TECHNOLOGICAL FLOW IN ULTRASONIC WELDING OF COPPER CONDUCTORS USED IN THE AUTOMOTIVE FIELD

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ABSTRACT: Ultrasonic welding is the new method used in industry for a wide range of operations: assembly of wire harnesses and heavy cables for cars, trucks and industrial machines, assembly of solar cells that constitute solar panels, welding of larger metal parts, spot welding - including wire-to-terminal welding - in a single impulse, fast and clean joining of thin aluminium and copper foils and last but not least the precise crimping and sealing of copper and aluminium tubes. The current work wants to present this system by presenting a case study. Compared to crimping or pressure welding, this process offers numerous advantages. In addition to the excellent electrical properties of the joint and extremely low energy consumption, this method is particularly characterized by complete process control and process data management.

KEYWORDS: welding, ultrasound, copper, flow

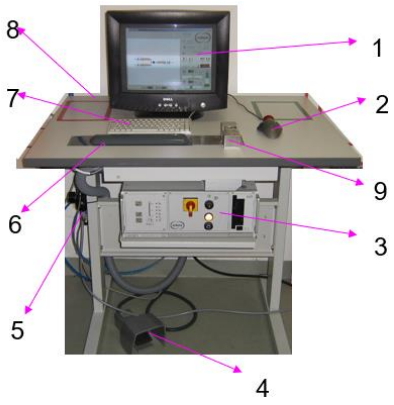
1. INTRODUCTION

The ultrasonic welding consists in the transformation of mechanical vibration energy working at a frequency higher than 18000 Hz, [1]. There are three important elements in the process: electric and acoustic vibration power, discharge force, welding time, holding time, holding pressure, ultrasonic oscillation frequency and ultrasonic oscillation amplitude. The process is carried out at a temperature lower than the melting temperature of the base materials. So, there is no heat influenced zone (HIZ) and therefore no changes in the structure of the materials and implicitly no changes in properties [2,3].

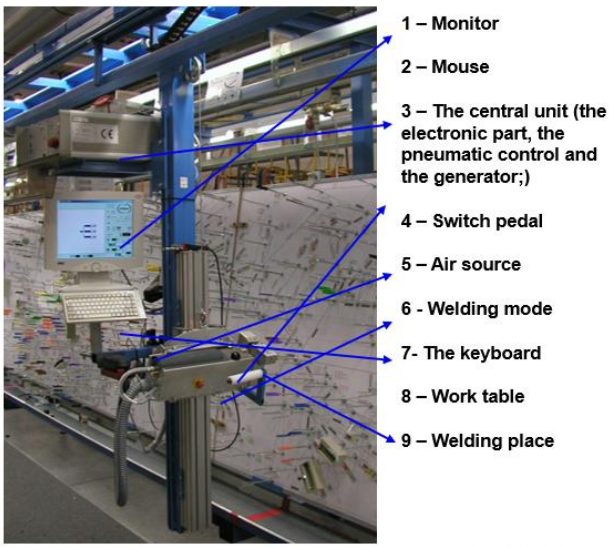
1.1 The equipment used

The study was carried out within the APTIV-Ineu Company using the Schunk Minic PC/IV machine, according to figure 1, [4].

The machine to cut to length and check the crimping height, the breaking force at the terminal - The operator receives the orders from the automatic system at the machine without being able to influence the work order (only from the office the order can be changed). It has all the information related to the module, saved in the network. At each module change, work samples are made that certify the quality of the product. These samples are archived for 6 months.



a) In line (assembly line)



b) On the work table (Lead Prep and on the lines)

Figure 1. Schunk Minic PC/IV machine [4]

Ultrasonic equipment is a complicated one that includes a computerized control system. Ultrasonic machines are of different shapes, depend on needs and come from different suppliers.

2. STAGES IN THE MANUFACTURING LINE

They are the following, [5,6]:

The storage area at the entrance to the factory- The wires are stored on reels in the shelf, protected from moisture and temperature fluctuations. Waiting for the production process, depending on the consumption, the following modules are ordered. The shelf stock is a minimum of 2 days and a maximum of 4 days of production.

The feed area of the thread cutting machine - Depending on the consumption, the threads are brought to the rack from the machines, where they are placed according to the need, at each machine, for the programmed modules, for the next hours. The machine operator orders the reel based on a card order system (Kanban).

The machine to cut to length and check the crimping height, the breaking force at the terminal - The operator receives the orders from the automatic system at the machine without being able to influence the work order (only from the office the order can be changed). It has all the information related to the module, saved in the network. At each module change, work samples are made that certify the quality of the product. These samples are archived for 6 months. The Komax machine cuts the wires to the required length and applies the terminals.

The terminal feed - Each machine has 2 terminal stations which are applied to the wires. Wires can be crimped, with one terminal or two. At any crimping error, the terminal is automatically cut by the machine. Terminals are contact elements for the installation, very sensitive, in some cases with gold insert.

The storage after cutting - After the cutting operation the modules are placed in the shelf, waiting for production. Each module has a cutting batch, defined based on the consumption of a maximum of 2 days of production. The terminals are protected during storage and transport with protective cups. They are taken from the shelf by carriers based on the production order (Kanban card) and distributed to the zones.

The storage in wire rack prior to welding - In the production areas the wires retain the terminal protection until entering in production. Here the operator prepares the welding module which can contain up to 7-8 wires.

The coils placed on the stand before welding - The welding modules are placed, waiting, on the stand at the welding machine. On the stand only one module can be waiting.

The actual welding - In actual welding, the operator uses gloves to avoid contamination of the wires. The pre-cut PVC insulation for the batten protection is now only removed with the specially dedicated device.

The sealing tube mounting area - If necessary, a sealing protection tube is applied to some welds. After application, they are fixed in the device on the heating machine.

Inserting the sealing tubes into the heating machine - After fastening, the tubes are heated and become sealed. Each module is tested for water tightness.

The racking for assembly line - After completion all modules are racked. Likewise, we have a cut batch defined based on consumption. From here they go directly to the assembly area.

3. THE PROCEDURE FOR ENSURING THE QUALITY OF THE WELDED JOINT WHEN PREPARING THE WIRES

The materials used in the production line are as follows: M6158 for 0.13 mm wires - tensile test force is 39N, M3130 for 0.35 mm wires - tensile test force is 68N, M3232 for 0.50 wires mm to 2.50mm tensile test force is from 92N to 365N. Insulated with PVC resistant from -40^0C to 105^0 C.

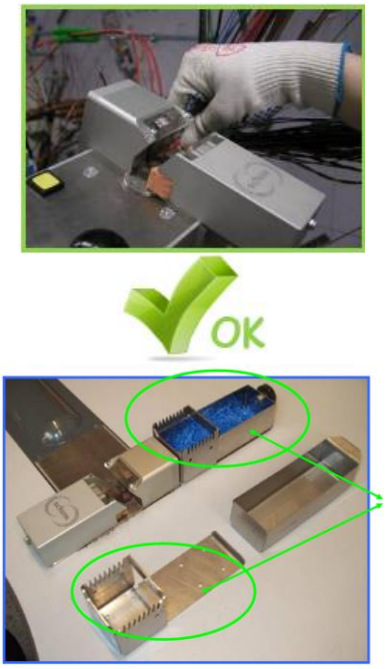


Figure 2. Strippers and equipment at the time of welding[4]

When the wire is stripped, the cutting machine leaves a piece of insulation on the strands to protect them from contamination or oxidation, which causes welding defects and errors, according to figure 2.

In the assembly line, the strands without protection (without cover) will be cut and stripped again. The wire protection, the piece of insulation, must be removed only before welding. When the wire is stripped, the cutter leaves a piece of insulation on the strands to protect them from contamination or oxidation, which causes defects, [7,8].

In the assembly line for wires without protection (without pre-cut insulation), the strands will be cut and stripped again.

The copper wires are protected from external factors by an insulation, usually made of PVC. The image shows the wire or conductor that makes up the wiring. The wire consists of insulators and copper strands. The wire is stripped to allow welding.

4. PROGRAMMING OF THE ULTRASONIC WELDING EQUIPMENT

The pneumatic pressure is used to apply the force required to perform the weld, according to figure 3.

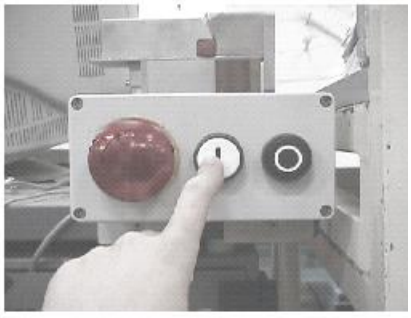


Figure 3. Air pressure control unit

This pressure is controlled using a control unit. The unit can be positioned anywhere, in the working space, limited to 1.5m.

In the older software versions, before version 1.27, you have to press the "Crtl+Alt+Del" keys at the same time. When a box appears, in which to enter a password, press the "Enter" key. In versions higher than 1.27, the program starts automatically, without operator assistance.

4.1 The stages of realization of the production schedule

In the production program (production screen) the following steps are performed in order to choose the joint. If the key appears in the red circle in the program, it means a program error, according to figure 4. Within the company, it is clearly established that the removal of any error is carried out by an authorized person, [9].

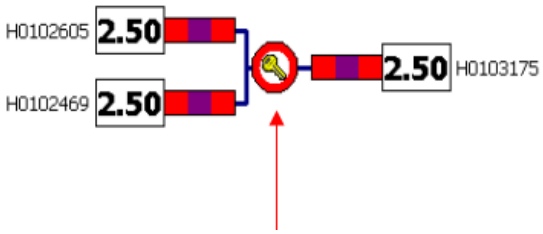


Figure 4. Error signal

I. Press the F2 key on the keyboard or click with the mouse on the icon indicated in the image and the type of joint is selected, according to figure 5.

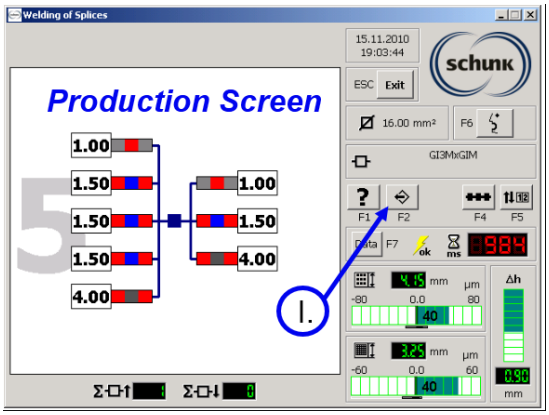


Figure 5. Choosing the type of joint

II. Open the list of splices, according to figure 6.

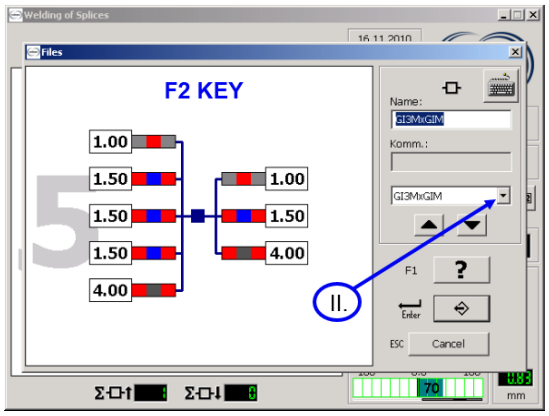


Figure 6. Open the splice list

III. From this list, select the welded joint that we want to make, according to figure 7.

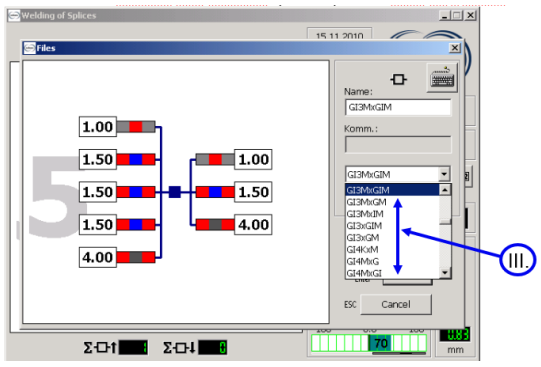


Figure 7. Select the welded joint you want to program

IV. Confirm the selection by pressing the "Enter" key on the keyboard, according to figure 8.

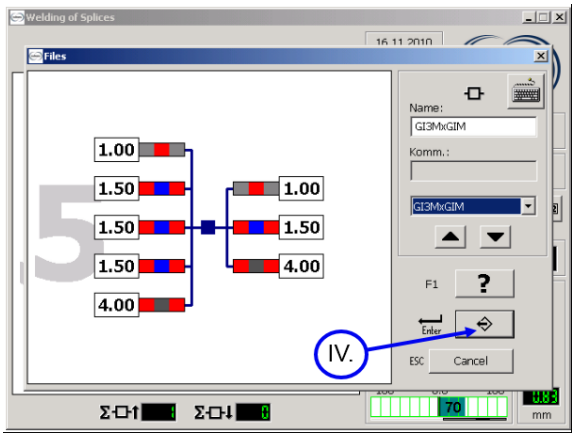


Figure 8. Confirm the selection

V. Splice welding can be done, according to figure 9.

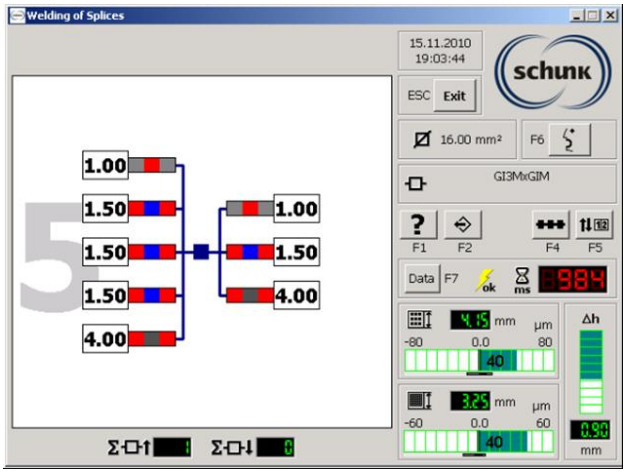


Figure 9. Making the weld

5. OPTIMIZING WELDING TECHNOLOGY AT US

The technological sheet contains the following data: Table 1 Data in the technical sheet, Cable: DIN.

Table 1. Input data

Cable:	**DIN**
Splice:	**K2**
Approval Date:	**January 17, 2019**
Process Color:	GREEN
Condition:	**Normal**

Where: Cabel- the standard for copper wire, K2 – joint code where K is the wire cross-section of 2.5 mm^2 and 2 the number of wires, Approval Date – the date on which the welded joint was homologated, according to table 2.

Table 2. The wire type

Wire type	**The cross section of the wire (mm^2)**	**Number of strands (elements) no./diameter**	**Norm**
M3232 (FLRY-B)	2.50	50	DIN
M3232 (FLRY-B)	2.50	50	DIN

GREEN – is the acceptance following the pull-out test, i.e. the joint withstands a pull-out force over 365N. Normal – it is not a critical process so it can only be welded with the parameters given by the card process, otherwise I need the client's approval, according to table 3, 4 and 5.

Table 3. The verification force

Preferred traction force	**105N**	**Wire section (mm)**	2.50	**Capacity**	
Actuation force	88N	Wire type	M3232 (FLRY-B)	Average checking force	116,528
Minimum force	70N			Reliability coefficient	2,56

Table 4. Welding parameters, [4]

Energy	**500 ±10%[J]**	**Max.**	**550[J]**	**Min.**	**450[J]**	**Power**	**1800[W]**
Pressure	2.550 ±10%[bar]	Max.	2.805[bar]	Min.	2.295[bar]	Time	0,35[s]
Amplitude	90 ±10%[%]	Max.	99[%]	Min.	81[%]	Initial height	2400[mm]
Height	3.000 ±0.07[mm]	Max.	3.07[mm]	Min.	2.93[mm]	Final height	1930[mm]

Table 5. Wire type: M3232=FLRY-B copper wire with cross section 2.5 mm^2, [4]

Measurements		Quality windows		Working pressure	
Measured height [2]:	**1.900**±0.08[**mm**]	Initial height:	**120**[**mm**]	Nominal:	**1**[**bar**]
Measured width [2]:	**2.960**±0.15[**mm**]	Final height:	**100**[**mm**]	Minimum:	**1**[**bar**]

5.1 Welding limits and tolerances

Also, the following dimensions of the joint must be respected:

The copper strips can only exceed between 0-1mm the welded joint area, this can only be checked visually. The distance between the insulation and the beginning of the welded area must be between 3-6mm, according to figure 10.

When you want to start welding, the black button must be pressed or the pedal if there is one.

After programming the machine: When the type of welded joint is selected the "moving guide" changes

to the programmed height and the "Anvil" applies pressure to the welded joint.

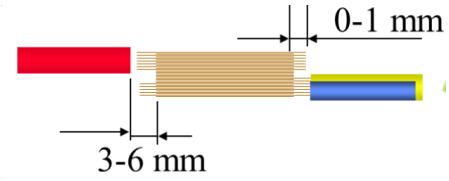


Figure 10. Dimensions of copper strands, [4]

The initial pressure of the "Anvil" is 3 bars (always at the beginning of the weld) to allow the monitoring of the compaction height and the initial height. At the same time the sonatrode starts the vibration process. Before the welding is finished, the monitoring system checks the welding height and the final height. All these movements allow the control of the weld.

6. COMPARISON BETWEEN USW AND UCAB WELDING

Notations: USW-ultrasonic welding, UCAB-pressure welding.

As a comparison, the USW process is cheaper due to the fact that it does not use any additional material and is even safer, being a computer-controlled process.

6.1 Visual presentation for compliance of UCAB splices

UCAB is a joint made by cold pressure welding made with the help of external clips. This procedure is applied in the company, when we have to join dissimilar copper and aluminium wires. The following rules must be respected for this jointing:

It is NOT allowed to have strands missing from the strands, damaged, protruding or not included in the splice, The edges of the terminal must be visible in the crimping area of the clip, Burrs on the sides of the terminal larger than the thickness of the material in the terminal are NOT allowed, The trumpet must be formed on both sides of the terminal, The bridge must be formed on both sides of the terminal and not be bent, The end of the strands must exceed the extremity of the terminal, but not more than 2 mm, according to figure 11.

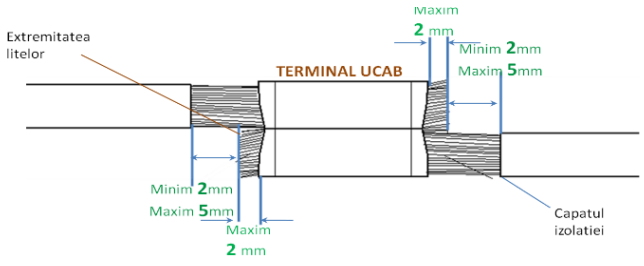


Figure 11. UCAB type joint

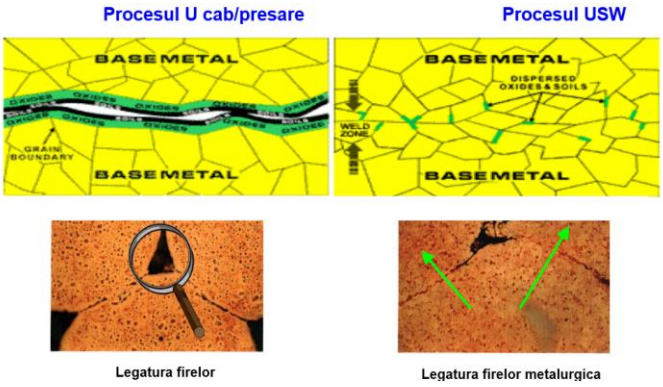
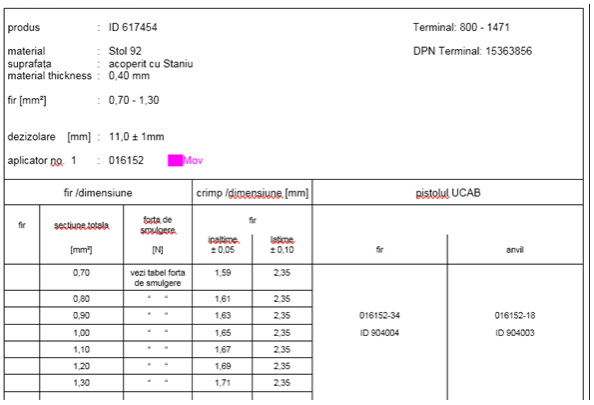


Figure 12. Micrographic analysis for UCAB and USW procedures, [9]

The strands of the wire cannot touch the insulation of the other wires. The insulation is not allowed to be between the welding tools. The extremity of the strands must be aligned with the anvil, according to figure 12.

6.2 UCAB technology

The clean surface of the metal welds together very well, a metallurgical bond is created but without reaching the melting temperature. UCAB welding parameters, according to the figure 13.



produs	: ID 617454		Terminal: 800 - 1471	
material	: Stol 92		DPN Terminal: 15363856	
suprafata	: acoperit cu Staniu			
material thickness	: 0,40 mm			
fir [mm²]	: 0,70 - 1,30			
dezizolare [mm]	: 11,0 ± 1mm			
aplicator no. 1	: 016152 Mov			

fir /dimensiune		crimp /dimensiune [mm]		pistolul UCAB	
fir	sectiune totala [mm²]	forta de smulgere [N]	fir inaltime ± 0,05	latime ± 0,10	fir	anvil
	0,70	vezi tabel forta de smulgere	1,59	2,35		
	0,80	" "	1,61	2,35		
	0,90	" "	1,63	2,35	016152-34	016152-18
	1,00	" "	1,65	2,35	ID 904004	ID 904003
	1,10	" "	1,67	2,35		
	1,20	" "	1,69	2,35		
	1,30	" "	1,71	2,35		

Figure 13. UCAB welding parameters

When positioning the wires in the machine, the operator must ensure that he has his hands as far as possible from the welding area because the welded joint heats up during welding. The temperature is directly proportional to the thickness of the wire, according to figure 14.

Figure 14. Correct positioning in the joint area for UCAB,[9]

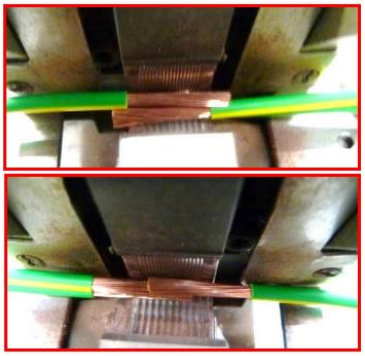


Figure 15. Wrong and correct positioning in the UCAB welding zone,[9]

On the other hand, it will be difficult to correctly position the wires between the machine components to make a good welded joint, according to figure 15.

7. CONCLUSIONS

During the study, the comparison between pressure welding and ultrasonic welding was considered. A very important thing for the implementation of ultrasonic welding was the control of welded joints and the study of defects. As a summary there can be:

- broken wires, which can cause difficulties in the transmission of current, the test force below the imposed value, errors in the size of the welded joint can occur. Defect that is not allowed.

- missing wires, the operator did not check the image given by the machine, consequence: size error and incorrect wiring.

- dimensional wrong wires causes: wrong identification of the wires, wrong arrangement or the operator does not check the image given by the monitor, consequences: the circuit will not have the required electrical dimensions.

Burning of the PVC insulation, loose wires, non-welded joint, burr joint, Lack of grooves (tooling shape – waves), lines over the insulation, etc.

To eliminate all these defects, the machine has an integrated control system, which checks if the joint has been welded within the specified parameters (Pre-Height, Final Height, Welding Time). If an error has been detected, the machine will beep and display the type of error in detail. The machine will not count this joint as good product, but will count it as defective (error) and send alert messages.

But it is observed that the quality of the product is largely determined by the operator or the quality control, which makes it impossible to remove 100% of defects. The only solution is to automate the manufacturing line, but that requires better trained and better paid maintenance people.

8. ACKNOWLEDGEMENTS

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