

Performance Specification for Ultrasonically Welded Wire Terminations

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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 evaluating ultrasonically welded wire-to-terminal metallurgical bonds. The examples used are specific to the linear weld type of process equipment. USCAR-38 is not applicable for "Splice Welding". The specification is applicable to wire-on-pad configurations with a typical weld shown in Figure 1. This test specification subjects parts under test to environmental exposures to simulate a lifetime of field exposure for a road vehicle. Exposures called-out in this specification include Thermal Shock, Temperature Humidity Cycling and mechanical abuse. This test specification is intended to evaluate the strength and performance of the interface between wires to an electrical terminal. Validation of the performance of the Terminal is a separate task and can be accomplished using a component validation test such as SAE/USCAR-2, which evaluates whether the entire connection system is acceptable.



**Figure 1 - Wire-to-pad weld configuration defined in USCAR-38
(USCAR-38 is not applicable for wire-to-wire splice welding)**

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 SAE/USCAR-38 test sequence may not be applicable. Parts used in custom applications must pass tests simulating the actual conditions encountered before they can be considered acceptable for that application.

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°C to +150°C. Applied voltage may be either low (0 - 60 VDC) or high (to 600V). USCAR-38 applies to all wire lengths and includes a special test for wires shorter than 500mm where a weld is done after another component has been assembled to the wire (test samples must be made from the exact production-intent welding process to assess potential process damage risk 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 without crimped insulation wings are applicable.

3) 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 spec.

4) Applicable wire sizes: Copper wire sizes between 0.22mm² to 85mm² per ISO 6722-1 wire specification and aluminum (per ISO 6722-2) sizes from 0.5mm² to 120mm² are applicable. Other wire types may be tested per this specification but cannot claim compliance to this specification since those sizes are out of our experience. Examples of representative "other" wires types are: compressed core, compacted core, solid wire core, and wire core materials other than copper, copper alloy, aluminum, or aluminum alloy. Examples of different center core materials are copper-clad or steel-center-core wires.

5) 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 spec 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 SAE/USCAR-38 test report where all tests per Table 5.1 meet the criteria of a good weld. 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. The report must identify whether the short wire test per section 4.8 was or was not performed and the results.

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:

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

NOTE: The above are process and quality parameters. See Appendix C for a related list of "design" parameters recommended to be used to develop the correct tooling and process settings.

2. REFERENCE DOCUMENTS

2.1 Normative References (Required to perform tests)

- SAE/USCAR-2: Performance Specification for Automotive Electrical Connector Systems (for initial validation)
- SAE/USCAR-21: Performance Specification for Cable-to-Terminal Electrical Crimps (for wire seal parts only)

2.2 Informative References

- SAE J1128: Low Voltage Primary Cable
- SAE J1127: Low Voltage Battery Cable
- ISO/DIN 6722 Low Tension Primary Cable (Copper, Part 1 and Aluminum, Part 2)
- AIAG Measurement Systems Analysis Reference Manual

2.3 Test Request Documentation

The laboratory test request/order shall 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. 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 3.4:

Table 3.4 - Default test tolerances

DESCRIPTION	TOLERANCE
Temperature	$\pm 3^{\circ}\text{C}$
Voltage	$\pm 5\%$
Current	$\pm 5\%$
Resistance	$\pm 5\%$
Length	$\pm 5\%$
Time	$\pm 5\%$
Force	$\pm 5\%$
Relative Humidity	$\pm 5\%$

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:

- A. Room Temperature $23 \pm 5^{\circ}\text{C}$
- B. Relative Humidity Ambient
- C. Voltage (DC) $14.0 \pm 0.1\text{V}$

3.6 Equipment

Table 3.6 highlights specialized equipment or devices with particular accuracy requirements used for USCAR-38 testing. Neither Table 3.6 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 3.6 - Equipment list

DESCRIPTION	REQUIREMENTS
DC Power Supply (Regulated)	0~20V 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 Volts DC 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 ~.08mm)
Force Tester	Capable of an accuracy of 1% of measurement
Thermal Shock Chamber	-40 to 150°C ± 3 (in 5 minutes or less)
Oven (alternate to Thermal Shock Chamber)	+150°C ±3
Temperature Chamber (alternate to Thermal Shock Chamber)	-40 °C ± 3
Video/photography equipment	As required to make clear pictures, including Cross-section micrographs

3.7 Definitions and Abbreviations

Terms defined in the definitions or glossary are capitalized (i.e. Room Temperature, Steady State, etc.). A list of definitions is in Appendix A. Abbreviations are 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&R's 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. The samples submitted for test shall be identified 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

All samples from all Test Groups (A, B, C, D, and E, if run) shall be visually inspected. This is a non-destructive test samples are to be saved for follow-on tests in that Test Group. Counting the sample size from all test paths shows that 117 samples need to be supplied to perform a validation on a single-wire termination group. For multiple wire terminations, double the number of samples are required. This is explained in 4.4.4 Step 6, Note 2 in more detail.

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. Examine the weld bond area on each sample prior to testing per the criteria in Section 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. FOR FINAL INSPECTION ONLY: 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 must meet the criteria of this section and not show the defects described in Table 4.2.5. 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 4.2.5 illustrates an ideal weld bond and Table 4.2.5.1 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.

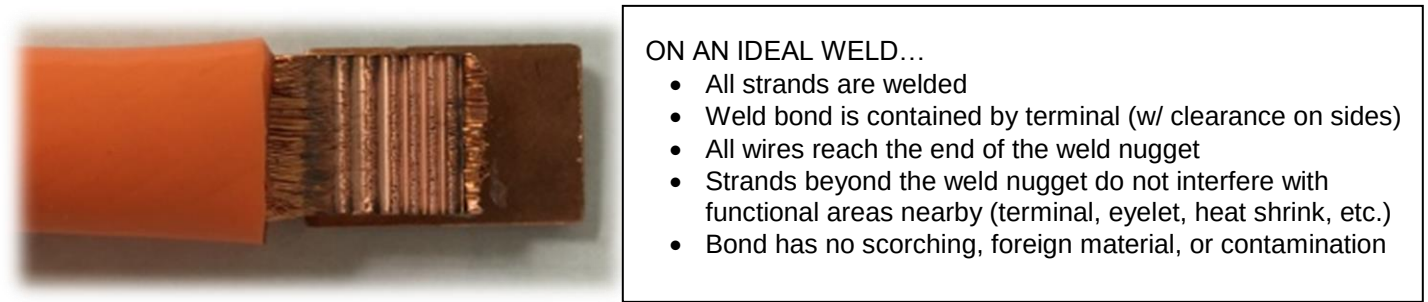


Figure 4.2.5 - Ideal weld bond appearance

1. General Appearance and function

The welding operation shall not change the terminal such that it interferes with device function and 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

- In sealed applications, the end of the wire core must not present any sharp surfaces that may damage a seal during a connector assembly or seal application processes. USCAR-2 provides specific tests to validate to this requirement.
- Strip length must 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

The Insulation Grip (if present) must meet the criteria in SAE/USCAR-21 4.2.5 #8 for general visual appearance and 4.3.5 #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 6mm² or smaller. The insulation grip moves the point of highest stress between welded and un-welded wire strands away from the weld bond area.)

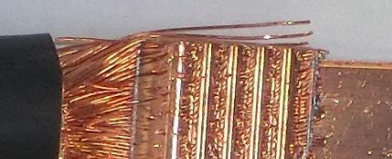
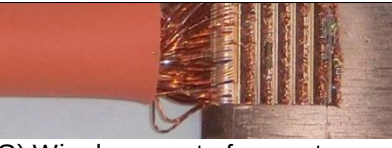
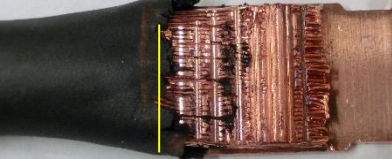
4. Cable Conductor appearance prior to welding

Any cable can be used provided it is the production-intended wire for the application. However, poor cable conductor appearance prior to welding is known to result in inconsistent welds. (Aluminum wire has been noted as sensitive to changes in appearance.) Table 4.2.5 parts F, K, and O give criteria rules related to the wire prior to welding.

5. Individual Cable Seal and Mat Seals

USCAR-21 criteria for visual inspection criteria must be met (if applicable). Sections 4.2.5 #10 and 4.3.5 #4 apply to cable seals and 4.3.5 #5 applies to mat seals.

Table 4.2.5 - Weld bond appearance criteria

Non-conforming Appearance Attribute	Requirement for 100 piece Capability Study for PV	Recommended criteria for production parts shipped to customer
 A) Weld nugget length shortened due to wire placement	Weld nugget length must not 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.	Same. NOTE: Wire brush is determined by the application and is not specified in USCAR-38.
 B) Tooling marks off the weld pad	Terminal position not allowed based on presence of non-transitional tooling marks off the weld pad.	Same
 C) Insufficient side clearance	Terminal pad must extend 0.5mm min. beyond nugget on both sides (to allow clamping). Note: deviation requests are common and need a case-specific assessment.	Same
 D) Strand loose	Completely unwelded strands are not allowed.	Same. Trimming by manually cutting strands might be acceptable to customer. Approval of trimming is not controlled in USCAR-38.
 E) Cut or broken strands away from weld nugget	Broken Strands (that break during weld process) are not allowed.	Cut, broken or missing strands are allowed if within the limits of Table 4.2.5.2 and strands sticking up past top of wire insulation are trimmed (this is often changed to reflect a customer-determined acceptable height).
 F) Strand cut/missing before weld	The condition of strands before weld is not inspected by the test lab. Cut, broken or missing strands after weld are allowed within the limits of Table 4.2.5.2.	Same. A separate control method for missing-strands-before-weld may be needed.
 G) Wire loops out of nugget	Looped wires are not allowed unless within the limits of Table 4.2.5.2 AND pushed back into the nugget.	Same
 H) Insulation compound in weld	1) No insulation in weld bond area. 2) Horn must be clear of insulation (Note yellow line shows where horn overlapped the insulation). Small amounts of insulation filaments not visible to the naked eye are allowed.	Small bits of insulation are recommended to be permitted in the weld bond area. The process must be adjusted to eliminate condition when found.