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Aspects concerning ultrasonic joining of multiwire connectors in automotive industry

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ABSTRACT

Purpose: This paper presents the general aspects concerning the development of innovative ultrasonic welding technologies at ISIM Timisoara and the advantages of using ultrasonic metal joining, compared with conventional joining methods, in the automotive industry for joining multiwire connectors from copper and aluminium.

Design/methodology/approach: In discussion is joining ultrasound multiwire copper conductors on copper 99.95% substrate, ultrasonic welding of copper and aluminium multiwire conductors onto Al99.95% support and welding dissimilar materials multiwire copper and aluminium conductors onto copper support.

Findings: Comparison of experimental results through mechanical testing, electrical conductivity testing, digital microscopy imaging and ultrasonic compaction highlights the potential development and use of aluminium as a replacement of connection to the copper wiring in automotive equipment.

Practical limitations/implications: The experimental results through mechanical testing, electrical conductivity, digital imaging microscopy, ultrasonic compacting, realized on Cu-Cu, Al-Al and Al-Cu samples, underscore the potential for using aluminium as a substitute for copper multiwire connectors in automotive industry.

Originality/value: Statistics show that the automotive industry together with aerospace and military equipment industries represent by excellence the innovative technologies drive and consist as a sensitive indicator for society changes in the tech areas.

Keywords: Ultrasonic joining; Aluminium; Copper; Ultrasonic compacting

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PROPERTIES

1. Introduction

Statistics show that the automotive industry together with aerospace and military equipment industries represent by excellence the innovative technologies drive and consist as a sensitive indicator for society changes in the tech areas. Numerous active applications of ultrasounds in various branches of technology particularly in the automotive industry, are due to the effects produced because of the properties ultrasonic waves possess: small wavelength, high particle acceleration can reach 10^9 times the acceleration of gravity, the possibility of steering an ultrasonic narrow beam in the desired direction, the possibility to concentrate and focus the energy in a limited area without affecting the environment in the vicinity where it is propagated [1]. The ultrasonic welding takes place at a much lower temperature than the melting point without the use of filler material. Ultrasonic welding behaviour of a material depends primarily on the hardness and modulus of elasticity, fatigue resistance and damping characteristics [2].

The damping capacity also depends on hardness. Materials have very good weldability when they have a high damping coefficient as aluminium and its alloys or copper and its alloys [3].

Ultrasonic Welding of multiwires connection for the automotive industry is an area of great interest in order to replace multiwires copper conductors with lightweight materials like aluminium and its alloys [4-6].

This paper contains the description of three representative cases, for ultrasound joining – experimental development activities of joining technologies and technology transfer made at ISIM Timisoara, at the request of partners from automotive connectors industry. In discussion is joining ultrasound multiwire copper conductors on copper 99.95% substrate, ultrasonic welding of copper and aluminium multiwire conductors onto Al99.95% support and welding dissimilar materials multiwire copper and aluminium conductors onto copper support. Comparison of experimental results through mechanical testing, electrical conductivity testing, digital microscopy imaging and ultrasonic compaction highlights the potential development and use of aluminium as a replacement of connection to the copper wiring in automotive equipment.

2. Conditions for carrying out the experimental program

2.1. Materials for welding

For the experiments it was used aluminium and copper materials whose characteristics are shown in Table 1.

Table 1.
Research materials

		Thickness, mm	Diameter, mm	No. of wires
Support materials	Cu99.95	1	-	-
	AlMgSi3	1.5	-	-
Multiwire materials	Cu 99.95	-	0.17	35
	Al99.51	-	0.17	20

2.2. Equipment and specialized devices

The ultrasound welding equipment used developed in the nucleus project and previous research programs, operates at a frequency of 20 kHz and 40 kHz. The flexible system for ultrasonic joining of multiwire conductors is shown in Fig. 1 and has the following features:

- adjustment of technological parameters with programmable automated digital unit XGB DR16S;
- automated monitoring of technological process;
- electro-pneumatic equipment operation;
- ultrasound generator 20 KhZ, 2500W;
- ultrasound generator 40 kHz, 900W;
- command and programming digital unit LS XBM – 16 S;
- ultrasound welding equipment 20 kHz, 2500 W;
- specialized ultrasonic welding equipment 40 kHz, 900 W.

2.3. Specialized welding sonotrodes, 20 kHz

Specialized program simulation [7], allowed knowledge of status parameters of sonotrodes developed and used in the experimental program, the amplification coefficient, placement of nodes and antinode, size of amplitude, variation curves of losses and internal stresses of the sonotrodes The internal stress state of the sonotrode, with a maximum of 57.3 N/mm^2, curve amplitude evolution, energy transfer and losses curves are shown in Fig. 2. The shape and size of the interface system with coupling elements are defined – booster or piezo-ceramic converter.

The characteristic elements of sonotrodes used in the experimental program are presented in Table 2.

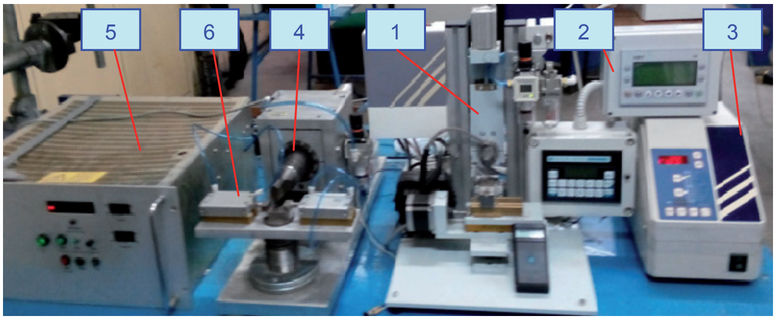

Fig. 1. Flexible system for joining multiwire conductors; 1. Programmable platform with stepper motor x,y, 40 kHz; 2. Ultrasounds generator 40 kHz; 3. Command and programming digital unit LS XBM – 16 S; 4. Ultrasound welding equipment 20 kHz; 5. Ultrasonic generator 20 kHz; 6. Flexible positioning for welding

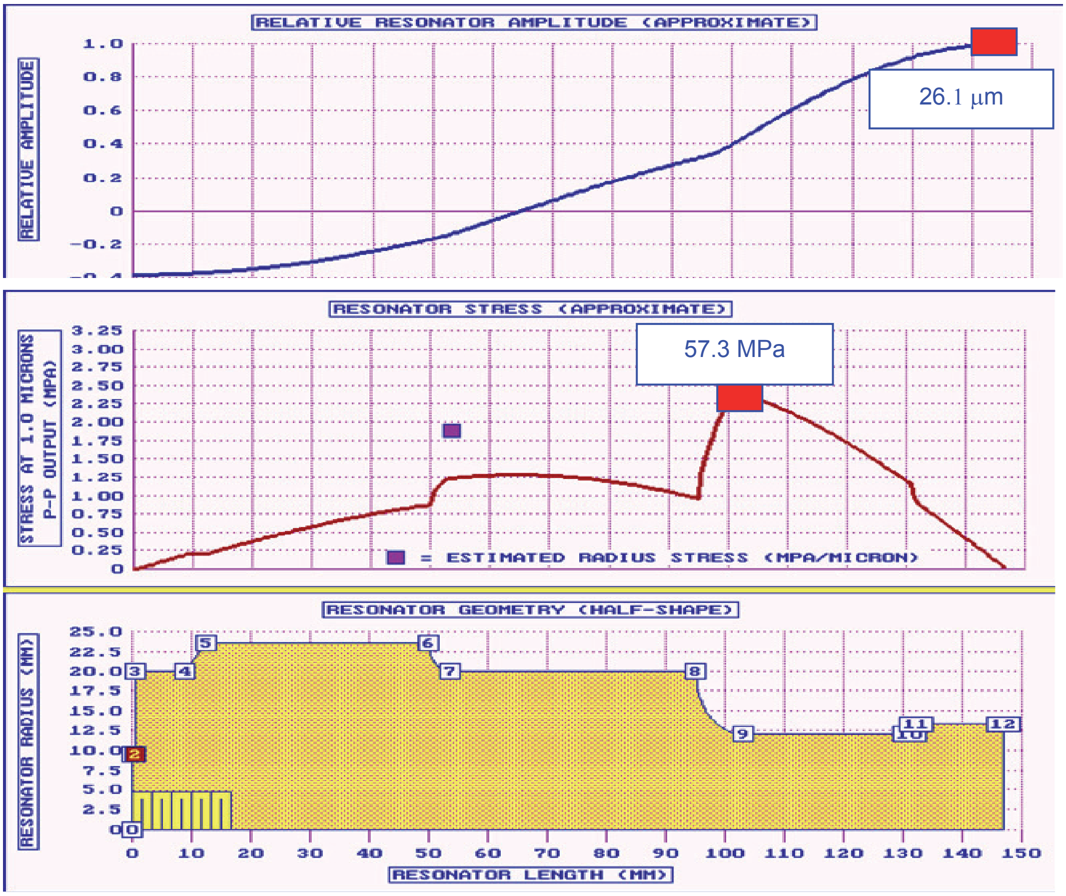

Fig. 2. Internal stress status of sonotrode – maximum de 57.3 N/mm^2

Table 2.
Sonotrode characteristics used in the experimental program

Material	V sound, m/s	Sonotrode length, Mm	Resonance frequency, kHz	Amplification factor	Maximum stress, Mpa/x=	Oscillation node coordinate, mm	Dissipated power, Watt
OLC45	5334	146.9	2.0	2.61	86.8/102.5	65.00	2.0 10^{-3}

Using specific laboratory equipment, the oscillation amplitude was measured at the sonotrode tip, in no-load conditions. This corresponds with the theoretical amplitude resulted from the mechanical resonator assembly line consisting of a piezo-ceramic converter, amplitude transformer 1:1, sonotrode 26.1 µm at the resonance frequency of 20 kHz.

The specific geometry in the active areas for the specialized sonotrode 20 kHz, used in the experimental program is presented in images from Fig. 3. The sonotrode type I, is characterised by an active surface of the 48 mm^2, consisting in 4 longitudinal striations with a gap of 0.5 mm and a depth of 0.42 mm with a number of 7 transversal striations.

3. Elaborating exploratory technologies for micro-joining multiwire conductors

Table 3 summarizes the parameters developed in the experimental programs of micro-joining multiwire conductors, pairs of materials in use, ultrasonic frequency, welding time in periods and system pressure for ensuring the welding technological force.

Ultrasonic welding technology regimes were identified in preliminary base welding experiments and are considered to be optimal in terms of visual appearance and sonotrode imprint on multiwire conductors and the imprint of the sonotrode on the surface of the copper terminal.

4. Structural and functioning characterization of micro-joining

Experiment no 1. Welding multiwire copper conductor onto copper support terminal electric connector copper 99.95 (1 mm thick) at 20 kHz;

Shape and configuration of the welded area together with correspondent results of the samples by infrared thermography and digital microscopy using the HIROX 1300 device are presented in Fig. 4.

The maximum temperature in the focusing area of the FLIR SYSTEMS THERMOVISION A 40 analyser presented in Fig. 4a indicates a temperature of 400ºC developed by the welding equipment in 2.5 seconds from the start of the ultrasound welding cycle.

Digital microscopy of the joint (Fig. 4c) highlights distinct areas of joining surfaces.

Experiment no. 2. Welding multiwire copper and aluminium conductor onto copper support terminal connector support of copper 99.95 (1 mm thick) at 20 kHz ;

Shape and configuration of the welded area together with correspondent results of the samples by infrared thermography and digital microscopy using the HIROX 1300 device are presented in Fig. 5.

The maximum temperature in the focusing area of the analyser FLIR SYSTEMS THERMOVISION A40, Fig. 5a indicates a temperature of 150ºC, developed by the equipment in 1.5 seconds from the start of the ultrasonic welding cycle. The rapid rise in temperature is due to the small size of the parts namely copper 1.0 mm thick.

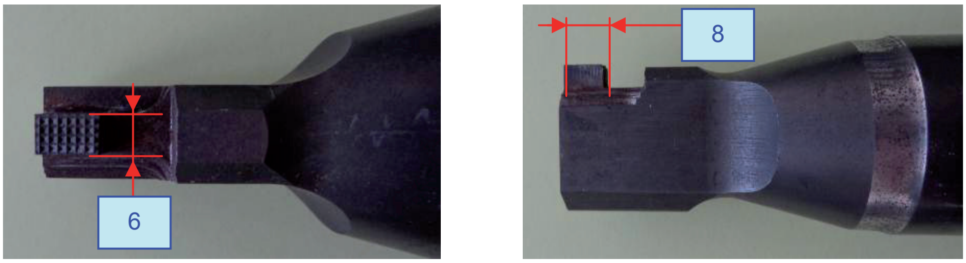

Fig. 3. Active zones geometry of sonotrodes

Table 3.
Experimental program parameters

Experiment	Technological parameters Frequency, kHz	Welding time, Periods	Pressure, Bars
Experiment no. 1. Cu 99.95 + multiwire Cu 99.95 3x1.75 mm^2	20	325	5.1
Experiment no. 2. Cu 99.95 + multiwire Cu 99.95 1x1.75 mm^2 + multiwire Al99.95 2x1.75 mm^2	20	310	4.9
Experiment no. 3. AlSi3 + multiwire Al99.95 3x1.75 mm^2	20	120	2.9

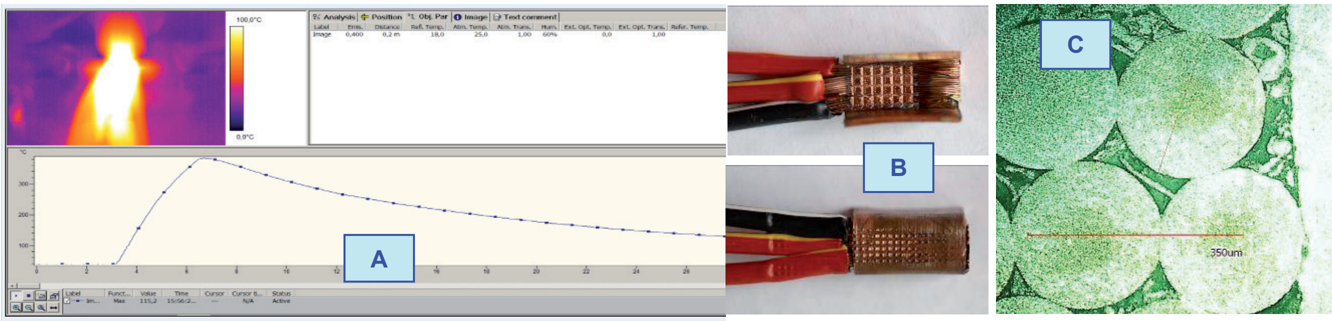

Fig. 4. Thermography analysis and digital microscopy using HIROX 1300; A – thermography analysis; B – macro image; C – ultrasonic welded joint

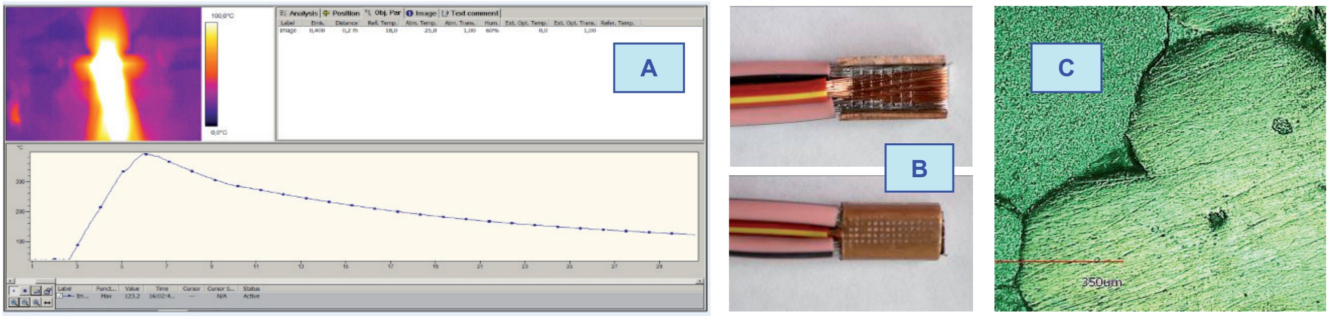

Fig. 5. Thermography analysis and digital microscopy using HIROX 1300; A – thermography analysis; B – macro image; C – ultrasonic welded joint

Digital microscopy of the joint (Fig. 5c) reveals distinct areas of ultrasonic joined surfaces.

Experiment no 3. Welding multiwire aluminium conductor onto AlMgSi3 support terminal in electric connector configuration (1.5 mm thick) at 20 kHz ;

Shape and configuration of the welded area together with correspondent results of the samples by infrared thermography and digital microscopy using the HIROX 1300 device are presented in Fig. 6.

The maximum temperature in the focusing area of the analyser FLIR SYSTEMS THERMOVISION A40, Fig. 6a indicates a temperature of 195ºC, developed by the equipment in 1.0 seconds from the start of the ultrasonic welding cycle. The rapid rise in temperature is due to the small size of the parts namely aluminium alloy 1.5 mm thick.

Digital microscopy of the joint (Fig. 6c) reveals distinct areas of ultrasonic joined surfaces.

Ultrasonic welded specimens were mechanically tensile tested through the use of Zwig Roell Proline 500 equipment in accordance with ISO 14273-2000. The results of the experimental program are presented selectively for the 3 groups of materials tested in Table 3 and associated diagrams for the experiment 1, Fig. 7a; Fig. 7b associated diagram for experiment 2, and Fig. 7c associated diagram for Experiment 3.

Tensile tests carried and presented in Table 3 and in diagrams in Fig. 7, shows the best results with an average of 1300 N, at a hard welding regime with a welding time of 325 periods and a pressure of 5.1 bars compared to ultrasound multiwire aluminium cable joints welded onto copper support (Fig. 7b) also joined in a hard welding regime with a welding time of 310 periods and a pressure of 4.9 bars pneumatic pressure from the technological welding force system.

Ultrasonic welding program results from tensile tests presented in Fig. 7c are obtained from a soft welding regime with a welding time of 120 periods and 2.9 bars of pressure. They show that the potential of joining technologies for aluminium multiwire conductors in large sections can constitute an alternative to joining technologies for multiwire copper conductors.

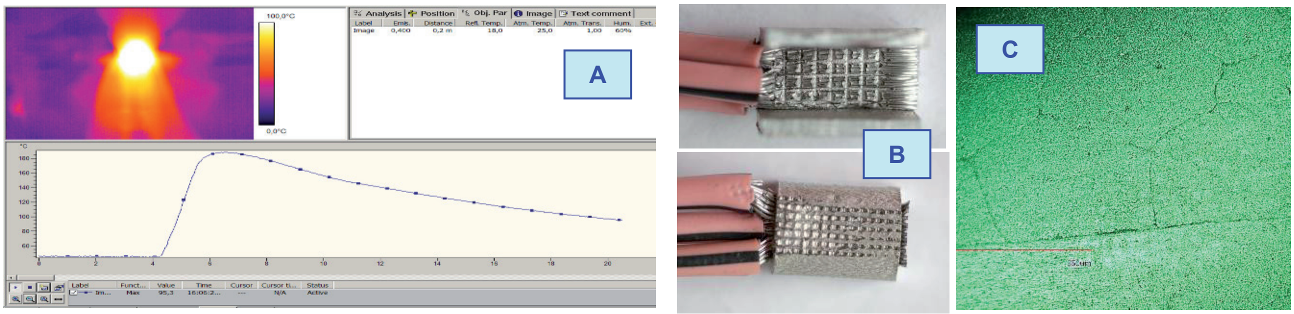

Fig. 6. Thermography analysis and digital microscopy using HIROX 1300; A – thermography analysis; B – macro image; C – ultrasonic welded joint

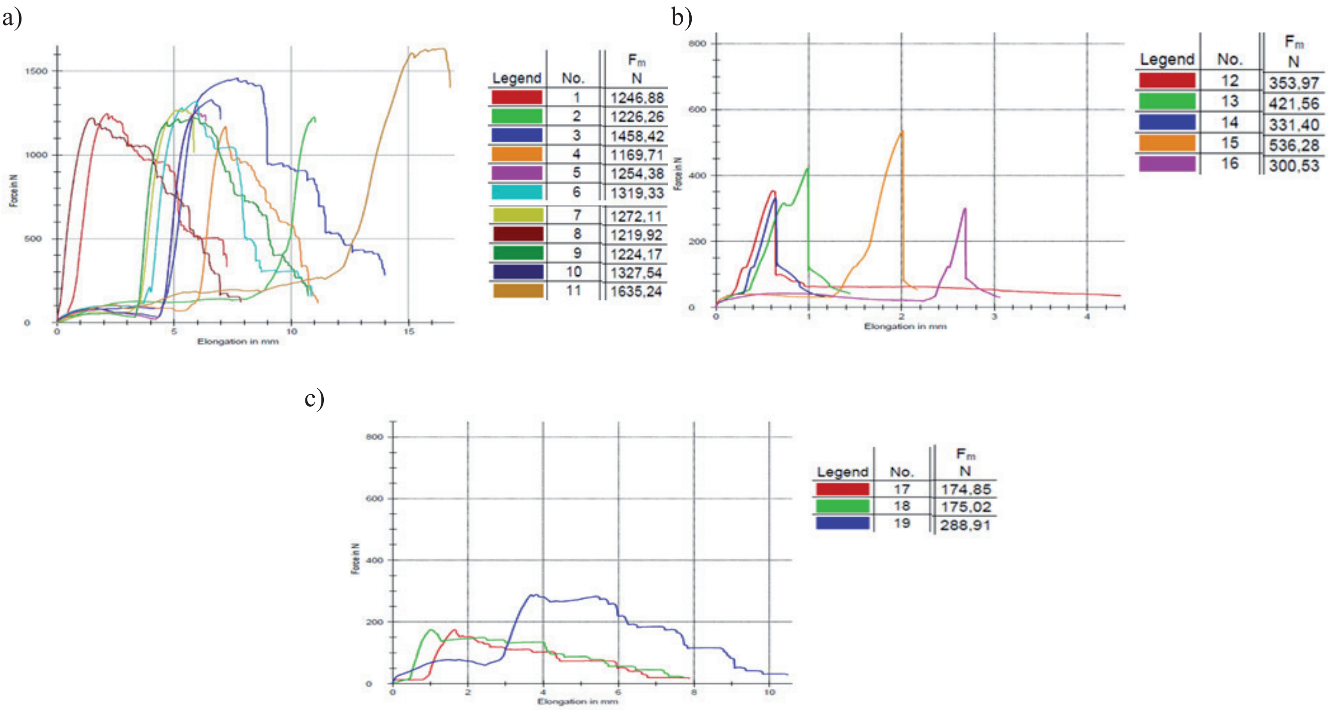

Fig. 7. Tensile test diagram a) multiwire Cu welded onto Cu 99.95 support; b) multiwire Cu-Al welded onto Cu 99.95 support; c) multiwire Al welded onto AlSi3 suppor

5. Conclusions

1. The experimental program highlighted the important influence in the ultrasound joining process of the active geometry of the sonotrode and anvil together with base energy parameters of the ultrasound welding process, welding time, welding force and ultrasonic micro vibrations amplitude.
2. The experimental ultrasonic joining program of multiwire aluminium and copper conductors onto aluminium support – dissimilar joints shows the possibility for making certified technologies for industrial applications.
3. The results of the experimental joining program of aluminium multiwire conductors onto aluminium support highlights the potential of developing and applying large

section aluminium connectors as replacements of copper wiring in automotive equipment.

4. The experimental research will be continued with optimization of the process parameters, welding frequency in correlation with acoustic process parameters, oscillations amplitude, sound waves intensity, contact pressure, joining materials type and thickness.

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