Performance Specification for Ultrasonically Welded Wire Terminations

SAE/USCAR-38 REVISION 2
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PERFORMANCE SPECIFICATION FOR ULTRASONICALLY WELDED WIRE TERMINATIONS

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1. SCOPE

This specification defines test methods and performance criteria for ultrasonically welded wire-to-terminal bonds as shown in Figure 1. This specification subjects parts to environmental exposures to simulate a lifetime of field exposure for a road vehicle. Exposures referenced in this specification include thermal shock, temperature humidity cycling, and mechanical stress. This specification is intended to evaluate the strength and performance of the interface between wires and the electrical terminal pad. The graphics used are specific to the linear weld type of process equipment. Validation of the terminal is a separate task (refer to a component validation test such as SAE/USCAR-2).

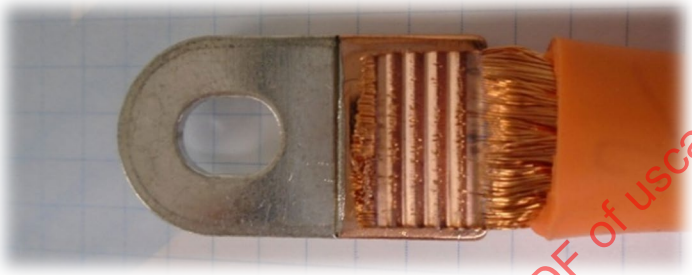


Figure 1 - Wire-to-pad weld configuration

If the weld under test (WUT) is different than described in this section or is subjected to conditions beyond what is typical of automotive use, the test sequence may not be applicable. Ensure that parts used in other conditions are validated for the actual conditions encountered.

Vehicle and product conditions applicable to use of this specification are:

1. Applicable use: This specification is applicable where the wire and terminal are part of an electrical connection system used in road vehicles at ambient temperatures from -40 to +150 °C. Applied voltage may be either low (0 to 60 VDC) or high (to 1000 VAC or VDC). USCAR-38 applies to all wire lengths and includes a special test for wires shorter than 500 mm where a weld is done after another component has been assembled to assess potential process damage to the terminal at the other end of the wire. Wire harness makers typically will be given the responsibility to track short wire applications per a statement in the applicable engineering statement of work.

2. Applicable designs: The procedures described are applicable to buss, terminal, or device connections, including eyelet and battery terminations comprising either single or multiple wire terminations. Designs with and without crimped insulation wings are applicable.

3. Applicable multiple wire configurations: For multi-wire welds, 12 or fewer wires is preferred since having over 12 wires increases the cost and complexity of the weld. A design review is recommended for welds having over 12 wires to see if splitting the splice into smaller pieces is a better choice. Welds of ≥20 wires are not applicable (because welds of that complexity require equipment capability assessments beyond the scope of USCAR-38). The ratio of the smallest wire size to the total weld cross-sectional area is recommended to be at least 1:10 (i.e., the smallest cable must be at least 10% of the total cross-sectional area of the weld).

4. Applicable wire: This specification was developed using clean, bare, uncoated, stranded automotive wire. Wire with tin coatings, applied lubricants, or contamination is known to affect the mechanical and electrical performance of ultrasonically welded cable terminations, and are not applicable to be evaluated per this specification. USCAR-38 is not applicable for wire-to-wire splice welding (USCAR-45 is applicable).

5. Applicable wire sizes and types: Copper wire sizes between 0.22 to 150 mm^2 per ISO 6722-1 or ISO 19642-3 and aluminum sizes between 0.5 to 150 mm^2 per ISO 6722-2 or ISO 19642-4 are applicable. Other wire types may be tested but cannot claim compliance. Examples of “other” wire types are compressed core, compacted core, solid wire core, and center strand materials other than copper, copper alloy, aluminum, or aluminum alloy. Examples of different center strand materials are copper-clad or steel-center-core wires.

6. The validation process described applies only to linear ultrasonic welding, typically with pressure, energy, and amplitude set as inputs and weld time controlled by limiting energy based on “feedback” from process monitoring sensors. Using process feedback assures the energy-per-weld is maintained. If the equipment used to make samples for USCAR-38 testing is different from this description, this specification may need to be modified or may not be applicable.

1.1 Conformance Requirements

To claim conformance to this specification, the weld characteristics used to ultrasonically terminate a cable to a component must be traceable to a satisfactory SAE/USCAR-38 test report. The specific cable and component configuration (including stranding, actual cable cross-sectional area, component base material, and thickness as well as the tooling description) must be detailed in the report.

1.2 Ultrasonic Weld Characteristics

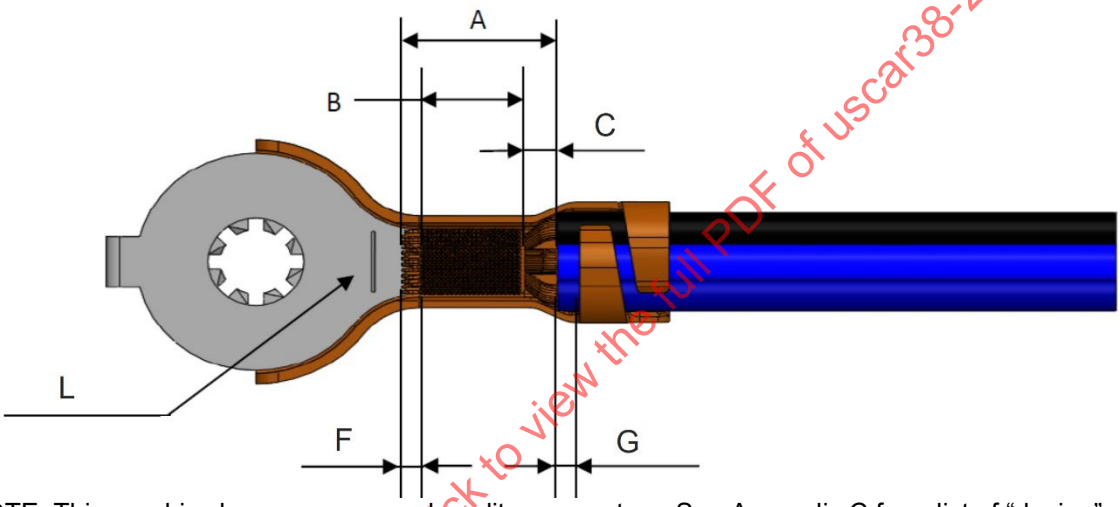
1.2.1 Ultrasonically welded termination bond performance is characterized by:

1. Mechanical bond strength (measured by cable-to-component tensile and peel strength).

2. Electrical connection quality (measured by cable-to-component resistance or voltage drop).

3. Consistent weld attributes and parameters (characterized by these attributes, with some shown in Figure 2).

A. Strip length
B. Weld bond length
C. Weld bond width
D. Insulation crimp height
E. Insulation crimp width
F. Wire brush limit
G. End of insulation limit
H. Wire prep (strip length and alignment)
J. Weld bond height
K. Weld position
L. Terminal position limit
M. Tooling profile or part number
N. Cable part number
O. Number or cables being welded
P. Terminal part number
Q. Wire core material (plating on wire)
R. Welder manufacturer and model
S. Welder supplier part number for horn, anvil and gathering blocks, and fixture



NOTE: This graphic shows process and quality parameters. See Appendix C for a list of “design” parameters recommended to develop the correct tooling and process settings.

Figure 2 - Key parameters of the wire-to-pad configuration

2. REFERENCED DOCUMENTS

2.1 Normative References (required to perform tests)

SAE/USCAR-2 Performance Specification for Automotive Electrical Connector Systems

SAE/USCAR-21 Performance Specification for Cable-to-Terminal Electrical Crimps

2.2 Informative References

SAE J1128 Low Voltage Primary Cable

SAE J1127 Low Voltage Battery Cable

ISO 6722 Automotive Cable

ISO 19642 Automotive Cable

AIAG Measurement Systems Analysis Reference Manual

2.3 Test Request Documentation

The laboratory test request/order must provide location and documentation of test samples, identify the type of test to be performed, and describe any special tests that are not a part of this specification. Any revisions or deviations from any tests in this specification must include detailed instructions for each change.

Note that sample groups with different weld dimensions need be tested per the method of Appendix D. Care must be taken to identify all samples correctly with the process settings used to weld them. Note that the selection of the process settings to be tested are not controlled in this document; selection of settings is done prior to submitting samples for USCAR testing.

No specific format for the report is required, as long as the required information is provided. Since some customers have requirements for specific report formatting, it is recommended an agreement on report format is made before testing.

3. GENERAL REQUIREMENTS

3.1 Record Retention

The supplier shall maintain a central file for the storage of laboratory reports and calibration records. Such record storage must be in accordance with established ISO and AIAG policies and practices.

3.2 Sample Documentation

All test samples shall be identified in accordance with established (i.e., ISO or AIAG) policies and practices.

3.3 Sample Size

Minimum sample sizes are given for each test in this specification in Table 9. No part or device may be represented as having met this specification unless the minimum sample size has been tested and all samples of the group tested have met the applicable acceptance criteria for that test. It is never permissible to test a larger group then select the minimum sample size from among those that passed and represent that this specification has been met.

3.4 Default Test Tolerances

Default tolerances, expressed as a percentage of the nominal value unless otherwise indicated, are shown in Table 1.

Table 1 - Default test tolerances

Description	Tolerance	Description	Tolerance
Temperature	±3 °C	Length	±5%
Voltage	±5%	Time	±5%
Current	±5%	Force	±5%
Resistance	±5%	Relative Humidity	±5%

3.5 Test Default Conditions

When specific test conditions are not given either in the product design specification, the test request/order, or elsewhere in this specification, the following conditions apply:

1. Room Temperature: 23 °C ± 5 °C

2. Relative Humidity: Ambient

3. Voltage: 14.0 VDC ± 0.1 VDC

3.6 Equipment

Table 2 highlights specialized equipment or devices, with accuracy requirements, used for USCAR-38 testing. Neither Table 2 nor the list in each test section is all-inclusive; items of customary laboratory equipment and supplies will also be required. Use of equipment with a lesser range is acceptable for specific tests where the required range for that test can be met. The equipment range specified does not preclude use of equipment with a larger range, but the accuracy must remain within the specified tolerance.

Table 2 - Equipment list

Description	Requirements
DC Power Supply (Regulated)	0~20 V current sized as required
Micro-Ohmmeter	20 mV maximum open circuit voltage 100 mA maximum test current 0.01 mΩ resolution
Digital Multimeter (DMM)	Capable of measuring 0.001-50 VDC with accuracy of 0.5% of measurement
Millivolt Meter	Capable of measuring 0-100 mV DC with accuracy of 0.5 mV
Thermocouples	Type “J” or “T” as required (wire size ~0.08 mm)
Force Tester	Capable of an accuracy of 1% of measurement
Thermal Shock Chamber	-40 to 150 °C ± 3 °C (in 5 minutes or less)
Oven (alternate to thermal shock chamber)	+150 °C ± 3 °C
Temperature Chamber (alternate to thermal shock chamber)	-40 °C ± 3 °C
Video/Photography Equipment	As required to make clear pictures, including cross-section micrographs

3.7 Definitions and Abbreviations

A list of definitions is in Appendix A. A list of abbreviations used in this document is in Appendix B.

3.8 Measurement Resolution

Unless otherwise specified, meters and gages used in measurements of the test sample(s) shall be capable of measuring with a resolution one decimal place better than the specified value. For example, even though a wire diameter specified as 0.1 mm might actually be the same as one specified as 0.10 mm, calipers capable of 0.01 mm resolution may be used to measure the first wire but a micrometer with 0.001 mm resolution is required to measure the second wire.

3.9 Test Repeatability and Calibration

All equipment used for testing shall be calibrated and maintained along with periodic gage “R&Rs,” in accordance with individual test facility certification requirements and applicable standards. The AIAG publication “Measurement Systems Analysis Reference Manual” can be used as a guideline. A list of instruments and equipment used for the USCAR test, date of the last calibration, and when the next calibration is due is to be included in each USCAR test report.

4. TEST PROCEDURES AND ACCEPTANCE CRITERIA

4.1 General Testing Requirements

The test procedures in this section are stand-alone tests and may be used as such. However, they are normally used as a sequential test. Knowledge of test group construction is required to overcome any redundancies in sample preparation or procedures. For example, if samples have already been prepared for the preceding test in a sequence, it should be obvious that the sample preparation step for that individual test (included so that test can be used as a stand-alone test) should be skipped. The general testing requirements are:

1. Part submitted for test shall conform to the dimensional characteristics specified on the applicable engineering drawing(s) of the part.

2. Any engineering development, prototype, or production part may be submitted for test provided the design is documented.

3. Identify the samples submitted for test by description, part number, and revision level where applicable.

4. Parts must be representative of the process used in production. For example, terminals may have residual die lubricant on them so this same condition must prevail for test samples. (Similarly, if the terminal for the WUT is plated or coated, it is not permissible to remove the plating or coating or to clean the samples prior to performing the welding process unless these additional processes are a documented part of the volume production weld process. Cable core and insulation cannot be cleaned for the same reason.) Equipment and tooling used to make samples must be production-intent. This is critical since ultrasonic welding is sensitive to process and material conditions.

5. USCAR recommends that samples submitted for test be prepared per Appendix C. However, sample preparation is beyond the scope of this document and any properly documented samples may be tested.

4.2 Visual Inspection

4.2.1 Purpose

This test is used to document the physical appearance of test samples and to assist in the evaluation of the effects of environmental conditioning on test samples using descriptions, photographs, and/or videos. Examinations in most cases can be accomplished using available lighting in the lab.

4.2.2 Sample Size

Size will vary depending on configuration. See Table 9.

4.2.3 Equipment

1. Photographic equipment able to take general and cross-section micrograph pictures.

2. Video equipment able to take general component pictures.

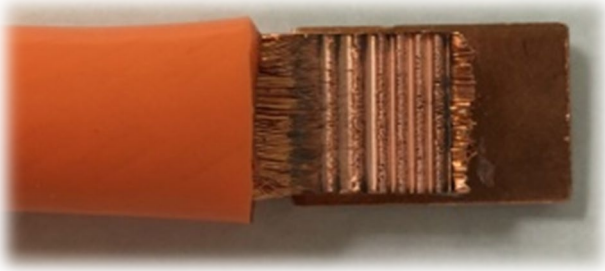
4.2.4 Procedure

1. If inspection is being done prior to testing, examine the weld bond area per the criteria in 4.2.5. Note any manufacturing or material defects such as poor wire-to-weld transition, loose strands, cut strands, or long strands that interfere with component function. Take photographs and/or video recordings of one representative sample to be tested and keep as an untested part sample. (Only one photo is required for the WUT. The photo step does not have to be repeated even if called for in different test paths.)

2. If inspection is being done after testing and/or conditioning, re-examine each test sample and note in detail any observable changes such as physical distortions, cracks, etc. Compare the tested and/or conditioned samples to the control sample, the videos, and/or the photographs, recording any differences in the test report.

4.2.5 Acceptance Criteria

All samples submitted shall meet the criteria of this section and not show any defect described in Table 3. If the component supplier's appearance requirements are stricter than those specified, then the component supplier requirements shall apply. Note that the descriptions are generic and specific terminals will need to have customized quality criteria developed and agreed to by the customer. Figure 3 illustrates an ideal weld bond and Table 4 illustrates acceptable but not ideal weld bonds for reference. The criteria given are based on weld bond robustness only and do not consider application-specific failure criteria related to part appearance or interference with neighboring parts.



ON AN IDEAL WELD:
- All strands are welded.
- Weld bond is contained by terminal (w/ clearance on sides).
- All wires reach the end of the weld nugget.
- Strands beyond the weld nugget do not interfere with functional areas nearby (terminal, eyelet, heat shrink, etc.).
- Bond has no scorching, foreign material, or contamination.

Figure 3 - Ideal weld bond appearance

1. General Appearance and Function

   The welding operation shall not change the terminal such that it interferes with device function. Weld must not result in interference between wire and covers, eyelet studs, or parts added in follow-on operations. A design review must be performed separate from this test to assure no interference is possible with mating components at all tolerances.

2. End of Wire Core

   a. In sealed applications, the end of the wire core shall not present any sharp surfaces that may damage a seal during a connector assembly or seal application processes. Customer and supplier determine what test is applicable. USCAR-2 provides tests to validate sealing that may be applicable.

   b. Strip length shall be sufficient to keep cable insulation out of the weld area and be long enough to allow wire strands to extend to the end of the weld area.

3. Insulation Grip

   For single-wire welds, the insulation grip (if present) shall meet the criteria in SAE/USCAR-21, 4.2.5, Step 8 for general visual appearance and 4.3.5, Step 3 for cross-section attributes. (The insulation grip adds strain relief to the weld bond. Terminal makers are encouraged to provide insulation grips for terminals that have a total wire cross section of 6 mm^2 or smaller. The insulation grip moves the point of highest stress between welded and un-welded wire strands away from the weld bond area.)

   For multi-wire welds with an insulation grip present, apply the inspection method of USCAR-21, 4.2.5, Step 8 and 4.3.5, Step 3. Any cable can be used provided it is a production-intended wire for the application.

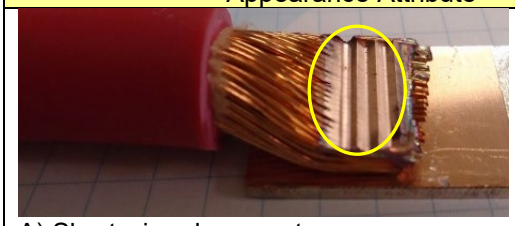
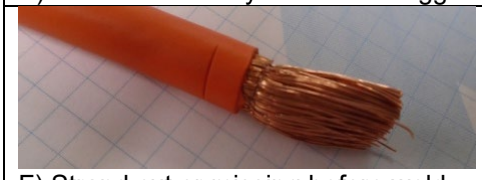
4. Cable Appearance

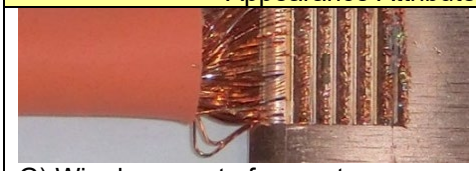
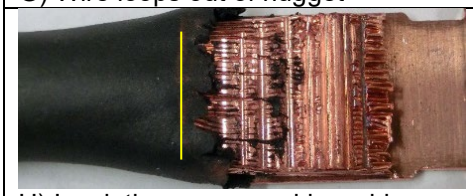
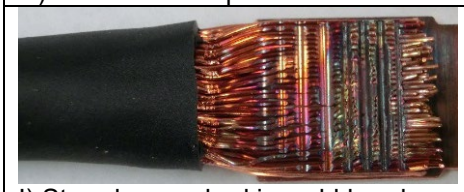
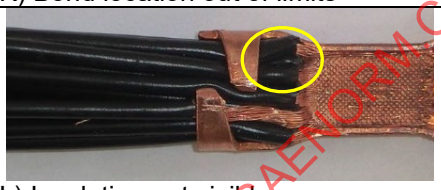
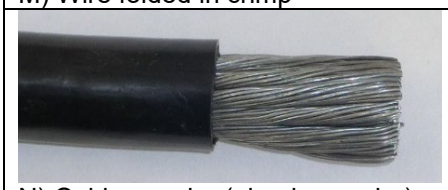
Poor cable conductor appearance, prior to welding, is known to result in inconsistent welds. Aluminum wire has been noted as highly sensitive to changes in appearance. Consistent samples are recommended.

5. Individual Cable Seal and Mat Seals

USCAR-21 criteria for visual inspection criteria shall be met for single wire terminations, if applicable. Sections 4.2.5, Step 10 and 4.3.5, Step 4 apply to samples with cable seals. Section 4.3.5, Step 5 applies only to mat seal designs.

Table 3 - Weld bond appearance requirements

Appearance Attribute	Requirement for USCAR-38
 A) Short wire placement	Weld nugget length cannot be shortened due to wire placement under horn. (This applies to the nugget overall; individual strands do not have to go to horn end or be exactly the same length.)
 B) Tooling marks off the weld pad	No tooling marks are allowed off the weld pad. See Table 4, item B for information on transitional marks.
 C) Insufficient side clearance	Terminal pad must extend 1.0 mm or more beyond the nugget on both sides to allow for clamping. NOTE: Deviation requests are common on this topic and need a case-specific assessment.
 D) Strand loose	Loose strands are not allowed. See Table 4, item D for instructions for manual trimming.
 E) Cut strands away from weld nugget	Cut, broken, or missing strands are allowed within the limits of Table 5. No broken strands are preferred as a demonstration of process robustness.
 F) Strand cut or missing before weld	Requirement removed. (The condition of strands before weld is not inspected by the test lab; good samples are expected.)

Appearance Attribute	Requirement for USCAR-38
 G) Wire loops out of nugget	Looped wires are not acceptable. See Table 4, item G for information on how looped wires can be pushed back.
 H) Insulation compound in weld	Insulation must end before weld bond starts. Individual insulation filaments are allowed under the weld. (The yellow line that shows where the horn overlapped the insulation resulting in a reject.)
 I) Strands scorched in weld bond	Requirement removed. Discoloration by scorching is allowed. However, if there is discoloration in addition to other concerns with the weld, the discoloration may be considered as evidence of overwelding. (Overwelding is not acceptable.)
 J) Contaminated strands	Incoming strand condition is not applicable to the weld validation. The condition of strands before weld is not inspected by the test lab; good samples are expected.
 K) Bond location out of limits	Bond location must not interfere with terminal's function. Strand ends must be within marked limits for bond location if present on terminal.
 L) Insulation not visible	On multi-wire applications where the WUT has an insulation grip, the end of the insulation must be visible between the weld bond and the insulation grip.
 M) Wire folded in crimp	On multi-wire applications, wires may not fold or shift due to the insulation wings.
 N) Oxide on wire (aluminum wire)	Requirement removed. (The condition of strands before weld is not inspected by the test lab; good samples are expected.)

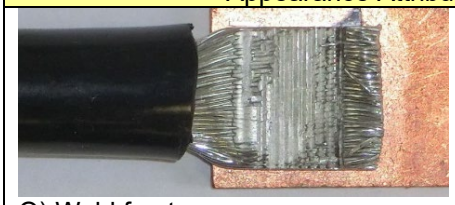
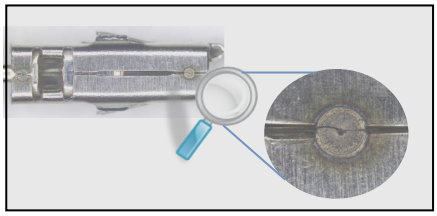
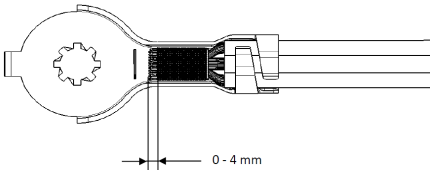
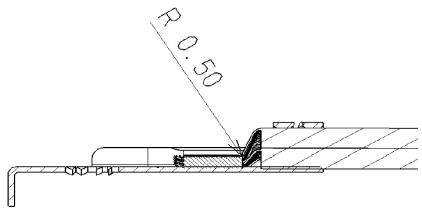
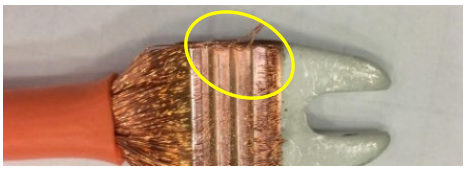
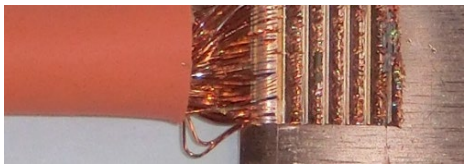
Appearance Attribute	Requirement for USCAR-38
 O) Weld fracture	No visible spalling, fracture, or separation of the nugget (typically only a concern on aluminum).
 P) Damage to the terminal being welded	No cracks or damage allowed to terminal box or beams (either of terminal under test or terminal at other end of wire being welded). Sections 4.8 and 4.9 have related testing.
 Q) Multi-wire brush length variance is excessive	On multi-wire applications, brush length cannot vary more than 4 mm between strands of different wires and must be within marked position line if present.
 R) Multi-wire bunching radius too sharp	On multi-wire applications, the radius at the transition of multi-wire welds must be 0.5 mm minimum (to avoid the “waterfall” condition).

Table 4 - Acceptable but not ideal weld bond attributes

Appearance Attribute	Details on Part Acceptability	Reference to Similar Part That is Not Acceptable in Table 3
 A) Weld is partially off the weld pad	A radius knurl (or other transition tooling) off the weld pad is allowed.	Part B
 B) Partially welded strand	Partially welded strand is allowed, provided it is clipped.	Part D
 C) Loops out of nugget but not stray	Loops above the outside diameter of insulation are allowed if pushed back.	Part G

NOTES:

This section is provided as a reference to identify acceptable parts. Each application is different, however, and will have unique requirements that supersede this section.

1. The above are acceptable based on weld bond robustness and electrical stability. They do not suggest ideal samples.
2. This section does not consider application-specific failure criteria such as how the weld may interfere with neighboring parts or sealing sleeves.
3. Customer requirements are used to define the part-specific criteria. It is common for additional criteria to exist based on the specific customer's application.
4. Weld relative position is not a criterion for weld acceptance. The applicable requirement is that the validated weld must be defined by position and that position must be controlled in production.

Table 5 - Allowable broken or missing strands

Strand Count on Cable[1]	Broken or Missing Strand Limit
1 to 7-strand cable	0 broken or missing strands allowed
8 to 19-strand cable	Up to 1 broken or missing strand allowed
20 to 37-strand cable	Up to 2 broken or missing strands allowed
38 and higher strand count	Up to 5% of total strand count can be broken or missing, using visual inspection to assess the outermost layer of the weld[2].

NOTES:

[1] "Strand Count" applies to individual cables. For multi-cable welds, evaluate each cable based on strand count in that specific cable.

[2] Having 5% of strands missing indicates poor processes and should not be tolerated due to the bad workmanship it indicates. However, a design with 5% missing strands is known to perform acceptably. (NOTE: This was demonstrated on copper wire only.)

4.3 Welded Termination Cross-Section Analysis

4.3.1 Purpose

Cross-sectional analysis provides direct evidence of a strong and uniform mechanical bond needed to assure bond function. The cross section is compared to known good cross sections as a means of direct evaluation. It may also be used as a diagnostic aid in determining why a weld termination fails a portion of this test. Failure to pass the electrical and mechanical requirements of this specification may be caused by insufficient or excessive weld bond compaction and may be identified by visual appearance under 10X magnification.

4.3.2 Sample Size

Two samples are called for. Only one sample is sectioned. The other is retained for reference.

4.3.3 Equipment

Cross-sectioning equipment capable of sectioning the weld with minimal disturbance to the terminal and cable stranding.

4.3.4 Procedure

1. Photograph the weld bond.

2. Make a cross-section cut in a valley (low point) as near to the midpoint of the welded bond area as possible. Make the cross-section cut as near to the midpoint of the welded bond as possible. In Figure 4, the vertical "section line" shows where to perform the cross section on the part.

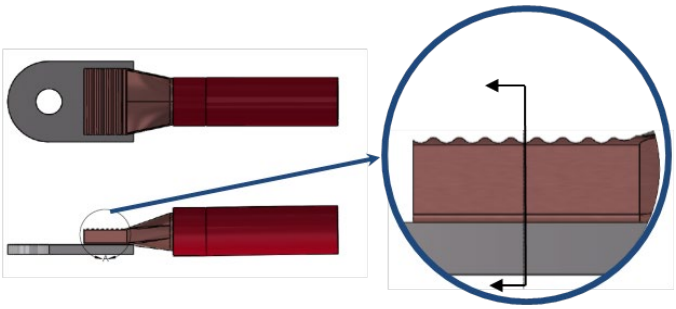


Figure 4 - Location of cross-sectional cut (center of weld, in valley)

3. Photograph the cross section.

4. Measure the area of the wire core cross section after weld as described in Figure 5. Not all cross sections are rectangular. Use measuring methods appropriate to the design geometry.

5. Calculate the ratio of final-to-initial wire cross-sectional area per Equation 1. To calculate the initial wire cross section, measure the area of any individual strand and multiply by the strand count (or calculate per the weight method in ISO 6722-1 or ISO 19642-1). Fully surrounded air gaps are counted as part of the final area.

$$C(\%) = \frac{F}{A} * 100 \quad \text{(Eq 1)}$$

where:

C = compaction ratio (%)

F = cross-sectional area of wire and trapped air after weld

A = wire cross-sectional area before weld

Calculations for sample at left per Equation 1

F = Wire cross-sectional area after weld = 12.187 mm²
A = Wire cross-sectional area prior to weld = 11.496 mm²
C = Compaction Ratio = 106%

F is calculated using commercially available software.
Area of F is shown as the boxed outline.

Figure 5 - Cross-sectional compaction calculation

4.3.5 Acceptance Criteria

1. The cross-sectioned weld bond shall have all strands in contact with either the weld pad or other strands. No unwelded strands are allowed. See Figure 6 for a cross section of an ideal weld (having slightly compressed strands and all strands in contact with the surface). Entrapped air gaps are acceptable and expected (which explains ratios over 100%).

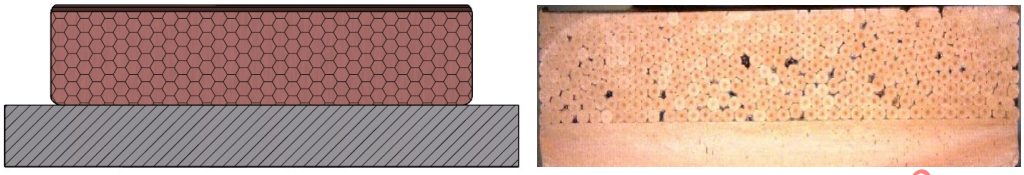


Figure 6 - Ideal cross section: illustration (left) and photograph (right)

2. The ratio of final wire area to initial wire area should be close to values in Table 6. Significant variances from Table 6 should be highlighted in the report. It is recommended that the reason for large variances be understood.

Table 6 - Ratio of initial wire area to final wire area

Wire Type	Typical Ratio
Copper Wire	107%
Aluminum Wire	88%

3. For multi-wire welds with sidewalls, the total cross-sectional area shall be contained within the terminal sidewalls.

4. For multi-wire welds, the weld section shall not have a large imbalance between the right and left sides of the weld, based on a visual assessment.

5. For terminals with sidewalls, strands on an edge of a weld nugget shall contact terminal sidewalls, unless specifically identified as permitted on the terminal drawing. (The center of a nugget may be above the sidewall height.)

NOTE: Applied cable seal retention is assessed as a separate test. When an applied cable seal is present, refer to SAE/USCAR-21 Section 4.6.

4.4 Weld Bond Tensile and Peel Strength

4.4.1 Purpose

This test provides a method to measure component-to-cable retention of weld bonds in tensile and peel conditions. Tensile test applies to all welds, but peel applies only to wires <6 mm^2 (bond peel strength is not meaningful for wires 6 mm^2 and larger since the terminal will bend before the peel occurs, resulting in a condition where the test cannot be completed).

4.4.2 Equipment

1. Device capable of measuring weld bond dimensions (caliper, etc.).

2. De-crimping tool or other suitable means of opening insulation grip wings without damaging the weld bond. It is acceptable to make the samples with the insulation grip not crimped to avoid this step.

3. Force tester with appropriate fixture(s). Fixture design and setup is dependent on the specific WUT.

4.4.3 Samples

4.4.3.1 Peel Test Samples

Two samples for each weld group are tested per Table 10. Only terminals welded to wires smaller than 6 mm^2 are tested; 6 mm^2 and larger wires are evaluated using minimum weld width recommendations. For multiple wire terminations, see 4.4.5 to determine if additional samples need to be tested per test path B2 of Table 9.

4.4.3.2 Weld Bond Tensile Samples

One hundred samples are tested per Table 9 column C1. For multiple wire terminations, see 4.4.5 to determine whether additional samples need to be tested using test path C2 of Table 9.

4.4.4 Peel Strength Test Procedure

1. Check to see if an insulation crimp is present and closed. If closed, open the crimp with a suitable tool so that the peel force will reflect only the welded conductor. Visually inspect the de-crimped area to ensure that none of the conductor strands have been damaged. Do not test any specimens that have damaged conductor strands.

   NOTE: An insulation grip is recommended for welds with 6 mm^2 and smaller wires.

2. Measure and record the conductor weld bond height, width, and length. Measure and record all process setting parameters and machine feedback results (weld time and weld height, typically) as available.

3. Load sample in test fixture. Remove slack in cable to prevent incorrect test results due to “jerking.”

4. Perform peel test on smallest and largest individual wires, if applicable, for multi-wire welds using separate samples. Apply a force at an angle of either 90 degrees or 180 degrees to the direction of the welded wire(s) at a rate between 50 and 250 mm/min. Measure and record peel force required to separate the wire/cable from the component for each specimen under test.

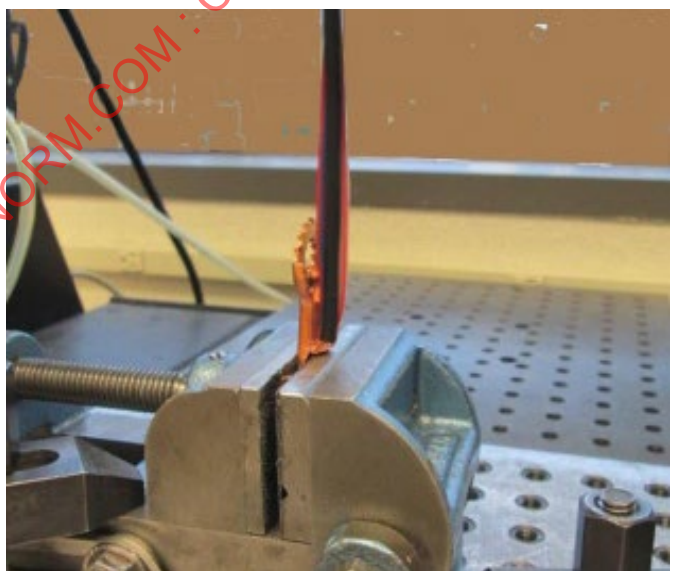


Figure 7 - Peel strength test showing 180 degree peel setup

4.4.5 Tensile Strength Test Procedure

1. Open insulation crimp if the WUT has an insulation grip to allow the tensile pull force test to be performed on leads with the insulation grip wings open (not crimped).

2. Place WUT in fixture and remove slack. Test only on taut leads; remove slack in cable before performing test. This prevents incorrect test results due to “jerking.”

3. Measure and record the conductor weld bond height, width, and length. (See Appendix C for guidance on design of weld configuration.)

4. Confirm the insulation grip is open. If not, open it with a suitable tool so that the pull force will reflect only the welded conductor connection.

5. Visually inspect the de-crimped area to ensure that none of the conductor strands have been damaged. Do not test any specimens that have damaged conductor strands.

6. Apply an axial force at a rate between 50 and 250 mm/min (100 mm/min is recommended) and pull to failure. Record the peak value for each sample. Calculate and record average and standard deviation for each group.

   a. For multiple-wire terminations with conductor sizes all within one size step, pull the smallest conductor (for example, for a 0.35/0.50 double, pull the 0.35 mm^2 wire).

   b. For multiple terminations with conductors more than one wire size apart, pull one of the smallest and one of the largest size cables. Use a new specimen for each wire pulled. See Figure 8 for a typical lab setup.

   Examples of testing requirements with multiple terminations greater than one wire size apart:

   a. For a double wire 0.5 mm^2/1.0 mm^2: Pull both wires since size differs by two wire sizes.

   b. For a triple wire 0.5 mm^2/1.0 mm^2/2.0 mm^2: Pull the 0.5 mm^2 and the 2.0 mm^2 wires (largest and smallest).

   c. For a triple wire 0.50/0.50/2.0 mm^2: Pull one of the 0.5 mm^2 and the 2.0 mm^2 wire (largest and smallest).

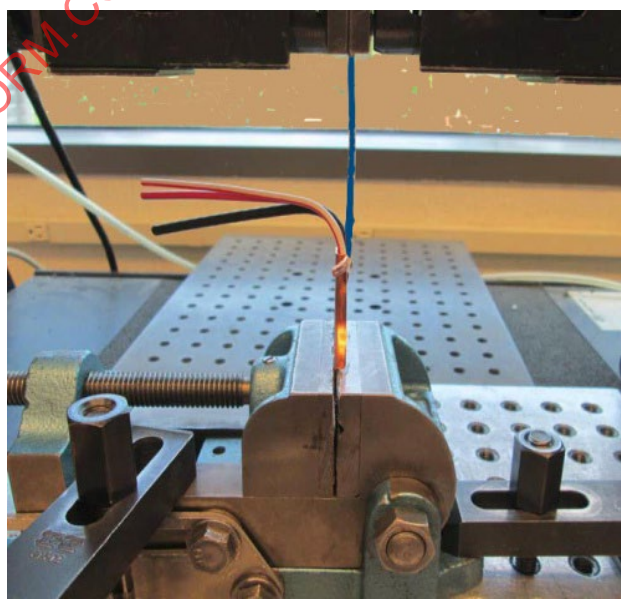


Figure 8 - Tensile strength test showing multiple wires pulled individually

7. Calculate the lower 3 sigma limit for the 40 pieces made with nominal settings. Record the result.

8. Identify and record where each strand broke: (1) at transition, (2) in cable, or (3) in test equipment fixture.

4.4.6 Acceptance Criteria

1. Based on the sample size, select the applicable condition in the following:

   a. For tests with sample size of 30 or more, the “mean minus three standard deviations” of the pull value shall satisfy Table 7.

   b. For tests with sample size under 30, all samples in the test group shall satisfy Table 7.

   NOTE: If a WUT fails due to terminal failure prior to meeting the minimum pull force per Table 7/Appendix F, this terminal is inappropriate for this wire and the application is not acceptable.

2. Peel strength shall satisfy Table 7.

3. The weld width shall satisfy Table 7 (for single wire welds) or Appendix F (for multi-wire welds) to be compliant without additional review. If a sample does not meet the width in the tables, WUT must be reviewed to understand how mechanical strength is achieved despite the nontypical weld pad construction. The WUT is approved if the expert assessment is that the weld design is robust.

   NOTE: Nonconforming weld widths are at an increased chance of failing other tests.

Table 7 - Pull/peel requirements and weld width

Wire Size[2] (mm^2)	Copper Wire[3]			Aluminum Wire[3]		
	Pull Strength[6] (N)	Min Peel Strength[4] (N)	Weld Width Range[5] (mm)	Pull Strength[6] (N)	Min Peel Strength[4] (N)	Weld Width Range[5] (mm)
0.22	50	10	0.5-1.0	X[1]	-	-
0.35	55	11	0.5-1.0	X[1]	-	-
0.50	85	17	0.5-1.0	50	10	-
0.75	120	24	0.5-1.0	85	17	-
1.0	170	34	1.0-1.2	120	24	-
1.5	225	45	1.2-1.8	150	30	-
2.0	250	50	1.8-2.5	180	36	-
2.5	275	55	1.8-2.5	200	40	-
3.0	350	70	3.0-3.6	240	48	-
4.0	375	75	3-5	260	52	-
5.0	400	80	3-5	280	56	-
6.0	435	-	4- 6	300	-	4-6
8.0	500	-	4-6	350	-	4-6
10.0	800	-	6-10	400	-	6-8
12.0	1000	-	6-8	450	-	6-8
14.0	1025	-	6-8	500	-	6-8
16.0	1050	-	8-10	550	-	8-10
18.0	1100	-	8-10	600	-	8-10
20.0	1200	-	8-10	650	-	8-10
25.0	1350	-	10-12	850	-	10-12
30.0	1500	-	10-12	1000	-	10-12
35.0	1700	-	11-13	1200	-	12-14
40.0	1850	-	11-13	1400	-	12-14
50.0	2200	-	13-16	1650	-	14-17
60.0	2200	-	13-16	1800	-	17-19
70.0	2400	-	16-20	1880	-	17-21
85.0	2700	-	18-22	2000	-	18-22
95.0	3000	-	18-22	2050	-	19-25
110.0	3200	-	18-24	2150	-	19-25
120.0	3400	-	20-28	2200	-	22-30
150.0	3600	-	28-36	2350	-	30-38

NOTES:

(1) "X" in tensile strength column indicates insufficient experience with this size to determine a limit.

(2) Sizes listed are per ISO 6722 or ISO 19642. For intermediate or non-ISO wire sizes, use criteria for the next larger size or interpolate the table values.

(3) Select "Copper" or "Aluminum" based on the wire type only; do not consider the terminal material.

(4) "Peel strength" is a requirement only for wires smaller than 6 mm^2.

(5) For multiple wire welds, use Tables F1 and F2 in Appendix F.

(6) Pass or fail is not directly determined from the table value for sample size ≥30. Values shown in the table are used to compute weld tensile strength lower 3 sigma limit described in 4.4.5, Step 7.

4.5 Accelerated Environmental Exposure (Thermal Shock) Conditioning

4.5.1 Purpose

This environmental conditioning procedure details the requirement for establishing the functional performance of electrical and electronic components when subjected to alternating high and low temperature environments. Rapid transfer between the two environments tests the component's ability to withstand drastic temperature changes.

NOTE: Humidity exposure, used to test other components, is not considered a significant environmental stress for ultrasonic metallurgical welding and is not used.

4.5.2 Samples

At least ten specimens for each WUT shall be tested per Table 9.

4.5.3 Equipment: Thermal Shock Chamber

4.5.4 Procedure

1. Set chamber controls to the temperatures and dwell times shown in Figure 9. Set the number of cycles to 72.
2. Allow the chambers sufficient time to achieve the programmed temperature.
3. Place the sample group(s) in the chamber.
4. Start the test program.

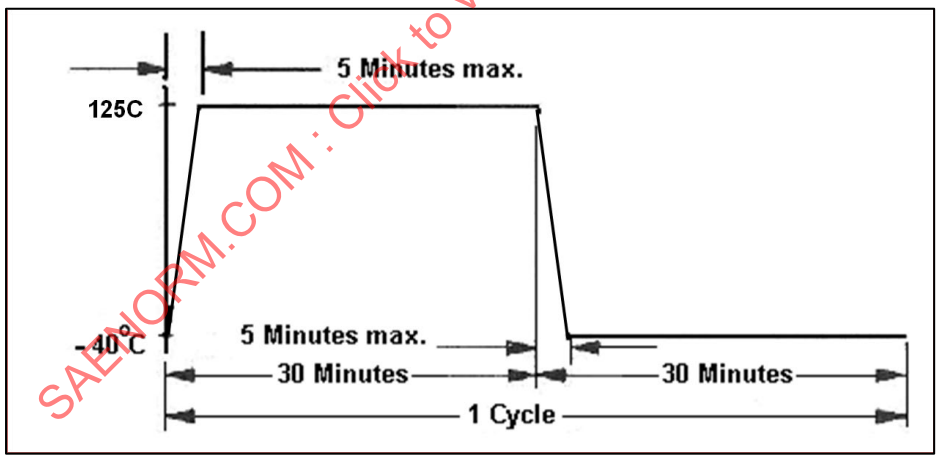


Figure 9 - Thermal shock chamber temperature profile

5. When the 72-cycle test program is complete, shut off the thermal shock chamber and remove the sample group(s).
6. Record the actual operating temperatures, actual dwell times, and any test irregularities and include in the report.

4.5.5 Acceptance Criteria

This is a conditioning procedure and therefore has no criteria. The acceptance criteria are applied in other tests of the sequence as shown in Table 10.

4.6 Deleted (formerly Vibration Test)

The vibration and mechanical shock section has been deleted based on evidence that vibration does not cause a welded terminal to fail. However, vibration from the weld process can cause failures so an added inspection to detect welder-induced damage (from close welds on the same wire) has been added as 4.8. This inspection can be considered the functional replacement for 4.6.

4.7 Electrical Resistance Measurement (Dry Circuit and Voltage Drop)

4.7.1 Purpose

This procedure describes how to measure electrical resistance of cable/wire to component. Two methods are provided:

1. For total cable core cross-sectional area ≤6 mm^2, use dry circuit method.

2. For total cable core cross-sectional area >6 mm^2, use voltage drop method.

4.7.2 Sample Preparation

1. A sample length of 150 mm is recommended; however, any length >100 mm is acceptable as long as there is no effect on the weld bond. The same length shall be used for all deduct specimens. Exception: Production-intent configurations under 500 mm must be prepared in production configuration.

2. Prepare the resistance measurement point(s). For single cable welds, prepare a point on the cable 100 mm ± 3 mm minimum from the rear edge of the terminal conductor grip (or end of pad if there is no grip) by applying solder to stripped wire at Point C per Figure 10A or 10B as applicable. (Use of a measurement point >100 mm is acceptable as long as the measurement length is consistent for all samples.) For welds comprising multiple cables, prepare a measurement point on each cable 6 mm^2 or smaller (for dry circuit measurement). Electrically join all cables over 6 mm^2 to form points C and D per Figure 10B (for creation of voltage drop measurement point).

3. Apply solder to the cable/wire(s) stripped in Step 2. Solder helps to obtain consistent measurement readings.

4. Note that Table 9 instructs to prepare three deduct specimens for each WUT. Using the three samples, apply solder to the weld-to-terminal interface to simulate parts with no electrical resistance in the bond. Mark these as “deduct” samples for calibration used in 4.7.4, Steps 4, 5, and 6.

4.7.3 Equipment

1. Micro-ohmmeter per Table 2. Applies to dry circuit method.

2. DC power supply (0~20 V, 100 A or as required). Applies to voltage drop method.

3. Digital voltmeter. Applies to voltage drop method.

NOTE: Not all equipment is needed. Select equipment based on which method will be used.

4.7.4 Procedure

1. Perform a visual inspection of components per 4.2.

2. Ensure samples are thoroughly dry but otherwise untouched; cleaning or rinsing of corrosion products is not allowed.

3. Place samples as instructed below, depending on type of test being performed.

   DRY CIRCUIT: Place samples on measurement surface individually and minimize the movement of samples.

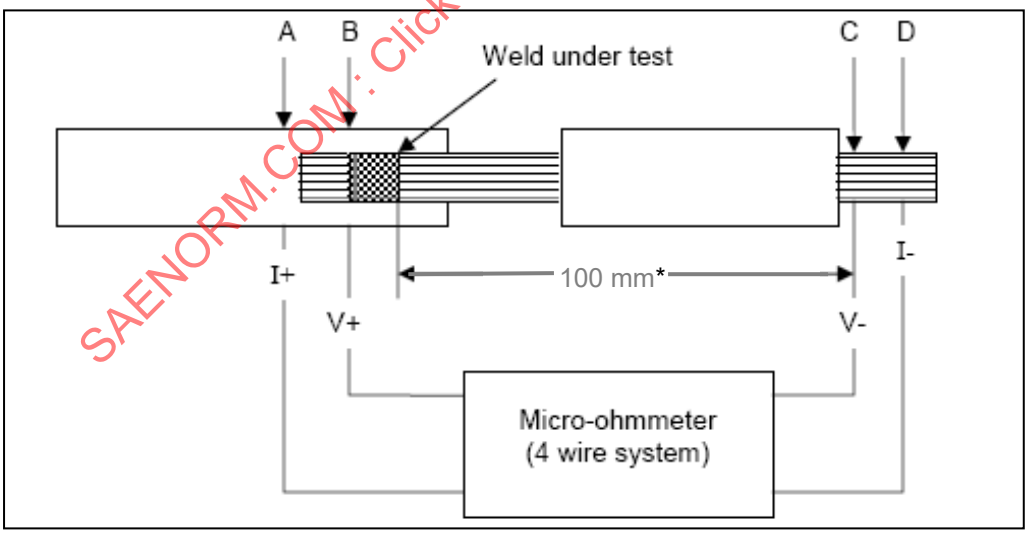
   VOLTAGE DROP: Place samples in series, powered as a single circuit.

   Ensure points “B” and “C” are accessible on all samples (split bolts, eyelet terminals crimped the end of the specimen, or welds are acceptable methods for connecting samples in series).

4. For each deduct specimen made in 4.7.2, Step 2, measure and record the resistance between Point B and Point C of Figure 10A or Figure 10B, as applicable for test type. If dry circuit method is used, measure resistance directly using the meter specified in 4.7.3, Step 1. If voltage drop method is used, calculate resistance by measuring amps and voltage drop in mV between Point B and Point C using the meter per 4.7.3, Step 3. Calculate resistance using the equation 1 mV/A = 1 mΩ. Calculate the average of the three deduct samples and record. Repeat for all required measurement points per 4.7.2, Step 2.

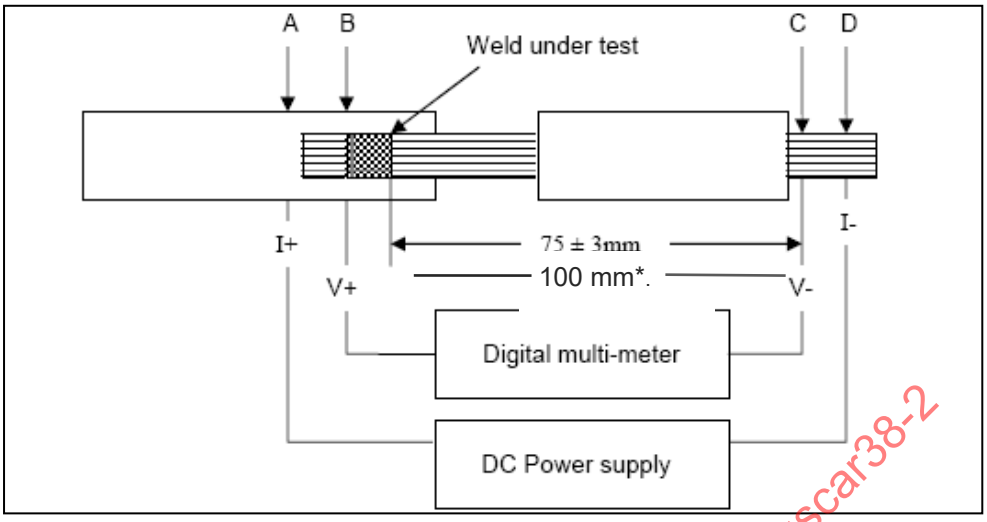
5. Using the same measurement method as in Step 4, measure and record the total resistance on all WUT samples at all required measurement points.

6. The weld resistance is equal to the total WUT resistance measured in Step 5 less the resistance of the average of the deduct samples measured in Step 4. Reminder: The deduct specimens measured in Step 4 must be the same as those under test measured in Step 5. The only difference is the solder on the weld bond of the deduct samples.



*Any dimension >100 mm is acceptable if the same length ±3 mm is used for the deduct sample. A and B are on the weld pad and C and D are on the cable.

Figure 10A - Dry circuit measurement points for total cross-sectional area ≤6 mm²



*Any dimension >100 mm is acceptable if the same length ±3 mm is used for the deduct sample. A and B are on the weld pad and C and D are on the cable.

Figure 10B - Voltage drop measurement points for total cross-sectional area >6 mm²

4.7.5 Acceptance Criteria

Upon completion of the accelerated aging test, all samples must not exceed the resistance (mV/A or mΩ) values shown in Table 8.

Table 8 - Allowable voltage drop or resistance

Wire Size (mm^2)⁺	Test Voltage (V)	Test Current (A)	Max Voltage Drop or Resistance mV/A (mΩ)*	Max Change from Initial V Drop or R mV/A (mΩ)*
≤6	<20 mV (Dry Circuit)	<0.1	0.55	0.33
>6 and <12	In compliance	50	0.15	0.09
≥12 and <20	In compliance	75	0.11	0.07
≥20 and <30	In compliance	100	0.08	0.05
≥30 and <40	In compliance	100	0.06	0.04
≥40 and <50	In compliance	100	0.05	0.03
≥50 and <60	In compliance	100	0.04	0.02
≥60 and ≤120	In compliance	100	0.03	0.02
>120	In compliance	100	0.03	0.02

* mΩ are displayed directly or are calculated using the equation 1 mV/A = 1 mΩ. It is used for wires >6 mm^2.
⁺ Wire size refers to total wire core area. Intermediate sizes may be linearly interpolated.

4.8 Screening Test for Damage to Weld Bonds on the Far End of a Short Wire

4.8.1 Purpose

This is a screening test that can predict a risk of low weld bond strength and terminal damage. This test assesses whether the WUT sends excessive ultrasonic energy through the wire, putting nearby components at risk. Damage at the far end of a 300 mm cable has been observed, and components within 500 mm are considered at risk.

NOTE: Damage to nearby components must be evaluated on parts within 500 mm of a welded bond, per 5.2. Other evaluations in addition to USCAR-38 may also be required by test requester.

This test indirectly evaluates the weld energy being transmitted by comparing tensile strength of the WUT to an identical terminal 200 mm away from the WUT. By comparing pull values, the two welds on the near and far sides provide data on whether the first weld was or was not weakened by the welding process on the second weld.

This is a generic screening test and is not a substitute for testing the specific application in its exact manufacturing configuration. Any cable length under 500 mm must have the validation performed in the as-manufactured condition.

Figure 11 - Typical short cable requiring screening test

4.8.2 Samples

1. Table 9 defines how many samples are required. A typical sample is shown in Figure 11.

2. Ultrasonically terminate on both ends with the identical WUT on cable 200 mm long. The same terminal on each end is intentional. The same terminal can be used since this is only a screening test showing relative performance.

4.8.3 Procedure

1. Weld the samples as described in 4.8.2 on both sides (two weld bonds, one on each end of the sample cable). Identify which terminal was the first weld on each sample.

2. Inspect for damage per 4.2.

3. Perform pull test per 4.4.5 by grasping both sides simultaneously in the fixture. Pull to failure.

4. Record the force to cause the failure and whether the first or second WUT to be welded that failed.

5. Perform tensile test per 4.4.5 on the WUT that did not break in Step 3 and record peak force.

6. Tally how many times the sample failed at the first location to be welded. Calculate and record the percentage of samples failed at the location compared to the total number of samples.

4.8.4 Acceptance Criteria

This screening test indicates the sensitivity of the WUT to damage nearby weld bonds with excess energy. Meeting the criteria can give confidence that the weld setup parameters used will not create damage to nearby terminals in short-wire configurations. Failure to meet the criteria does not reject an otherwise acceptable validation. The validation using production-intent short wires must perform a full validation on the specific configuration to be put in production using 4.8.3.

1. If the fraction of cables tested that broke on the first-welded terminal (per 4.8.3, Step 5) is 70% or more, the WUT is deemed to be “process-sensitive” in configurations shorter than 500 mm. This is not a failure but is useful information that predicts trouble in double weld configurations (where the second weld will negatively impact the first weld).

2. If the average pull force in 4.8.3, Step 4 is less than 80% of the average pull force value recorded in 4.4.5, Step 6 (the one-ended termination), the WUT is deemed to be “process-sensitive” in configurations shorter than 500 mm.

3. If the inspection in 4.8.3, Step 2 shows any damage caused by the welding process, the WUT is deemed to be “process-sensitive” in configurations shorter than 500 mm.

NOTE: If a test result determines that WUT is “process-sensitive,” it can predict a risk with short cables but will not predict performance on cables longer than 500 mm. In applications where the above criteria are not met, a process change is recommended to lessen the energy transferred through the wire. This is typically done with product (cable or terminal) and process (welder, weld tooling or weld setting) changes. Any change requires new validation testing.

4.9 Visual Inspection for Terminal Cracks

4.9.1 Purpose

This is an additional visual inspection used to compare samples made with different processes. It determines if the weld process might result in the creation of cracks in parts of terminal that are not in the weld area.

4.9.2 Samples

Prepare samples as follows:

1. Group 1: Ten pieces, unwelded terminals.

2. Group 2: Ten pieces, terminals welded using production-intent process (made of samples that are welded using input settings of: maximum amplitude, minimum pressure, and 110% of maximum energy).

3. Group 3: Ten pieces, only needed if a damper is used in the weld process. Group is comprised of samples welded using production intent process, but with the damper removed. Welding is done using the same input settings as Group 2.

4.9.3 Procedure

Inspect all groups for cracks using unwelded samples (Group 1) for comparison. Magnified inspection of terminal geometry is recommended for crack observation, with optimal magnification selected in the test lab. Document any differences between the groups (that indicate changes from processing).

4.9.4 Acceptance Criteria

There are two modes of acceptance:

1. WUT is accepted if welded terminals from Group 2 do not exhibit cracks or damage when compared to Group 1.

2. If a sample in Group 2 exhibits cracks, but the damper works and Group 3 does not exhibit cracks, then the WUT is conditionally accepted, with the constraint that the damper must be used.

5. VALIDATION REQUIREMENTS FOR WELDED WIRE/CABLE TERMINATION

5.1 Requirements and Conformance Determination

Conformance to USCAR-38 requires meeting the requirements of all applicable test groups in Table 10 with a minimum sample size per Table 9.

5.2 Requirements for (Short Wire) Applications

Applications shorter than 500 mm are considered special since the short length introduces the additional failure mode of transferred energy to nearby components. For these short applications, the exact production configuration, made in the exact production sequence must be used to perform the USCAR-38 tests; no representative cable segments can be used. Any terminal previously welded to the opposite end of the WUT must be fully re-validated with extra care taken to look for damage per Table 3, item Q. Terminal makers performing initial validations are encouraged to perform Table 10, Sequence E to identify weld processes that have an increased potential for causing damage to nearby terminals. Failing Sequence E is often an indication that there will be trouble validating the exact harness configuration when shorter than 500 mm.

5.3 Requirements for Reference Validations

5.3.1 Purpose

Validation by “reference” to a similar configuration that passed USCAR-38 is offered to avoid repeating nearly identical tests when the outcome can be predicted. This section defines what common conditions are required.

5.3.2 Allowable Use of a “Reference” Validation

Use of a “reference” validation must satisfy items 1, 2, and 3:

1. The reference part that has already been validated has the same weld characteristics defined in 1.2.1.

2. These attributes must be the same between reference and WUT part: terminal part number (and therefore same weld pad material, plating, thickness, orientation of wire to terminal), cable, application tooling, and process settings.

3. The referenced validation must have been performed to the latest level of USCAR-38 (no reference validations to back-level specifications).

5.3.3 Exceptions

The only exception to 5.3.2 is that the cable/wire part number may be different as long as the following stay the same: insulation outside diameter, material, compression, and cross-sectional area. Cables with more than 80 strands may differ a total of 3% in strand count between samples on test and be considered the same. All other wires are different. (Example: 7- and 19-strand construction for a wire cannot be considered the same nor can different standards of the same size such as SAE, ISO, and JIS wire types. These wires have different conductor core cross-sectional areas, even if the strand count is the same and must be validated for the WUT.)

Table 9 - Sample quantity per test group

Process Intensity Level for WUT (see Appendix D)	Cross Section and Sample Retention	Bond Peel Strength[2]	Bond Peel Strength[1][2]	Bond Tensile Strength[1]	Bond Tensile Strength[1]	Accelerated Environmental Aging	Collateral Damage to Nearby Components[3]	Insulation Crimp[4]	Screening for Terminal Cracks
Test Group	A	B	B2	C	C2	D	E	F	G
Quantity at “most intense” settings	2	2		30	30		50		
Quantity at “nominal” settings				40	40			10	
Quantity at “least intense” settings	2	2	2	30	30	10^5			
Quantity (refer to 4.9.2 for details)									30

NOTES:

(1) Test Groups B2 and C2 are conditional. Include samples if the WUT has multiple wires in the weld and wire sizes differ by two sizes or more. See 4.4.5, Step 6 for examples. If WUT is multi-wire, test largest wire in Groups B and C and smallest wire in Groups B2 and C2.

(2) Include samples only if a wire in the WUT is <6 mm. There is no technical benefit to test larger wires.

(3) Include samples only if instructed, typically, when WUT has at-risk unrelated components within 500 mm of WUT. See 5.2 for details on when USCAR recommends to test.

(4) Include samples only if WUT has an insulation crimp. See 4.8.

(5) Prepare at least 13 specimens for each WUT; three are for making deduct samples and ten are for testing.

Table 10 - Tests required for validation

	Test Name	Weld Nugget Cross Section	Bond Peel Strength[2]	Bond Peel Strength (Multi-Wire Only)[1][2]	Bond Tensile Strength	Bond Tensile Strength (Multi-Wire Only)[1]	Accelerated Environmental Aging	Collateral Damage Assessment[3]	Insulation Crimp[4]	Screening for Terminal Cracks
	Test Group	A	B	B2	C	C2	D	E	F	G
4.1	General	1	1	1	1	1	1	1		1
4.2	Visual Inspection	2	2	2	2	2	2, 7	2, 5		2
4.3	Cross Section and Compaction Analysis	3								
4.4.4	Weld Bond Peel Strength Test		3	3						
4.4.5	Weld Bond Tensile Strength Test				3	3	8			
4.5	Accelerated Environmental Exposure (Thermal Shock)						4			
4.7	Electrical Resistance (Dry Circuit and Voltage Drop)						3, 5			
4.8	Damage Assessment to Nearby Components (Only on Short Wires)							3		
4.9	Screening for Terminal Cracks						6	4		3
	Insulation Crimp Validation per USCAR-21 section 4.3.5								1	

NOTES:

(1) Test Groups B2 and C2 are conditional and are only performed if the WUT has multiple wires in the weld. If WUT is multi-wire, test largest wire in Groups B and C and smallest wire in Groups B2 and C2.

(2) Perform only if a wire in the WUT is <6 mm.

(3) Perform only if instructed.

(4) Perform only if WUT has an insulation crimp. See 4.8.