Performance Specification for Welded Wire-to Wire Splices

SAE/USCAR-45
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PERFORMANCE SPECIFICATION FOR WELDED WIRE-TO-WIRE SPLICES

Notice about interim revisions: Editorial updates or clarifications may be made as “interim revisions” if the EWCAP review team determines that a formal revision is not needed. Interim revisions are documented as “revision letters” and are available on the USCAR website at: http://ewcap.uscarteams.org/revisions.html

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1. SCOPE

SAE/USCAR-45 defines test methods and performance requirements for ultrasonically-welded wire-to-wire splices for automotive applications. Face-to-face, butt splice, and center strip configurations per Figure 1 can be tested. The tests

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defined in this specification subject samples on test to stresses that simulate a lifetime of exposure for a road vehicle. Stresses called out in this specification include thermal shock, temperature/humidity cycling and mechanical stress from different directions.

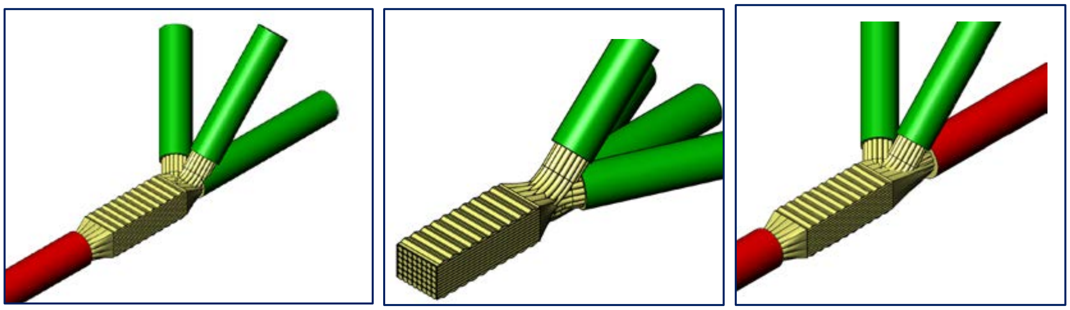


FIGURE 1 - APPLICABLE SPLICE CONFIGURATIONS: FACE-TO-FACE SPLICE (LEFT), BUTT SPLICE (CENTER), AND CENTER STRIP (RIGHT)

1.1 Applicability

The vehicle and product conditions applicable to use of this specification are:

1) Applicable vehicle environments: USCAR-45 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 +125°C. It is applicable to applied voltages that are either low (0 - 60 VDC) or high (to 600V). This is a design validation (DV) specification; process controls are not covered. (Wire harness makers typically will be given the responsibility to develop processes and perform process controls.) The procedures described are applicable to wire-to-wire splices but do not consider placement of the splice within a wire harness. For example, rules on the minimum distance between welded splices in a harness is not evaluated in this specification.

2) Applicable weld configurations: USCAR-45 is known to be applicable for face-to-face and butt splices as described in Figure 1. Validation is possible for weld configurations not meeting the above design limits but we do not have experience beyond the design range listed below. Outside this range, an engineering assessment is needed to determine whether the USCAR-44 testing is applicable.

   a) The total number of wires in the splice ≤ 12

   b) The difference in wire count on opposing sides of a splice ≤ 8 (exception: butt splice and center strip configurations)

   c) The ratio of the smallest wire size to the total weld cross-sectional area is a minimum ratio of 1:10. (This means the smallest cable must be at least 10% of the total cross-sectional area of the weld... needed to detect small wire).

3) Applicable wire and cable: USCAR-45 is applicable for individual wires between 0.13mm2 and 50mm2 per ISO 19642-3. This specification was developed using clean, bare, uncoated, stranded automotive copper wire. Wires with tin coatings, applied lubricants, or contamination are known to affect the mechanical performance of ultrasonically welded splices and may not be applicable for USCAR-45 validation. There are no specific limitations on wire insulation type. Wires with silicone-based water blocking gel in them are not applicable to USCAR-45 validation.

4) Applicable manufacturing processes: The validation process described applies to linear ultrasonic welding and has sections specifically designed to apply to processing with linear ultrasonic welding equipment. If the equipment used to make samples for USCAR-45 testing is different from this description, USCAR-45 may need to be modified or may not be applicable. If the weld under test is different than what is listed as applicable or is subjected to conditions beyond typical automotive use, an engineering assessment is required to determine applicability of USCAR-45 is applicable.

1.2 Weld features

Table 1 lists the features that define a weld. Figure 2 illustrates weld features that are also key measurable dimensions (with letters A through E matching ID letters of Table 1). Weld features are developed prior to USCAR-45 testing; USCAR-45 does not provide a method for development of the tooling and the weld schedule (process settings) used to make the WUT. Weld parameter development should be done using sound engineering practices such as application of historical lessons with similar parts, use of equipment maker's recommendations, and analysis of results with trial parts. Testing a weld that has been developed properly has an increased chance that the samples submitted for test will pass.

TABLE 1 - KEY WELD FEATURES

ID	DESCRIPTION
A.	Weld bond length
B.	Wire brush
C.	Wire transition (uninsulated unbonded length)
D.	Weld bond width
E.	Weld bond height
F.	Wire strip length and alignment
G.	Tooling profile
H.	Construction and quantity of cables welded
I.	Wire core material (including plating on wire)
J.	Weld equipment specifications

1.3 Splice performance

The capability of a splice is characterized by the key attributes listed below.

1. Acceptably high mechanical tensile bond strength (measured by tensile strength of the cable-to-cable junction).
2. Acceptably high mechanical peel strength (measured by peel strength of the cable-to-cable junction).
3. Stable electrical connection (measured by resistance or voltage drop).
4. Consistent attributes and parameters of the weld and its assembly process.

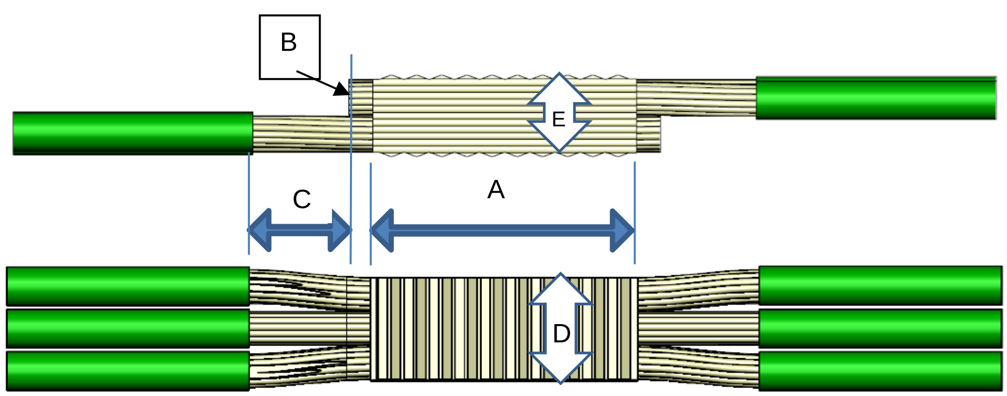


FIGURE 2 - WELD FEATURES PER TABLE 1- SIDE VIEW (ABOVE) AND TOP VIEW (BELOW)

2. REFERENCE DOCUMENTS

2.1 Normative References

ISO 19642-3 Primary Cable (Copper core wire, stranded, formerly ISO 6722-1)

2.2 Informative References

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.

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 in Table 10. 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 2. Some default conditions are also listed. When specific test tolerance or condition is not given either in the product design specification, the test request/order or elsewhere in this specification, the default condition applies.

TABLE 2 - DEFAULT TEST TOLERANCES

DESCRIPTION	TOLERANCE	DEFAULT CONDITION
Temperature	± 3˚C	23 ± 5˚C
Relative Humidity	± 5%	Ambient
Voltage	± 5%	14.0 ± 0.1V
Current	± 5%	
Resistance	± 5%	
Length	± 5%	
Time	± 5%	
Force	± 5%	
Force tester speed	+150 mm/min. - 50 mm/min.	100 mm/min.

3.5 Equipment

Table 3 highlights specialized equipment or devices with particular accuracy requirements used for USCAR-45 testing. Neither the table 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 - EQUIPMENT LIST

DESCRIPTION	REQUIREMENTS
DC Power Supply (Regulated)	0~20V. Current capability as required per Table 9 for the wire size of the WUT
Milli-Ohmmeter	20 mV max. open circuit voltage, 100 mA max. current, 0.01 mΩ resolution and 1% accuracy.
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
Force Tester	Capable of an accuracy of 1% of measurement
Thermal Shock Chamber	Capable of -40 to 125°C ± 3C, switching between temperatures in 5 min. or less.
Video/photography equipment	As required to make clear pictures, including cross-section micrographs

3.6 Definitions and Abbreviations

Terms defined in the definitions section are capitalized (i.e. Room Temperature, Steady State, etc.). A list of definitions and abbreviations are in Appendix A.

3.7 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.

3.8 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 test, date of the last calibration, and when the next calibration is due is to be included in each test report.

4. TEST PROCEDURES AND 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 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.

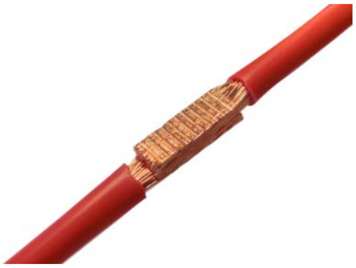
3. The samples submitted for test must be identified by description, part number, and revision level where applicable. Weld bond height, width, and length, and all process setting parameters used to make the welds (including machine feedback results of weld time and energy, as available) shall be recorded and included in the test report.

4. Samples quantities must meet the minimum needed for design validation. Increased sample sizes may be desired to provide a prediction of process capability in addition to the basic USCAR-45 validation.

5. Samples must be made using the same process as what is being validated. A USCAR-45 validation applies to the specific configuration tested. Cable core and insulation cannot be cleaned. Equipment and tooling used to make samples must be production-intent.

4.2 Visual Inspection

Figure 3 illustrates an ideal weld bond and lists ideal weld attributes. This figure is for reference and is not part of any criteria.



ON AN IDEAL WELD…
- All strands are welded
- Weld bond is long enough to make a suitable bond
- All strands extend past the weld nugget, but just slightly
- Bond has no scorching, foreign material, or contamination

FIGURE 3 - IDEAL WELD BOND APPEARANCE

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.

4.2.2 Equipment

Visual inspection, in most cases, can be accomplished using available lighting in the lab. Also needed is:

1. Photographic equipment able to take general pictures.

2. Video equipment, optional, for added documentation.

4.2.3 Procedure

1. Examine the weld bond area on each sample per the criteria in Tables 4, 5, and 6 of Section 4.2.4. Note any manufacturing or material defects such as poor wire-to-weld transition, loose strands, cut strands, or long strands. Take photographs and/or video recordings of one representative sample and keep as an untested part sample. Measure the brush length using a millimeter scale and no magnification. Only if needed (due to low resolution of a millimeter scale measurement), repeat brush length measurement using a more accurate measurement method.

2. FOR INITIAL INSPECTION ONLY: Take measurements on 2 parts per WUT from test group A (Table 10) to describe incoming WUT. Record all measurements taken. References to dimensions are per Figure 2 and Table 1. Note that Dimension B is measured in Table 4. Dimensions D and E are measured in cross-sectional analysis, Section 4.3.

At minimum, record the following:

a) Weld bond length (Dim. A) Horn and anvil side – Measure peak-to-peak as shown in Figure 4.

b) Wire transition length (Dim. C) – Measure 2 parts per WUT from weld group A.

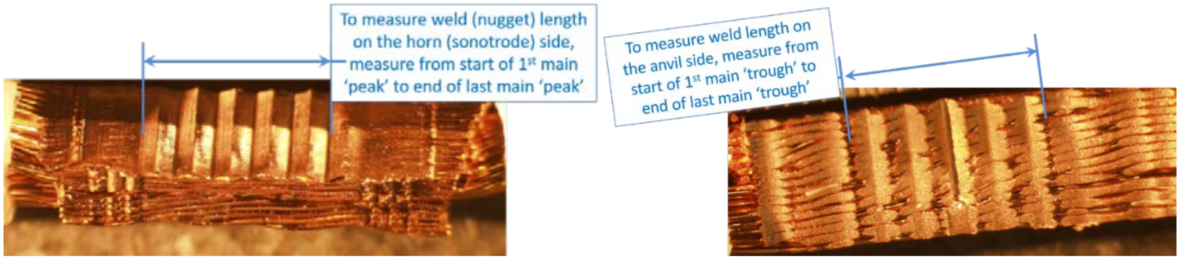


FIGURE 4 - MEASUREMENT METHOD FOR DIMENSION 4.2.3.2. A (HORN) AND B (ANVIL)

3. FOR FINAL INSPECTION ONLY (after testing and/or conditioning steps): 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 and record any differences in the test report.

4.2.4 Acceptance Criteria

All samples shall meet the criteria described in Tables 4, 5, and 6. Specifically:

- Brush End (High and Low Limits) measurements meet the criteria in Table 4.
- No sample exhibits a visual attribute listed unacceptable in Table 5.
- No sample has strand breakage in excess of what is allowed in Table 6. (Note that missing strands, even if acceptable, indicates a poor process and should not be tolerated for ongoing production. The allowed levels are based on what has been shown to perform acceptably).

Note that the criteria listed are based on weld bond robustness only. USCAR-45 does not consider application-specific failure modes such as interference with neighboring parts.

TABLE 4 - WELD BOND DIMENSIONAL CRITERIA

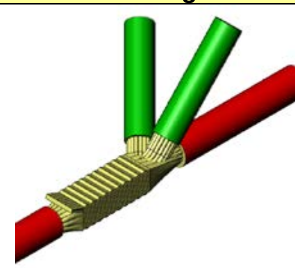
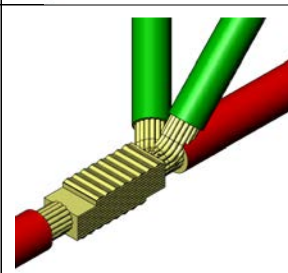
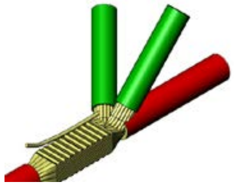
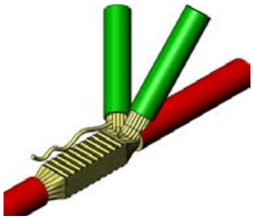
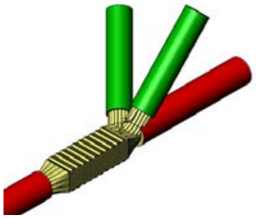
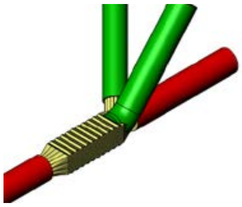
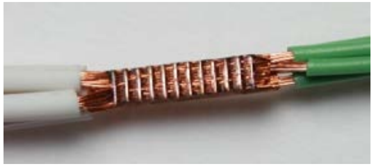
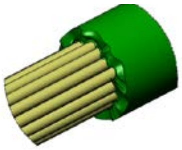
Weld Attribute	Requirement	Illustration of non-conforming weld
Brush End High Limit (Protrusion)	No strand may exceed 1.5 mm maximum when measured using a millimeter scale and no magnification. (Ref: Dimension B of Figure 2).	
Brush End Low Limit (Retraction)	All strands shall be 0 or greater when measured using a millimeter scale and no magnification. (Ref: Dimension B of Figure 2). (Negative values are indicitative of retracted wires (not fully underneath the tooling).	

TABLE 5 - WELD BOND APPEARANCE CRITERIA

Weld Attribute	Requirement	Illustration of non-conforming weld
Unwelded frayed strand	There shall be no frayed or stray or unwelded strands.	
Unwelded floating strand	There shall be no floating strands (welded in middle of weld only).	
Broken or cut strands	There shall be no strands that appear to be broken from the welding process (determined by the wire break being in the A to C junction from Figure 2). Broken strands observed within region "A" are not judged.	
Insulation in Weld	Insulation shall not be caught or pinched in the ultrasonic weld area.	
Burned Appearance or Discoloration	There shall be no burned or scorched appearance, dark discoloration, foreign material, or contamination on the weld surface or at the front and rear boundaries of the ultrasonic weld or wire insulation.	
Melting Damage	Melting at the end of the insulation, caused by heat generation during welding, shall not be excessive nor hinder practical use of the splice. Melting may not reduce wire flexibility or produce excessive odor.	

NOTES:

1. Each application is different and is likely to have unique requirements that add-to or supersede this section. Any additional requirements are provided by customer.

2. The criteria listed have been determined to be acceptable based on weld bond robustness and electrical stability and are not an assessment of process controls (that are likely to require more stringent controls). Process controls are not covered in this specification.

3. This section does not consider application-specific failure modes such as the weld interacting/interfering with neighboring parts or sealing sleeves. Customer requirements are needed to address application-specific items.

4. The relative position of a weld to other wire harness features is not a criterion for weld acceptance. Acceptable weld position in a wire harness is not evaluated in USCAR-45.

TABLE 6 - MAXIMUM ALLOWABLE BROKEN OR MISSING STRANDS

Strand Count of Cable [1]	Broken or Missing Strand Limit within region C [2]
1 to 7-strand cable	0 broken or missing strands allowed
8 to 19-strand cable	1 broken or missing strand allowed
20 to 37-strand cable	2 broken or missing strands allowed
38 strands and greater	5% of total strand count can be broken or missing (using visual inspection to assess the outermost layer of the weld only).

(1) Broken strand count refers to individual visible cables, not the total quantity of strands.
(2) Criteria applies within region "C" of Fig. 2; no broken strands are allowed at the "A" to "C" junction.

4.3 Cross-Section Analysis

4.3.1 Purpose

Cross-sectional analysis of the weld area provides direct evidence of a strong and uniform mechanical bond needed to assure 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 failed to meet a test requirement.

4.3.2 Equipment

1. Equipment to create a cross-section micrograph for the applicable cable size.

2. Equipment to obtain a clear cross-sectional micrograph (10X min. magnification) with individual wire strands visible. The choice of equipment is up to the lab provided using it results in minimal disturbance to the cable and stranding.

3. Equipment to measure weld nugget attributes listed in Table 2.

4.3.3 Procedure

1. Confirm a photograph of the weld bond has been taken prior to making the cross-sectional cut.

2. Make a cross-section cut as near to the mid-point (in a valley, if applicable) of the weld bond as possible. Use tools that will not damage the WUT.

3. Measure height and width of the burr as shown in Figure 5.

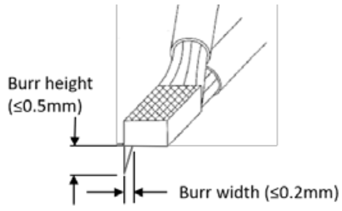


FIGURE 5 - BURR MEASUREMENT IN CROSS-SECTION

4. Measure the Weld bond width and height (Dimensions D and E, Figure 2) at the center of the weld.

5. Calculate the area of the wire core cross section before weld. Either measure the area of an individual wire strand and multiply by the strand count for that wire type or calculate the wire core area per the "weight method" in ISO 19642-3.

6. Calculate the area of the wire core cross-section after welding by measuring the cross-section and computing as required. Note that automated software exists to perform this function and is typically used. Fully-surrounded air gaps are counted as part of the area of the wire core.

7. Calculate the compaction ratio (final-to-initial wire cross sectional area ratio) per Formula 1.

FORMULA 1 - COMPACTION RATIO FROM CROSS-SECTIONAL PHOTOGRAPH

$$C(\%) = \frac{F}{A} * 100$$

Where:
C = Compaction Ratio (%)
F = Cross-sectional area of wire and trapped air after weld
A = Wire area before weld (calculated by adding area of individual strands or using“density” method per ISO 19642-3)

4.3.4 Acceptance Criteria

1. All strands in the cross-section shall be in full contact with the weld nugget when examined at 10X magnification.

2. The height and width of the burr from the ultrasonic welding connection part shall be 0.5mm or less (height) and 0.2mm or less (width) as shown in Figure 5.

4.4 Weld Bond Tensile Strength

4.4.1 Purpose

The tensile strength of a weld bond is used to assess the ability of a weld to survive when subjected to mechanical stress.

4.4.2 Equipment

Force tester with appropriate load cells and fixturing specific for the WUT.

4.4.3 Procedure

1. Select the wires to be pulled. Select the smallest wire first. Then, on the opposing side (for face-to-face splices), select the smallest wire on that side. For center splice designs, assure the same continuous wire is not tested on both ends. Assure that a “bare splice” is under test (splices with heat shrink or other reinforcements are not acceptable validation samples, except as additional information when asked for by test requestor). Note that butt splices do not require tensile testing since they are not subjected to tensile stresses.

2. Load sample in fixture as shown in Figure 6, capturing smallest cable in the moveable jaw and an opposing individual cable on the fixed jaw. Remove slack in cable to prevent incorrect test results due to “jerking.”

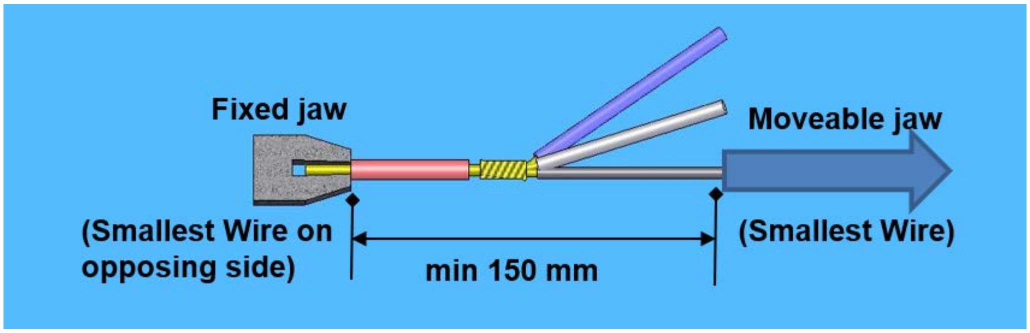


FIGURE 6 - PULL STRENGTH SET-UP SHOWING PULL OF SMALLEST WIRE

3. Apply a force aligned to the direction of the welded wires at a rate between 50 and 250 mm/minute (100 mm/minute is typical). Measure and record peak tensile force to separate the wires. [Repeat Steps 2 and 3 for each sample.]

4. For all test groups: Calculate and record average, maximum, and minimum values for the test group.

5. For Test Group B only, calculate standard deviation for all samples of test group and calculate the lower 3 sigma value.

4.4.4 Acceptance Criteria

For Test Group B samples, the lower 3 sigma value of the tensile strength (calculated in 4.4.3, Step 5) shall meet or exceed the "Group B" value of Table 7 for the wire size under test. If a WUT fails, a strength reinforcement, such as heat shrink tubing, may be added to the splice. If WUT meets criteria when retested, parts are acceptable.

1. For Test Group C the tensile strength of all samples shall equal or exceed the "Group C" value in Table 7. NOTE: This is the measured value, not the calculated lower 3 sigma value. If a test fails, retesting and meeting this requirement with a WUT with added reinforcements such as heat shrink is acceptable.

TABLE 7 - PULL (TENSILE) REQUIREMENTS

Wire Size [(1)]	Group B [(2)] X-3σ (N)	Group C [(2)] (N)
0.13	50	34
0.35	55	47
0.5	80	68
0.75	115	98
1.0	160	136
1.5	200	170
2.0	225	191
2.5	250	213
3.0	350	298
4.0	375	319
5.0	400	340
6.0	435	370
8.0	500	425
10	800	680
12	1000	850
14	1025	871
16	1050	893
18	1100	935
20	1200	1020
25	1350	1148
30	1500	1275
35	1700	1445
40	1850	1573
50	2200	1870

(1) Wire sizes are defined in ISO 19642-3. For non-ISO wire sizes, interpolate to determine the applicable value.

(2) Groups B and C refer to the test groups of Table 10.

4.5 Weld Bond Peel Strength

4.5.1 Purpose

The peel strength of a weld bond is used to assess the ability of a weld to survive situations where wires are stressed as-if being peeled apart, typical in assembly operations.

4.5.2 Equipment

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

4.5.3 Procedure

1. Load WUT in the test fixture so that the smallest wire is in the moveable jaw of the fixture. Place the largest wire available for testing in the fixed jaw. The peeling action that results must match the peeling action shown in Figure 7. The largest and smallest wires of the WUT must be pulled 180° apart.

2. Apply a force and measure and record peak peel force to separate the wires.

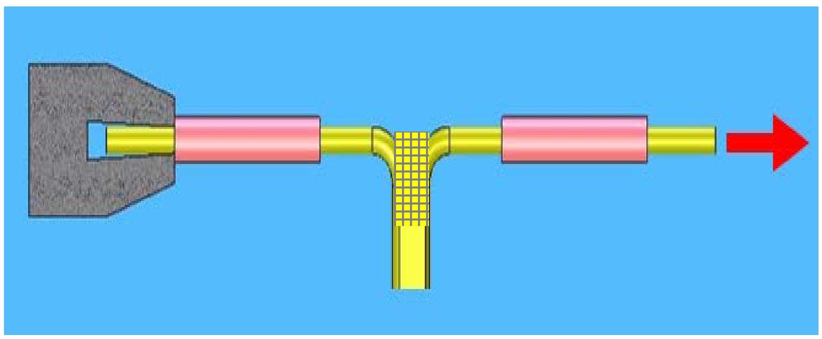


FIGURE 7 - PEEL STRENGTH TEST SET-UP (BUTT SPLICE SHOWN)

4.5.4 Acceptance Criteria

Measured peel strength of all samples shall equal or exceed the value listed in Table 8. If required value per Table 8 is not achieved, it is allowed to make an identical WUT with added reinforcements (such as heat) and retesting.

TABLE 8 - PEEL FORCE REQUIREMENTS

Wire Size (1)	Peel Force (N)	Wire Size (1)	Peel Force (N)
0.13	10	8	100
0.35	11	10	160
0.50	16	12	200
0.75	23	14	205
1.0	32	16	210
1.5	40	18	220
2.0	45	20	240
2.5	50	25	270
3.0	70	30	300
4.0	75	35	340
5.0	80	40	370
6.0	87	50	440

NOTE:
(1) Wire sizes refer to ISO 19642-3. For non-ISO wire sizes, use criteria for the next larger size or interpolate.

4.6 Thermal shock conditioning

4.6.1 Purpose

Thermal shock conditioning is an environmental conditioning procedure that simulates being subjected to alternating high and low temperature environments. Rapid transfer between the two environments tests the ability of the WUT to withstand drastic temperature changes typical of automotive use. NOTE: humidity exposure, often used in conjunction with thermal shock conditioning, is not a significant environmental stress for ultrasonic welding and is not applied here. Ultrasonic welds have a metallurgical bond that is not affected by humidity.

4.6.2 Equipment:

Thermal shock chamber capable of the cycle shown in Figure 8.

4.6.3 Procedure

1. Set chamber controls to the temperatures and dwell times shown in Figure 8. Set the number of cycles to 72.

2. Calculate cycle times that include sufficient time to achieve the programmed temperature; the 30-minute dwell time does not start until the chamber has reached its required temperature.

3. Place the sample group(s) in the chamber.

4. Start the test program. Record the actual operating temperatures, actual dwell times, and any test irregularities and include in the report. (Note: the insulation may discolor or shrink if the wire is rated at less than 125C. This is not a concern if the wire temperature rating is less than 125C.)

5. When the 72-cycle test program is complete, remove the samples.

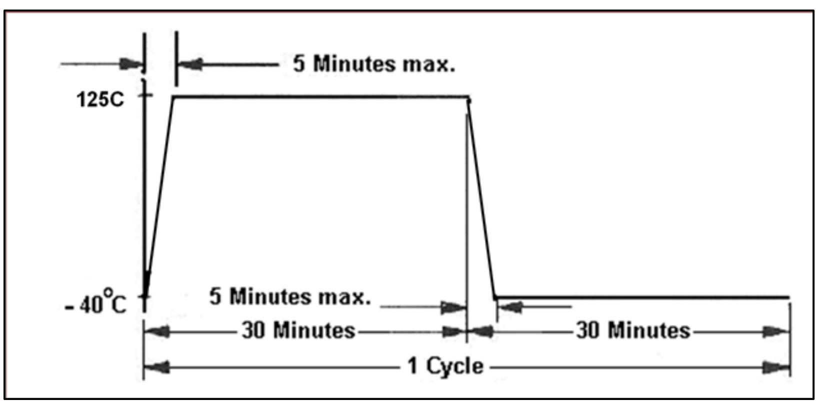


FIGURE 8 - THERMAL SHOCK CHAMBER TEMPERATURE PROFILE

4.6.4 Acceptance Criteria

The acceptance criteria for subsequent tests shown in Table 10 shall be fulfilled.

4.7 Electrical Resistance (Voltage drop) Measurement

4.7.1 Purpose

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

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

4.7.2 Sample preparation

1. Strip the wire (making conductor exposed) so the configuration of Figure 9 can be accomplished. Note that 150mm ±3mm in Figure 9 is the total distance from end-to-end. (150mm is specified however other lengths are acceptable with customer approval as long as there is no effect on the weld bond. The same length shall be used for all samples. If there are multiple wires, strip only the wire with the smallest wire size

2. Apply solder to the wire stripped in Step 1. (Solder helps to obtain consistent measurement readings.)

3. For the 3 samples marked as “deduct” samples, apply solder to the weld nugget to simulate parts with no electrical resistance in the bond. Clearly mark these as ‘deduct’ samples.

4.7.3 Equipment:

Not all listed equipment is needed. Use Table 9 to determine equipment type and test voltage/current for the WUT.

1. Micro-ohmmeter per Table 3 (if wire size of WUT calls for dry circuit method in Table 9).

2. DC Power supply, per Table 3. Amperage as required (if wire size of WUT calls for voltage drop method in Table 9).

3. Digital Voltmeter per Table 3 (if wire size of WUT calls for voltage drop method in Table 9).

4.7.4 Procedure

1. Place samples on measurement surface individually. Minimize the movement of samples. For DRY CIRCUIT testing, use a micro ohmmeter to measure resistance. For VOLTAGE DROP testing per Table 9, use a power supply and volt meter.

2. Place probes A, B, C, and D as applicable for test method. Assure placement repeatability at points B and C is within ±3mm (measurement accuracy depends on consistent placement of the probe and careful probe placement is needed). For butt splices, 150±3mm dimension includes the distance to the beginning of the nugget and then back for the same total 150mm length. Always apply probes to the smallest wire on each side. Do not connect to the same wire on both sides in the case of a center-splice design. Apply current or turn-on equipment as applicable.

3. For each of the 3 “deduct” samples, measure and record the resistance between Point B and Point C of Figure 9. If dry circuit method is used, measure resistance directly using micro ohm meter. If voltage drop method is used, measure voltage and Amps and calculate resistance between points B and C using the equation 1mV/A = 1mΩ. Calculate the average of the 3 deduct samples and record.

4. Using the same measurement method, measure and record the resistance for each sample.

5. Calculate the weld resistance of the WUT by subtracting the average “deduct” resistance from the resistance between points B and C of Figure 9. Record results.

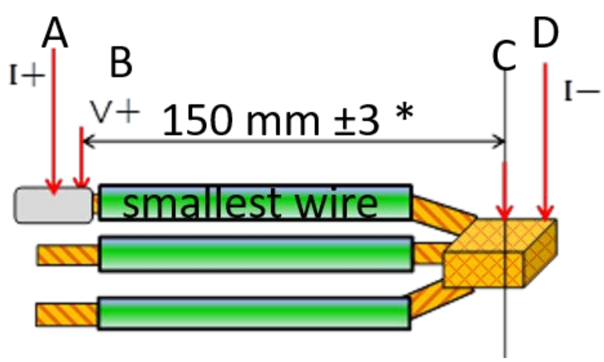


FIGURE 9 - DRY CIRCUIT AND VOLTAGE DROP MEASUREMENT POINTS

4.7.5 Acceptance Criteria

The resistance value for all samples shall be at or below the value shown in Table 9 for the applicable wire size.

TABLE 9 - MAXIMUM ALLOWABLE VOLTAGE DROP OR RESISTANCE

Wire Size (1)	Test Voltage (V)	Test Current (A)	Max. (mΩ) (2)	Max. Change from initial V Drop or R mV/A (mΩ) (2)
≤6	<20mV	<100mA	0.55	0.33
>6 and <12	As required (3)	50A	0.15	0.09
≥12 and <20	As required (3)	75A	0.11	0.07
≥20 and <30	As required (3)	100A	0.08	0.05
≥30 and <40	As required (3)	100A	0.06	0.04
≥40 and <50	As required (3)	100A	0.05	0.03
≥50 and <60	As required (3)	100A	0.04	0.02
≥60 and ≤120	As required (3)	100A	0.03	0.02

NOTES:

(1) Wire sizes listed are per ISO 19642-3. For non-ISO wire sizes, use criteria for the next larger size or interpolate the table values.

(2) mΩ reading is displayed directly for wires ≤ 6mm^2 and is calculated by dividing mV reading by applied Amps to get equivalent mΩ in mV/A for wires > 6mm^2.

(3) Voltage is not set. The circuit resistance will determine voltage. This is also known as “voltage in compliance”

5. VALIDATION REQUIREMENTS

5.1 Conformance Determination

1. If the requirements of test sequences A, B, C, D and E of Table 10 are met, then the weld described by the tooling, settings, and wire tested are in conformance with USCAR-45. Note that USCAR-45 is a “DV” (design validation) only. Process validation is performed separately.

5.2 Reference Validations

Validation by “Reference” is earned by comparison of a weld configuration to a similar configuration that has already passed USCAR-45. The reference method is offered to avoid repeating tests when the outcome can be safely predicted. It is not common for reference splice validations except to allow a single test to validate different temperature class cables as long as all other attributes are the same. This section defines what common attributes are required for a reference validation. USCAR does not recommend a reference validation except when the conditions listed are met. All reference validations require agreement between the customer and the supplier.

- Wire conductor type, size, and stranding
- Outside diameter of insulation
- Material of insulation (Exception: Cables with XLPE or PVC insulation.)
- Tooling, equipment, and process settings
- Cross-sectional area or aspect ratio of finished weld
- Bunching method for asymmetrical wire (Exception: Cables with more than 80 strands may differ a total of 3% in strand count between tested and reference samples be considered the same and valid for a reference validation. All other wire stranding configurations are considered different (For example, 7 and 19-strand construction for a wire cannot be considered the same nor can different specifications 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 10 - TESTS REQUIRED FOR VALIDATION

	Test Name	Cross-Sectional Analysis	Bond Tensile Strength	Bond Tensile Strength (Incorrectly Made)	Bond Peel Strength	Performance after Environmental Aging
	Test Group	A	B	C	D	E
	Sample size minimum for group	2	30[2]	5[3]	10[2, 6]	13[2,4]
4.1	General	1	1	1	1	1
4.2	Visual Inspection	2	2	2	2	2, 6
4.3	Welded termination Cross-Section and compaction Analysis	3[1]				
4.4	Weld Bond Tensile Strength		3 [5]			7[5]
4.4 [3]	Weld Bond Tensile Strength (same test “4.4” but performed on incorrectly made samples)			3		
4.5	Weld Bond Peel Strength		3 [5]		3	
4.6	Thermal Shock Conditioning					4
4.7	Electrical Resistance Measurement					3, 5

NOTES:

[1] Perform measurement of weld attribute dimensions on both samples. Separate sample group after measurement using one sample for photographs and cross-section analysis and save the other part as a representative sample.

[2] If tensile or peel test is of a configuration at risk to fail requirements due to a low cable tensile strength (this is seen occasionally on small wire sizes with annealed copper strands), doubling the sample size is recommended. If the test fails, the extra samples can have a reinforcement added to the weld area (such as by adding dual-wall heat shrink) and then retested per section 4.4.

[3] Samples intentionally made with worst-case wire orientation in the welding fixture are required for this test. Use samples with the biggest wire intentionally located on the anvil side of the ultrasonic tooling. All process tooling and settings are to be the same as for typical samples. Clearly identify samples as having “worst-case wire orientation for Group C.”

[4] Prepare 13 samples. Ten samples are for measurement and three are for an electrical resistance “deduct” reference. Construct the three reference samples by soldering the weld nugget to eliminate weld resistance.

[5] Pick the applicable test for step 3 based on the application: “Weld Bond Tensile Strength” is the default test. If “Weld Bond Tensile Strength” test of the smallest wire is not possible due to WUT being a “butt splice” configuration, replace test 4.4 with test 4.5 (Weld Bond Peel Strength).

[6] Skip test path D for “Butt splice” type samples. They are not subjected to tensile stresses.

APPENDIX A- DEFINITIONS AND ABBREVIATIONS

Cable:

An assembly made up of several strands of wire (the conductor) and its insulating covering manufactured to a specific configuration. See wire

Conductor:

A part of a cable which has the specific function of carrying electrical current.

Conductor Core Cross Sectional Area:

A calculated value of: strand count times cross-sectional area of a single strand.

Cpk

A measure of process capability. Estimates what the process is capable of producing, considering that the process mean may not be centered between the specification limits. Cpk assumes a normal distribution and a process that is in control. A Cpk of 1.67 statistically predicts a process yield of 99.9999%. Cpk value is calculated from this equation:

Cpk = ([Sample average] – [Table 6 specification limit value]) / [3*Sample standard deviation]

Design Validation (DV):

Tests that are conducted to demonstrate that the design intent is met. Manufacturing must be aware of the weld design parameters and maintain them in production.

Insulation:

That part of a cable that electrically separates the conductor from the external environment.

Linear Weld:

A type of ultrasonic weld process equipment where the motion is back-and-forth in a single axis.

Low Energy:

Applications which have an open circuit voltage of 5 volts or less. This definition is chosen to enable easy selection of the type of testing acceptable based on the electronic circuit application.

Lower Spec Limit:

An input value used in the calculation for CPK process capability.

Micrograph:

High magnification photography with sufficient resolution to clearly see all wire strands in the cross-sectional evaluation process.

Nugget:

The area of wires that are fused together in the welding process.

Power:

Applications that have an open circuit voltage greater than 5 volts. Typically, these are lighting, resistance, motor, or relay circuits. Current levels may range from milli-amps to full cable rating.

Process Validation (PV):

In-process tests, performed on production parts, with the production intent equipment in the final production facility. This testing is used to demonstrate process capability and conformance to the specification.

PVC

Polyvinyl chloride.

Sample Group:

An identically prepared group of specimens.

Sample:

An individual part in a test group

Strand:

One of the individual wires in a conductor.

USCAR, LLC:

Abbreviation for United States Council for Automotive Research LLC, a consortium of representatives from Ford, General Motors and FCA US, LLC, formed to promote joint research in non-competitive areas that can strengthen the US automotive industry (www.uscar.org).

Wire:

Synonymous with cable and may also be used to describe individual strands.

WUT

Weld Under Test - Synonymous with “Sample.

XLPE

Cross-linked polyethylene

APPENDIX B - QUALITY CONTROL TECHNIQUES

This is reference information. This appendix lists process control methods that are commonly in use and successful. Process control is not a requirement of USCAR-45 and the information can only be used for reference.

USCAR specifications describe tests to validate parts and do not provide any specific quality control methods. The important task of developing process controls must be developed between the supplier and the customer based on the specific quality expectations involved. This section is provided as a starting point for discussion in development of the process controls. Table 11 lists the more common quality control techniques used for welding. It contains a list of control strategies with a short description of the input and output variables.

TABLE 11 - QUALITY CONTROL TECHNIQUES USED FOR WIRE-TO-WIRE WELDING

#	Method	Description
1	Weld Time	Weld time is a response that varies as needed to obtain the required energy. Weld time should be stable from part to part in an in-control process. An unusual change in weld time suggests something has changed in the process. It is recommended that a process control be established to stop production when the weld time departs from the mean value by an agreed-on number of standard deviations.
2	Initial / Final Height	Initial and Final weld height, measured by sensors in the weld machine, should be relatively constant. Any inconsistency suggests something has changed in the process. It is recommended that a process control be developed using the initial and/or final height to give confidence that the incoming materials and weld processes have not changed from the parts used in the validation.
3	Visual Appearance	This is a USCAR-45 requirement but the method and frequency of inspection is not controlled in this specification. An inspection using an agreed-on method and schedule is recommended.
4	Tool wear	Unusual tool wear suggests something has changed in the process or materials being welded. It is recommended tool wear be part of the quality control plan.
5	Pull (tensile) strength	Pull force is the most correlated metric to field performance. It is recommended that measuring the pull force to break the weld be a process control. Note that pull is a destructive test, which is not efficient.

APPENDIX C - REVISION RECORD

DATE	SECTION	SUMMARY OF CHANGES MADE
May, 2018	All	Initial release.