Before proceeding, an adequate quantity of test coupons and panels of the various types required in these tests shall be prepared using the instructions in Clause 4. If required or desired, material characterization may be performed per Clause 5 if this has not been done.

11.2.2 The appropriate welding parameters and electrodes shall be determined for the material being tested by consulting Table 4a, 4b, or 4c. A new set of electrodes shall be installed per Clause 8, and the electrode-face/weld size stabilization shall be performed per Clause 9 using the selected parameters.

11.2.3 After the stabilization procedure has been completed, it shall be ascertained that all welding parameters are still at their specified values and that the hold time is set to the short hold time (see Table 4a, 4b, or 4c). All required information shall be entered on the Welding Data Sheet (Form B-1 or equivalent) according to 9.2.2. The items in 9.2.3 shall be checked, and all required data shall be recorded per 9.2.4 as welds are made and tested. Figure 9 shows the surface orientation of peel-test samples (coated sheet steel only) that shall be kept constant for all tests.

11.2.4 The minimum weld button size (MWS) shall be calculated for the sheet thickness being tested using the formula found in 6.7.1.

11.3 I_{MIN} . Current Determination. All welds are at the short hold time.

11.3.1 Based on weld size and welding current data from the weld stabilization procedure (Clause 9), the current setting shall be adjusted low enough to produce a weld that is at least 0.5 mm smaller than the MWS (ideally 0.5 mm to 1.0 mm smaller than the MWS). One peel-test sample shall be welded and tested at this current. If the resulting weld size is:

(1) smaller than MWS–0.5 mm, step 11.3.2 follows.

(2) larger than MWS–0.5 mm (e.g., larger than 3.1 mm for an MWS of 3.6), the current shall be reduced in increments of 300 A, and one peel-test sample shall be welded and tested at each increment until the weld size is smaller than MWS–0.5 mm. When this condition has been met, step 11.3.2 follows.

11.3.2 The current setting shall be increased in increments of approximately 100 A. At each increment, one peel-test sample (any orientation type) shall be welded and tested until a weld is obtained that satisfies both the MWS and the fracture mode requirements (see 6.7.6) for I_{MIN} . *NOTE: After both I_{MIN} criteria have been met by a peel-test sample, a reduction in current is **never** allowed even though the fused region diameter may be greater than the minimum.* The orientation type [C, L, or R (see Figure 7)] of the first peel sample that meets both I_{MIN} criteria shall be recorded.

11.3.3 Using both of the other two sample orientation types not used in step 11.3.2 (i.e., if orientation C was used in step 11.3.2, L and R shall be used in this step), two peel-test samples shall be welded and tested at the same I_{MIN} current setting found in step 11.3.2.

11.3.3.1 If both of these samples meet the I_{MIN} criteria, step 11.3.4 follows.

11.3.3.2 If either of these samples does not satisfy the I_{MIN} criteria, the current setting shall be increased in increments of approximately 100 A, and peel-test samples shall be welded and tested until samples of all three orientations (all welded consecutively at the same current setting) meet the I_{MIN} criteria. After this criterion is met, step 11.3.4 follows.

11.3.4 I_{MIN} shall be calculated (in kA rounded to the nearest 0.1 kA) by averaging the current (recorded to 0.1 kA) measured for the test welds (second weld) from the final three peel-test samples in steps 11.3.2 and 11.3.3.1 or step 11.3.3.2. The average of the measured currents for these samples is the I_{MIN} current. This current shall be coded I_{MIN} and be recorded on the Welding Data Sheet.

11.3.5 The average weld size shall be calculated (rounded to the closest 0.1 mm) for the three peel samples mentioned in 11.3.4. This mean weld size is the I_{MIN} weld size diameter. The mean shall be coded D_{MIN} and be recorded on the Welding Data Sheet.

11.4 I_{MAX} . Current Determination. All welds are at the short hold time.

11.4.1 Starting from the I_{MIN} current established in 11.3, the current setting shall be increased in increments of approximately 100 A. At each increment, one peel-test sample shall be welded and tested until either of the two I_{MAX} criteria [expulsion (interfacial) or severe electrode-to-sheet sticking for both welds of the peel sample] is met. *NOTE: At each increment, the peel sample orientation is to be changed so that the three types of peel samples are sequentially used (e.g., C, then L, then R, then C, etc.).* The orientation type [C, L, or R (see Figure 7)] of all peel-test samples shall be recorded. Once one sample meets either of the I_{MAX} criteria, **welding shall cease immediately**.

11.4.2 The current measured for the test weld (second weld) of the last sample (the one that meets either of the two I_{MAX} criteria) is the I_{MAX} current. This current shall be coded I_{MAX} . The size of this weld shall be coded ID_{MAX} . Both I_{MAX} and ID_{MAX} shall be recorded on the Welding Data Sheet.

11.4.3 After I_{MAX} has been determined, duplicate individual and composite carbon tip imprints of the electrode faces shall be made on the Tip Imprint Data Sheet being used.

11.4.4 The total number of welds (one peel sample = two welds) made in 11.3 and 11.4 shall be recorded on the Welding Data Sheet, being certain not to count any imprint strokes or other nonweld strokes as welds when a mechanical weld counter is used. The weld counter shall then be reset to zero.

11.5 Hold-Time Sensitivity (HTS) Test. The objective of this test is to determine how sensitive a given steel grade is to different rates of thermal quenching (weld cooling). The weld cooling rate in this test is varied by varying the hold time (time the electrodes remain in contact with the weld after the welding current is terminated). Two hold times, short and long, and two weld sizes, small (MWS) and large (FDWS), are employed in this test. The hold times are programmed times at a frequency of 60 Hz and do not necessarily reflect actual contact time.

Table 8 provides the required test panels and hold time and welding current conditions. This test is accomplished by making a series of seven welds on each HTS panel. Two groups of four HTS panels with a total of eight test panels are required for this test. Four of the eight test HTS panels are welded at I_{MWS} to obtain MWS representing a small weld size and the other four are fabricated at I_{FDWS} to have a FDWS weld size which represents a large weld size. In each of the two weld size groups, two panels are welded with short hold time and two welded with long hold time.

Each welded HTS panel is sectioned into individual samples (one weld per sample); samples from four of the panels are destructively peel tested, and samples from the other panels are for metallographic/hardness evaluation (see Table 8). Weld-size and fracture modes are then determined from each peeled sample.

11.5.1 Restabilization of the Electrode Faces. Based on the I_{MIN} and I_{MAX} data from 11.3 and 11.4, the current shall be reset to a level which will produce a weld size that is approximately 80% to 90% of the specified electrode face diameter (e.g., 4 mm to 4.5 mm for a 5 mm electrode face). 19 welds shall then be made on an electrode conditioning panel. The objective of these welds is to restabilize the electrode faces from the expulsion, sticking, or both that was encountered during the I_{MAX} determination.

11.5.2 Welding The HTS Panels

11.5.2.1 Determining I_{MWS} (current required to achieve the Minimum Weld Size)

(1) **Preliminary I_{MWS} Determination with Peel Samples.** With the weld controller set to the “short” hold time (see Tables 4a, 4b, and 4c) and the current set approximately 300 A–500 A less than that determined in step 11.3, the current shall be increased in increments of approximately 100 A, welding and testing one peel-test sample (any sample orientation) at each increment until a weld size that is within the MWS + allowable tolerance is obtained.

The allowable tolerance for sheet thicknesses less than or equal to 1.29 mm is +0.4/–0.0. The allowable tolerance for sheet thicknesses greater than or equal to 1.3 mm is +0.6/–0.0.

Table 8
Conditions/Combinations for Hold-Time Sensitivity (HTS) Tests

Panel No.	Weld Size	Current	Hold Time ^a	Panel Use
1	MWS	I_{MWS}	Short	Peel Test
2	MWS	I_{MWS}	Short	Met./Hardness
3	MWS	I_{MWS}	Long	Peel Test
4	MWS	I_{MWS}	Long	Met./Hardness
5	FDWS	I_{FDWS}	Short	Peel Test
6	FDWS	I_{FDWS}	Short	Met./Hardness
7	FDWS	I_{FDWS}	Long	Peel Test
8	FDWS	I_{FDWS}	Long	Met./Hardness

^a See Tables 4a, 4b, and 4c.

If these allowable tolerances from the MWS cannot be achieved, the I_{MWS} weld current setting which comes closest but does not exceed MWS +0.4 mm (for sheet thickness less than or equal to 1.29 mm) or MWS +0.6 mm sheet thickness greater than or equal to 1.3 mm is used.

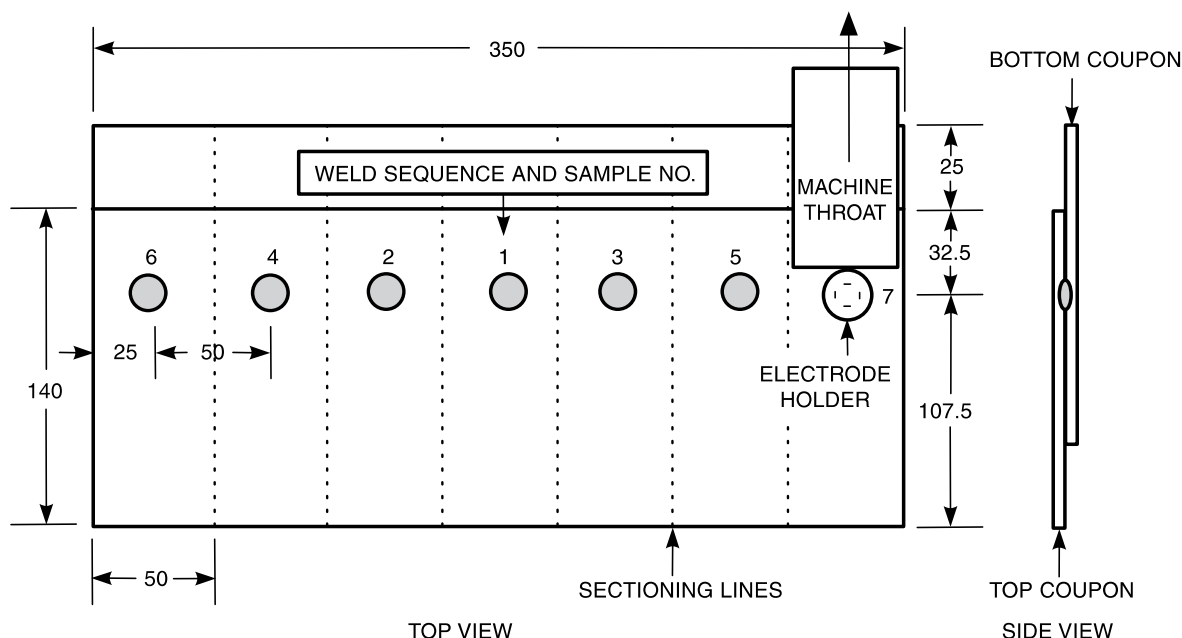
Example: If Sample 5 = 3.7 mm and Sample 6 = 4.3 mm for specified MWS of 3.9 mm, the setting for Sample 6 is used for continuing to step 11.5.2.1(2).

If Sample 5 = 3.7 mm and Sample 6 = 4.4 mm, then the setting for Sample 5, which comes closest to the MWS of 3.9 mm, is used for continuing to step 11.5.2.1(2).

(2) **Final I_{MWS} Determination with Setup HTS Panel Samples.** After the preliminary I_{MWS} has been established with the peel samples, verification that MWS +0.4 mm for $t \leq 1.29$ mm and + 0.6 mm for $t \geq 1.3$ mm will be achieved with actual HTS panels has to be conducted. With the current at the I_{MWS} setting established with peel samples in 11.5.2.1(1), the first setup HTS panel is to be welded in the prescribed sequence shown in Figure 18. After completion of all seven welds, the panel is sectioned as per 11.5.3. All sections are then peel tested, their average weld size diameters measured, and the mean weld size diameter calculated for the 7 welds. It shall then be determined whether condition (a) or (b) noted below applies.

(a) If the mean button diameter of the first setup panel's welds is within MWS +0.4/-0.0 for sheet thicknesses less than or equal to 1.29 mm, and for sheet thickness greater than or equal to 1.3 mm is MWS +0.6/-0.0 and no expulsion welds were noted, the procedure continues in 11.5.2.2.

(b) If the mean button diameter of the first setup panel's welds is not within MWS +0.4/-0.0 for sheet thicknesses less than or equal to 1.29 mm, and for sheet thickness greater than or equal to 1.3 mm is MWS +0.6/-0.0 mm, additional setup panels are to be welded. The correct I_{MWS} for test panel welds is established by adjusting the current setting up or down (depending whether the mean is below or above the tolerance) in increments of about 100 A, welding and testing setup panels (all seven welds are made at the same current increment setting) until the mean weld size diameter of a setup HTS panel meets the MWS +0.4/-0.0 for sheet thicknesses (t) less than or equal to 1.29 mm, and for sheet



Note: All dimensions are in mm.

Figure 18—Weld Layout for HTS Panels

thickness greater than or equal to 1.3 mm is MWS +0.6/–0.0 mm tolerance. *NOTE: If the above tolerance cannot be achieved, the setting with the closest achievable mean that is not greater than MWS +0.4/–0.0 (for $t \leq 1.29$ mm or MWS +0.6/–0.0 mm for $t \geq 1.3$ mm) shall be used. Thus, the correct or final I_{MWS} current setting is that which produces the mean weld size diameter which is closest to the MWS without exceeding the stated tolerance on a setup HTS panel.* For the following examples, a size tolerance of MWS +0.6/–0.0 mm for $t \geq 1.3$ mm is used. The following examples cover several possible scenarios:

(i) If Mean 1 = 5.0 mm and Mean 2 (at the next higher current increment) = 5.6 mm for a MWS of 5.0 mm, the current setting of Mean 1 shall be used. (When both means are within equal tolerance, the smaller weld size is preferred.)

(ii) If Mean 1 = 4.9 mm and Mean 2 (at the next higher current increment) = 5.7 mm for a MWS of 5.0 mm, the current setting of Mean 2 shall be used. (While both exceed tolerance, all welding must be at MWS or greater.)

(iii) If Mean 1 = 4.9 mm and Mean 2 (at the next higher current increment) = 5.6 mm for a MWS of 5.0 mm, the current setting of Mean 2 shall be used. (Mean 1 exceeds MWS +0.6/–0.0 mm tolerance.)

11.5.2.2 Welding HTS Test Panels 1 & 2 (Short Hold Time). Once the correct I_{MWS} current setting is determined (per 11.5.2.1) with the setup HTS panels, test panels 1 and 2 shall be welded at the I_{MWS} current and short hold time using the designated weld sequence and spacing as shown in Figure 18. The welding current of each weld is to be recorded and the mean I_{MWS} current should be calculated. Each panel and weld shall be properly coded before sectioning.

11.5.2.3 Welding HTS Test Panels 3 & 4 (Long Hold Time). Without adjusting the current setting (that used for welds on HTS test panels 1 and 2 in 11.5.2.2), the hold time is to be increased to 90 cycles and test panels 3 and 4 shall be welded. The welding current of each weld is to be recorded and the mean I_{MWS} current should be calculated. Each panel and weld shall be properly coded before sectioning.

11.5.2.4 Determining I_{FDWS} (current required to achieve the Face-Diameter Weld Size)

(1) **Preliminary I_{FDWS} Determination with Peel Samples.** With the weld controller set to the “short” hold time (see Table 4a, 4b, or 4c) and the current set to that used in step 11.5.1, the current shall be increased in increments of approximately 100 A, welding and testing one peel-test sample (any sample orientation) at each increment until a weld size that is within the FDWS ± 0.2 mm for $t < 1.29$ mm and ± 0.3 mm for $t > 1.3$ mm tolerance is obtained. *NOTE: If expulsion is encountered, welding shall cease and the previous nonexpulsion setting for the preliminary I_{FDWS} shall be used.* If the required tolerance from the FDWS cannot be achieved, the setting which comes closest but does not exceed FDWS +0.2 mm for $t < 1.29$ mm and +0.3 mm for $t > 1.3$ mm and is without any expulsion is used. For example: if Sample 5 = 4.7 mm and Sample 6 = 5.3 mm for an FDWS of 5.0 mm, yet Sample 6 had expulsion, the setting for Sample 5 is used for continuing to step 11.5.2.4 (2).

(2) **Final I_{FDWS} Determination with Setup HTS Panel Samples.** After the preliminary I_{FDWS} has been established with the peel samples, verification that FDWS ± 0.2 mm for $t < 1.29$ mm and ± 0.3 mm for $t > 1.3$ mm will be achieved with actual HTS panels has to be conducted. With the current at the I_{FDWS} setting established with peel samples in 11.5.2.4(1), the first setup HTS panel is to be welded in the prescribed sequence shown in Figure 18. After completion of all seven welds, the panel is sectioned as per 11.5.3. All sections are then peel tested, their average weld size diameters measured, and the mean weld size diameter calculated for the 7 welds. It shall then be determined whether condition (a) or (b) noted below applies.

(a) If the mean weld size diameters of the first setup panel’s welds are within FDWS ± 0.2 mm for $t < 1.29$ mm and ± 0.3 mm for $t > 1.3$ mm and no expulsion welds were noted, the procedure continues in 11.5.2.5.

(b) If the mean weld size diameters of the first setup panel’s welds are not within FDWS ± 0.2 mm for $t < 1.29$ mm and ± 0.3 mm for $t > 1.3$ mm and/or expulsion welds were noted, additional setup panels are to be welded. The correct I_{FDWS} for test panel welds is established by adjusting the current setting up or down (depending whether the mean is below or above the tolerance) in increments of about 100 A, welding and testing setup panels (all seven welds are made at the same current increment setting) until the mean weld size diameter of a setup HTS panel meets the FDWS ± 0.2 mm for $t < 1.29$ mm and ± 0.3 mm for $t > 1.3$ mm shall be used. Thus, the correct or final I_{FDWS} current setting is that which: (1) produces no expulsion, and (2) produces the mean weld size diameter which is closest to the FDWS without exceeding the FDWS +0.2 mm for $t < 1.29$ mm and +0.3 mm for $t > 1.3$ mm tolerance on a setup HTS panel. The following examples cover several possible scenarios for HTS at FDWS weld sizes:

(i) If Mean 1 = 4.9 mm and Mean 2 (at the next higher current increment) = 5.1 mm for a FDWS of 5.0 mm and none of the welds for either Mean 1 or Mean 2 exhibited expulsion, the current setting of Mean 2 shall be used. (When both means are within equal tolerance, the larger weld size is preferred.)

(ii) If Mean 1 = 4.9 mm and Mean 2 (at the next higher current increment) = 5.2 mm for a FDWS of 5.0 mm and none of the welds for either Mean 1 or Mean 2 exhibited expulsion, the current setting of Mean 1 shall be used. (Mean 1 is closer to the FDWS.)

(iii) If Mean 1 = 4.6 mm and Mean 2 (at the next higher current increment) = 5.4 mm for a FDWS of 5.0 mm and none of the welds for either Mean 1 or Mean 2 exhibited expulsion, the current setting of Mean 1 shall be used. (Mean 2 exceeds +0.3 mm tolerance.)

(iv) If Mean 1 = 4.6 mm and Mean 2 (at the next higher current increment) = 4.8 mm for a FDWS of 5.0 mm, **but** the last weld (test weld of sample 3) in the Mean 2 group **exhibited expulsion**, the current setting of Mean 1 shall be used.

11.5.2.5 Welding HTS Test Panels 5 & 6 (Short Hold Time). Once the correct I_{FDWS} current setting is determined (per 11.5.2.4) with the setup HTS panels, test panels 5 and 6 shall be welded at the I_{FDWS} current and short hold time using the designated weld sequence and spacing as shown in Figure 18. The welding current of each weld is to be recorded and the mean I_{FDWS} current should be calculated. Each panel and weld shall be properly coded before sectioning.

11.5.2.6 Welding HTS Test Panels 7 & 8 (Long Hold Time). Without adjusting the current setting (that used for welds on HTS test panels 5 and 6 in 11.5.2.5), the hold time is to be increased to 90 cycles and test panels 7 and 8 shall be welded. The welding current of each weld is to be recorded and the mean I_{FDWS} current should be calculated. Each panel and weld shall be properly coded before sectioning.

11.5.3 Sectioning and Testing of HTS Panels

11.5.3.1 Sectioning. After all eight (8) HTS panels are welded, each panel shall be sectioned into individual HTS samples by shearing or saw cutting at the dotted lines in Figure 18. The width of these samples is given in Figure 18. *NOTE: All samples are to be properly coded prior to sectioning so that panel and weld codes are not lost during the sectioning operation.*

11.5.3.2 Peel Testing. All welds from Panels 1, 3, 5, and 7 shall be peel tested using standard peel testing techniques and equipment. The size of each weld shall be measured and recorded per standard procedure (see 6.7.4), and the weld button fracture mode shall be determined (see 6.7.5) and recorded. *NOTE: The entire fused region (button and interfacial fracture) and the weld button are to be measured. The diameter for the total fused region shall be enclosed in brackets.* For example: 3.6 mm (4.9 mm) indicates that the mean diameter of the pulled out, partial button is 3.6 mm and the mean diameter of the fused region is 4.9 mm.

11.5.3.3 Metallographic/Hardness Testing. *NOTE: Hardness testing shall be performed at the discretion of the party for whom the material is tested. Hardness testing is highly recommended on high-strength sheet steels (Groups 3 and 4), but may be applied to groups 1 and 2 steels as well.*

(1) **Sample Preparation.** Two HTS samples shall be randomly selected from each of the even-numbered panels (Panels 2, 4, 6, and 8). One of the samples from each panel shall be sectioned slightly offset from its weld centerline so that the centerline is parallel to the sample length [see Figure 19(A)]. These samples are defined as the longitudinal metallographic samples and are to be coded as such. The other sample from each panel shall be sectioned slightly offset from its weld centerline so that the centerline is perpendicular to the sample length [see Figure 19(B)]. These samples are defined as the transverse metallographic samples and are to be coded as such. *NOTE: The offset from the weld centerline has to be sufficient so that the specimens can be ground and polished to the centerline of the weld during specimen preparation.* All specimens shall be mounted and polished to the centerline for metallographic examination and micro-indentation hardness testing.

(2) **Weld Microstructure.** After completion of the final polish, photomicrographs (10X to 20X) may be taken of all specimens in the unetched condition. After the desired photographs of the unetched samples are taken, the specimens shall be etched in a suitable etchant to bring out the weld features (weld nugget, heat-affected zone) and base metal. Any specified or desired (as determined by the specifying party) photomicrographs and photomicrographs shall be taken after etching and prior to hardness testing.

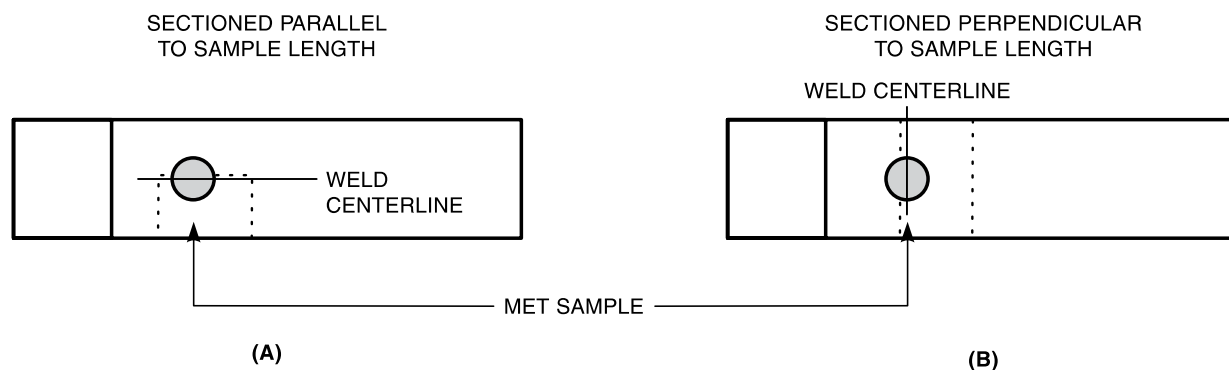


Figure 19—Sectioning of Test Welds for Metallographic Examination and Hardness Testing

(3) **Hardness Testing.** Hardness testing shall be performed as shown in Figure 20 (diagonal traverse across the weld from base metal of top coupon to base metal of bottom coupon) using a suitable instrument for microindentation hardness testing (Vickers or Knoop). All hardness testing shall be performed at a temperature of $23^{\circ}\text{C} \pm 5^{\circ}\text{C}$. A constant force that is between 0.2 kg (1.961 N) and 1 kg (9.807 N) shall be used for all indentations. All indentations shall be made at 0.4 mm spacing or no less than three times the mean diagonal of any two adjacent indentations. *NOTE: If the distance between the centers of two adjacent indentations is less than three times the mean diagonal of either indentation, the spacing should be increased.* The approach velocity of the indenter shall not exceed 200 $\mu\text{m}/\text{second}$. The time from initial application of force until the test force is reached shall not exceed 10 seconds. The duration of the test force shall be 10 seconds to 15 seconds. The results shall be reported in tabular or graphical form.

11.6 Shear and Cross Tension Tests. The objective of these tests is to determine the shear tension and direct (cross) tension strengths of a test material at two hold times (short and long, see Table 4) and two weld sizes. The hold times are programmed times at a frequency of 60 Hz and do not necessarily reflect actual contact time. Test welds are made at both the I_{MWS2} and I_{FDWS2} current. Table 9 should be referenced for the required combinations and conditions. *NOTE: FDWS weld size = specified, dressed electrode-face diameter listed in Table 4, MWS weld size = specified per 6.7.1.*

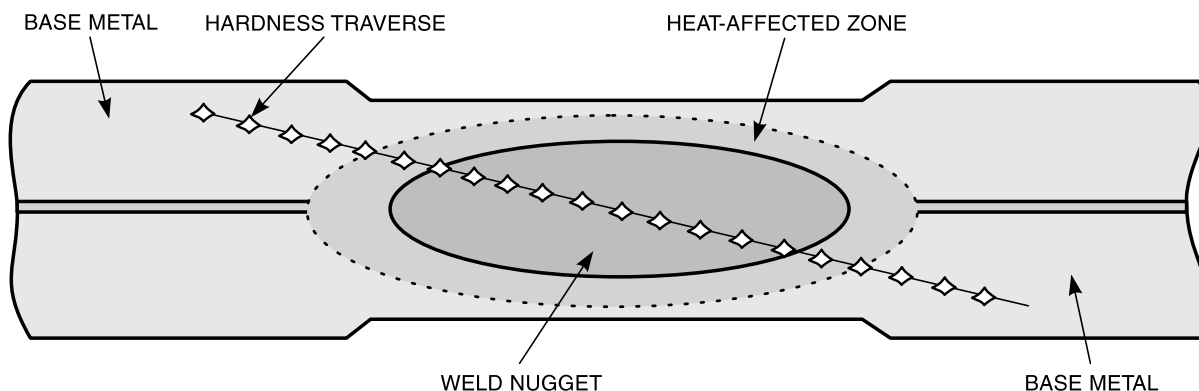


Figure 20—Cross-Sectioned Weld and Hardness Traverse

Table 9
Conditions/Combinations for Shear and Cross Tension Tests

Condition No.	Weld Size	Current	Hold Time ^a
1	MWS	I_{MWS2}	Short
2	MWS	I_{MWS2}	Long
3	FDWS	I_{FDWS2}	Short
4	FDWS	I_{FDWS2}	Long

^a See Tables 4a, 4b, and 4c.

NOTE: Because all test welds on these samples are single welds, the I_{MWS} and I_{FDWS} currents required to produce the proper weld size may be slightly different (probably lower) from the I_{MWS} and I_{FDWS} current that is required for the HTS tests. To distinguish between the two currents, the current required for all shear and cross tension samples will be designated I_{MWS2} and I_{FDWS2} . Table 9 shows the combinations and conditions used. Table 10 and Figure 20 show the dimensions and schematic for the shear tension samples. Table 11 and Figure 22 show specimen dimensions and schematic for the cross tension samples.

11.6.1 Welding Shear and Cross Tension Samples

11.6.1.1 Determining I_{MWS2} (current required to achieve the MWS on shear and cross tension samples). The weld controller shall be set to the short hold time, and the welding current shall be reduced approximately 500 A from the I_{MWS} current setting (see 11.5) for the HTS panel welds. Starting from this current ($I_{MWS} - 500$ A), the current shall be increased in increments of 100 A, and one shear tension sample shall be welded (according to the specifications in Table 10 and Figure 21) and peel tested at each increment until a weld size of MWS is achieved. Once this criterion is met, two additional shear tension samples shall be welded at this current. These samples shall be peel tested, their weld sizes determined, and the mean weld size calculated for all three samples.

Table 10
Shear Tension Sample Dimensions

Sheet Thickness (mm)	Coupon Length L ^a (mm)	Coupon Width W ^b (mm)	Overlap O ^b (mm)	Sample Length SL ^a (mm)	Unclamped Length UL ^b (mm)	Gripped Length GL ^a (mm)
0.60–1.29	105	45	35	175	95	40
1.30–3.00	138	60	45	230	105	62.5

^a May be increased to accommodate gripping fixtures.

^b Tolerance: ± 1 mm.

Table 11
Cross Tension Sample Dimensions

Sheet Thickness (mm)	Coupon Length L ^a (mm)	Coupon Width W ^b (mm)	Overlap O (mm)	Hole Spacing HS ^c (mm)
0.60–3.00	150	50	50	100

^a Tolerance: $+0, -0.5$ mm.

^b Tolerance: $+0, -1.0$ mm.

^c Tolerance: ± 0.2 mm.

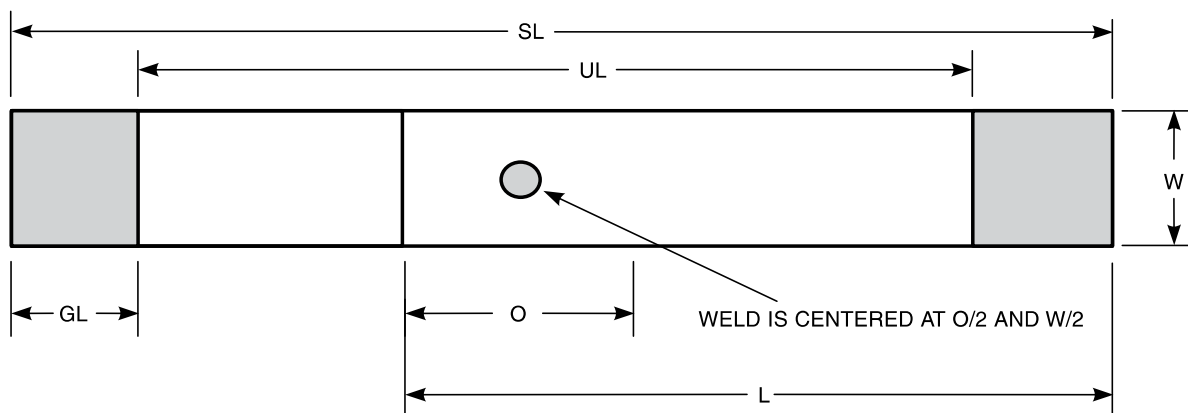


Figure 21—Schematic for Shear Tension Samples

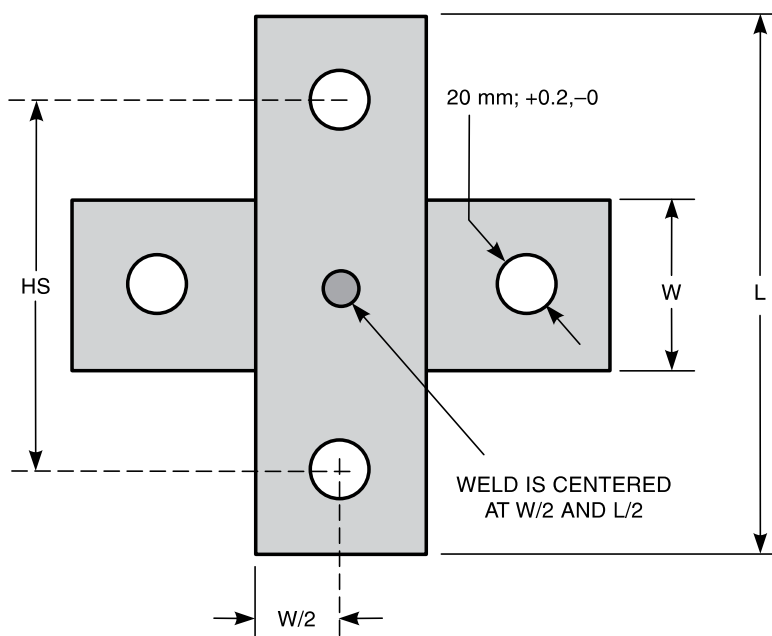


Figure 22—Schematic for Cross Tension Samples

If the mean weld size of these three samples is less than the MWS (+0.4 mm for $t < 1.29$ mm and +0.6 mm for $t > 1.3$ mm), the current shall be increased in increments of 100 A until the proper weld size is reached by the mean of three shear tension samples (all three welded consecutively at the same current setting). This current shall be coded I_{MWS2} .

11.6.1.2 Welding the Shear and Cross Tension Samples at the Short Hold Time. Once the I_{MWS2} current setting is determined (per 11.6.1.1), three shear tension samples shall be welded (according to the specifications in Table 10 and Figure 21) and three cross tension samples shall be welded (according to the specifications in Table 11 and Figure 22). The welding current of each weld shall be recorded and each specimen is to be properly coded.

11.6.1.3 Welding the Shear and Cross Tension Samples at the Long Hold Time. Without adjusting the I_{MWS2} current used to weld the specimens in 11.6.1.2, the hold time is increased to 90 cycles, three shear tension samples are

welded (according to the specifications in Table 10 and Figure 21), and three cross tension samples are welded (according to the specifications in Table 11 and Figure 22). The welding current of each weld shall be recorded and each specimen is to be properly coded.

11.6.2.1 Determining I_{FDWS2} (current required to achieve the FDWS on shear and cross tension samples).

The weld controller shall be set to the short hold time, and the welding current shall be reduced approximately 500 A from the I_{FDWS} current setting (see 11.5) for the HTS panel welds. Starting from this current ($I_{FDWS} - 500$ A), the current shall be increased in increments of 100 A, and one shear tension sample shall be welded (according to the specifications in Table 10 and Figure 21) and peel tested at each increment until a weld size that is 90% (or slightly greater) of the FDWS is achieved. Once this criterion is met, two additional shear tension samples shall be welded at this current. These samples shall be peel tested, their weld sizes determined, and the mean weld size calculated for all three samples.

If the mean weld size of these three samples does not equal or *slightly* exceed the FDWS, the current shall be increased in increments of 100 A until the FDWS is reached or *slightly* exceeded by the mean of three shear tension samples (all three welded consecutively at the same current setting). This current shall be coded I_{FDWS2} . *NOTE: If expulsion is encountered on any weld, welding shall cease, and the current setting that is one increment below where expulsion was noted shall be used for I_{FDWS2} .* If the tolerance of ± 0.3 mm from the FDWS cannot be achieved, the current setting that produces the closest achievable tolerance that is not greater than $FDWS + 0.2$ mm for $t < 1.29$ mm and $+0.3$ mm for $t > 1.3$ mm and is without *any* expulsion welds in the three samples shall be used. The following examples cover several possible scenarios:

(1) If Mean 1 = 4.9 mm and Mean 2 (at the next higher current increment) = 5.1 mm for an FDWS of 5.0 mm and none of the welds for either Mean 1 or Mean 2 exhibited expulsion, the current setting for Mean 2 shall be used. (When both means are within equal tolerance, the larger weld size is preferred.)

(2) If Mean 1 = 4.9 mm and Mean 2 (at the next higher current increment) = 5.2 mm for an FDWS of 5.0 mm and none of the welds for either Mean 1 or Mean 2 exhibited expulsion, the current setting for Mean 1 shall be used. (Mean 1 is closer to the FDWS.)

(3) If Mean 1 = 4.6 mm and Mean 2 (at the next higher current increment) = 5.4 mm for an FDWS of 5.0 mm and none of the welds for either Mean 1 or Mean 2 exhibited expulsion, the current setting for Mean 1 shall be used. (Mean 2 exceeds $+0.3$ mm tolerance.)

(4) If Mean 1 = 4.6 mm and Mean 2 (at the next higher current increment) = 4.8 mm for an FDWS of 5.0 mm, but the last weld (sample 3) in the Mean 2 group exhibited expulsion, the current setting for Mean 1 shall be used.

11.6.2.2 Welding the Shear and Cross Tension Samples at the Short Hold Time. Once the I_{FDWS2} current setting is determined (per 11.6.2.1), three shear tension samples are welded (according to the specifications in Table 10 and Figure 21) and three cross tension samples are welded (according to the specifications in Table 11 and Figure 22). The welding current of each weld shall be recorded and each specimen is to be properly coded.

11.6.2.3 Welding the Shear and Cross Tension Samples at the Long Hold Time. Without adjusting the I_{FDWS2} current used to weld the specimens in 11.6.2.2, the hold time is increased to 90 cycles, three shear tension samples are welded (according to the specifications in Table 10 and Figure 21), and three cross tension samples are welded (according to the specifications in Table 11 and Figure 22). The welding current of each weld shall be recorded and each specimen is to be properly coded.

11.6.3 Testing of Shear and Cross Tension Specimens. For each sample, the ultimate tensile load shall be recorded. Also, the size of each weld shall be measured and recorded per standard procedure (see 6.7.4), and the weld button fracture mode shall be determined (see 6.7.5) and recorded. *NOTE: The entire fused region (button and interfacial fracture) and the weld button are to be measured. The diameter for the total fused region shall be enclosed in brackets.* For example: 3.6 mm (4.9 mm) indicates that the mean diameter of the pulled out, partial button is 3.6 mm and the mean diameter of the fused region is 4.9 mm.

11.6.3.1 Shear Tension Samples. All testing shall be performed at room temperature ($20^{\circ}\text{C} \pm 5^{\circ}\text{C}$) on a suitable, calibrated tensile testing machine. A cross head velocity of 10 mm/minute shall be used for all tests. The specimens shall be gripped so that the ungripped (UL) and gripped (GL) lengths are as listed in Table 10. Shims of the same thickness as the test material shall be used on all specimens as shown in Figure 23.

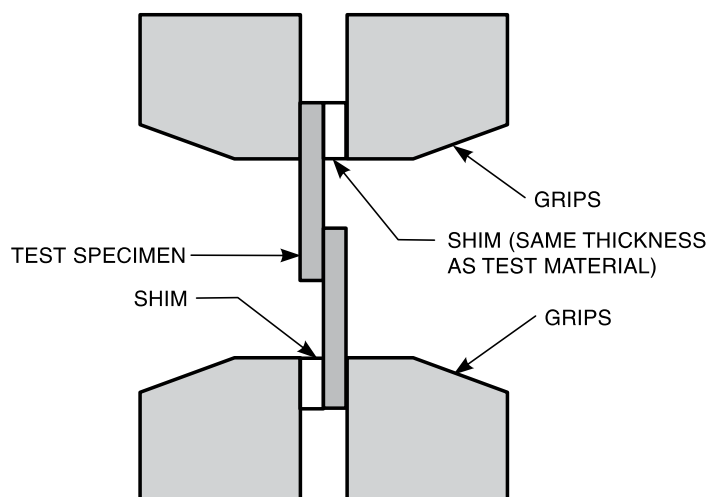


Figure 23—Schematic for Testing of Shear Tension Samples

11.6.3.2 Cross Tension Samples. All testing shall be performed at room temperature ($20^{\circ}\text{C} \pm 5^{\circ}\text{C}$) on a suitable, calibrated tensile testing machine. A cross head velocity of 10 mm/minute shall be used for all tests. The specimens shall be gripped in a suitable fixture so that bending of the specimen is minimized. A typical gripping fixture (two required) is shown in Figure 24.

11.7 Replication. Any individual or all portions of the Weld Property Test may be replicated as many times as deemed necessary by the party specifying the test.

11.8 Test Report. All of the following items shall be reported on the Weld Property Test Report [Form B-5 (see Annex B) or equivalent].

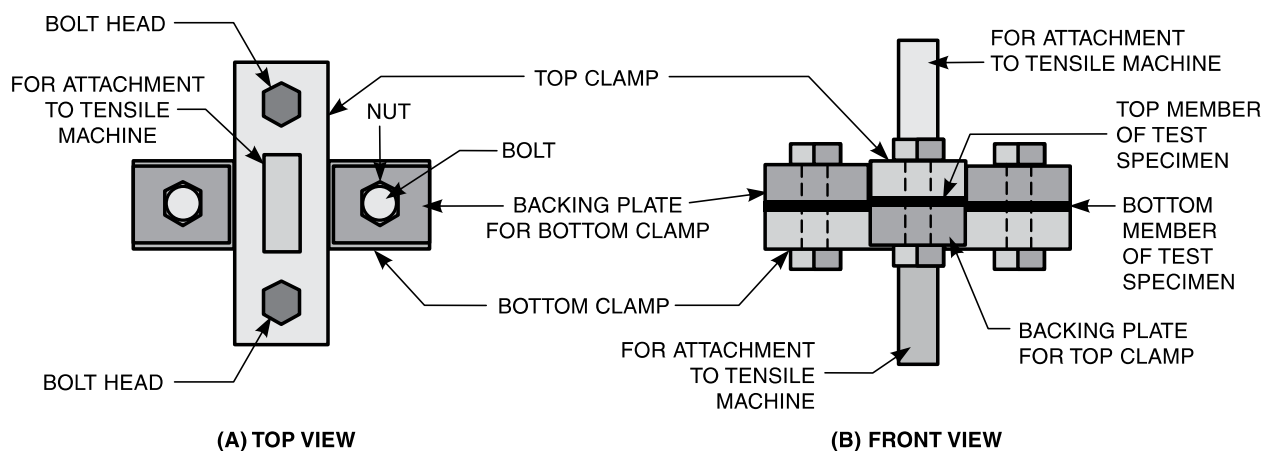


Figure 24—Test Fixture Schematic for Testing of Cross Tension Samples

11.8.1 General Items

- (1) Date(s) of test and the report date
- (2) Name and address of testing facility
- (3) Name of test operator and signature of person approving the test report
- (4) List and description of all test equipment
- (5) Any variances to specified test equipment
- (6) All welding parameters (including electrodes)

11.8.2 Current Level and Current Range Data for Each Replication

- (1) I_{MIN} .
- (2) I_{MAX} .
- (3) Current range ($I_{MAX} - I_{MIN}$.)

11.8.3 Hold Time Sensitivity Data

- (1) Mean I_{MWS} and I_{FDWS} welding currents for each hold time
- (2) Individual and mean button *and* fused region diameters for each hold time
- (3) Fracture Mode of all welds detailed by category
- (4) Plot or tabular list of hardness traverse (optional)

11.8.4 Shear Tension Data

- (1) Mean I_{MWS2} and I_{FDWS} welding currents for each hold time
- (2) Individual and mean button *and* fused region diameters for each hold time
- (3) Fracture Mode of all welds detailed by category
- (4) Individual and mean strength at each hold time

11.8.5 Cross Tension Data

- (1) Mean I_{MWS2} and I_{FDWS} welding currents for each hold time
- (2) Individual and mean button *and* fused region diameters for each hold time
- (3) Fracture Mode of all welds detailed by category
- (4) Individual and mean strength at each hold time

12. Current Break-Through Test

12.1 Scope. This procedure describes a resistance spot welding Current Break-Through Test designed to determine the effect that a lubricant, conductive paint, or other sheet surface treatment (collectively referred to as surface treatment throughout this clause) has on the initiation of current flow during welding. If the surface treatment increases the contact resistance of the sheet surface significantly, difficulties in initiating current flow may be encountered. This behavior could lead to inadequate nugget development or no weld at all, depending on how much of the weld time is required to break-through the resistive coating. Such a condition may not be acceptable as it could lead to discrepant welds. The surface treatments for which this test may be applied should be specified by the party for whom testing is performed. The aging of lubricants, conductive paints, or other sheet surface treatment is important to the results obtained in the break-through test, but outside the scope of this document. This test can also be applied to adhesives and sealers if the test originator specifies the aging period of the material to be applied, as well as the handling of the coupons during the test. The originator would need to specify how the material was to be applied (poured, spread, brushed, etc.), the thickness of the material after application, the position on the coupons where the material must be placed, and any other processing infor-

mation (e.g., whether covered with adhesive and immediately made into a “sandwich,” or left “open face” during the aging period prior to the test).

12.2 Equipment. The Current Break-Through Test is conducted with the welding and test equipment described in Clause 7, except that “Constant Current” controls are not permitted. A welding current analyzer with the capability of measuring and printing out the welding current reading at each half cycle or a high speed (100 mm/second minimum) strip chart recorder is required to monitor and record each half-cycle of the welding current.

12.3 Test Materials. The only test materials required for this test are peel-test coupons of the test material and, if available, of the control material without the surface treatment. If it is possible to remove the surface treatment (by degreasing or chemical removal of the treatment) to restore the samples to the untreated condition, such samples should be used as the control material.

12.3.1 The peel-test coupons should be of the dimensions shown in Table 2 for the thickness of material being tested. The peel-test coupons should be extracted according to the instructions in Clause 4. Approximately 100 coupons are typically sufficient to conduct this test. *NOTE: If the surface treatment is on only one side of the sheet, this side shall receive the surface ID mark (see 4.4).*

12.3.2 All test materials shall be tested as received unless the party for whom the testing is being performed specifies otherwise. All treatments or processing requested by the submitter to the as-received samples shall be documented on the welding data sheet.

12.4 Test Preparation

12.4.1 Electrode Installation and Dressing. The electrodes specified in Tables 4a, 4b, and 4c for the thickness of material being tested shall be installed and dressed according to Clause 8.

12.4.2 Welding Parameters. Welding parameters shall be set to those specified in Tables 4a, 4b, and 4c for the thickness of material being tested. Since only one weld is made per peel-test sample, the weld spacings (WS) listed in Table 5 do not apply. However, the coupon overlap dimensions (A) and weld location for Weld 2 (B) in Figure 5 and Table 5 apply.

12.4.3 Electrode-Face and Weld-Size Stabilization. It is not necessary to condition the electrodes using the Electrode-Face and Weld-Size Stabilization Procedure of Clause 9 for the Current Break-Through Test.

12.5 Determination of the Current Break-Through Test Current (I_{CBT}). The current that is to be used for welding the test samples is designated as I_{CBT} and is defined as the current that produces a weld size that is closest to (but does not exceed) the electrode-face diameter without causing expulsion. If expulsion is encountered before reaching a weld size that equals the electrode-face diameter, the highest nonexpulsion current is used even though the weld size is not equal to the electrode-face diameter. *NOTE: All welds for determining I_{CBT} are made with the control (untreated) test material using single-weld peel-test samples. No upslope shall be used for the welding current in this test.*

12.5.1 After completion of electrode installation and electrode dressing, one single-weld peel-test sample shall be welded at the default starting current listed in Table 7 for the material thickness being welded. The surface orientation of all test samples shall be with the marked surfaces facing each other, as shown in Figure 25. The “Code C” sample orientation shown in Figure 7 should be used throughout the test. This weld is then peel tested and measured using the standard procedures described in 6.7.4. After weld size measurements are complete, it is to be determined whether 12.5.1.1 or 12.5.1.2 applies, and the applicable instructions are to be followed.

12.5.1.1 If this weld exhibited no expulsion and is smaller than 90% of the face diameter of the electrodes (4.5 mm for a 5 mm electrode face), the current is to be increased in increments of approximately 300 A. At each increment, single-weld peel-test samples shall be welded and tested until the mean weld size approximates 90% the electrode-face diameter or expulsion is attained. If expulsion is not attained at the current that produces a weld size that is 90% of the electrode-face diameter, the current is then increased in increments of approximately 100 A. At each increment, single-weld peel-test samples shall be welded and tested until the mean weld size equals the electrode-face diameter or expulsion is attained.

12.5.1.2 If this weld exhibited expulsion, the current is to be decreased in increments of approximately 100 A. At each increment, single-weld peel-test samples shall be welded and tested until a no-expulsion weld is obtained.

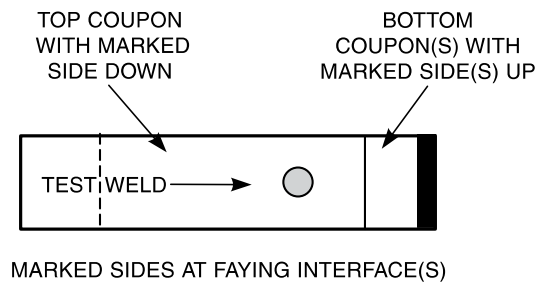


Figure 25—Surface Orientation of CBT Peel-Test Samples

12.5.2 Using the definition for I_{CBT} (see 12.5), I_{CBT} shall be determined by examining the data from 12.5.1.1 or 12.5.1.2, and the weld controller shall be set to the I_{CBT} current.

12.6 Welding the Current Break-Through Control and Test Samples

12.6.1 The weld controller shall be set to the I_{CBT} current determined in 12.5.2.

12.6.2 Current Monitoring

12.6.2.1 If a current analyzer (capable of providing current readings for every half-cycle of welding current and having printing capability for all half-cycles) is used for monitoring half-cycle welding current, the “Print” feature is to be enabled. A printout of I_{EFF} and of each half-cycle’s current shall be obtained for each weld. Figures 26A, 26B, and 26C show typical printouts. (See 12.7 for more details on analysis procedures.)

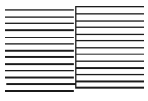
12.6.2.2 If a high-speed strip chart recorder is used for monitoring half-cycle welding current, the recorder has to be adjusted so that its scale is large enough to make accurate length measurements of the current peaks. The strip chart also has to be capable of a 100 mm/second chart speed. The strip should be turned on just prior to welding each sample and turned off after completion of each weld. A trace of all half-cycles of the current shall be obtained for each weld. Current break-through time (CBTT) is determined by measuring the heights of all peaks (from the current polarity cross-over), calculating the mean height, and calculating the percentage that each of the peaks are of the mean height. (See 12.7 for more details on analysis procedures.)

12.6.3 Welding the Control Samples. The control samples are used to establish the typical current trace or output for the machine being used so that the electrical characteristics of the machine’s current output do not affect the analysis of the current data of the test material. If the welding current does not reach 95% of the steady state value (the value observed when no test material is placed between the coupons) then either equipment or material problems exist, and must be resolved. The samples may be peel tested and their weld sizes measured, but this is not mandatory since the test criterion is current break-through time, not weld size. *NOTE: It is possible that no-fusion welds will be achieved with the four-coupon stack-up, but that is nothing to be concerned about because current break-through (the test criterion) takes precedence.*

12.6.3.1 Two-Coupon Stack-Up. One two-coupon stack-up weld (see Figure 25) shall be made on each of five single-weld peel-test samples using the control material (no treatment). These should be coded xxxxC2-y, where xxxx is the material code, C2 indicates control material with 2-coupon stack-up, and y is the test weld number.

12.6.3.2 Four-Coupon Stack-Up. One four-coupon stack-up weld shall be made on each of five single-weld peel-test samples using the control material (no treatment). These should be coded xxxxC4-y, where xxxx is the material code, C4 indicates control material with 4-coupon stack-up, and y is the test weld number.

12.6.3.3 Each weld shall be clearly coded and is to have a printout or a clear peak-to-peak trace of all half-cycles of its welding current. Each printout or trace is to be identified with the test code of the welded sample.

EFCT CUR. = 8.92 KA PEAK CUR. = 14.76 KA CNDT ANGLE = 129° DEVIATION = -10% WELD TIME = 10.0 CV				EFCT CUR. = 8.80 KA PEAK CUR. = 14.40 KA CNDT ANGLE = 130° DEVIATION = -12% WELD TIME = 10.0 CV				EFCT CUR. = 13.08 KA PEAK CUR. = 20.91 KA CNDT ANGLE = 164° DEVIATION = +30% WELD TIME = 10.0 CV (FIRST 3 = 0% HALF-CYCLES)			
											
83%→	1	9.22KA 8.39KA	127° 125°	82%→	1	7.23KA 9.19KA	119° 135°	8%→	1	1.05KA 1.83KA	61° 57°
94%→	2	9.06KA 8.74KA	129° 127°	104%→	2	9.67KA 9.58KA	136° 136°	37%→	2	4.90KA 10.00KA	142° 155°
	3	9.03KA 8.84KA	129° 127°		3	8.90KA 8.87KA	129° 130°		3	12.09KA 12.86KA	163° 164°
	4	9.00KA 8.84KA	127° 127°		4	8.58KA 8.87KA	126° 130°		4	12.44KA 12.95KA	164° 166°
	5	8.90KA 8.90KA	127° 129°		5	8.71KA 8.90KA	127° 130°		5	13.60KA 14.08KA	169° 170°
	6	8.97KA 8.97KA	127° 127°		6	8.71KA 8.93KA	129° 130°		6	14.24KA 14.66KA	170° 171°
	7	9.00KA 8.93KA	127° 127°		7	8.68KA 8.93KA	127° 130°		7	14.59KA 13.08KA	171° 160°
	8	8.90KA 9.06KA	127° 129°		8	8.61KA 9.00KA	127° 130°		8	13.02KA 11.28KA	160° 145°
	9	8.97KA 9.00KA	127° 129°		9	8.65KA 8.90KA	127° 130°		9	11.22KA	147°
	10	8.45KA 9.00KA	123° 129°		10	8.71KA 8.90KA	127° 130°				
(A) 0 Half-Cycles of CBTT				(B) 1 Half-Cycle of CBTT				(C) 8 Half-Cycles of CBTT			

**Figures 26A through 26C—Examples of
Current Analyzer Printouts for Welds on Three Materials**

12.6.4 Welding the Test Material Samples. The samples may be peel tested and their weld sizes measured, but this is not mandatory since the test criterion is current break-through time, not weld size. *NOTE: It is possible that no-fusion welds will be achieved with the four-coupon stack-up, but that is nothing to be concerned about because current break-through (the test criterion) takes precedence.*

12.6.4.1 Two-Coupon Stack-Up. One two-coupon stack-up weld shall be made on each of five single-weld peel-test samples using the test material. These should be coded xxxxT2-y, where xxxx is the material code, T2 indicates test material with 2-coupon stack-up, and y is the test weld number.

12.6.4.2 Four-Coupon Stack-Up. One four-coupon stack-up weld shall be made on each of five single-weld peel-test samples using the test material. These should be coded xxxxT4-y, where xxxx is the material code, T4 indicates test material with 4-coupon stack-up, and y is the test weld number.

12.6.4.3 Each weld shall be clearly coded and is to have a printout or a clear peak-to-peak trace of all half-cycles of its welding current. Each printout or trace is to be identified with the test code of the welded sample.

12.7 Analyzing the Welding Current Data

12.7.1 Using the current analyzer printout or strip chart trace for each test sample (control and test materials), the percentage that each half-cycle's current is of the steady state current (I_{EFF}) shall be calculated. If it is obvious that the percentage exceeds the minimum current break-through threshold of 90% of the steady state current after several half-cycles, there is no need to calculate the percentage for the remaining half cycles.

12.7.2 Each half-cycle that is below the 90% limit is considered to have not achieved current break-through. Figures 26A, 26B, and 26C show typical printouts. Figure 26A shows an output for a material where no current break-through time (CBTT) was required. The current is already above 100% of the mean (effective) current (8.92 kA) for the first half-cycle. Therefore, the CBTT is 0. Figure 26B shows an example where the first half-cycle does not achieve the minimum threshold of 90% of the mean current (8.80 kA). Therefore, the CBTT of this weld is 1 half-cycle. Figure 26C shows an example where the first 3 half-cycles did not pass any measurable current and the next 4 half-cycles did not achieve the minimum threshold of 90% of the mean current (13.08 kA). The CBTT of this weld is 7 half-cycles.

12.7.3 The number of half-cycles that are below the 90% minimum are to be counted, summed, recorded, and reported (per 12.8) for each weld. The pass/fail criteria shall be specified by the client for whom the testing is performed.

12.8 Test Report. A test report, similar to that shown in Annex B, Form B-6, should be issued to summarize the test results. All welding and test data should be reported in the blank areas.

12.8.1 General Items

- (1) Date(s) of test and the report date
- (2) Name and address of testing facility
- (3) Name of test operator and signature of person approving the test report
- (4) Test codes and test material data and description
- (5) List and description of all test equipment
- (6) Any variances to specified test equipment
- (7) All welding parameters (including electrodes)
- (8) Lubricant/surface treatment/adhesive properties [type, aging conditions (if any), thickness or coating weight (if applicable), etc.]

12.8.2 I_{CBT} and Weld Size Diameter Established in 11.5

- (1) I_{CBT}
- (2) Weld size diameter at I_{CBT}

12.8.3 Data from All Current Break-Through Samples with the Control Material

- (1) The mean (effective) welding current (I_{EFF}) for each of the five 2-coupon stack-up test welds
- (2) The CBTT (in number of half cycles) for each of the five 2-coupon stack-up test welds
- (3) The mean (effective) welding current for each of the five 4-coupon stack-up test welds
- (4) The CBTT (in number of half cycles) for each of the five 4-coupon stack-up test welds
- (5) The number of samples failing the criterion of no more than one half-cycle of CBTT

12.8.4 Data from All Current Break-Through Samples with the Test Material

- (1) The mean (effective) welding current (I_{EFF}) for each of the five 2-coupon stack-up test welds
- (2) The CBTT (in number of half cycles) for each of the five 2-coupon stack-up test welds
- (3) The mean (effective) welding current for each of the five 4-coupon stack-up test welds
- (4) The CBTT (in number of half cycles) for each of the five 4-coupon stack-up test welds
- (5) The number of samples failing the criterion of no more than one half-cycle of CBTT

13. Design of Experiments (DoE) Test Procedure for Resistance Spot Welding Characterization of High Strength and Advanced High Strength Steels

13.1 Introduction and Overview. The DoE test procedure is intended to examine the robustness of a specific sample of high strength steel to variations in key weld process variables. It is intended for steel grades in Groups 3 and 4 steels (see Table 1). The DoE evaluates joint properties on the basis of visual, metallographic, and weld mechanical property assessments and utilizes a 4-factor, 2-level, 16-run full factorial design. The factors (or variables) and responses (or measurements) used in the DoE are shown in Table 12. The test levels of the DoE factors are summarized in Table 13 with material and thickness specific test levels listed in Tables 15 and 16. Statistical analysis of the response data is intended to supply information considered important to acceptance of high strength sheet steel for automotive use.

13.2 Equipment

13.2.1 Spot Weld Equipment. The type of equipment and weld controller used are to be user defined and the equipment information included in the specified DoE Welding Test Reports.

Table 12
DoE Experimental Design

DoE Characteristic	Description or Value
Factors (variables)	Weld Size Weld Force Weld Time Hold Time
Responses	Peak Load Energy Weld Fracture Appearance Weld Indentation-Moving Electrode Weld Indentation-Fixed Electrode Weld Current (required current for a specific condition)
Number of Runs	16
DoE Resolution	Full Factorial
Mechanical, Metallographic, and Retention Test Samples Welded per Run	5 shear tension (3 for mechanical testing, 1 metallographic sample as indicated, and 1 retention) and 5 cross tension (3 for mechanical testing and 2 retention)

Table 13
DoE Factor Level Summary

Factor	Low (Level 1)	High (Level 2)
Weld Size	MWS	$5\sqrt{t}$
Weld Force	Tabulated value, varies as a function of sheet thickness	Low level +25% Rounded to nearest 0.1 kN
Weld Time	Tabulated value, varies as a function of sheet thickness and coating condition	Low level +25% Rounded to nearest 0.1 kN
Hold Time	Tabulated value, varies as a function of sheet thickness	90 cycles

13.2.1.1 A single phase 60 Hz AC welding machine as detailed in Clauses 6 and 7 of this procedure is suitable for this testing procedure.

13.2.1.2 A medium frequency direct current (MFDC) welding machine can also be used with this procedure. The frequency of MFDC power used shall be included in the final report.

13.2.2 Electrodes

13.2.2.1 Electrode Material Specification. Electrodes shall be from RWMA Group A, Class 1 ZrCu (RWMA Number 1.15000) material.

13.2.2.2 Electrode Geometry. Cold-formed, female, B-nose/domed electrode caps as detailed in Figure 27 and Table 14 should be utilized.

13.3 Sample Preparation. An adequate quantity of peel-test, endurance test panel coupons, shear tension coupons, and cross tension coupons shall be prepared per the requirements of Clause 4. Verify that all coupons are clean and nonoily. If necessary, wipe clean with a soft cloth. Approximately 200 ft² of material will be required.

13.4 B-Nose (Dome) Electrode Installation and Stabilization

13.4.1 Electrode Installation and Imprints. As per Clause 8 of this procedure the stabilization method used in this procedure changes the SWS from an electrode-based dimension to a material gauge-based dimension. All other aspects of the Clause 9 stabilization procedure can be utilized. Once stabilization is completed, no electrode dressing is permitted.

13.4.2 B-Nose Electrode-Face and Weld-Size Stabilization Procedure

NOTE: This stabilization procedure for the DoE is slightly modified from Clause 9.

The following adjustments are required when performing the stabilization procedure, outlined in Clause 9, for the DoE.

- (1) Stabilization Weld Size (SWS) shall be 4.5t, rounded to closest 0.1 mm.
- (2) Default weld currents (if required) are listed in Table 15.
- (3) Welding Parameters to be used are per Table 16 or 17, low level (L) settings.

13.5 DoE Procedure

13.5.1 The generalized DoE Matrix is shown below in Table 18.

13.5.2 DoE Welding Procedure

13.5.2.1 Complete the DoE Welding Report Cover Sheet—Form B-7.

13.5.2.2 A DoE must be completed on the same welding machine on which it was started.

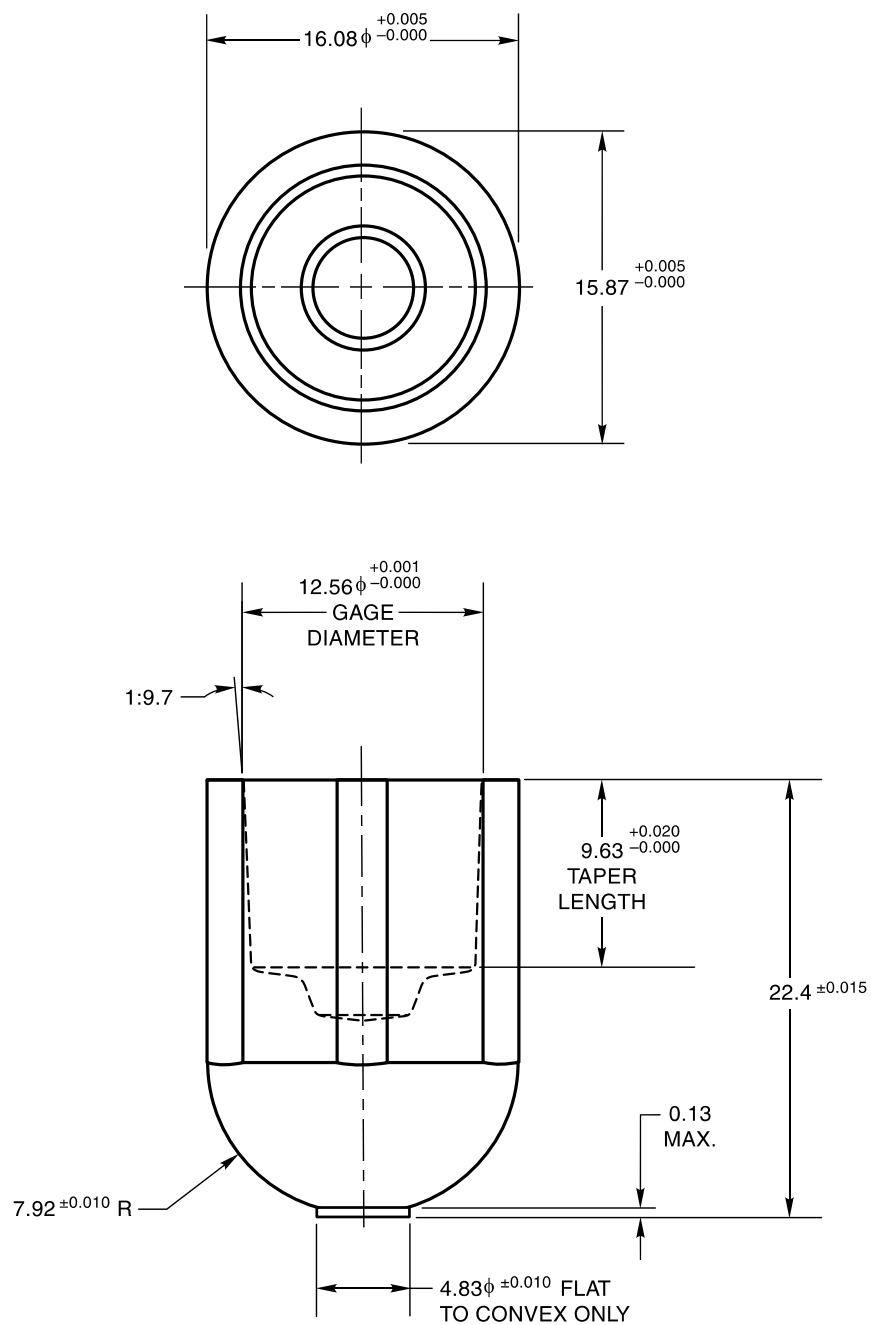
13.5.2.3 Confirm electrode stabilization has been completed per 13.4.

13.5.2.4 DoE Run Test Condition Setup Procedures

(1) Setup peel coupons are made per Clause 4, Table 2, except **only one weld is made per coupon pair**. The coupons should be assembled to form a shear tension type geometry test sample with the overlap area equivalent to the coupon width. A single spot weld should be placed in the center of the overlap area of a coupon pair sample. When welding setup and DoE test samples the sample orientation with respect to the welding machine throat is to be kept constant (see Figure 7).

(2) Establishing DoE setup welds for minimum weld size conditions (Runs 1–8).

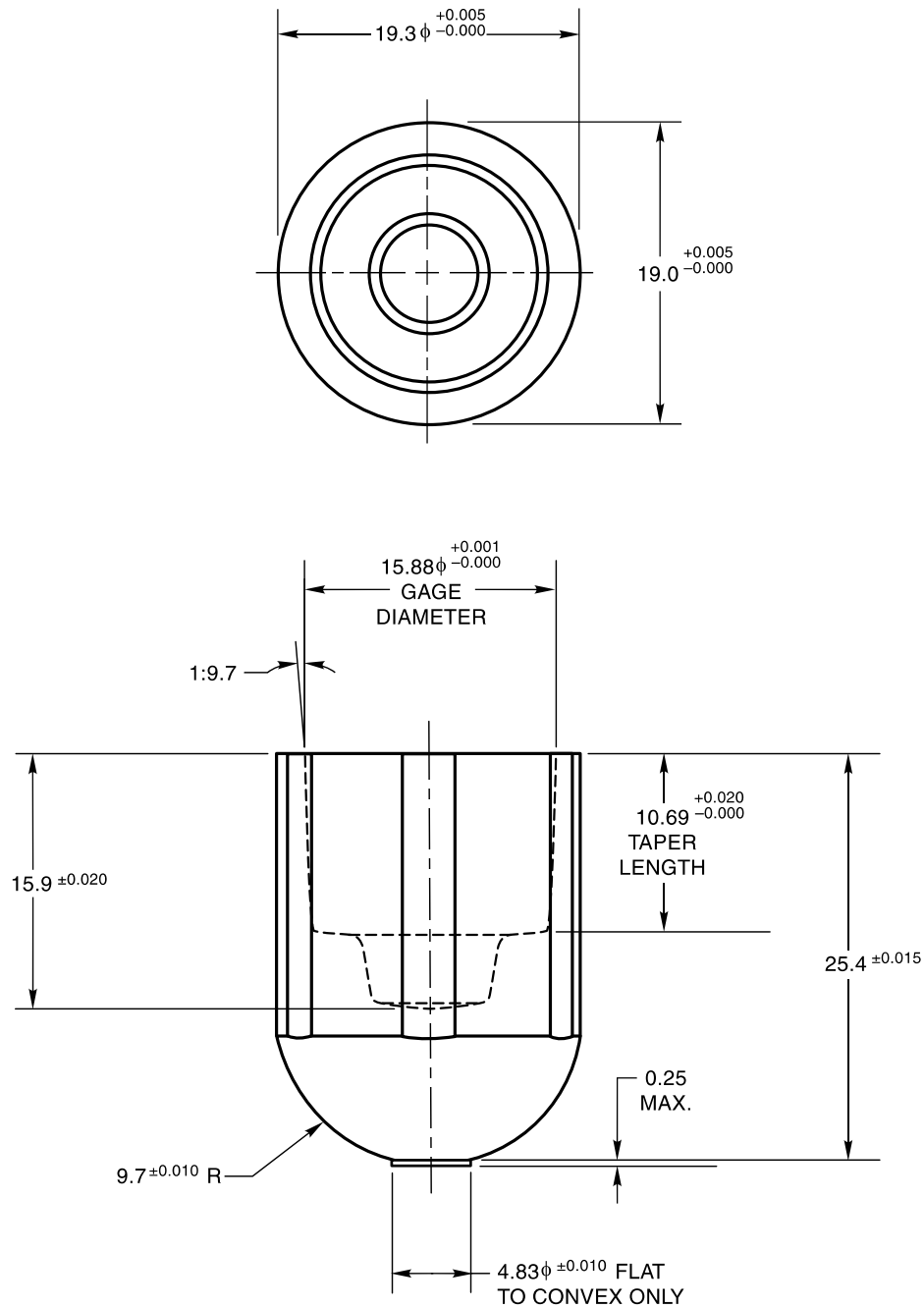
Starting with DoE Run #1, use peel setup coupons (with **only one weld made per coupon pair**) to determine the weld current producing the required minimum weld size utilizing the specified weld force, weld time, and hold time from either Table 16 or 17. Weld size is determined using a destructive peel test and measured by a caliper and/or a stereo-scope, depending on weld fracture mode. The weld size for a given condition is determined for two samples. Each sample shall be ± 0.2 mm of the specified weld size. If the weld current to make the specified weld size does not fall within the 50% to 90% heat level settings, or 50% to 90% current level settings, change the tap setting to meet this requirement. Record setup data on the DoE Welding Setup Data Sheet and Verification, Form B-8. Proceed to 13.5.2.5 and assemble the mechanical, metallurgical, and retention samples.



(A) Female B-Nose Electrode Cap, 15.87 mm Body Diameter

Source: Reproduced with permission from Luvata Ohio, Inc.

Figures 27A & 27B—Electrode Geometry

**(B) Female B-Nose Electrode Cap, 19.0 mm Body Diameter**

Source: Reproduced with permission from Luvata Ohio, Inc.

Figures 27A & 27B—Electrode Geometry

Table 14
Electrode Dimensions

Dimension Description	Body Diameter	
	15.87 mm	19.0 mm
Face Diameter	4.83 mm (± 0.25)	4.83 mm (± 0.25)
Body Diameter	15.87 mm ($+0.13/-0.00$)	19.0 mm ($+0.13/-0.00$)
Length	22.4 mm (± 0.38)	25.4 mm (± 0.38)
Radius on Domed Nose	7.92 mm (± 0.25)	9.7 mm (± 0.25)
Hole (Taper) Diameter	12.56 mm ($+0.03/-0.00$)	15.88 mm ($+0.03/-0.00$)
Taper Length	9.63 mm ($+0.51/-0.00$)	10.69 mm ($+0.51/-0.00$)

Table 15
DoE Default Initial Welding Currents (B-Nose)

Sheet Thickness (mm)	Current (kA)	
	Bare to Bare	Coated to Coated
0.78–1.02	5.5	7.0
1.03–1.23	6.0	7.5
1.24–1.44	6.5	8.0
1.45–1.64	7.0	8.5
1.65–1.84	7.5	9.0
1.85–2.09	8.0	9.5

Table 16
DoE Weld Parameters, Bare-to-Bare Faying Surface Condition

Sheet Thickness (mm)	Electrode Body Diameter (mm)	Weld Force (kN)		Weld Time ^a (cy)		Hold Time (cy)	
		L	H	L	H	L	H
0.78–1.02	15.9	3	3.8	7	9	2	90
1.03–1.23	15.9	3	3.8	8	10	2	90
1.24–1.44	15.9	4.2	6.3	8	10	2	90
1.45–1.64	15.9	4.2	6.3	9	12	2	90
1.65–1.84	19	5.3	8	5-1-5	7-1-7	5	90
1.85–2.09	19	5.3	8	7-1-7	9-1-9	5	90

^a x-y-x denotes weld-cool-weld time.

Table 17
DoE Weld Parameters, Coated-to-Coated Faying Surface Condition

Sheet Thickness (mm)	Electrode Body Diameter (mm)	Weld Force (kN)		Weld Time ^a (cy)		Hold Time (cy)	
		L	H	L	H	L	H
0.78–1.02	15.9	3	3.8	11	14	2	90
1.03–1.23	15.9	3	3.8	12	15	2	90
1.24–1.44	15.9	4.2	6.3	12	15	2	90
1.45–1.64	15.9	4.2	6.3	5-1-5-1-5	7-1-7-1-7	5	90
1.65–1.84	19	5.3	8	6-1-6-1-6	8-2-8-2-8	5	90
1.85–2.09	19	5.3	8	5-1-5-1-5-1-5	7-2-7-2-7-2-7	5	90

^a x-y-x denotes weld-cool-weld time.

Table 18
DoE Run Matrix

DoE Run No.	DoE Factors				Responses					
	Weld Size	Weld Force	Weld Time	Hold Time	Peak Load (lbs)	Energy (J)	Fracture Face	Indentation		Measured Weld Current
								Moving Electrode Side	Fixed Electrode Side	
1	Low	Low	Low	Low						
2	Low	Low	Low	High						
3	Low	Low	High	Low						
4	Low	Low	High	High						
5	Low	High	Low	Low						
6	Low	High	Low	High						
7	Low	High	High	Low						
8	Low	High	High	High						
9	High	Low	Low	Low						
10	High	Low	Low	High						
11	High	Low	High	Low						
12	High	Low	High	High						
13	High	High	Low	Low						
14	High	High	Low	High						
15	High	High	High	Low						
16	High	High	High	High						

(3) Establishing DoE setup welds for large weld size conditions (Runs 9–16).

Starting with DoE Run #9, use peel setup coupons (with **only one weld made per coupon pair**) to determine the weld current producing the required large weld size using the specified weld force, weld time, and hold time in Tables 16 or 17. **The specified large weld size must be obtained without expulsion.** If expulsion is encountered during welding on any one test sample, discard that sample and repeat making that particular sample. If expulsion is encountered on more than three samples for a particular run, discontinue making the test samples and contact the customer for guidance. Weld size is determined using a destructive peel test and measured by a caliper and/or a stereoscope, depending on weld fracture mode. The weld size for a given condition is determined for two samples. Each sample shall be ± 0.2 mm of the specified weld size. If the weld current to make the specified weld size does not fall within the 50% to 90% heat level settings, or 50% to 90% current level settings, change the tap setting to meet this requirement. Record setup data on the DoE Welding Setup Data Sheet and Verification, Form B-8. Proceed to 13.5.2.5 and make mechanical, metallurgical, and retain samples.

13.5.2.5 Production of Mechanical and Metallographic test samples for DoE Runs

(1) Sample Assembly—Shear Tension and Cross Tension Samples

NOTE: None of the samples produced per the procedure outlined in this clause should exhibit expulsion. If expulsion is encountered during welding on any one test sample, discard that sample and repeat making that particular sample. If expulsion is encountered on more than three samples for a particular run, discontinue making the test samples and contact the customer for guidance.

(a) After the setup procedure for a DoE run is successfully completed, weld a shear tension specimen. Verify that the specified weld size (± 0.2 mm) is obtained on the shear tension specimen by performing a destructive peel test. If necessary, adjust the weld current and weld and test additional shear tension specimens. Continue until the average of three consecutive specimens is within ± 0.2 mm of the specified weld size with no single specimen having a weld size greater than ± 0.3 mm of the specified weld size.

(b) When step (a) above has been successfully completed, weld five (5) Shear Tension and five (5) Cross Tension test samples. Test samples are to be labeled in accordance with the instructions below. Complete the Shear Tension and Cross Tension DoE Welding Data Sheets with Measured Responses (Form B-9) with information for Measured Weld Current, Current Setting on the timer, and Tap Setting where appropriate for each sample. Enter the specific DoE Factor Levels in the appropriate columns.

All samples should be uniquely identified. A possible format for marking the test samples is detailed below:

(Test #) – (Weld Current Type) – (DoE Run Number) – (Replicate Number)

Example: Test #1-AC-R1-5

Test # refers to any internal company specified identification number.

Weld Current Type (either AC or DC)

DoE Run # refers to the run number of the DoE and will be a whole number from 1 to 16 prefixed by the letter R.

Replicate Number refers to a sequential numbering of the replicates made for shear tension, cross tension, metallographic, and retention samples using the conditions for the specified DoE Run. The replicate number is unique for each sample—none of the shear tension, cross tension, metallographic, and retention samples have the same replicate number.

(c) After step (b) is complete, weld a verification shear tension specimen with the same weld settings. This sample should be destructively peeled and the weld size measured. The weld size should be ± 0.2 mm of the specified weld size. If the weld size is not within ± 0.2 mm but is within (or at) ± 0.3 mm weld two additional samples. Evaluate all three samples for the following: average is within ± 0.2 mm of the specified weld size with no single specimen having a weld size greater than ± 0.3 mm of the specified weld size. If the evaluation indicates that the required verification weld size has not been maintained the assembly procedure for the run must be repeated and all samples assembled labeled as non-conforming and set aside.

(d) Obtain electrode imprints after all small weld size runs (1 through 8) and after all large weld size runs (9 through 16).

(e) Repeat 13.5.2.5 for each run until the test assembly sequence is complete for the DoE.

13.6 Metallographic Evaluation

13.6.1 Metallographic samples will be taken from the following DoE Runs: 1, 4, 6, 7, 10, 11, 13, and 16. The metallographic samples shall be cross-sectioned slightly off-center so that after mounting, sanding, polishing, and etching, the approximate centerline of the weld nugget can be viewed. The welds shall be viewed under both low magnification (approximately 12X to 20X) and high magnification (approximately 100X). The welds must be properly identified and the following information reported for each weld:

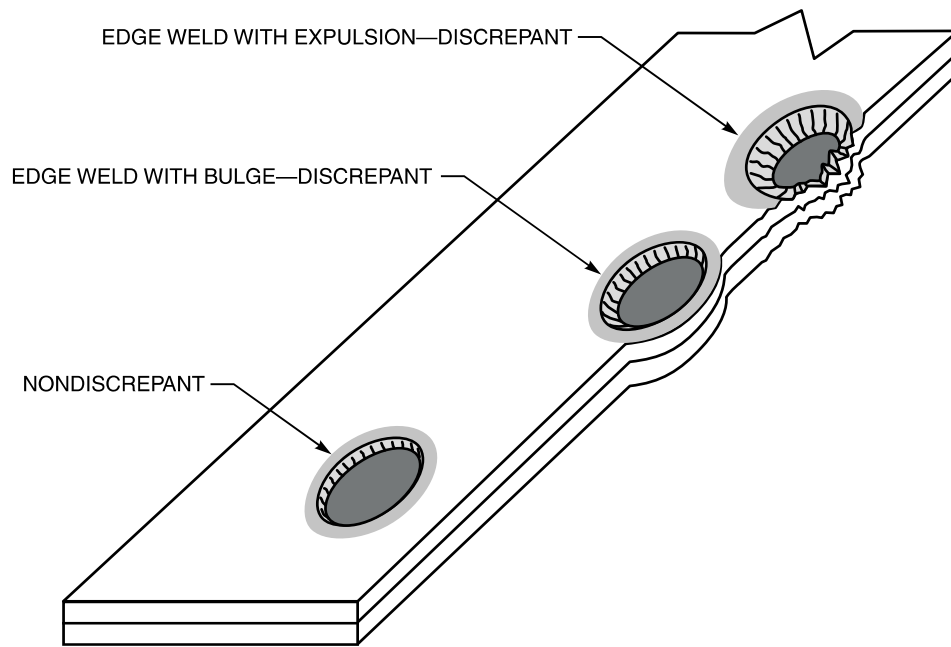
- (1) Both sheet metal thicknesses
- (2) Percent Indentation for both sheets
- (3) Percent Weld Nugget Penetration into both sheets
- (4) Weld Nugget Diameter
- (5) Photos at low magnification (12X to 20X)
- (6) Anomalies such as cracks, voids, porosity, etc. and photos of the anomalies at appropriate magnification.
- (7) Microhardness traverses for samples from DoE Runs 10, 11, 13, and 16

13.7 Weld Property Evaluation

13.7.1 Weld Surface Inspection. Evaluate each sample for surface features as described below. Discrepant welds should be discarded and new weld samples prepared for testing.

13.7.1.1 Surface Inspection Criteria

(1) **Edge Weld.** A spot weld area, as defined by the impression left by the electrodes, which is not fully contained within all original edges of the sheet metal, is a discrepant weld (see Figure 28).



Source: Reproduced from AWS D8.1M:2007, Figure 1.

Figure 28—Examples of Edge Welds

(2) **Surface Cracks.** The acceptability of surface cracks, found when visually inspecting welds without a magnification device, depends on the steels being welded and the position of the cracks as shown in Figure 29.

(3) **Holes.** A weld is discrepant when, upon visual inspection without a magnification device, any opening contained within the electrode impression is found extending through the stack-up.

(4) **Indentation.** Indentation is the ratio of the amount of weld depression to the before welded sheet thickness, expressed as a percentage. Indentation should be less than 30% of the thickness of each outside sheet of the welded joint (see Figure 30). Care must be taken during measurement if distortion is present. Distortion must not add to the value of the indentation.

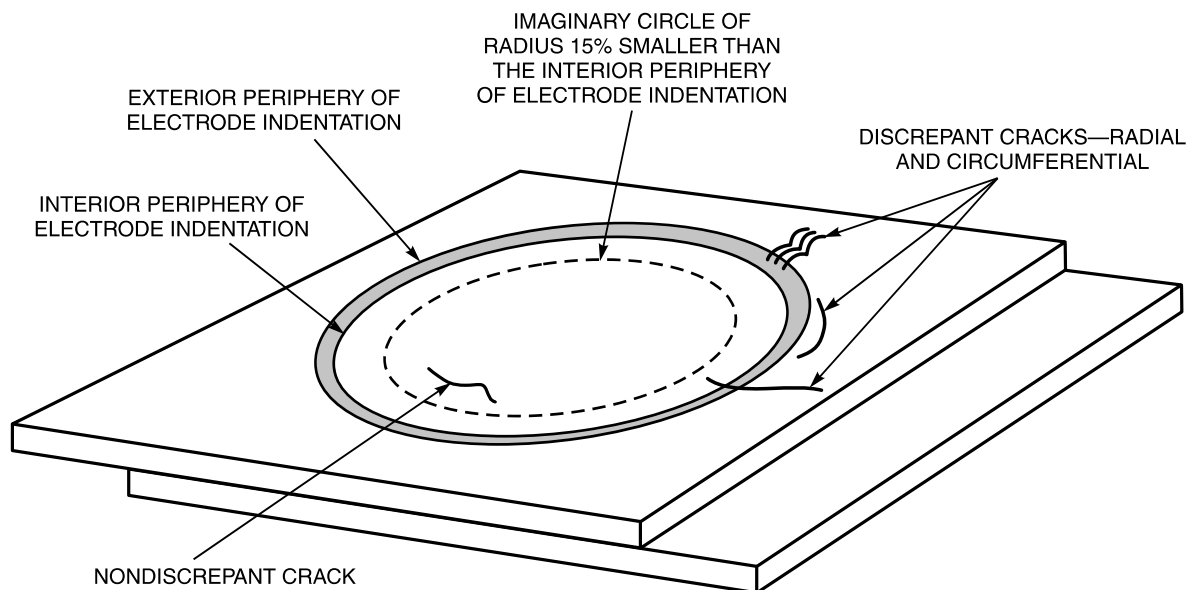
13.7.2 Mechanical Property Testing. All response measurements should be recorded on the DoE Welding Data Sheet (Form B-9).

13.7.2.1 All shear tension and cross tension testing shall be performed at room temperature ($20^{\circ}\text{C} \pm 5^{\circ}\text{C}$). A cross head velocity of 10 mm/minute shall be used for all tests. A load versus displacement curve is to be generated for each test. Peak load is to be measured in kN (kilo-Newton) and displacement in mm. For calculating energy, use the maximum load as a cut-off point. Energy is to be reported in J (joules).

13.7.2.2 Each tested shear tension and cross tension specimen should be characterized for weld size and fracture appearance.

13.7.2.3 Indentation shall be measured in accordance with AWS D8.1M for both top and bottom electrodes.

13.7.2.4 The weld current level required for each DoE run shall be recorded.



Discrepant Conditions:

Groups 1 and 2:

1. Spot welds with surface cracks in the area defined by the outside 15% of the linear distance between the interior periphery line and the center of electrode impression (see drawings above).
2. Spot welds with surface cracks adjacent to the periphery of the electrode impression (see drawings above).

Groups 3 and 4:

When at least one of the steels in the stackup belongs to Group 3 or 4, no surface cracks are allowed unless specifically approved by the customer.

Source: Reproduced from AWS D8.1M:2007, Figure 2.

Figure 29—Surface Cracks

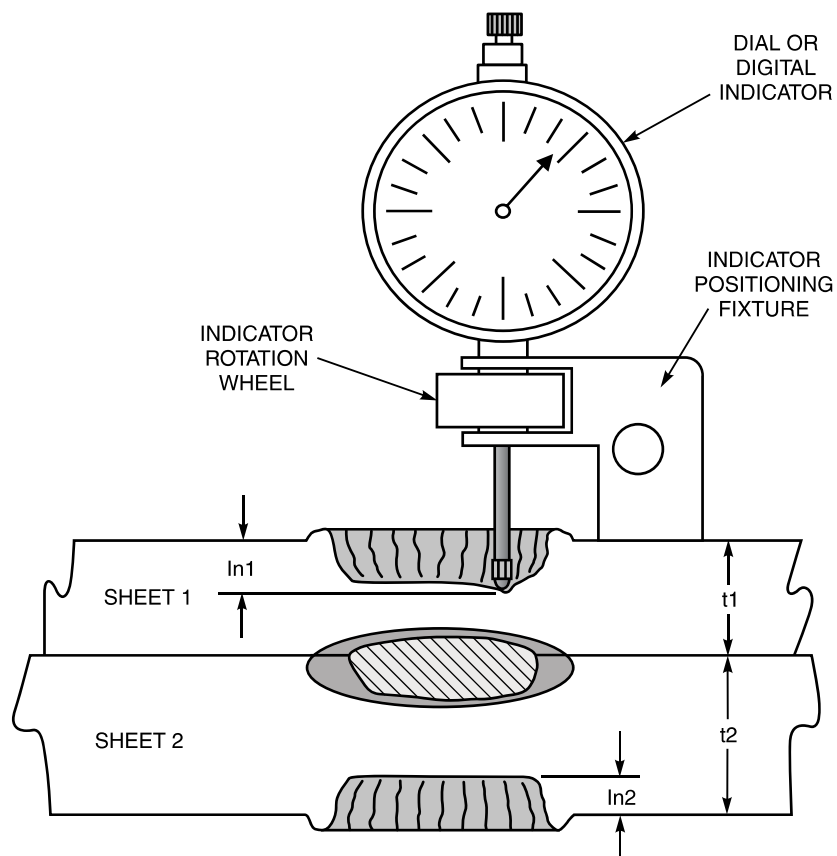
13.8 DoE Analysis

13.8.1 Data Analysis. The DoE statistical analysis should be performed using appropriate statistical software. Data from both DoEs should be analyzed with respect to the following responses: Peak Load and Energy. The DoE statistical analysis shall be performed at an alpha value equal to 0.05. A Full 4-Factorial DoE will be run. The reduction of the model should be in accordance with prearranged customer requirements. All statistical plots (Main Effects, Normality, Pareto, Residual, etc.) should be in accordance with prearranged customer requirements.

13.8.2 Response Analysis Graphical Representation. The graphical representation of the results may include electrode indentation, and other plots in accordance with prearranged customer requirements.

13.9 Reporting. The report of the results must include, but is not limited to, the following items:

- (1) Machine information
- (2) Weld parameter information
- (3) Weld data
- (4) Mechanical property data
- (5) Metallographic data
- (6) DoE analysis



$$\% \text{ INDENTATION SHEET 1} = In1/t1 \times 100$$

$$\% \text{ INDENTATION SHEET 2} = In2/t2 \times 100$$

Source: Reproduced from AWS D8.1M:2007, Figure 3.

Figure 30—Indentation Measurement

Annex A (Informative)

Electrodes

This annex is not part of AWS D8.9M:2012, *Test Methods for Evaluating the Resistance Spot Welding Behavior of Automotive Sheet Steel Materials*, but is included for informational purposes only.

This annex describes the electrode type and dimensions that are typically used for most material qualification testing of sheet steel materials. However, if performing the DoE method, or required by special circumstances, other electrode types (e.g., 13.2.2) may be used with the consent of the party for whom the testing is performed. If electrodes other than those listed in Table A.1 are used, special note of this deviance is to be made on the welding data sheets and all test reports.

A1. Electrode Geometry

Male, truncated cone electrode caps having the dimensions listed in Table A.1 and Figure A.1, and having the properties in Clause A2 shall be used for all testing except where special circumstances apply.

A2. Electrode Composition and Properties

The electrodes shall be produced to RWMA Group A, Class 2 CuCr (RWMA 2.18200) specifications with a 75 Rb minimum hardness.

Table A.1
Electrode Specifications and Dimensions

	Electrode Type	1	2	3	4	5	6	Tol.
	Dressed Face Diameter (mm)	4.5	5.0	6.0	7.0	8.0	9.0	±0.2
A	Face Diameter (mm)	4.4	4.9	5.9	6.9	7.9	8.9	±0.1
B	Body Diameter (mm)	15.9	15.9	15.9	19.0	19.0	22.0	±0.1
C	Length (mm)	29.0	29.0	29.0	32.0	32.0	32.0	±0.2
D	Shank Length (mm)	12.7	12.7	12.7	15.9	15.9	15.9	±0.2
E	Face Thickness (mm)	9.7	9.7	9.7	9.7	9.7	9.7	±0.5
F	Hole Diameter (mm)	8.1	8.1	8.1	9.7	9.7	12.7	±0.3
G	Taper Loc. (mm) Option 1	9.9	9.9	9.9	13.4	13.4	13.4	±0.1
	(mm) Option 2	9.9	9.9	9.9	12.7	12.7	12.7	±0.1
H	Taper Dia. (mm) Option 1	10.54	10.54	10.54	14.33	14.33	17.81	±0.01
	(mm) Option 2	10.54	10.54	10.54	12.725	12.725	15.57	±0.01
T	Taper Angle ^a	1.43°	1.43°	1.43°	1.43°	1.43°	1.43°	±0.05°
Angle	Bevel Angle	45°	45°	45°	45°	45°	45°	±1°

^a 1.43° = Resistance Welding Manufacturers Association (RWMA) Taper No 5. 1.43° (1°26') is equivalent to a diameter reduction ratio of 1/20, i.e., H – G/20 = diameter at shank end (without edge chamfering). Other tapers (RWMA #6 or others) are also permissible if required to fit your electrode adapters.

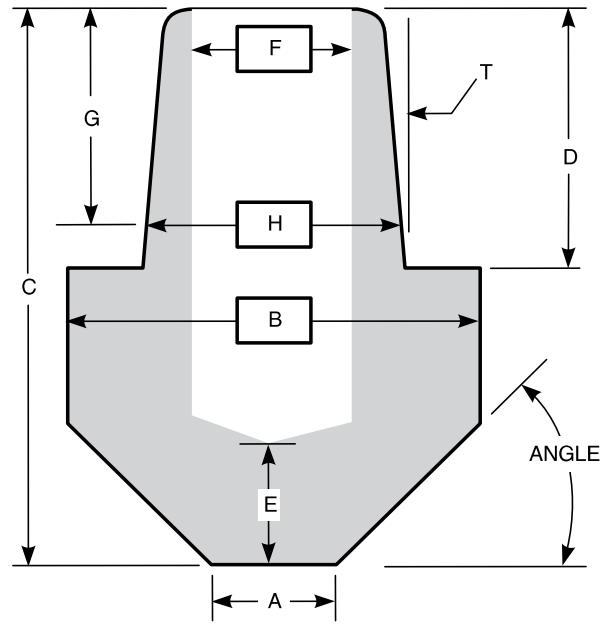


Figure A.1—Spot Welding Electrode Diagram

Annex B (Informative)

Data Forms

This annex is not part of AWS D8.9M:2012, *Test Methods for Evaluating the Resistance Spot Welding Behavior of Automotive Sheet Steel Materials*, but is included for informational purposes only.

Found in this annex are standard forms for recording welding data, tip imprints, material data, and test results. It is strongly recommended that copies of these forms (available from AWS) be used whenever conducting the test methods of this document. However, variations of these forms to suit the user's needs are permissible. The following clauses provide a brief description of each form.

B1. Welding Data Sheet (Form B-1)

This form is used for recording all welding test data and welding parameters listed on the forms. Page 1 (front page) of Form B-1 is shown on page 65, and Page 2 (continuation page) is shown on page 66. The continuation pages are designed for recording of additional data in a test and thus do not contain the equipment, parameter, and other information found on the cover page. The test code, date, and page numbers shall be entered on all continuation pages required per test. Besides welding parameters and test data, the following shall be recorded on Page 1:

- (1) Laboratory name and address, test code and type, and test operator and date
- (2) Sheet steel type and thickness; coating type and nominal coating weight; and coil, heat, or other identification (ID) number
- (3) Welding machine ID, control type, and tap setting; electrode ID, nominal face diameter, and face thickness; and cooling tube diameter
- (4) Current analyzer type and ID; force gauge type and ID; welding mode (manual or robotic); and panel type (standard or optional)

B2. Tip Imprint Data Sheets (Forms B-2-DOPT1 and B-2-DOPT2)

These forms are used for recording the as-machined, measured electrode face diameters before and after dressing and all tip imprint measurements listed on the form. Pages 1 of Forms B-2-DOPT1 and B-2-DOPT2 are shown on pages 67 and 68, respectively. Page 2 for both forms is shown on page 69. If possible, these forms should also be used for taking the tip imprints in the boxes provided.

B3. Test Material Data Sheet (Form B-3)

This form is used for recording the test material's properties and other data. Page 1 of Form B-3 is shown on page 70 and lists the mandatory data. Page 2, Optional Material Data, (shown on page 71) is for optional mechanical property and surface roughness data.

B4. Endurance Test Report (Form B-4)

Form B-4 is used to report information and data from the Endurance Test. Page 1 (shown on page 72) is used for reporting all test material data, test equipment information, and welding parameters. Test results from the Endurance Test are reported on Page 2, Endurance Test Data (shown on page 73).

B5. Weld Property Test Report (Form B-5)

Form B-5 is used to report information and data from the Weld Property Test. All test material data, test equipment information, and welding parameters are reported on Page 1 (shown on page 74). Test results from the Weld Property Test are reported on Pages 2, 3, and 4 (shown on pages 75–77).

B6. Current Break-Through Test Report (Form B-6)

Form B-6 is used to report information and data from the Current Break-Through Test. All test material data, test equipment information, and welding parameters are reported on Page 1 (shown on page 78). Test results from the Current Break-Through Test are reported on Page 2 (shown on page 79).

B7. DoE Test Report Cover Sheet Report (Form B-7)

Form B-7 is used to report equipment information and data from the DoE. All test equipment information and data are reported on Page 1 (shown on page 80).

B8. DoE Welding Setup and Verification Report (Form B-8)

Form B-8 is used to report information and data from the setup required to establish the DoE sample assembly parameters. All test data, test equipment information, and welding parameters are reported on Page 1 (shown on page 81). The continuation of this report is detailed on Page 2 (shown on page 82).

B9. DoE Welding Data Sheet with Measured Responses Report (Form B-9)

Form B-9 is used to report the welding data and measured responses for the actual DoE test samples. All test data relating to shear tension samples is reported in Form B-9-ST (shown on pages 83–85). All test data relating to cross tension samples is reported in Form B-9-CT (shown on pages 86–88).

[illegible]

Date _____

[illegible]

Comments

	Top Electrode			Bottom Electrode		
	Minimum	Maximum	Mean (T)	Minimum	Maximum	Mean (B)
Undressed (As machined)						
After First Dressing						
After Last Dressing			= T			= B

Carbon Paper Tip Prints			Tip Print Code	Print Measurements								
				Top Electrode (mm)			Bottom Electrode (mm)			Composite (mm)		
Composite	Top Electrode	Bottom Electrode		Min.	Max.	Mean	Min.	Max.	Mean	Min.	Max.	Mean
			After Last Dressing			(TFD)			(BFD)			

[illegible]

Form B-2-DOPT2

DOPT2—Tip Imprint Data Sheet (Page 1)

(Used when direct measurements of the electrode faces after dressings are made with tip prints)

Laboratory Name _____

Address _____

Test Code _____ Test Type _____ Test Date _____

Test Operator _____

Comments _____

Directly Measured Electrode Face Diameters (mm)

Electrode Face Diameters of Undressed (As-Machined) Electrodes	Top Electrode (mm)			Bottom Electrode (mm)		
	Minimum	Maximum	Mean (T)	Minimum	Maximum	Mean (B)

Carbon Paper Tip Prints			Code	Print Measurements								
				Top Electrode (mm)			Bottom Electrode (mm)			Composite (mm)		
Composite	Top Electrode	Bottom Electrode		Min.	Max.	Mean	Min.	Max.	Mean	Min.	Max.	Mean
			UD-1			TUD-1			BUD-1			
			UD-2			TUD-2			BUD-2			
Example: $TU = (TUD-1 + TUD-2)/2$				TU =			BU =					
Example: $TCF = TU - T$				TCF =			BCF =					
CF = $(TCF + BCF)/2$				CF =								
			AD1-1			TAD1-1			BAD1-1			
			AD1-2			TAD1-2			BAD1-2			
Example: $TD1 = (TAD1-1 + TAD1-2)/2$				TD1 =			BD1 =					
Example: $TCD1 = TD1 - CF$				TCD1 =			BCD1 =					
			AD2-1			TAD2-1			BAD2-1			
			AD2-2			TAD2-2			BAD2-2			
Example: $TD2 = (TAD2-1 + TAD2-2)/2$				TD2 =			BD2 =					
Example: $TCD2 = TD2 - CF$				TCD2 =			BCD2 =					

Date _____

Form B-3 Test Material Data Sheet (Page 1)

Laboratory Name _____

Address _____

Coil No. or ID _____ Reporter Name _____ Report Date _____

Steel Grade _____ Coating Type _____ Nominal Coating Wt. _____ g/m² _____ g/m²

Surface Lubricants _____ Brand Name _____ Type _____ Post-Coating Treatment _____ Brand Name _____ Type _____

Comments _____

Mandatory Material Data

Sheet Thickness

Trimmed Edge X (mm)	1/4 Point (mm)	Center Point (mm)	3/4 Point (mm)	Trimmed Edge Y (mm)	Mean (mm)	Std. Dev. (mm)

Sheet Coating Weight

Side (Top ^a or Bottom)	Trimmed Edge X (g/m ²)	Center Point (g/m ²)	Trimmed Edge Y (g/m ²)	Mean (mm)	Std. Dev. (mm)	Test Method Used

^aTop side is marked side.

Sheet Coating Composition (% Weight)

Sample Number	Sample 1						Sample 2					
Element												
Top ^a Side												
Bottom Side												

^aTop side is marked side.

Sheet Substrate Composition (% Weight)

Element												
Analysis												

Form B-3 (Continued)

Optional Material Data (Page 2)

Mechanical Properties							
Category	Yield (MPa)	UTS (MPa)	Elong. (%)	R	N	Test Method Used	Comments
Sample 1							
Sample 2							
Sample 3							
Mean							

Sheet Surface Roughness												
	Ra						Peak Count					
Reading No.	1	2	3	4	5	Mean	1	2	3	4	5	Mean
Top ^a Side												
Bottom Side												

^aTop side is marked side.

Form B-4 Endurance Test Report (Page 1)

For Test Code _____

Laboratory Name _____

Report Date _____

Address _____

Reported By _____

Telephone No. _____

Approved By _____

Fax No. _____

Title _____

Material Data

Coil No. or ID _____ Steel Grade _____ Mean Thickness _____ mm

Top Bottom

Coating Type _____ Mean Coating Wt. _____ g/m² _____ g/m²

Brand Name Type Brand Name Type

Surface Lubricants _____ Post-Coating Treatment _____

Other Data or Comments _____

Equipment Information

Welding Machine Type _____ Model Number _____ Machine Capacity _____ kVA

Welding Machine Tap _____ Weld Controller Name _____ Controller Mode _____

Air Cylinder Size _____ Air Cylinder Type _____ Head Velocity _____ mm/sec

Current Analyzer Brand & Model No. _____ Force Gage Brand & Model No. _____

Top Elect. Bot. Elect.

Electrode Type (No.) _____ Dressed Face Dia. _____ mm Face Thick _____ mm _____ mm

Cooling Tube—OD Dia. _____ mm Flow Meter Brand _____ Flow Meter Model No. _____

Comments or Variances to Specified Equipment _____

Welding Parameters

Weld Force _____ kN Welding Mode _____ Welding Rate _____ welds/min.

Set Squeeze Time _____ cy Weld Time _____ cy Set Hold Time _____ cy Actual Hold Time _____ cy

Water Water

Off Time (Repeat Welding) _____ cy Flow _____ l/min. Temp. _____ °C Panel Type _____

Comments or Variances to Specified Parameters _____

Form B-4 (Continued)

Endurance Test Report (Page 2)

For Test Code _____

Endurance Limit and Operating Current

Endurance Limit	I _{OP}
Test 1 _____ welds	_____ kA
Test 2 _____ welds	_____ kA
Test 3* _____ welds	_____ kA
Mean _____ welds	

Current Levels, Current Ranges and Weld Button Sizes

Test 1 I _{MAX.} _____ kA	ID _{MAX.} _____ mm	Test 1 Fil _{MAX.} _____ kA	FiID _{MAX.} ^a _____ mm
–Test 1 I _{MIN.} _____ kA	ID _{MIN.} _____ mm	–Test 1 Fil _{MIN.} _____ kA	FiID _{MIN.} _____ mm
=Test 1 ICR _____ kA	_____	=Test 1 FCR _____ kA	
Test 2 I _{MAX.} _____ kA	ID _{MAX.} _____ mm	Test 2 Fil _{MAX.} _____ kA	FiID _{MAX.} _____ mm
–Test 2 I _{MIN.} _____ kA	ID _{MIN.} _____ mm	–Test 2 Fil _{MIN.} _____ kA	FiID _{MIN.} _____ mm
=Test 2 ICR _____ kA	_____	=Test 2 FCR _____ kA	
Test 3 ^a I _{MAX.} _____ kA	ID _{MAX.} _____ mm	Test 3 ^a Fil _{MAX.} _____ kA	FiID _{MAX.} _____ mm
–Test 3 ^a I _{MIN.} _____ kA	ID _{MIN.} _____ mm	–Test 3 ^a Fil _{MIN.} _____ kA	FiID _{MIN.} _____ mm
=Test 3 ^a ICR _____ kA	_____	=Test 3 ^a FCR _____ kA	
Mean I _{MAX.} _____ kA		Mean Fil _{MAX.} _____ kA	
–Mean I _{MIN.} _____ kA		–Mean Fil _{MIN.} _____ kA	
=Mean ICR _____ kA		=Mean FCR _____ kA	
Mean All I _{MAX.} _____ kA	_____	^a FiID _{MAX.} = D _{MAX.} at Final I _{MAX.} .	
–Mean All I _{MIN.} _____ kA			
=Mean ICR _____ kA			

Mean Electrode-Face Diameters (in mm)

When Measured	Replication 1			Replication 2			Replication 3 ^a		
	Top	Bot.	Comp.	Top	Bot.	Comp.	Top	Bot.	Comp.
As Machined			—			—			—
After Final Dressing									
After Stabilization									
After Initial I _{MAX.}									
At 1000 Welds ^a									
At 2000 Welds ^a									
At 3000 Welds ^a									
At 4000 Welds ^a									
At 5000 Welds ^a									
At 6000 Welds ^a									
At 7000 Welds ^a									
At 8000 Welds ^a									
At Endurance Limit									
After Last Weld									

^a Optional wherever Note a is shown on this page.

Form B-5 Weld Property Test Report (Page 1)

For Test Code _____

Laboratory Name _____

Report Date _____

Address _____

Reported By _____

Telephone No. _____

Approved By _____

Fax No. _____

Title _____

Material Data

Coil No. or ID _____

Steel Grade _____

Mean Thickness _____ mm

Coating Type _____

Mean Coating Wt. _____ g/m² _____ g/m²

Top

Bottom

Brand Name

Type

Brand Name

Type

Surface Lubricants _____

Post-Coating Treatment _____

Other Data or Comments _____

Equipment Information

Welding Machine Type _____

Model Number _____

Machine Capacity _____ kVA

Welding Machine Tap _____

Weld Controller Name _____

Controller Mode _____

Air Cylinder Size _____

Air Cylinder Type _____

Head Velocity _____ mm/sec

Current Analyzer Brand & Model No. _____

Force Gauge Brand & Model No. _____

Electrode Type (No.) _____

Dressed Face Dia. _____ mm

Face Thick _____ mm _____ mm

Top Elect.

Bot. Elect.

Cooling Tube—OD Dia. _____ mm

Flow Meter Brand _____

Flow Meter Model No. _____

Comments or Variances to Specified Equipment _____

Welding Parameters

Weld Force _____ kN

Welding Mode _____

Welding Rate _____ welds/min.

Set Squeeze Time _____ cy

Weld Time _____ cy

Set Hold Time _____ cy

Actual Hold Time _____ cy

Off Time (Repeat Welding) _____ cy

Water

Flow _____ l/min.

Water

Temp. _____ °C

Panel Type _____

Comments or Variances to Specified Parameters _____

Form B-5 (Continued)

Weld Property Test Data (Page 2)

For Test Code _____

Current Levels, Current Ranges and Weld Button Sizes

Test 1 $I_{MAX.}$ _____ kA	$D_{MAX.}$ _____ mm	Test 2 ^a $I_{MAX.}$ _____ kA	$D_{MAX.}^a$ _____ mm
–Test 1 $I_{MIN.}$ _____ kA	$D_{MIN.}$ _____ mm	–Test 2 ^a $I_{MIN.}$ _____ kA	$D_{MIN.}^a$ _____ mm
=Test 1 CR _____ kA	_____	=Test 2 CR _____ kA	
Test 3 ^a $I_{MAX.}$ _____ kA	$D_{MAX.}^a$ _____ mm	Mean All $I_{MAX.}$ _____ kA	
–Test 3 ^a $I_{MIN.}$ _____ kA	$D_{MIN.}^a$ _____ mm	–Mean All $I_{MIN.}$ _____ kA	
=Test 3 ^a CR _____ kA	_____	=Mean All CR _____ kA	

Note: ^a = Optional Tests

Hold-Time Sensitivity Data

Hold Time	Mean I_{FDWS} Current (kA)	Mean Button (and Fused) Diameters (mm)
Setup Samples	_____	_____ (_____)
Short (_____ cy)	_____	_____ (_____)
Long (_____ cy)	_____	_____ (_____)

Hold Time	Fracture Mode Count 1 / 2 / 3 / 4 / 5 / 6 / 7 / 8	Hardness—See Attached Table or Figure
Setup Samples	/ _ / _ / _ / _ / _ / _ / _ /	
Short (_____ cy)	/ _ / _ / _ / _ / _ / _ / _ /	
Long (_____ cy)	/ _ / _ / _ / _ / _ / _ / _ /	

Hold Time	Mean I_{MWS} Current (kA)	Mean Button (and Fused) Diameters (mm)
Setup Samples	_____	_____ (_____)
Short (_____ cy)	_____	_____ (_____)
Long (_____ cy)	_____	_____ (_____)

Hold Time	Fracture Mode Count 1 / 2 / 3 / 4 / 5 / 6 / 7 / 8	Hardness—See Attached Table or Figure
Setup Samples	/ _ / _ / _ / _ / _ / _ / _ /	
Short (_____ cy)	/ _ / _ / _ / _ / _ / _ / _ /	
Long (_____ cy)	/ _ / _ / _ / _ / _ / _ / _ /	

Comments _____

Form B-5 (Continued)

Weld Property Test Data (Page 3)

Shear Tension Data

Hold Time	Mean I_{FDWS2} Current (kA)	Individual and Mean Button (and Fused) Diameters (mm)
Setup Samples	_____	_____ (_____)
Short (_____ cy)	_____	_____ (_____)
Long (_____ cy)	_____	_____ (_____)

Hold Time	Fracture Mode Count 1 / 2 / 3 / 4 / 5 / 6 / 7 / 8	Individual and Mean Shear Tension Strength (kN)
Setup Samples	/ _ / _ / _ / _ / _ / _ / _ / _ /	
Short (_____ cy)	/ _ / _ / _ / _ / _ / _ / _ / _ /	
Long (_____ cy)	/ _ / _ / _ / _ / _ / _ / _ / _ /	

Hold Time	Mean I_{MWS2} Current (kA)	Individual and Mean Button (and Fused) Diameters (mm)
Setup Samples	_____	_____ (_____)
Short (_____ cy)	_____	_____ (_____)
Long (_____ cy)	_____	_____ (_____)

Hold Time	Fracture Mode Count 1 / 2 / 3 / 4 / 5 / 6 / 7 / 8	Individual and Mean Shear Tension Strength (kN)
Setup Samples	/ _ / _ / _ / _ / _ / _ / _ / _ /	
Short (_____ cy)	/ _ / _ / _ / _ / _ / _ / _ / _ /	
Long (_____ cy)	/ _ / _ / _ / _ / _ / _ / _ / _ /	

Comments _____

Form B-5 (Continued) **Weld Property Test Data (Page 4)**

For Test Code _____

Cross Tension Data

Hold Time	Mean I_{FDWS2} Current (kA)	Individual and Mean Button (and Fused) Diameters (mm)
Setup Samples	_____	_____ (_____)
Short (_____ cy)	_____	_____ (_____)
Long (_____ cy)	_____	_____ (_____)

Hold Time	Fracture Mode Count 1 / 2 / 3 / 4 / 5 / 6 / 7 / 8	Individual and Mean Shear Tension Strength (kN)
Setup Samples	/ _ / _ / _ / _ / _ / _ / _ /	
Short (_____ cy)	/ _ / _ / _ / _ / _ / _ / _ /	
Long (_____ cy)	/ _ / _ / _ / _ / _ / _ / _ /	

Hold Time	Mean I_{MWS2} Current (kA)	Individual and Mean Button (and Fused) Diameters (mm)
Setup Samples	_____	_____ (_____)
Short (_____ cy)	_____	_____ (_____)
Long (_____ cy)	_____	_____ (_____)

Hold Time	Fracture Mode Count 1 / 2 / 3 / 4 / 5 / 6 / 7 / 8	Individual and Mean Shear Tension Strength (kN)
Setup Samples	/ _ / _ / _ / _ / _ / _ / _ /	
Short (_____ cy)	/ _ / _ / _ / _ / _ / _ / _ /	
Long (_____ cy)	/ _ / _ / _ / _ / _ / _ / _ /	

Comments _____

Form B-6 Current Break-Through Test Report (Page 1)

For Test Code _____

Laboratory Name _____

Report Date _____

Address _____

Reported By _____

Telephone No. _____

Approved By _____

Fax No. _____

Title _____

Material Data

Coil No. or ID _____ Steel Grade _____ Mean Thickness _____ mm

Coating Type _____	Mean Coating Wt. _____ g/m ²	Top	Bottom

Brand Name	Type	Brand Name	Type
------------	------	------------	------

Surface Lubricants _____ Post-Coating Treatment _____

Other Data or Comments _____

Equipment Information

Welding Machine Type _____ Model Number _____ Machine Capacity _____ kVA

Welding Machine Tap _____ Weld Controller Name _____ Controller Mode _____

Air Cylinder Size _____ Air Cylinder Type _____ Head Velocity _____ mm/sec

Current Analyzer Brand & Model No. _____ Force Gage Brand & Model No. _____

Electrode Type (No.) _____	Dressed Face Dia. _____ mm	Top Elect.	Bot. Elect.
		Face Thick _____ mm	_____ mm

Cooling Tube—OD Dia. _____ mm Flow Meter Brand _____ Flow Meter Model No. _____

Comments or Variances to Specified Equipment _____

Welding Parameters

Weld Force _____ kN Welding Mode _____ Welding Rate _____ welds/min.

Set Squeeze Time _____ cy Weld Time _____ cy Set Hold Time _____ cy Actual Hold Time _____ cy

Off Time (Repeat Welding) _____ cy	Water Flow _____ l/min.	Water Temp. _____ °C	Panel Type _____
------------------------------------	----------------------------	-------------------------	------------------

Comments or Variances to Specified Parameters _____

Form B-6

Current Break-Through Test Report (Page 2)

For Test Code _____

I_{CBT} Current (established in 12.5)

Machine Setting (kA or % Heat)	I _{CBT} (kA)	Weld Button Diameter at I _{CBT} (mm)

Current Break-Through Data for the Control Material (Samples Coded C)

Sample Code	Stack-Up (2- or 4-Coupon)	I _{EFF} ^a (kA)	CBTT ^b	% of I _{EFF} for Each CBTT Half-Cycle
C2-1	2-Coupon			
C2-2	2-Coupon			
C2-3	2-Coupon			
C2-4	2-Coupon			
C2-5	2-Coupon			
C4-1	4-Coupon			
C4-2	4-Coupon			
C4-3	4-Coupon			
C4-4	4-Coupon			
C4-5	4-Coupon			

^a I_{EFF} is the mean (effective) welding current (meter reading) of all half cycles. It should approximate I_{CBT}.

^b CBTT is the total number of half-cycles not achieving 90% of I_{EFF}.

Current Break-Through Data for the Test Material (Samples Coded T)

Sample Code	Stack-Up (2- or 4-Coupon)	I _{EFF} ^a (kA)	CBTT ^b	% of I _{EFF} for Each CBTT Half-Cycle
T2-1	2-Coupon			
T2-2	2-Coupon			
T2-3	2-Coupon			
T2-4	2-Coupon			
T2-5	2-Coupon			
T4-1	4-Coupon			
T4-2	4-Coupon			
T4-3	4-Coupon			
T4-4	4-Coupon			
T4-5	4-Coupon			

^a I_{EFF} is the mean (effective) welding current (meter reading) of all half cycles. It should approximate I_{CBT}.

^b CBTT is the total number of half-cycles not achieving 90% of I_{EFF}.

Form B-7 DoE Welding Test Cover Sheet Report

Check as Appropriate**Test Number**

_____ Static Shear Tension with AC Weld Current
 _____ Static Cross Tension with AC Weld Current
 _____ Static Shear Tension with MFDC Weld Current
 _____ Static Cross Tension with MFDC Weld Current

Material Data

Steel Supplier _____
 Steel Type _____
 Steel Coating _____
 Coil Number/Identification _____
 Avg. Sheet Thickness _____

Test Laboratory Information

Laboratory Name _____
 Address _____
 Telephone Number _____
 Fax Number _____
 Report Date _____
 Individual Performing Welding Part of DoE _____
 Individual Measuring DoE Responses _____
 Data Reported by _____
 Data Approved by (and Title) _____

Equipment Information

Welding Machine Manufacturer _____
 Welding Machine Type _____
 Model Number _____
 Machine Capacity _____
 Welding Machine Tap _____
 Weld Controller Name _____
 Controller Mode _____
 Air Cylinder Size _____
 Air Cylinder Type _____
 Head Velocity _____
 Weld Current Analyzer _____
 Force Gauge _____
 Caliper _____
 Electrode Type _____
 Nom. Electrode Face Dia. _____
 Cooling tube-OD Diameter _____
 Flow Meter _____
 Water Flow _____
 Water Temp. _____

	Static Shear Tension with AC Weld Current	Test Number
	Static Cross Tension with AC Weld Current	Steel Supplier
	Static Shear Tension with MFDC Weld Current	Steel Type
	Static Cross Tension with MFDC Weld Current	

Test Number

Date

Individual(s) Performing Testing

[illegible]

Test Number

Individual(s) Performing Testing

[illegible]

Form B-9-ST **DoE Welding Data Sheet with Measured Responses Report—Shear Tension (Page 1)**

Check as Appropriate

Static Shear Tension with AC Weld Current
 Static Shear Tension with AC Weld Current

Test Number
 Steel Supplier
 Steel Type

Date
 Test Number

Individual(s) Performing Testing

(ST= Shear Tension, Ret = Retained sample, DoE factors—Enter Actual Values)

DoE Run No.	Sample		DoE Factors					Responses						Current Setting	Tap Setting	
			Weld Size (mm)	Weld Force (lbs)	Weld Time (cy)	Hold Time (cy)	Peak Load (kN)	Energy (J)	Fracture Mode		Average Weld Current (kA)	Indentation				Measured Weld Current (kA)
									(1 to 8)	Weld Size		Moving Electrode Side	Fixed Electrode Side			
1	ID	Purpose														
	81	ST	Low	Low	Low	Low										
	82	ST														
	83	ST														
	84	Ret														
2	85	Ret														
	86	ST	Low	Low	Low	High										
	87	ST														
	88	ST														
	89	Ret														
3	90	Ret														
	91	ST	Low	Low	High	Low										
	92	ST														
	93	ST														
	94	Ret														
4	95	Ret														
	96	ST	Low	Low	High	High										
	97	ST														
	98	ST														
	99	Ret														
	100	Ret														

Form B-9-ST (Continued)
DoE Welding Data Sheet with Measured Responses Report—Shear Tension (Page 2)

DoE Run No.	Sample		DoE Factors					Responses					Current Setting	Tap Setting		
			Weld Size (mm)	Weld Force (lbs)	Weld Time (cy)	Hold Time (cy)	Peak Load (kN)	Energy (J)	Fracture Mode		Average Weld Current (kA)	Indentation			Measured Weld Current (kA)	
									Fracture Mode (1 to 8)	Weld Size		Moving Electrode Side				Fixed Electrode Side
ID	Purpose	Weld Size (mm)	Weld Force (lbs)	Weld Time (cy)	Hold Time (cy)	Peak Load (kN)	Energy (J)	Fracture Mode (1 to 8)	Weld Size	Average Weld Current (kA)	Moving Electrode Side	Fixed Electrode Side	Measured Weld Current (kA)	Current Setting	Tap Setting	
5	101	ST	Low	High	Low	Low										
	102	ST														
	103	ST														
	104	Ret														
	105	Ret														
6	106	ST	Low	High	Low	High										
	107	ST														
	108	ST														
	109	Ret														
	110	Ret														
7	111	ST	Low	High	High	Low										
	112	ST														
	113	ST														
	114	Ret														
	115	Ret														
8	116	ST	Low	High	High	High										
	117	ST														
	118	ST														
	119	Ret														
	120	Ret														
9	121	ST	High	Low	Low	Low										
	122	ST														
	123	ST														
	124	Ret														
	125	Ret														
10	126	ST	High	Low	Low	High										
	127	ST														
	128	ST														
	129	Ret														
	130	Ret														

Form B-9-ST (Continued)
DoE Welding Data Sheet with Measured Responses Report—Shear Tension (Page 3)

DoE Run No.	Sample		DoE Factors					Responses						Current Setting	Tap Setting		
			Weld Size (mm)	Weld Force (lbs)	Weld Time (cy)	Hold Time (cy)	Peak Load (kN)	Energy (J)	Fracture Mode		Average Weld Current (kA)	Indentation				Measured Weld Current (kA)	
									Fracture Mode (1 to 8)	Weld Size		Moving Electrode Side	Fixed Electrode Side				
ID	Purpose																
11	131	ST	High	Low	High	Low											
	132	ST															
	133	ST															
	134	Ret															
	135	Ret															
12	136	ST	High	Low	High	High											
	137	ST															
	138	ST															
	139	Ret															
	140	Ret															
13	141	ST	High	High	Low	Low											
	142	ST															
	143	ST															
	144	Ret															
	145	Ret															
14	146	ST	High	High	Low	High											
	147	ST															
	148	ST															
	149	Ret															
	150	Ret															
15	151	ST	High	High	High	Low											
	152	ST															
	153	ST															
	154	Ret															
	155	Ret															
16	156	ST	High	High	High	High											
	157	ST															
	158	ST															
	159	Ret															
	160	Ret															

Form B-9-CT
DoE Welding Data Sheet with Measured Responses Report—Cross Tension (Page 1)

Check as Appropriate

Static Cross Tension with AC Weld Current

Static Cross Tension with AC Weld Current

Test Number

Steel Supplier

Steel Type

Date

Test Number

Individual(s) Performing Testing

(CT= Cross Tension, Ret = Retained sample, DoE factors—Enter Actual Values)

DoE Run No.	Sample		DoE Factors				Responses						Current Setting	Tap Setting	
			Weld Size (mm)	Weld Force (lbs)	Weld Time (cy)	Hold Time (cy)	Peak Load (kN)	Energy (J)	Fracture Mode		Average Weld Current (kA)	Indentation			Measured Weld Current (kA)
	ID	Purpose							Fracture Mode (1 to 8)	Weld Size		Moving Electrode Side	Fixed Electrode Side		
1	81	CT	Low	Low	Low	Low									
	82	CT													
	83	CT													
	84	Ret													
	85	Ret													
2	86	CT	Low	Low	Low	High									
	87	CT													
	88	CT													
	89	Ret													
	90	Ret													
3	91	CT	Low	Low	High	Low									
	92	CT													
	93	CT													
	94	Ret													
	95	Ret													
4	96	CT	Low	Low	High	High									
	97	CT													
	98	CT													
	99	Ret													
	100	Ret													

Form B-9-CT (Continued)
DoE Welding Data Sheet with Measured Responses Report—Cross Tension (Page 2)

DoE Run No.	Sample		DoE Factors					Responses						Current Setting	Tap Setting	
	ID	Purpose	Weld Size (mm)	Weld Force (lbs)	Weld Time (cy)	Hold Time (cy)	Peak Load (kN)	Energy (J)	Fracture Mode		Average Weld Current (kA)	Indentation				Measured Weld Current (kA)
									Fracture Mode (1 to 8)	Weld Size		Moving Electrode Side	Fixed Electrode Side			
5	101	CT	Low	High	Low	Low										
	102	CT														
	103	CT														
	104	Ret														
	105	Ret														
6	106	CT	Low	High	Low	High										
	107	CT														
	108	CT														
	109	Ret														
	110	Ret														
7	111	CT	Low	High	High	Low										
	112	CT														
	113	CT														
	114	Ret														
	115	Ret														
8	116	CT	Low	High	High	High										
	117	CT														
	118	CT														
	119	Ret														
	120	Ret														
9	121	CT	High	Low	Low	Low										
	122	CT														
	123	CT														
	124	Ret														
	125	Ret														
10	126	CT	High	Low	Low	High										
	127	CT														
	128	CT														
	129	Ret														
	130	Ret														

Form B-9-CT (Continued)
DoE Welding Data Sheet with Measured Responses Report—Cross Tension (Page 3)

DoE Run No.	Sample		DoE Factors				Responses						Current Setting	Tap Setting		
	ID	Purpose	Weld Size (mm)	Weld Force (lbs)	Weld Time (cy)	Hold Time (cy)	Peak Load (kN)	Energy (J)	Fracture Mode		Average Weld Current (kA)	Indentation			Measured Weld Current (kA)	
									Fracture Mode (1 to 8)	Weld Size		Moving Electrode Side				Fixed Electrode Side
11	131	CT	High	Low	High	Low										
	132	CT														
	133	CT														
	134	Ret														
	135	Ret														
12	136	CT	High	Low	High	High										
	137	CT														
	138	CT														
	139	Ret														
	140	Ret														
13	141	CT	High	High	Low	Low										
	142	CT														
	143	CT														
	144	Ret														
	145	Ret														
14	146	CT	High	High	Low	High										
	147	CT														
	148	CT														
	149	Ret														
	150	Ret														
15	151	CT	High	High	High	Low										
	152	CT														
	153	CT														
	154	Ret														
	155	Ret														
16	156	CT	High	High	High	High										
	157	CT														
	158	CT														
	159	Ret														
	160	Ret														

Annex C (Informative)

Optional Endurance Test Panel

This annex is not part of AWS D8.9M:2012, *Test Methods for Evaluating the Resistance Spot Welding Behavior of Automotive Sheet Steel Materials*, but is included for informational purposes only.

When material quantity is limited, the optional panel described in this annex may be used. This annex provides the coupon dimension of the optional panel, lists the spacing required, provides data for calculating the amount of material required, and contains instruction for using this panel for the endurance test. The panel type that is used in the test are typically recorded on the Welding Data Sheet, using code “O” for the optional panel type and “S” for the standard type.

C1. Panel Preparation

Coupon preparation, shearing, and marking of the optional panels are typically performed according to the standard instructions in Clause 4.

C2. Panel Welding

Panel welding for the Endurance Test are typically conducted as in 10.5 but with these additional instructions for the optional test panel. Using a sufficient number of panels (so that the panels are cool when the next row of a panel is welded), one row of welds per panel is to be made on all panels of a set of panels until the 190 welds of a checkpoint are reached.

For Panels 1 through 4, Rows 1, 2, and 3 are welded in the sequence shown in Figure C.1, using the prescribed spacing listed in Table C.1. After completing Rows 1, 2, and 3, the panel is rotated 180° so that the same surface orientation is maintained as for the first three rows. Rows 4, 5, and 6 are welded as shown in Figure C.2. *NOTE: The instructions for panel row sequencing and surface orientation combinations (see 6.5.3 and 6.6.2) also apply for these panels.*

Table C.1
Coupon Dimensions, Weld Spacing, and Edge Distances for Optional Panels

Panel Number	Sheet Thickness (mm)	L ^a (mm)	W ^{b,c} (mm)	WS ^c (mm)	A & B ^c (mm)	Area 3 ^d (m ² /weld) ^e
1	0.60–0.69	280	98	14	14	0.000482
2	0.70–0.89	300	105	15	15	0.000553
3	0.90–1.29	360	126	18	18	0.000796
4	1.30–1.69	420	147	21	21	0.001083
5 (four rows)	1.70–2.09	480	120	24	24	0.001516
6 (four rows)	2.10–3.00	540	135	27	27	0.001918

^a L = (18 × WS) + 2A; Tolerance: ±3 mm.

^b For Panels 1 through 4: W = (5 × WS) + 2B; for Panels 5 and 6: W = (3 × WS) + 2B.

^c Tolerance: ±3 mm.

^d For calculating required material quantities (see 3.2).

^e 1 m² = 10.764 ft².

For Panels 5 and 6 a maximum of four rows is suggested because the panels are too large when six rows are used and too much mass is introduced into the welding machines throat, possibly increasing inductance/impedance and reducing the I_{OP} . Rows 1 and 2 are welded in the same sequence as Rows 1 and 2 shown in Figure C.1. After completing Rows 1 and 2, the panels are rotated 180° so that the same surface orientation is maintained as for the first two rows. Rows 3 and 4 are then welded the same as Rows 4 and 5 in Figure C.2. *NOTE: The instructions for panel row sequencing and surface orientation combinations (see 6.5.3 and 6.6.2) also apply for these panels.*

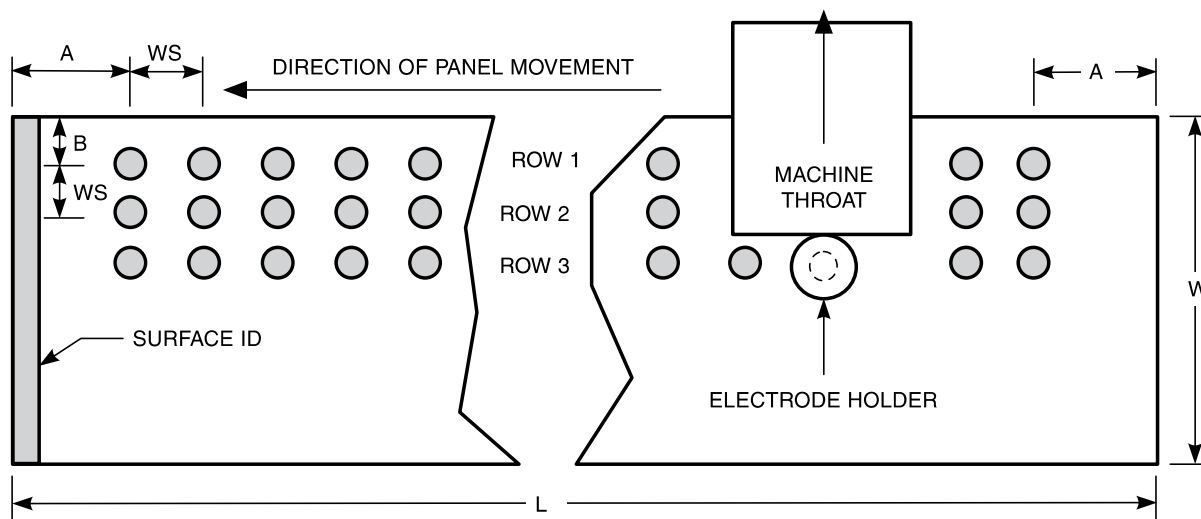


Figure C.1—Panel Row Sequencing, Weld Spacing, and Edge Distances for Rows 1 through 3 on the Optional Panel

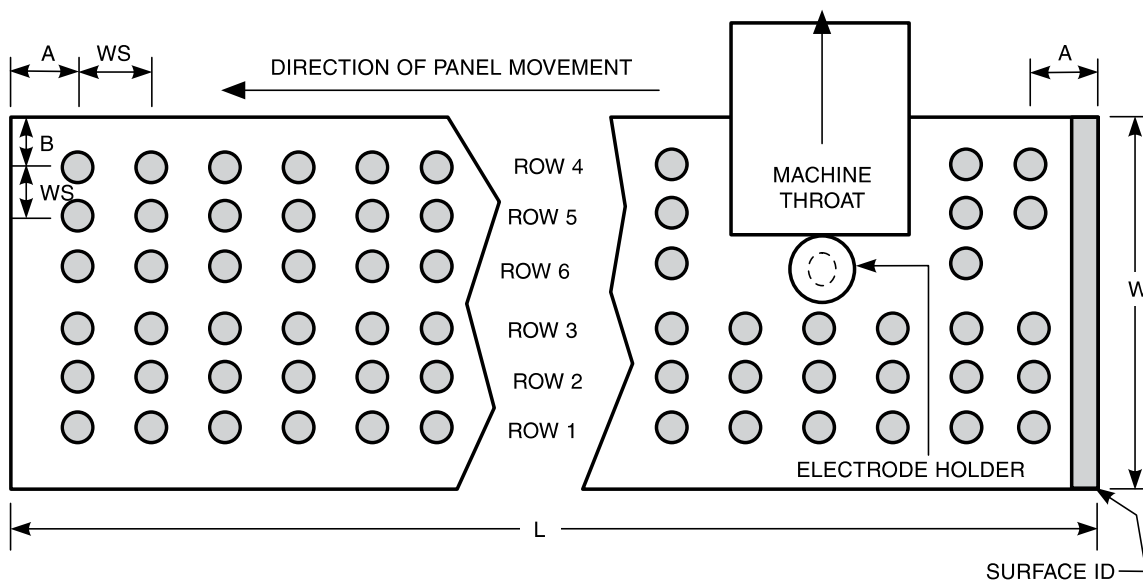


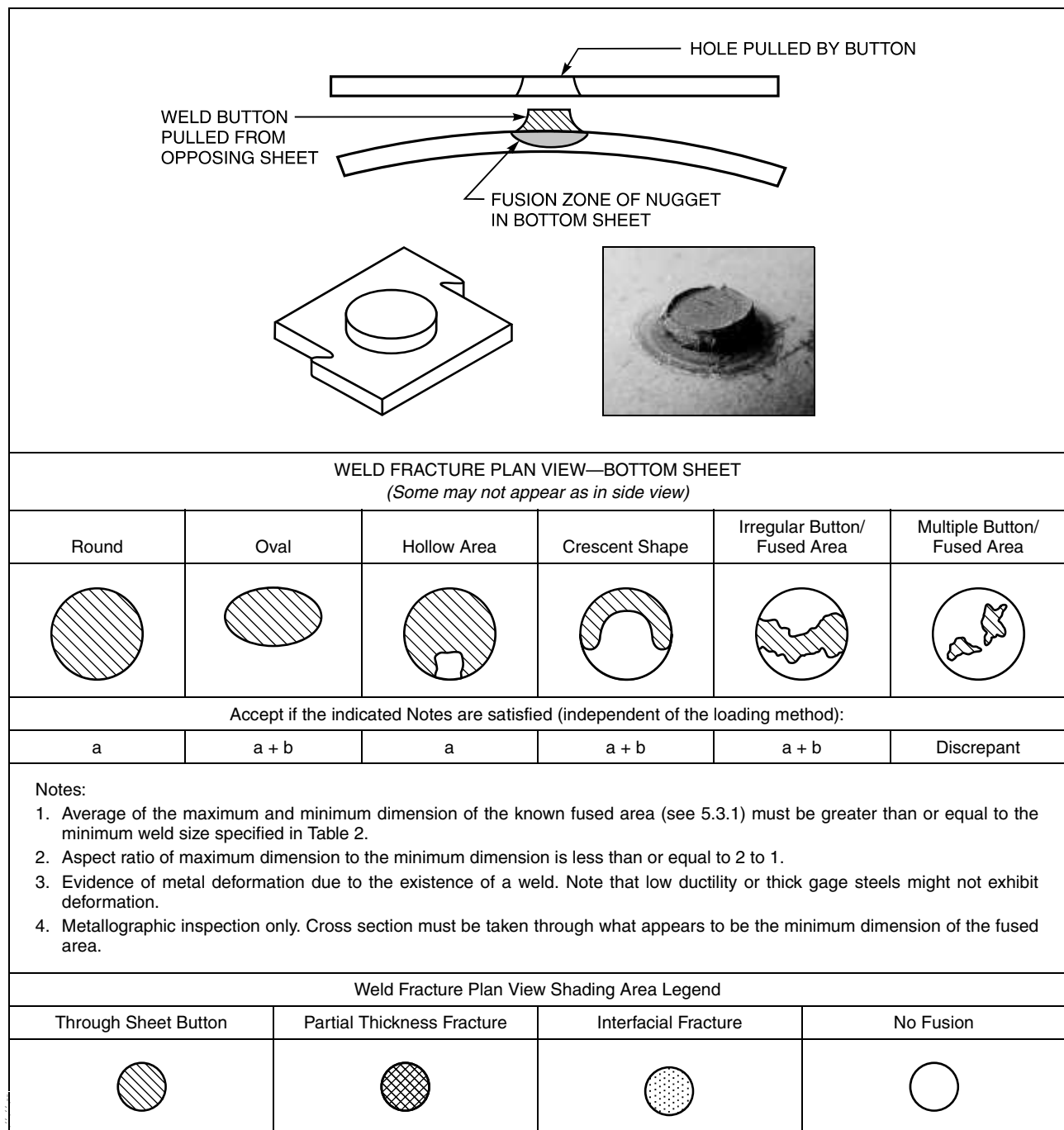
Figure C.2—Panel Row Sequencing, Weld Spacing, and Edge Distances for Rows 4 through 6 on the Optional Panel

Annex D (Informative)

Fracture Classification Charts

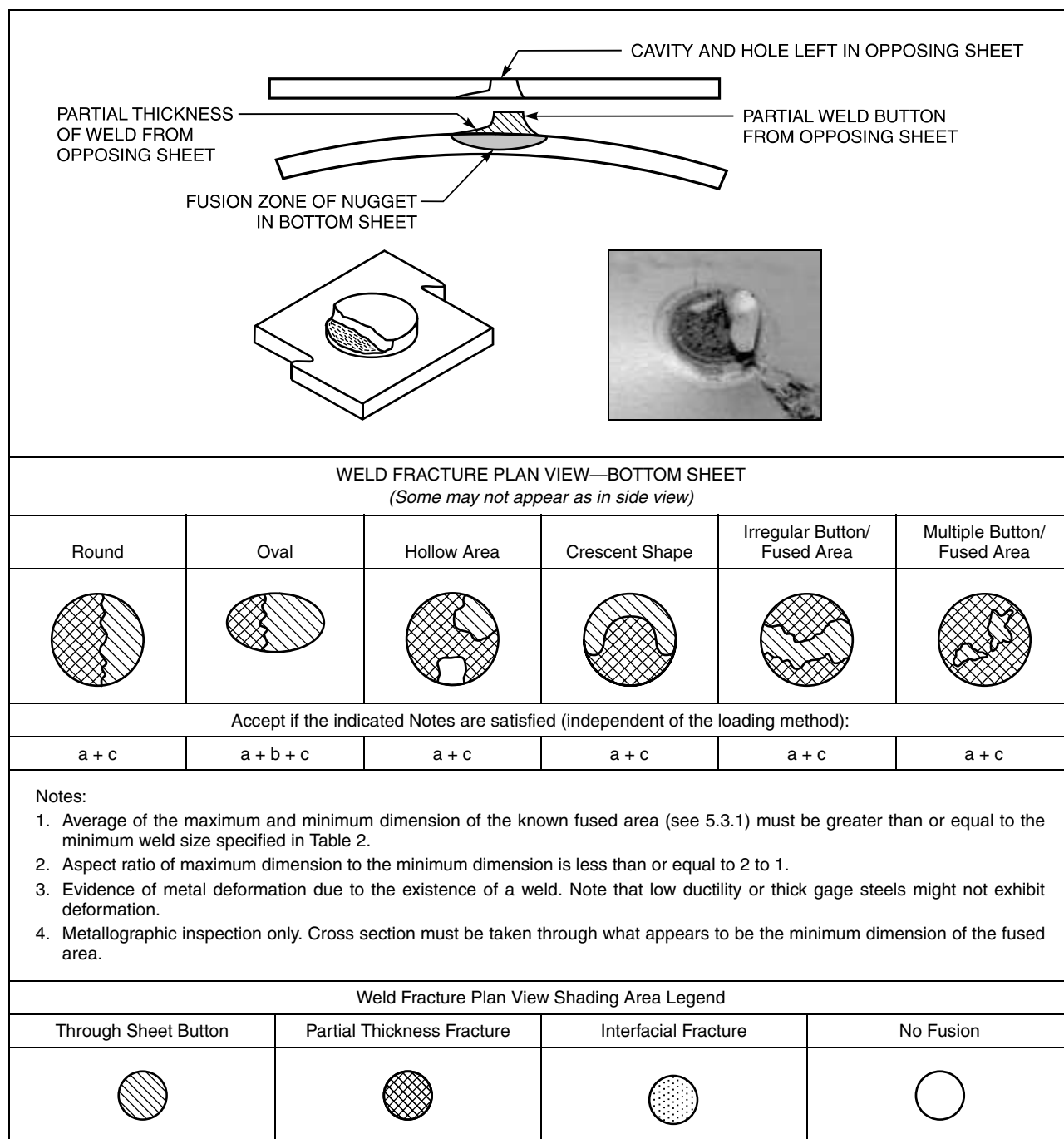
This annex is not part of AWS D8.9M:2012, *Test Methods for Evaluating the Resistance Spot Welding Behavior of Automotive Sheet Steel Materials*, but is included for informational purposes only.

The following fracture mode illustrations were excerpted from AWS D8.1M:2007, *Specification for Automotive Weld Quality—Resistance Spot Welding of Steel*.



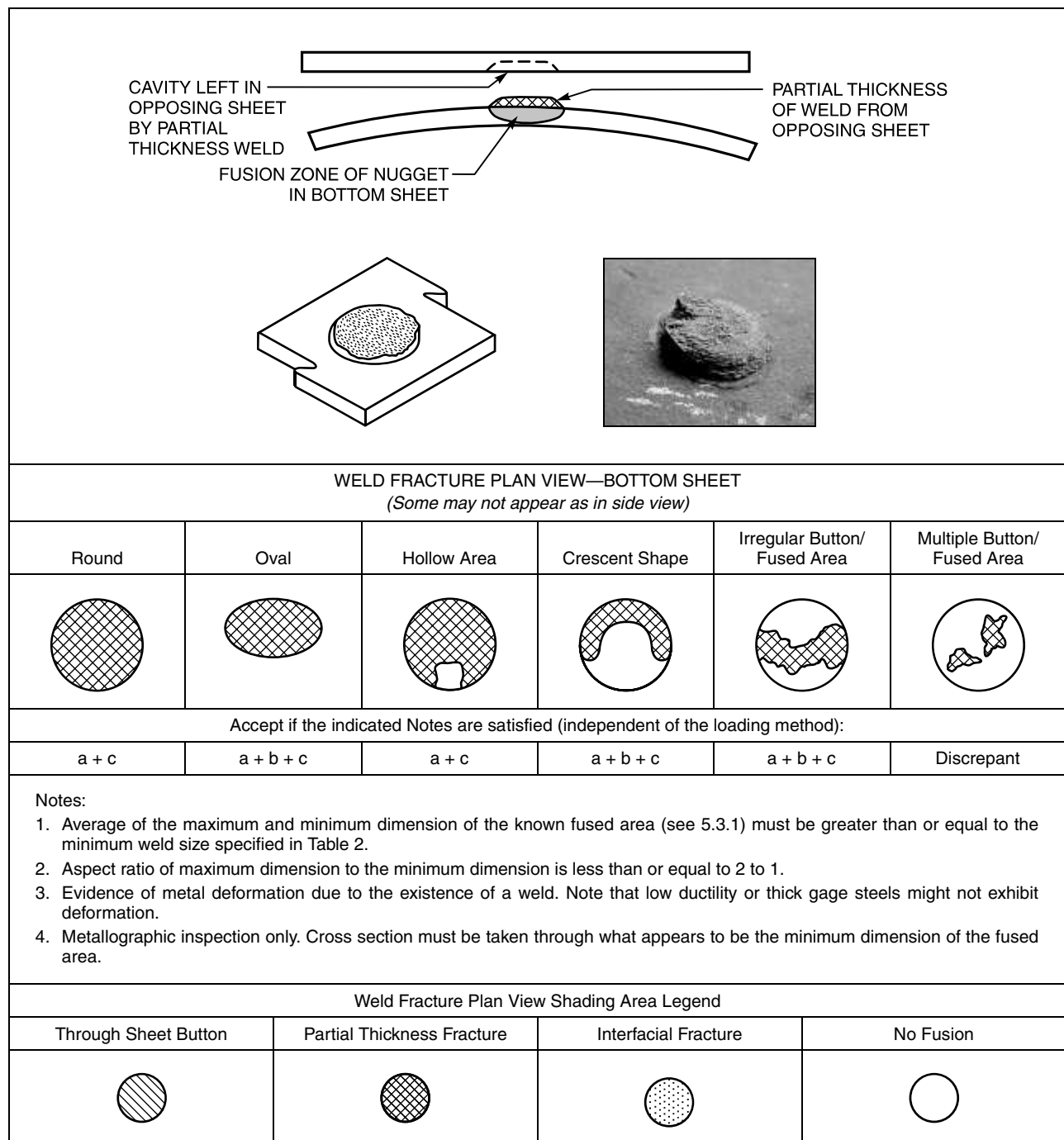
Source: Reproduced from AWS D8.1M:2007, *Specification for Automotive Weld Quality—Resistance Spot Welding of Steel*, Figure 10, Miami: American Welding Society.

Figure D.1—Fracture Mode 1—Button Pull



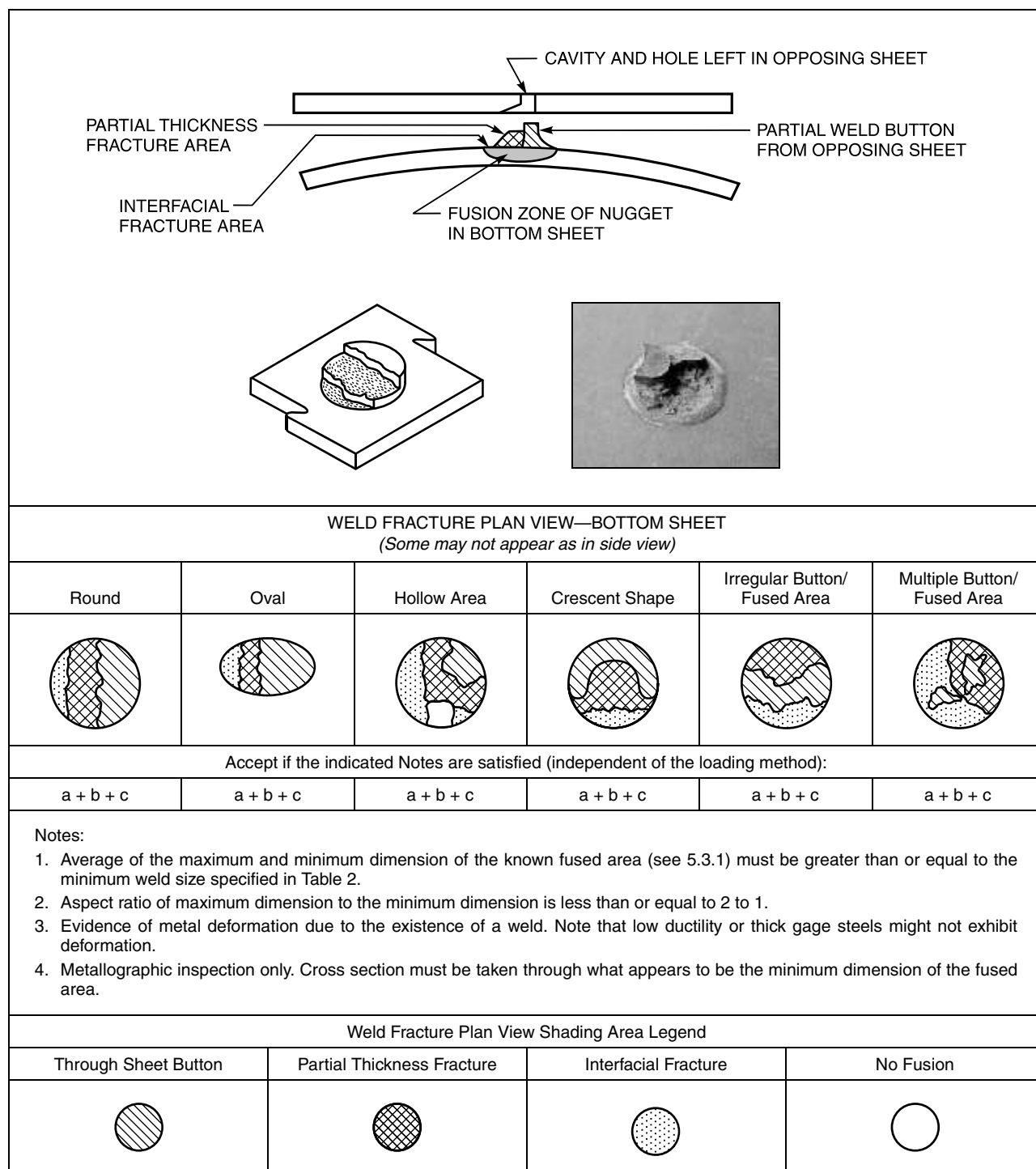
Source: Reproduced from AWS D8.1M:2007, *Specification for Automotive Weld Quality—Resistance Spot Welding of Steel*, Figure 11, Miami: American Welding Society.

Figure D.2—Fracture Mode 2—Partial Thickness Fracture with Button Pull



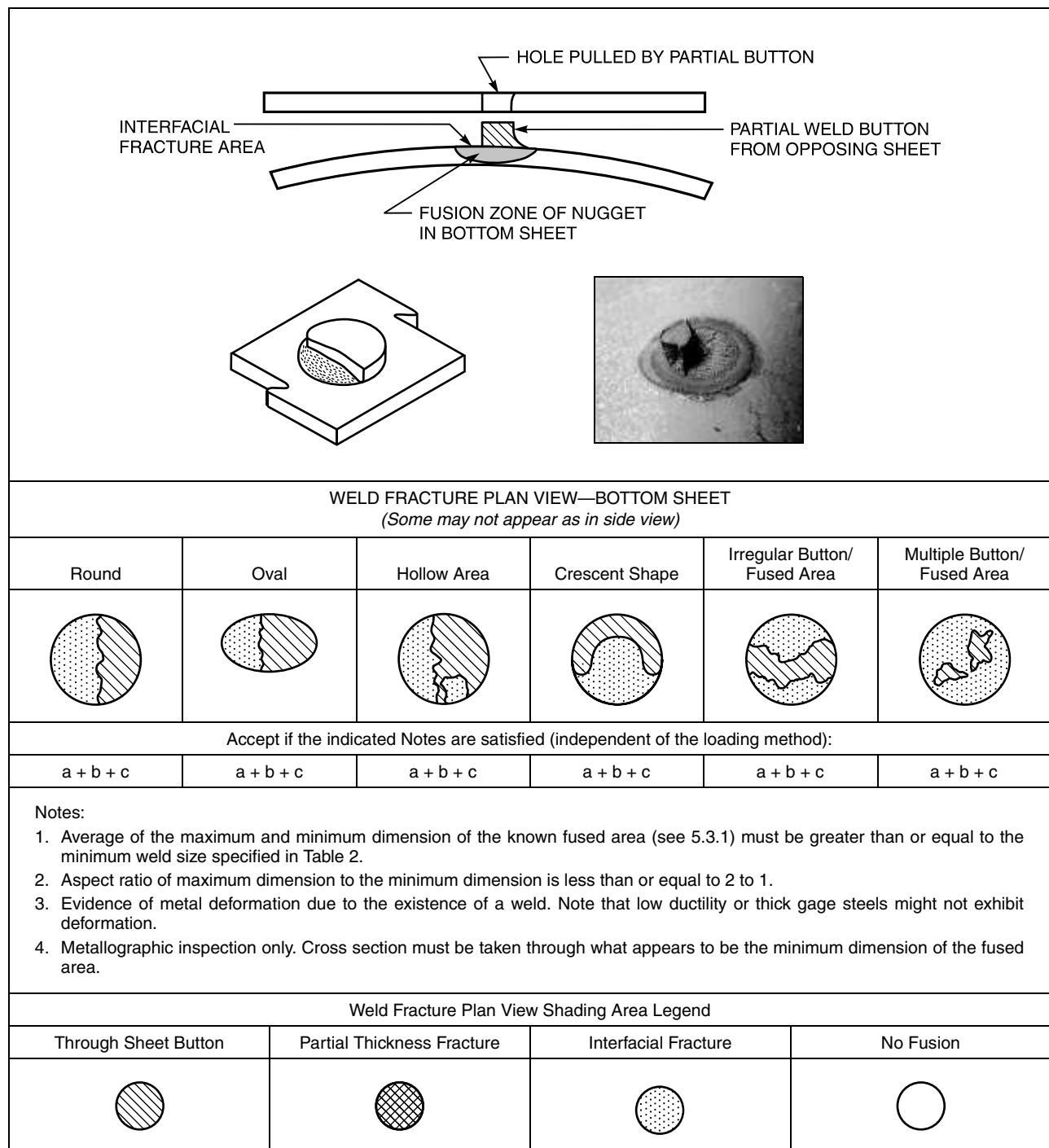
Source: Reproduced from AWS D8.1M:2007, *Specification for Automotive Weld Quality—Resistance Spot Welding of Steel*, Figure 12, Miami: American Welding Society.

Figure D.3—Fracture Mode 3—Partial Thickness Fracture



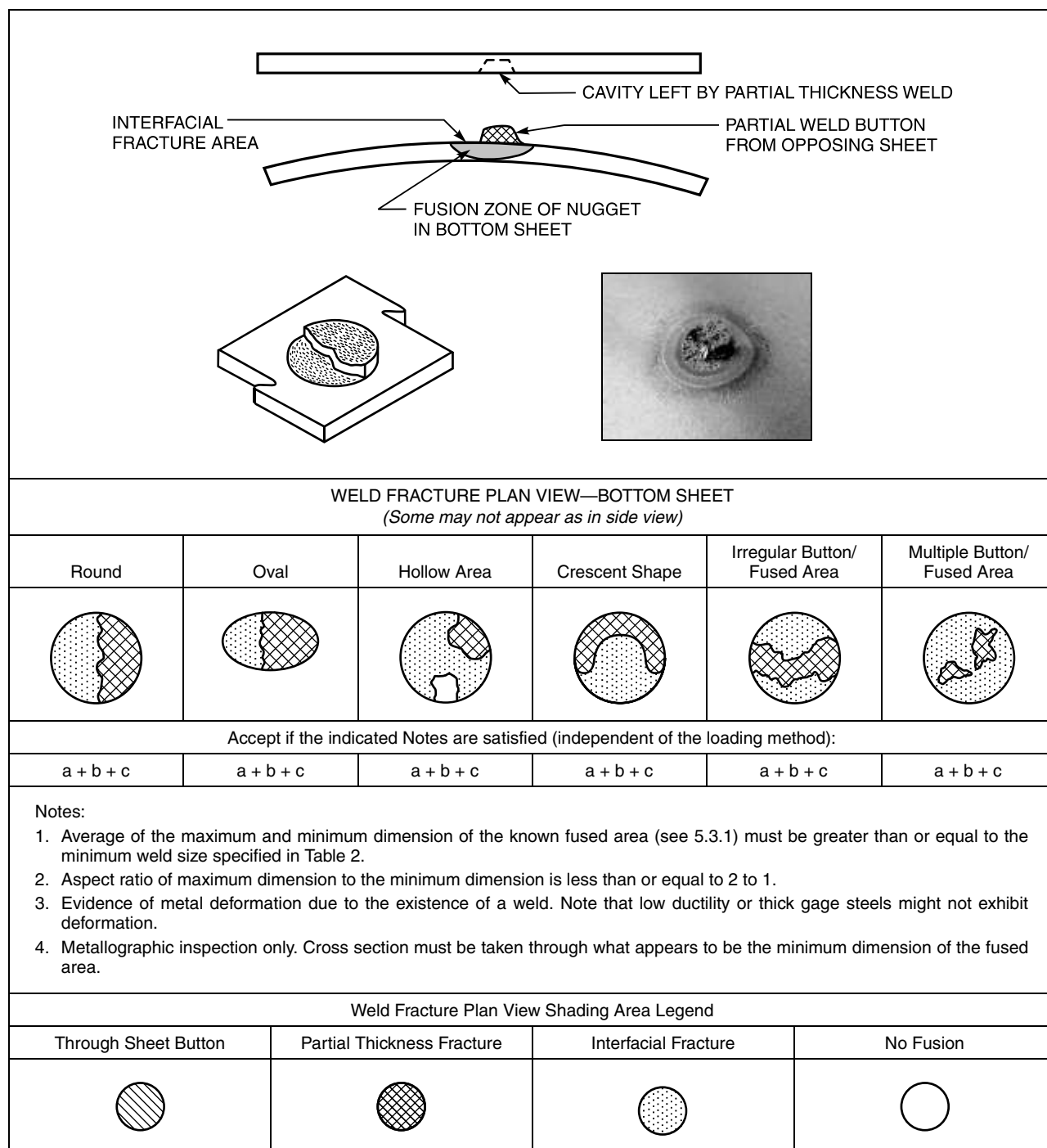
Source: Reproduced from AWS D8.1M:2007, *Specification for Automotive Weld Quality—Resistance Spot Welding of Steel*, Figure 13, Miami: American Welding Society.

Figure D.4—Fracture Mode 4—Interfacial Fracture with Button Pull and Partial Thickness Fracture



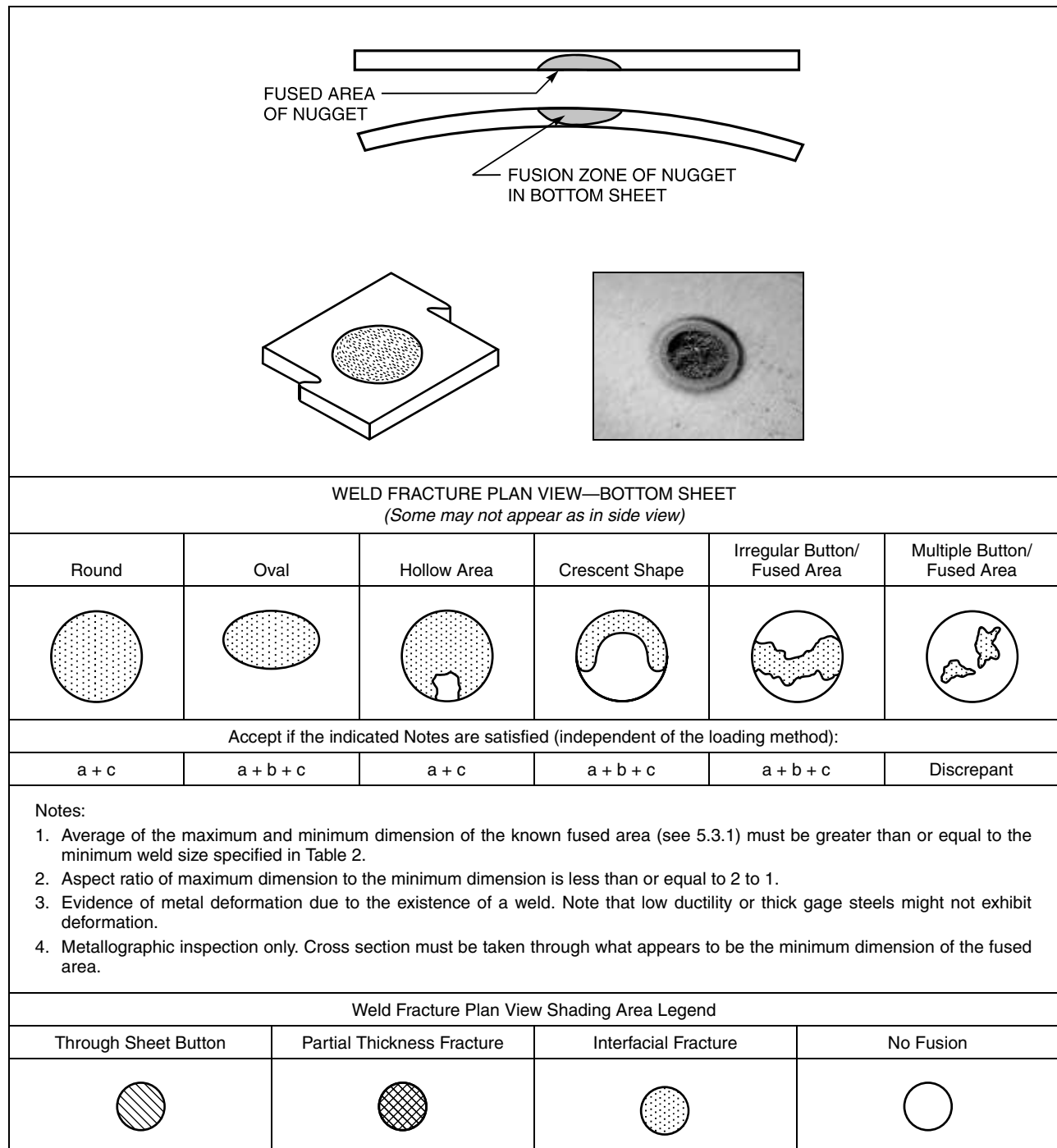
Source: Reproduced from AWS D8.1M:2007, *Specification for Automotive Weld Quality—Resistance Spot Welding of Steel*, Figure 14, Miami: American Welding Society.

Figure D.5—Fracture Mode 5—Interfacial Fracture with Button Pull



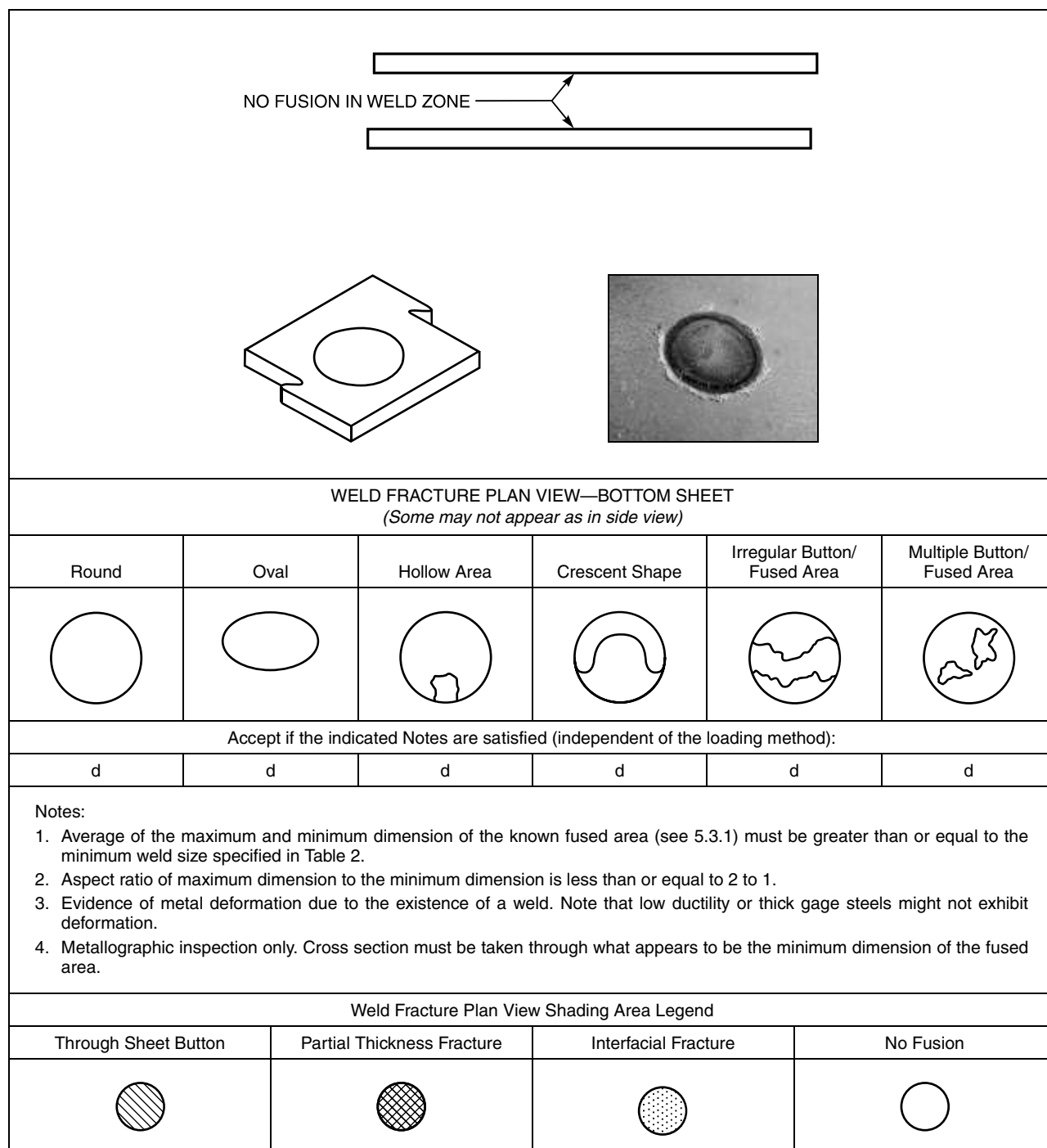
Source: Reproduced from AWS D8.1M:2007, *Specification for Automotive Weld Quality—Resistance Spot Welding of Steel*, Figure 15, Miami: American Welding Society.

Figure D.6—Fracture Mode 6—Interfacial Fracture with Partial Thickness Fracture



Source: Reproduced from AWS D8.1M:2007, *Specification for Automotive Weld Quality—Resistance Spot Welding of Steel*, Figure 16, Miami: American Welding Society.

Figure D.7—Fracture Mode 7—Interfacial Fracture



Source: Reproduced from AWS D8.1M:2007, *Specification for Automotive Weld Quality—Resistance Spot Welding of Steel*, Figure 17, Miami: American Welding Society.

Figure D.8—Fracture Mode 8—No Fusion

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Annex E (Informative)

Procedural Guidelines for Alternative Testing Methods

This annex is not part of AWS D8.9M:2012, *Test Methods for Evaluating the Resistance Spot Welding Behavior of Automotive Sheet Steel Materials*, but is included for informational purposes only.

E1. Introduction

The request to utilize alternative welding equipment, electrode caps, or weld schedules is generally driven by the desire to incorporate a specific manufacturing, engineering, and/or process standard with the material evaluation. The alternative methods are generally mutually exclusive from each other. For example, the incorporation of a specific weld timer does not also require the use of an alternative button size requirement. The one possible exception is that customer specific electrode caps are generally associated with customer specific weld schedules, and care should be exercised if these two items are not utilized in a common manner for a particular evaluation.

The procedural changes required due to the use of alternative methods may range from negligible to significant and these guidelines are intended to bring awareness to those potential changes. These procedural guidelines are not a replacement for sound engineering judgment. A well-planned and thought-out procedure will be essential for all material testing to ensure that the desired significant material characteristics are determined in a safe and efficient manner.

E2. Welding Equipment

The use of alternative welding equipment may permit the customer to determine how a particular material will perform in a unique situation. The following are examples of possible welding equipment deviations from the present D8.9M: utilization of DC welding current, requiring a specific weld controller and/or model number, requiring nonpneumatic force systems, or requiring a specific transformer manufacturer, voltage range, and/or model number.

E3. Electrode Caps and Weld Schedules

The use of alternative electrode caps and weld schedules may permit the customer to determine how a particular material will perform in a specific situation. The selection of an alternative electrode cap and/or weld schedule may be based on customer specific manufacturing, engineering, or process standards.

E4. Electrode Stabilization

The use of alternative electrode caps has the potential for significant electrode stabilization procedural changes. The electrode caps specified in Annex A detail a specific contact face diameter (based on the gauge of the material) and the electrode stabilization procedure (see Clause 9) is written based on these aforementioned contact face diameters. It should be noted that the Stabilization Weld Size (SWS) as defined in the AWS D8.9M is based on the contact face diameter of the electrode, not the gauge of the material being welded, and is always greater than the specified Minimum Weld Size (MWS) for the material to be welded. Thus any change to the contact face diameter (e.g., using an electrode of the type described in 13.2.2) may result in an electrode cap with an SWS that is less than the MWS.

The reduction in SWS resulting from the use of alternative electrode geometries, when applied to the D8.9M electrode stabilization procedure may result in an erroneous and inconsistent stabilization due to the unstable nature of the subsequently small weld size. The two possible alternatives that have been utilized when the SWS is less than the MWS are:

E4.1 Electrode Stabilization with SWS at $4.5\sqrt{\text{GMT}}$. This method of stabilization changes the SWS from an electrode based dimension to a material gauge based dimension. All other aspects of the Clause 9 stabilization procedure can be utilized.

E4.2 Electrode Conditioning. As an alternative to the stabilization procedure, 100 welds (or other number as determined by the customer) may be made on a flat panel to condition the electrodes. The welding current used should be sufficient to produce MWS. The welding time and other parameters should be chosen from Tables 4a, 4b, and 4c or should be appropriate for the gauge of steel being welded. Unlike in stabilization, in conditioning the weld size is not monitored over time. However, as the number of welds made is relatively small changes to weld size are not expected to be significant.

E5. Weld Endurance Test

The use of alternative testing methods does not typically affect the Weld Endurance Test (see Clause 10). The requirement relating to the determination of weld size, etc. is procedurally structured to accommodate most, if not all, of the possible alternatives outlined above. The alteration of the endurance weld rate or the inclusion of a current stepper are possible procedural changes that may be incorporated into this evaluation providing careful consideration is utilized to determine the proper checkpoints and procedural changes required to achieve them.

E6. Weld Property Test

The use of alternative testing methods may have an effect on the Weld Property Test (see Clause 11). The requirements relating to the determination of the Face Diameter Weld Size (FDWS) may not be directly applicable to electrode caps with contact face diameters that are small in relation to the GMT. (e.g., using an electrode of the type described in 13.2.2) The net effect is that the required FDWS may need to change from an electrode-based dimension to a material gauge-based dimension. The repeatability requirements of weld size, etc. as they relate to the mechanical test samples should be procedurally structured to accommodate the possible alternatives outlined above. The user should verify that the proper weld sizes are specified for the property testing to ensure that meaningful results are obtained.

E7. Current Break-Through Test

The use of alternative testing methods does not typically affect the Current Break-Through Test (see Clause 12). The one possible exception may be the use of DC welding current. This is due to the requirement that the weld controller must be utilized without the benefit of constant current or other feedback control methods. Care should be taken to ensure that the customer specified DC controller is able to apply automatic voltage compensation (AVC) in a manner consistent with the requirements of the procedure.

E8. Design of Experiments (DoE) Test

The use of alternative testing methods may have an effect on the Design of Experiments (DoE) Test (see Clause 13). Electrode geometry and material thickness are critical factors that control achievable weld sizes. The requirements relating to the determination of the weld size factor may require modification so that unfavorable electrode geometries are not utilized for a specific material gauge. The repeatability requirement of weld size as it is related to the mechanical samples is procedurally structured to accommodate most, if not all, of the possible alternatives outlined above providing the issues relating to establishing the weld size factor are addressed.

Annex F (Informative)

Informative References

This annex is not part of AWS D8.9M:2012, *Test Methods for Evaluating the Resistance Spot Welding Behavior of Automotive Sheet Steel Materials*, but is included for informational purposes only.

ANSI Z49.1, *Safety in Welding, Cutting, and Allied Processes*, American Welding Society.

ASTM A90, *Test Method for Weight of Coating on Iron and Steel Articles with Zinc or Zinc-Alloy Coatings*, American Society of Testing and Materials.

ASTM A754, *Test Method for Coating Thickness by X-Ray Fluorescence*, American Society of Testing and Materials.

RWMA, *Resistance Welding Manual*, Revised 4th Edition, American Welding Society.

World Auto Steel, *Advanced High Strength Steel (AHSS) Application Guidelines*, September 2006, World Steel Organization.

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Annex G (Informative)

Guidelines for the Preparation of Technical Inquiries

This annex is not part of AWS D8.9M:2012, *Test Methods for Evaluating the Resistance Spot Welding Behavior of Automotive Sheet Steel Materials*, but is included for informational purposes only.

G1. Introduction

The American Welding Society (AWS) Board of Directors has adopted a policy whereby all official interpretations of AWS standards are handled in a formal manner. Under this policy, all interpretations are made by the committee that is responsible for the standard. Official communication concerning an interpretation is directed through the AWS staff member who works with that committee. The policy requires that all requests for an interpretation be submitted in writing. Such requests will be handled as expeditiously as possible, but due to the complexity of the work and the procedures that must be followed, some interpretations may require considerable time.

G2. Procedure

All inquiries shall be directed to:

Managing Director
Technical Services Division
American Welding Society
550 N.W. LeJeune Road
Miami, FL 33126

All inquiries shall contain the name, address, and affiliation of the inquirer, and they shall provide enough information for the committee to understand the point of concern in the inquiry. When the point is not clearly defined, the inquiry will be returned for clarification. For efficient handling, all inquiries should be typewritten and in the format specified below.

G2.1 Scope. Each inquiry shall address one single provision of the standard unless the point of the inquiry involves two or more interrelated provisions. The provision(s) shall be identified in the scope of the inquiry along with the edition of the standard that contains the provision(s) the inquirer is addressing.

G2.2 Purpose of the Inquiry. The purpose of the inquiry shall be stated in this portion of the inquiry. The purpose can be to obtain an interpretation of a standard's requirement or to request the revision of a particular provision in the standard.

G2.3 Content of the Inquiry. The inquiry should be concise, yet complete, to enable the committee to understand the point of the inquiry. Sketches should be used whenever appropriate, and all paragraphs, figures, and tables (or annex) that bear on the inquiry shall be cited. If the point of the inquiry is to obtain a revision of the standard, the inquiry shall provide technical justification for that revision.

G2.4 Proposed Reply. The inquirer should, as a proposed reply, state an interpretation of the provision that is the point of the inquiry or provide the wording for a proposed revision, if this is what the inquirer seeks.

G3. Interpretation of Provisions of the Standard

Interpretations of provisions of the standard are made by the relevant AWS technical committee. The secretary of the committee refers all inquiries to the chair of the particular subcommittee that has jurisdiction over the portion of the standard addressed by the inquiry. The subcommittee reviews the inquiry and the proposed reply to determine what the response to the inquiry should be. Following the subcommittee's development of the response, the inquiry and the response are presented to the entire committee for review and approval. Upon approval by the committee, the interpretation is an official interpretation of the Society, and the secretary transmits the response to the inquirer and to the *Welding Journal* for publication.

G4. Publication of Interpretations

All official interpretations will appear in the *Welding Journal* and will be posted on the AWS web site.

G5. Telephone Inquiries

Telephone inquiries to AWS Headquarters concerning AWS standards should be limited to questions of a general nature or to matters directly related to the use of the standard. The *AWS Board Policy Manual* requires that all AWS staff members respond to a telephone request for an official interpretation of any AWS standard with the information that such an interpretation can be obtained only through a written request. Headquarters staff cannot provide consulting services. However, the staff can refer a caller to any of those consultants whose names are on file at AWS Headquarters.

G6. AWS Technical Committees

The activities of AWS technical committees regarding interpretations are limited strictly to the interpretation of provisions of standards prepared by the committees or to consideration of revisions to existing provisions on the basis of new data or technology. Neither AWS staff nor the committees are in a position to offer interpretive or consulting services on (1) specific engineering problems, (2) requirements of standards applied to fabrications outside the scope of the document, or (3) points not specifically covered by the standard. In such cases, the inquirer should seek assistance from a competent engineer experienced in the particular field of interest.

List of AWS Documents on Automotive Welding

Designation	Title
D8.1M	<i>Specification for Automotive Weld Quality—Resistance Spot Welding of Steel</i>
D8.7	<i>Recommended Practices for Automotive Weld Quality—Resistance Spot</i>
D8.8M	<i>Specification for Automotive Weld Quality—Arc Welding of Steel</i>
D8.9M	<i>Test Methods for Evaluating the Resistance Spot Welding Behavior of Automotive Sheet Steel Materials</i>
D8.14M	<i>Specification for Automotive Weld Quality—Arc Welding of Aluminum</i>

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