

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



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

3rd Edition

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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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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:

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

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:

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

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.

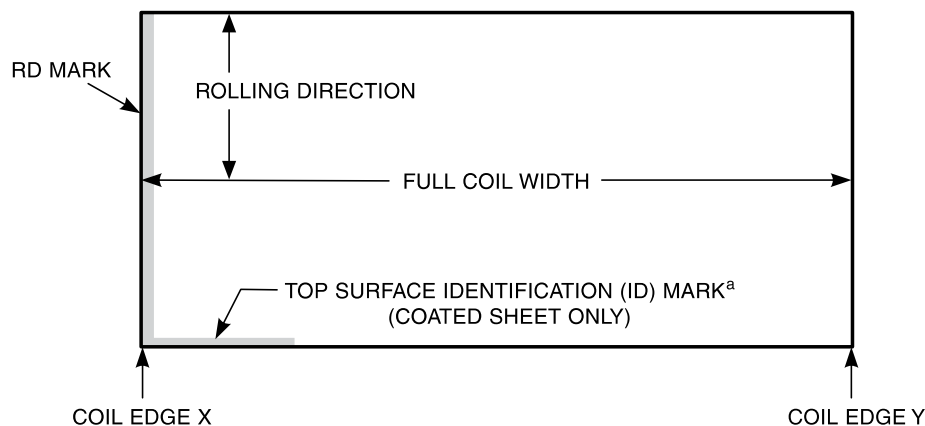
4.3 Rolling Direction (RD) Orientation. The rolling direction is shown in Tables 2 and 3.

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.

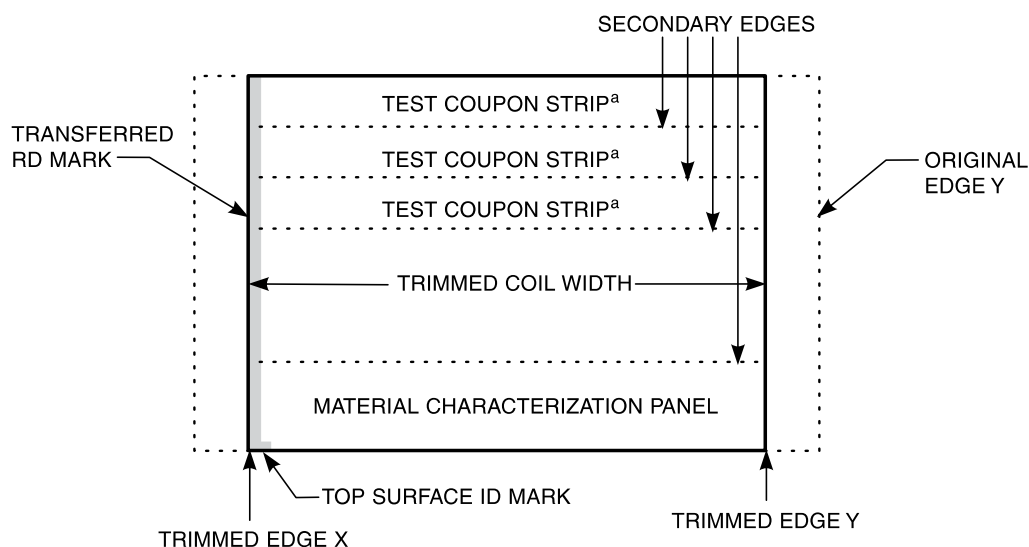
4.4.2 Coil Edge Removal. To eliminate any potential effects of edge coating weight and sheet thickness variations on test results, 100 mm $\pm$ 5 mm from each sheet's coil edges (X and Y) shall be sheared off and scrapped. After trimming Edge X, the RD mark shall be transferred as shown in Figure 2.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

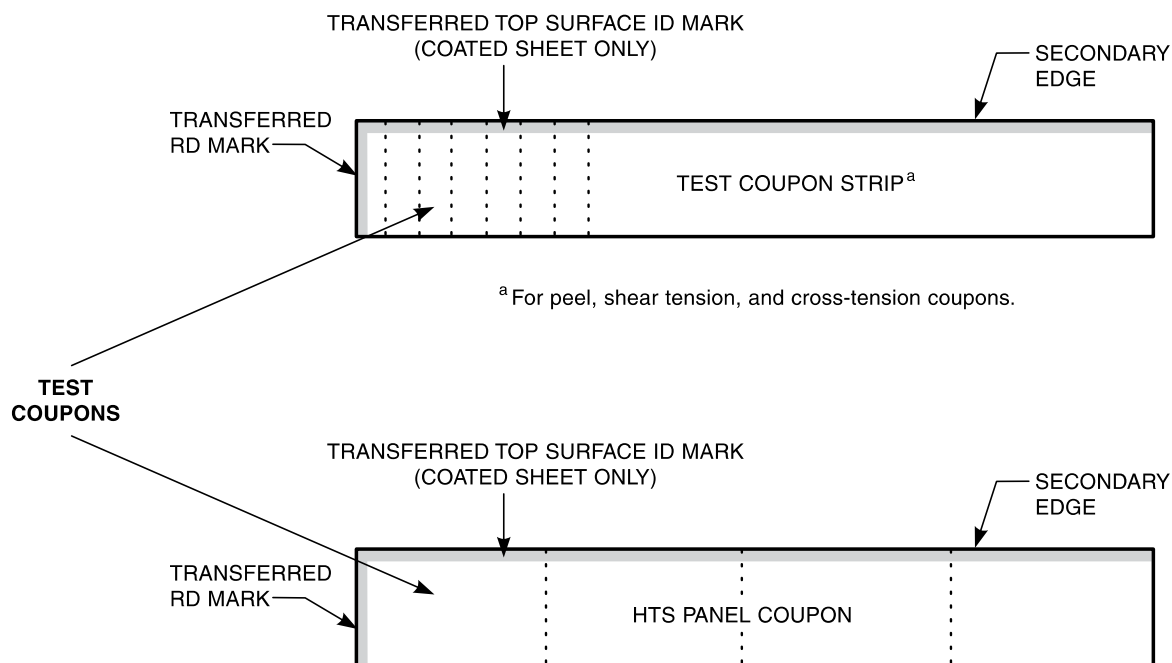


Figure 3A—Test Coupon Strips with Transferred Marks

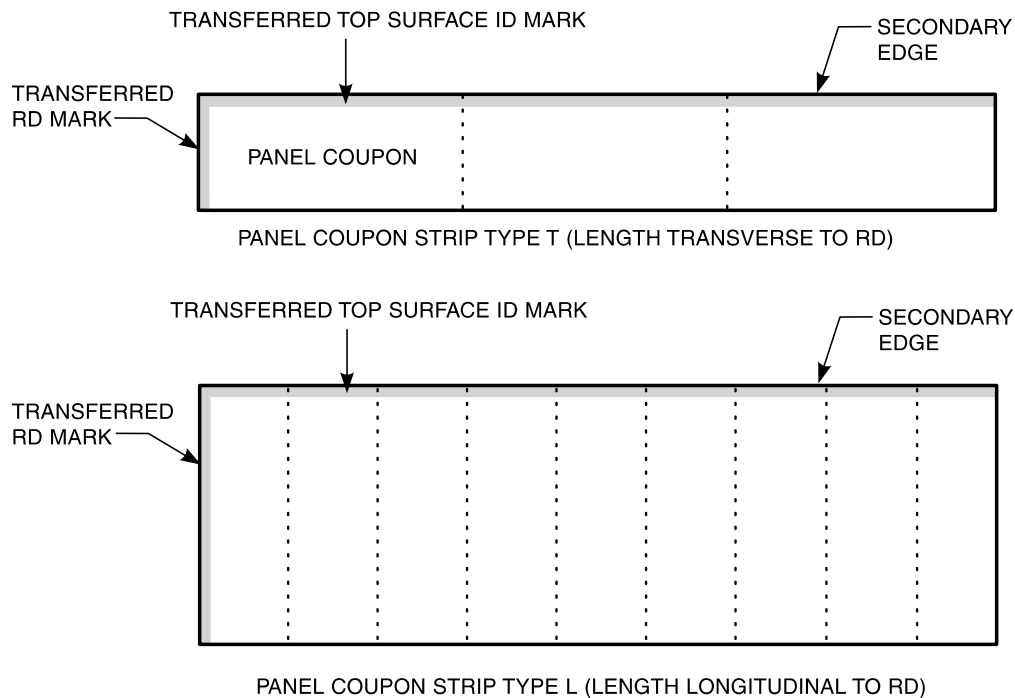


Figure 3B—Endurance Test Panel Coupon Strips with Transferred Marks

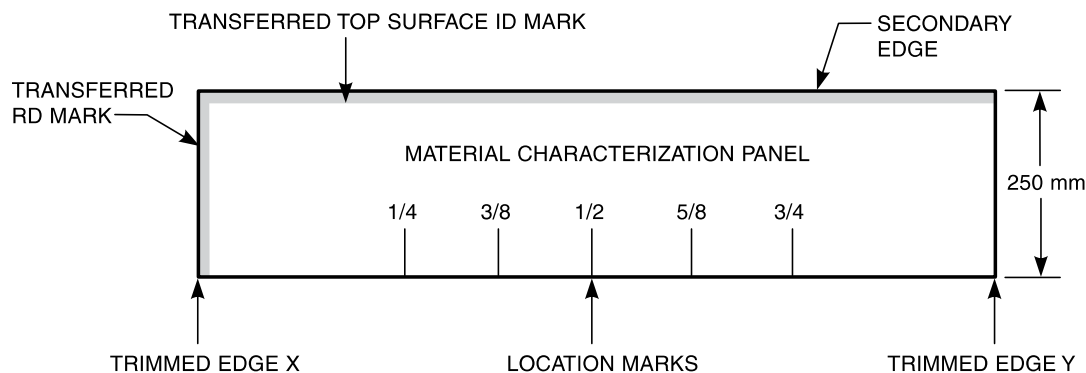


Figure 4—Material Characterization Panel with Transferred Marks

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.

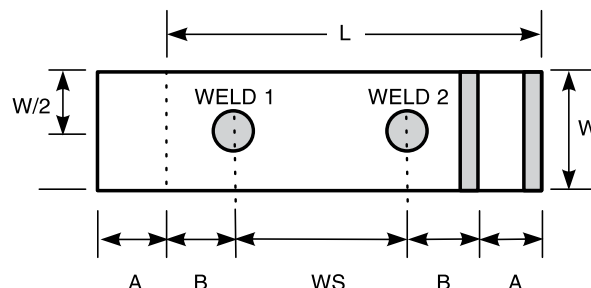


Figure 5—Weld Location, Spacing, and Coupon Overlap for Peel-Test Samples

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.

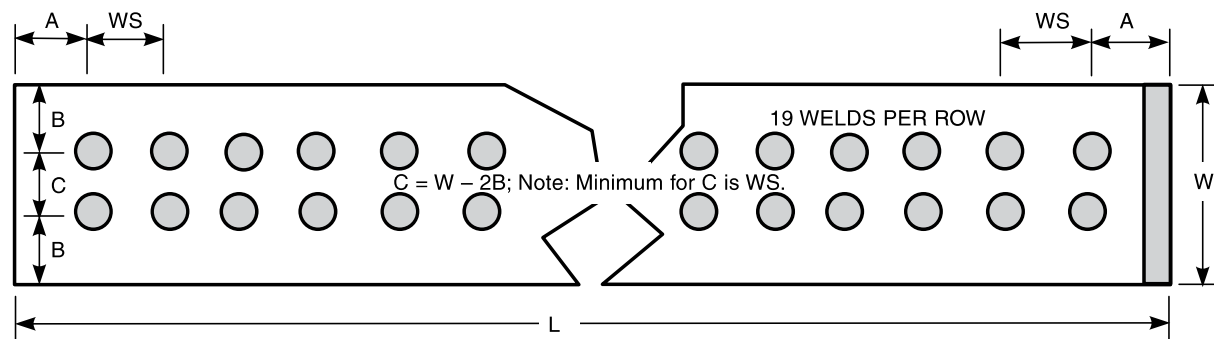


Figure 6—Weld Spacing and Edge Distances for
Endurance Test and Electrode Conditioning Panel Samples

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.

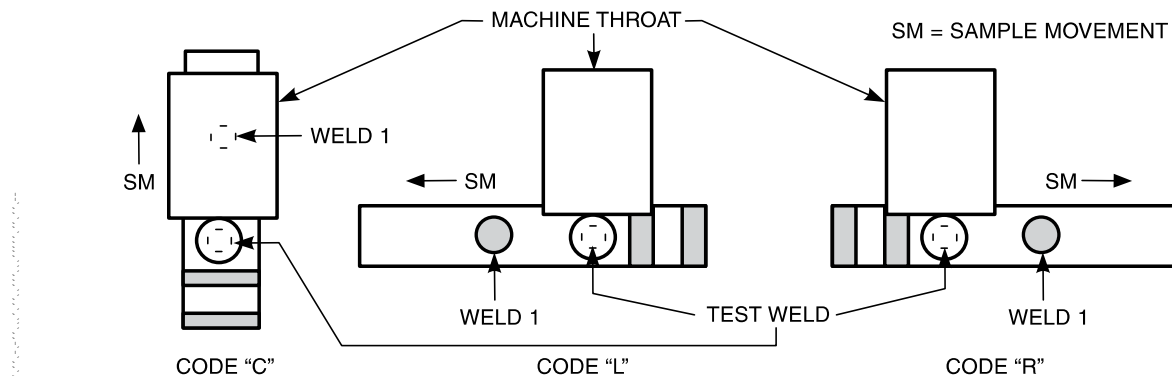


Figure 7—Top View of Peel Sample Orientations with Respect to Welding Machine Throat

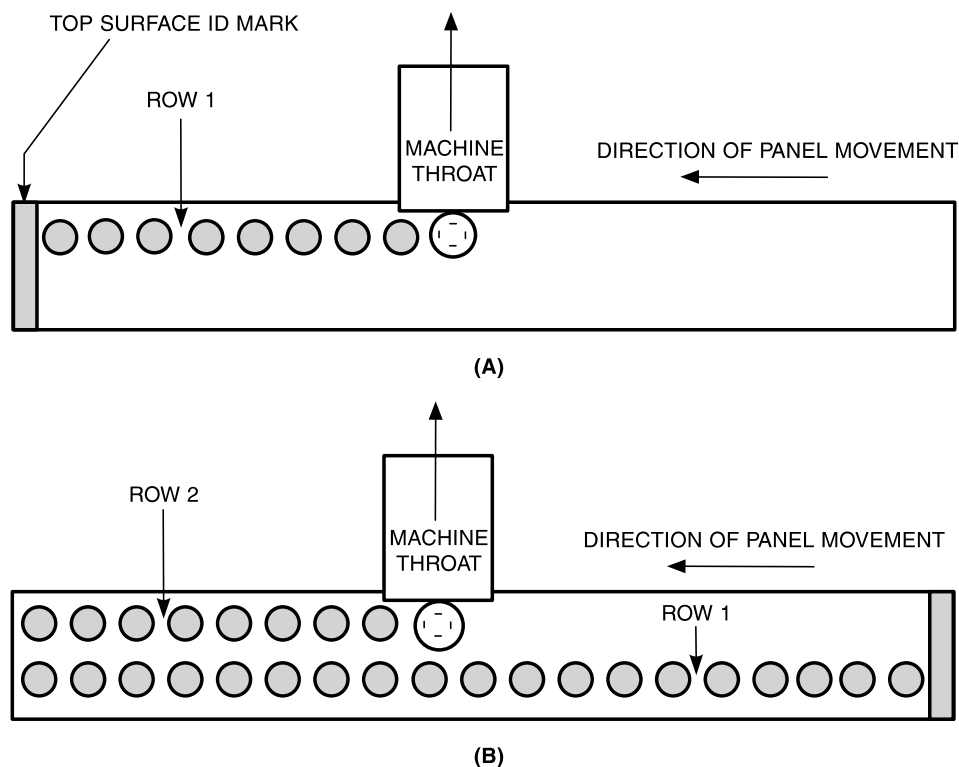


Figure 8—Panel Sample Orientations (A and B) with Respect to the Welding Machine Throat

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.

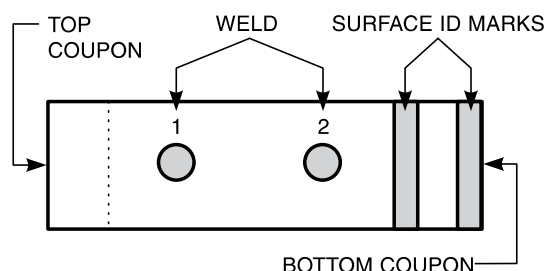


Figure 9—Surface Orientation of Peel-Test Samples

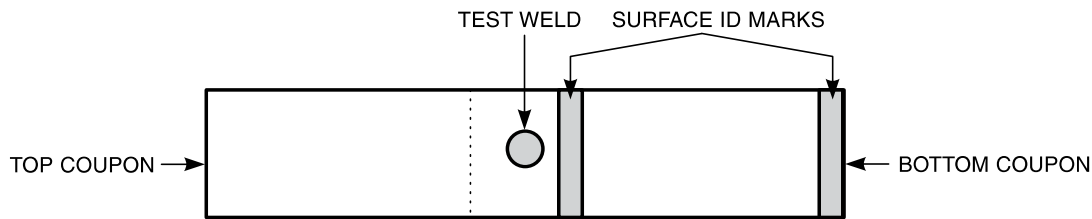


Figure 10—Surface Orientation of Weld Property Test Samples (Shear Tension Shown)

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:

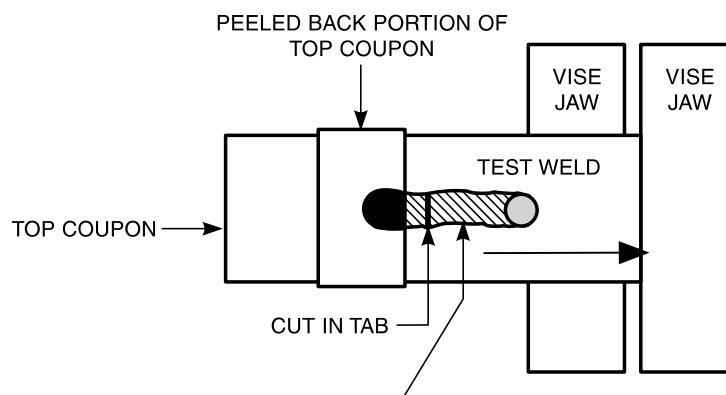
$$\text{FDWS} = \text{the specified electrode-face diameter (dressed, listed in Table 4)}$$

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.

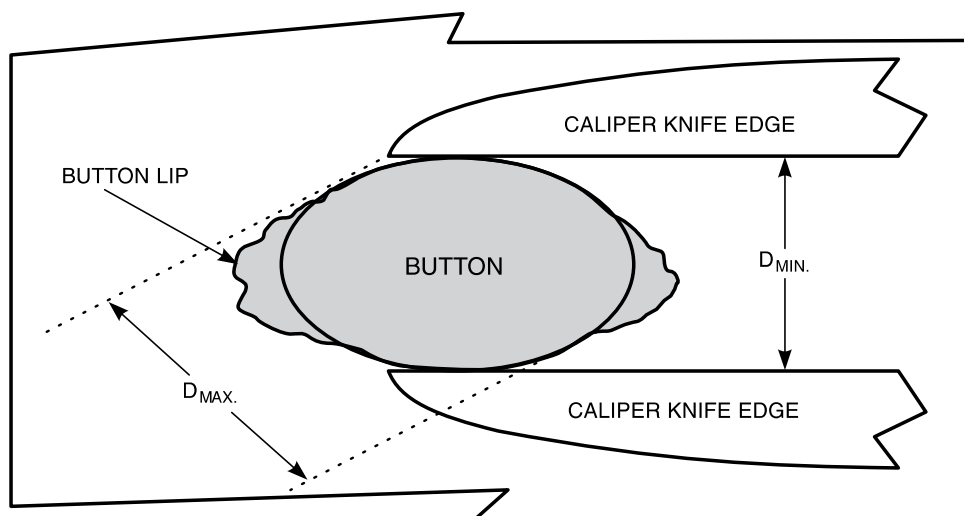


Figure 12A—Technique for Measuring Oval Weld Buttons

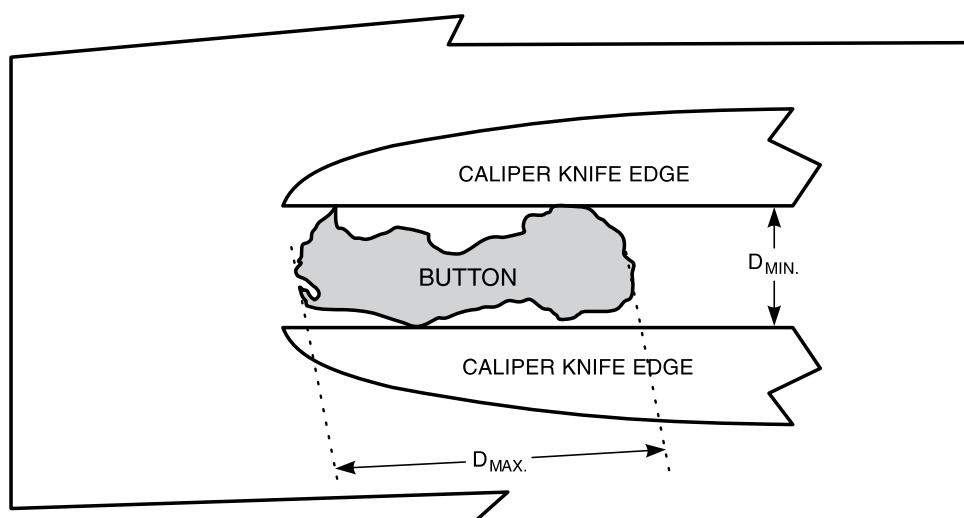


Figure 12B—Technique for Measuring Irregular Weld Buttons

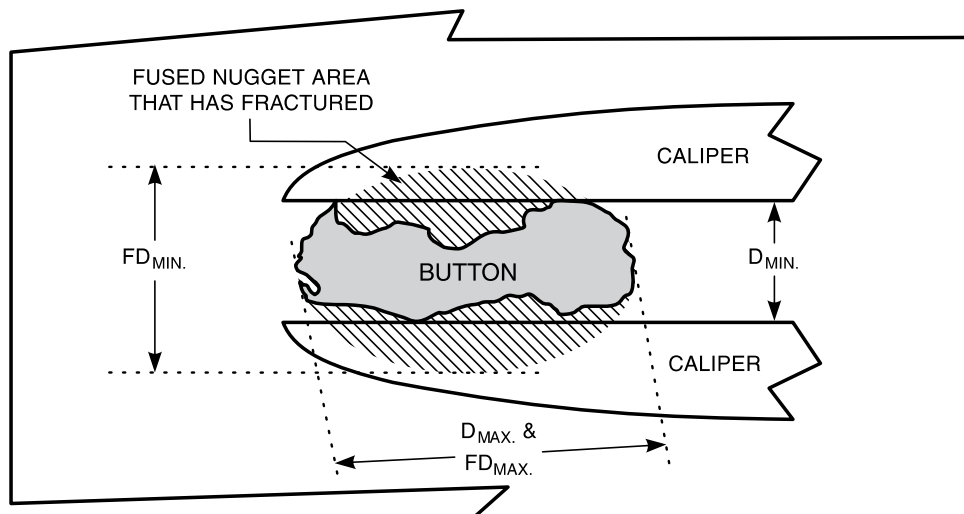


Figure 13—Technique for Measuring the Weld Button and Fused Diameters of Partial Interfacial Fractures

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.