MECHANICAL VALIDATION OF HV ELECTRICAL WIRES CONNECTION FOR ELECTRICAL VEHICLE OBTAINED THROUGH ULTRASONICALLY WELDED HV WIRES

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Abstract: World environmental organizations dealing with emission reduction requirements, and the Paris Agreement in 2015, where 195 countries adopted universal, legally binding global climate deal, strives to reduce the amount of harmful emissions, as well as to reduce global warming to well below 2ºC. This necessitated a more vigorous development and research into electric vehicles. Every electrical vehicle contains high voltage (HV) electrical distributed system (EDS) – a HV electrical wire harness.

The present work electrical connection obtained through ultrasonically welded wires for high voltage (HV) electrical distributed system (EDS) for electrical vehicle has been explored. The obtained high splice cross-section requires development of new equipment, as well as the determination of appropriate ultrasonic welding parameters. The present work is focused of the obtained welding joint and validation of subsequent validation of these parameters.

Keywords: capability analysis, splice geometry, pull out test, peel test, ultrasonic wire welding UWW.

1. Introduction

Electrical wire joints (connections) with total joint cross-section more than 60mm² using for HV wire harnesses which are obtained by ultrasonic wire welding UWW are not investigated well. Globally it is missing clear requirements and validation criteria for automotive OEM's. On the other hand ensuring and guaranteeing a reliable electrical connection in electric vehicle is with particular importance for the safety of people and the reliable operation of the electric vehicle.

This requires serious consideration of the choice of ultrasonic welding parameters and product validation, before release it in production.

The present work is focus on choosing the best welding parameters for obtaining the maximum best product quality in terms of strength characteristics (pull out force and peel shear force) and subsequent validation of ultrasonic welding joint (connection) using statistical capability index Cp, with purpose to ensure the necessary quality before release the production of welding joint.

In the present study HV shielded cables for electric powertrain, type: FHLR2GCB2G, produced by Coroplast Fritz Müller GmbH & Co. KG are used.

The main cable characteristics are presented in table 1[1]

The combinations of wires used for creating the ultrasonically welded wires joint (connection) is presented in figure 1[2]. As we can see the splice combinations is formed by 1 wire with cross-section of 25 mm² and 2 wires with cross-section of 35 mm². The total splice cross-section is 95 mm².

Table 1 Cable specification for HV wire harness using for powertrain of electrical vehicle.

Conductor material:	E-Cu ETP1 according DIN EN 13602
Conductor design:	stranded bare copper 1070 (±5%) x max. 0,21mm
Conductor diameter:	max. 8,5 mm
Core insulation:	mod. Silicon rubber SiR
Core diameter:	10,5 mm(-0,7)
Insulation wall thickness:	min. 0,64 mm
Colour code:	orange similar RAL 2003

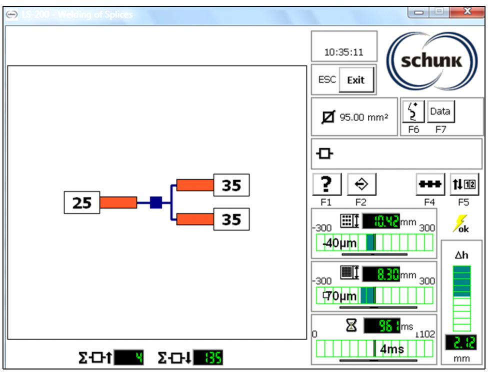

Figure 1: Illustration of user menu with the UW program, with the combination of wires that will be welded ultrasonically, total splice cross-section 95 mm².

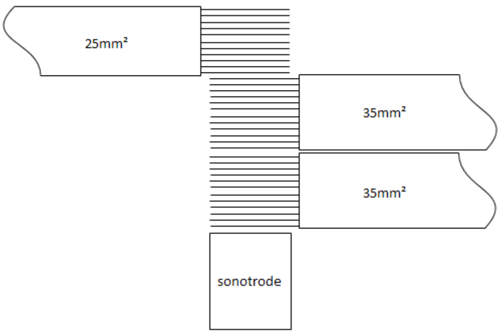

Figure 2: Illustration of sequence of wires placement (arrangements) in terms of sonotrode position.

Ultrasonic machine model LS200 used for these investigations is the new development for this year (2018). Machine manufacturer is Schunk Sonosystems GmbH.

Machine parameters and characteristics are presented in table 2. [5] [6]

Table 2 Technical specification of Ultrasonic Welding Machine (UWM) model LS-200, Schunk Sonosystems

Cross-section range	20 mm² - 200 mm²
Generator output	9 kW
Frequency	20 kHz
Applications	wire UW: Cu, AL Cascade
Pressure	6,5 bar
Power supply	3X400 V, N, PE

2. Methods

For the choosing of appropriate ultrasonic welding parameters and product validation, is used ultrasonic wire welding machine (UWWM), which is validated. This is done in order to be eliminated the probability of some product failure, due to machine condition. It means that the negative influence of product results due to machine inappropriate condition is eliminated. The machine inspection is done with calibrated measuring devices.

The welding joint is validated in terms of mechanical strength characteristics. In order to be proven the reliable product quality it is used statistical capability index CpkL for product validation. In our case the product is ultrasonic welding joint (nugget) with 3 wires with total joint cross-section 95mm ² (figure 1). The variable values for capability calculation are taken from 2 kind of mechanical tests: Pull out test and Peel (Share) test. On figures 2 and 3 are presented the scheme of both tests.

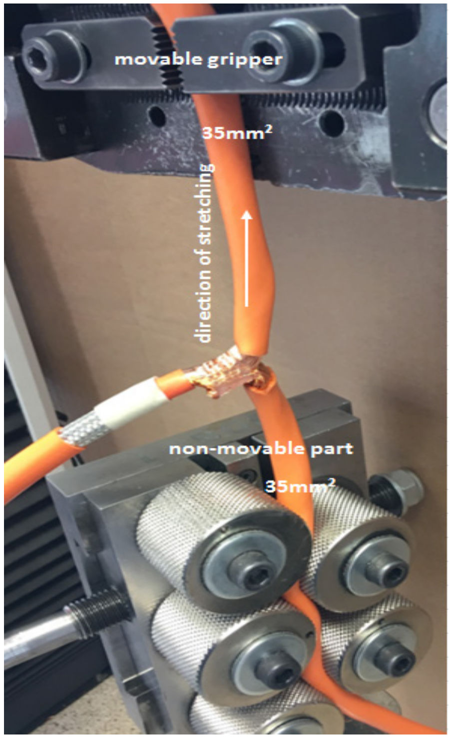

Figure 2: Illustration of Peel(share) test performing of splice with wires combination - left side: 1 time 25 mm², right side 2 times by 35 mm². Due to splice topology the Peel test is performed, sharing the 2 wires by 35 mm².

The best welding parameters (table 3) for the respective splice configuration (figure 1) and validation the product quality are defined based on the:

1. CpkL of mechanical strength characteristics (table 4);
2. Visual assessment of welding joint (figures 4 and 5);
3. Power curve generated by the UWM (figure 5).

The ultrasonic welding parameters are defined based on obtained best experimental results from pull and peel test. It is followed the logic: The best welding parameters are those parameters, which giving the best product quality results, which means: CpkL from Pull and Peel test results to be greater than 1,67. [2]

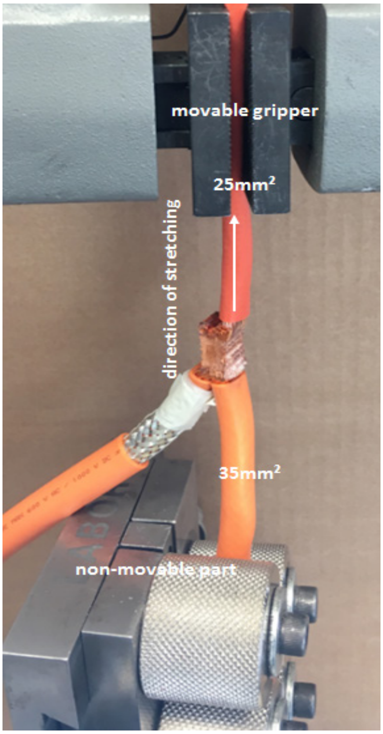

Figure 3: Illustration of Pull out test performing of splice with wires combination - left side: 1 time 25 mm², right side 2 times by 35 mm². Total splice cross-section 95 mm². Due to splice topology the Pull out test is performed, sharing the 2 wires: 35 mm² and 25 mm²

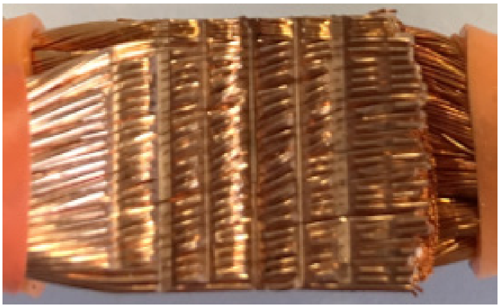

Figure 4: Illustration of visual aspect of the welding joint from anvil side

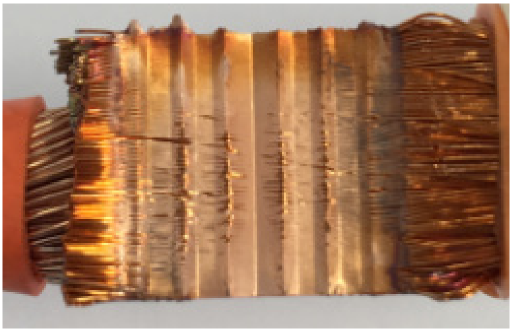

Figure 5: Illustration of visual aspect of the welding joint from sonotrode side

Table 3 Table with the most appropriate ultrasonic welding parameters defined based on the best obtained results from pull and peel tests.

Parameter	Value	Unit
Pressure	3,75	bars
Width	12,6	mm
Amplitude	100	%
Energy	7025	Ws

The formula for calculation the Cp is presented in formula (1)

$$Cpk_L = \frac{\mu - L}{3\sigma}, \quad (1)$$

where:

CpkL – lower process capability index;

μ – population mean value;
L – lower specification limit;
σ – standard deviation.

L pull out = 1350 N, L peel = 340 N [2]

In this investigation is used the CpkL lower capability index due to fact that according to ISO 6722 [9] the wires does not have maximum dimension of wire strand diameter, only minimum. It means that only the lower value must be controlled.

Pull and Peel tests are performed with tensile test machine model 3306, produced by Intron GmbH with load cell capacity of 30kN and the residual indicated force after removing a series of forces is not greater than ±0.05% full rated output.

Power curve shows how the ultrasonic welding process went. By power curve is giving information for the splice quality.

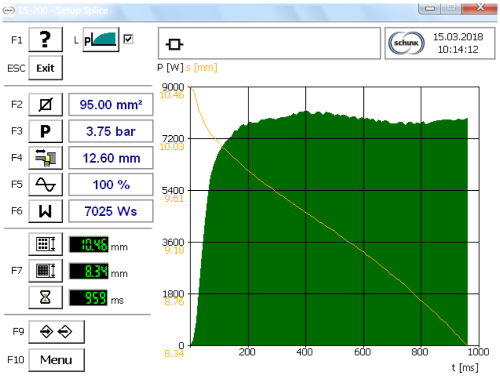

Figure 6: Illustration of Power curve

3. Results

The many tests on welding joints with different welding parameters (pressure, width, amplitude and energy), failed with respect to capability analysis (lower than 1,67 for Pull and Peel tests).

3.1. CpkL of mechanical strength characteristics (table 4)

The only good results from capability analysis for mechanical strength characteristic of the welding joints (Pull out and Peel tests) are obtained with welding parameters presented in table 3. In table 4 are presented the results from Pull out and Peel tests, which shows good capability index (CpkL >1,67). The CpkL for Pull test is 2,36 and for Peel test is 3,03.

3.2. Visual assessment of welding joint (figures 4 and 5)

The visual aspect of the welding joint is acceptable. The colours and footprint from anvil (figure 4) and sonotrode sides (figure 5) are normal. There are no any broken wire strands or burned wire insulation. The footprint from sonotrode side did not create fully melting of material. This is understandable from the small marks in the middle of the welding joint.

3.3. Power curve generated by the UWM (figure 5).

The obtained power curve with presented welding parameters in table 3, was the most appropriate one, in comparison with the other welding parameters. The power curve is with quick maximum power reach, which is good indicator for the quality of ultrasonic welding process during the wire joining. Power curve is kept with very good shape. The Energy distribution is smooth and time is kept less than 1 second, which is indicator for a good tendency for quality of the welding joint.

4. Conclusions

It is reached the goal of the study:

- It is defined the best welding parameters for the investigated splice combination (figure 1);
- It is reached good CpkL for the mechanical strength characteristics of the welding joint (table 4).

Based on obtained experimental results from:

- capability index for mechanical strength characteristics CpkL;
- visual assessment of the welding joint;
- generated power curve by the UWW machine,

we can conclude that the welding joint is validated successfully in terms of mechanical characteristics.

Through this study is presented approach for mechanical validation of ultrasonic welding joint validation for HV electrical connections used for electrical vehicles.

The method outlined above successfully can be implemented for appropriate product validation of electrical connections obtained through ultrasonic welding technology.

The results will depend from accuracy of the measuring devices, testing method and statistical method used for capability calculations.

5. References

[1] Wire specification for HV cables, Coroplast Fritz Müller GmbH & Co. KG

[2] Performance Specification for Welded wire-to wire splices, SAE/USCAR-45, June 2018

[3] Sutwin software, Schunk Sonosystems GmbH, 2018

[4] ISO TR 22514-4:2007(E), Statistical methods in process management – Capability and performance – Part 4: Process capability estimates and performance measures, first edition 2007.

[5] Operational Manual for Ultrasonic Welding machine model LS-200, Schunk Sonosystems GmbH, 2018

[6] Brochure for LS200, Schunk Sonosystems GmbH, 2018.

[7] Operator's guide M10-16281-EN Revision D, Series Load Cells Catalog Number 2530-400, Instron GmbH

[8] Operator's guide M10-16281-EN Revision

Table 4 Table obtained experimental results from Pull and Peel tests.

Pull test , N		Peel test, N	
1	4013,89	1	842,13
2	3047,06	2	847,81
3	3371,1	3	879,29
4	4005,91	4	869,66
5	3356,92	5	740,94
6	3505,55	6	848,58
7	3228,34	7	799,65
8	3459,27	8	787,66
9	3798,67	9	793,15
10	3372,18	10	848,27
11	3296,55	11	848,27
12	3233,84	12	777,04
13	3522,13	13	721,03
14	3392,76	14	872,6
15	3124,22	15	859
16	3253,37	16	856,7
17	3154,07	17	738,77
18	3353,03	18	746,43
19	3607,57	19	721,22
20	3657,88	20	738,94
21	3687,99	21	852,29
22	3988,3	22	722,73
23	3566,17	23	766,57
24	3239,1	24	866,02
25	4008,66	25	748,6
26	3736,22	26	853,74
27	3876,01	27	807,05
28	3580,57	28	796,99
29	3247,72	29	763,63
30	3295,08	30	747,33
31	3081,6	31	794,18
32	3745,48	32	759,83
33	3781,25	33	721,67
34	3390,85	34	811,16
35	3770,14	35	766,9
36	3243,96	36	855,31
37	3111,86	37	743,71
38	3050,92	38	861,44
39	3775,34	39	830,14
40	3375,66	40	730,84
41	3151,3	41	845,2
42	3947,81	42	839,48
43	3898,32	43	800,16
44	3313,47	44	835,82
45	3264,99	45	782,65
46	3918,88	46	850,52
47	3144,96	47	864,26
48	3144,51	48	819,38
49	3406,66	49	750,46
50	3966,19	50	861,69
min.	**3047,06**	**min.**	**721,03**
max.	**4013,89**	**max.**	**879,29**
R(?)	**966,83**	**R(?)**	**158,26**
μ	**3489,29**	**μ**	**803,74**
σ	**302,68**	**σ**	**51,02**
Cpk_L	**2,36**	**Cpk_L**	**3,03**

D, 3360 Series Dual Column Table Frames, Instron GmbH

[9] ISO 6722, Road vehicles – 60 V and 600V single-core cables – Dimensions, test methods and requirements, second edition 2006

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