Geometry influence of materials surface on the quality of ultrasonic metal welding

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1. Introduction

Ultrasonic metal welding (USMW) is a solid-state welding process in which similar or dissimilar metallic work pieces are joined by the application of high frequency vibrations which are in plane with the interface under moderate pressure. The high frequency relative motion between the parts leads to solid progressive shearing and localized joining of the parts. In USMW the temperature developed between the parts are very less compared to the melting point of the metal [1]. The ultrasonic welding of metals ensures a superior quality of the welded join, a good reproductibility, short machining time and reduced energy consumption, in comparison with same indicators valid for classic welding [2].

Mostly USMW it is used to weld non-ferrous metals like copper. The technology of ultrasonic welding is used in various areas but mostly in electronics, electrics industry and automotive industry [3].

Copper and brass alloys are extensively used in automobile industries, heat exchanger and electrical applications owing to its high thermal conductivity, strength and retention of strength at sufficiently elevated temperatures. The conventional welding process of copper and brass produces large heat affected zone (HAZ) and fusion zone (FZ), high shrinkage, variations in microstructures and properties, evaporative loss of alloying elements, high residual stress and distortion which calls for the development of a solid-state joining process in which metallurgical bonding between similar or dissimilar materials can be created without melting. One such solid-state joining process is ultrasonic metal welding (USMW) [4].

The research presented in this paper is complex which, in addition to studying aspects regarding problematic surface geometry influence of materials to be joined on quality of ultrasonic joining of Cu93.99 non-ferrous metallic materials, and also deals with issues related to elaboration of ultrasonic welding technology and elements of design and manufacture of sonotrode used for the ultrasonic joints.

2. Experimental

The objective of this study consists in making experimental research regarding analysis of joining materials surface geometries influence on the quality of ultrasonic joints of Cu93.99 non-ferrous metallic materials strips having 56x4x0,7mm in size and testing the tensile strength of the joint in accordance with ISO 14273:2000 standard. The chemical composition of the material is presented in Table 1.

Table1. Chemical composition of Cu93.99.

Chemical composition [%]			
Cu	Mo	Sn	Pb
93.990 ± 0.270	0.0397 ± 0.0029	5.950 ± 0.110	0.0219 ± 0.0059

For ultrasonic metal welding (USMW) of Cu93.99 an ultrasonic joining equipment from ISIM, was used for carrying out the study which operates at a frequency of 20kHz and generates a power of 3000W. The equipment allows the adjustment of the welding type, for which a sonotrode and anvil were made specifically for this application. This equipment used at experimental ultrasonic joining of Cu93.99 strips is presented in Figure 1.

The equipment consist of a ultrasonic generator (1), the stand (2), the ultrasonic ensemble (3) consisting of piezo-ceramic transducer, booster and sonotrode, command and control system for the air pressure (4) and the anvil (5).

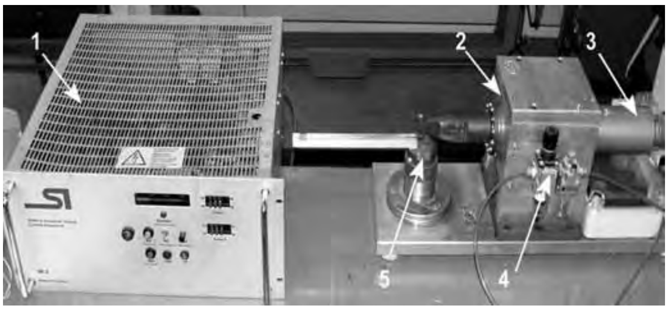

Figure 1. Specialized equipment for ultrasonic welding of Cu-Cu.

Realization of the sonotrode used during the experimental tests consisted in simulating using a specialized software [5] of sonotrode surfaces, mechanical processing of sonotrode surfaces and calibrating the resonance frequency of 20kHz by measuring using specific devices and specific mechanical processing. The shape and size of the simulated sonotrode are presented in Figure 2 together with the internal loading parameters along the length of the sonotrode, respectively the location of the half-wave nodes and antinodes and the amplitude variation along the length of the sonotrode.

The characterization elements of the sonotrode obtained after the simulation and used in the experimental program are presented in Table 2.

The measured amplitude of ultrasonic ensemble micro vibrations consisting of piezo-ceramic transducer, wave

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intermediary intensifier (1:1) and sonotrode, in the peak area is 52.2µm. The active area of the sonotrode (Figure 3) is a special construct having the active surface of 15.75mm^2, with striations in the longitudinal and transversal planes, spaced apart at 0.5 mm and having a depth of 0.25 mm.

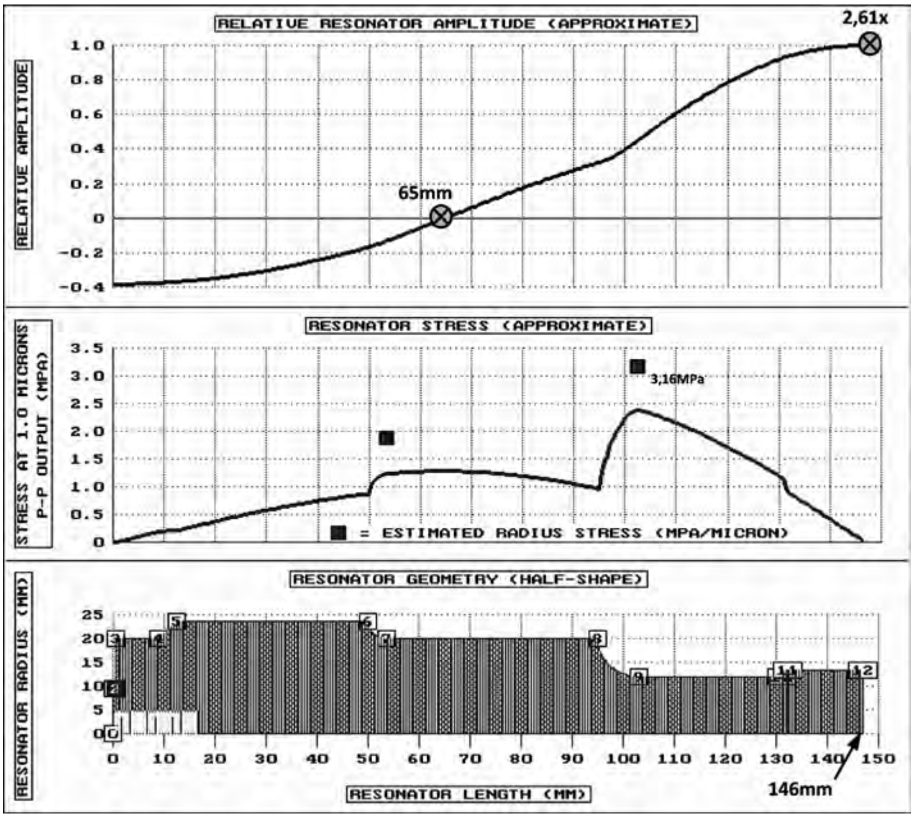

Figure 2. Diagrams of amplitude variation, largest axial stress and sonotrode shape after simulation - (1 micron output).

from an industrial partner. The second set of experimental tests, named from here on experiment type B, was made on samples of Cu93.99 which were processed with an energy concentrator in the shape of a support pad.

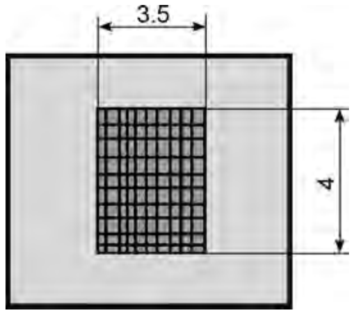

Figure 3. Schematic form of the active area of the sonotrode.

Table 3 presents the process parameters (local contact pressure, welding time, energy induced in the joint), data referring to length of joined samples, active surface area at the interface level and the tensile test results (tensile strength correlated with the active surface area at the interface level and the breaking force) made in accordance with ISO 14273:2000 standard, for ultrasonic joints obtained during experiment type A.

From the set of seven experimental tests conducted on samples without embossment, the best behavior (R_m = 50MPa, F_r = 782.73N) of ultrasonic joining was obtained for sample 6, using the parameters presented in Table 3.

Table 2. Sonotrode characterization after simulation.

Material	Sound speed [m/s]	Sonotrode length [mm]	Frequency [kHz]	Horn gain	Largest axial stress (at 102.5mm) [MPa]	Half-wave node [mm]	Power dissipated [Watt]
C45	5334	146.9	20	2.61	3.16	65	2.0 10-3

Table 3. Experimental results of ultrasonic joining - type A.

Sample	Ultrasonic welding parameters		Tensile strength, R_m [MPa]	Breaking force, F_r [N]	Samples length, L_0 [mm]	Active surface area at the interface level, S_0 [mm^2]
	Pressure, p [Bar]	Welding time, t_s [s]				
1	4	2.12	29	464.18	100	15.75
2		2.52	20	316.83		
3		3.12	40	625.39		
4		3.52	35	554.23		
5		3.92	35	556.39		
6		4.32	50	782.73		
7		4.72	45	704.31		

The experimental program focused on two groups of technological welding samples each having seven experiments. A first set of experimental tests, named from here on experiment type A, was made on samples without support pads received

Macroscopic aspect of the sample number 6 obtained after welding, for the experiment type A, is shown in Figure 4.

Table 4 presents the process parameters (local contact pressure, welding time, energy induced in the joint), data referring to length of joined samples, active surface area at the interface level and the tensile test results (tensile strength correlated with the active surface area at the interface level and the breaking force) made in accordance with ISO 14273:2000 standard, for ultrasonic joints obtained during experiment type B.

Comparing the interface of all the samples it can be observed a random dispersion of insular areas which is an inconvenience that does not allow obtaining repeatability and should be corrected. In this respect at one of the welded samples the surface geometry was modified by applying a concentrator embossment type. The role of the embossment is to provide an ultrasonic energy in a given area of the welded joint and thereby to ensure reproducibility.

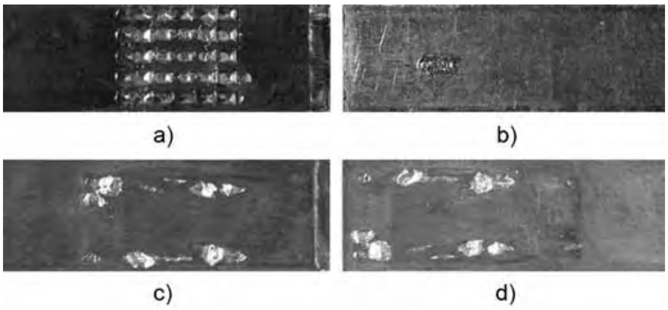

Figure 4. Macroscopic aspect of the sample 6 obtained for the experiment type A: a) - the area in contact with the sonotrode; b) - the area in contact with the anvil; c) and d) - the insular aspect of the welded area after the tensile test.

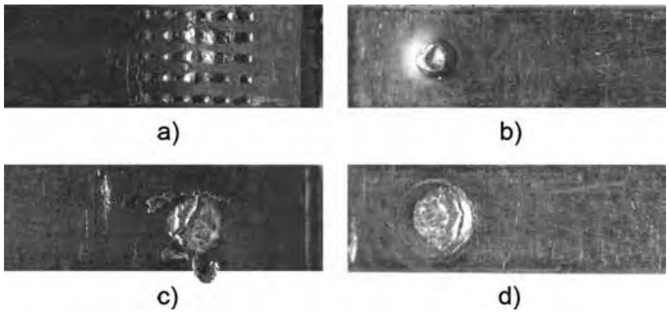

Figure 5. Macroscopic aspect of the sample 3 obtained for the experiment type B: a) - the area in contact with the sonotrode; b) - the area in contact with the anvil, c) and d) - the insular aspect of the welded area after the tensile test.

Table 4. Experimental results of ultrasonic joining - type B.

Sample	Ultrasonic welding parameters		Tensile strength, R_m [MPa]	Breaking force, F_r [N]	Samples length, L_0 [mm]	Active surface area at the interface level, S_0 [mm^2]
	Pressure, p [Bar]	Welding time, t_s [s]				
1	4	2.12	209	628.23	100	3
2		2.52	248	743.24		
3		3.12	253	756.52		
4		3.52	238	716.88		
5		3.92	232	700.79		
6		4.32	242	746.41		
7		4.72	224	683.65		

From the set of seven experimental tests conducted on samples with embossment, the best behavior (R_m = 253MPa, F_r = 756.52N) of ultrasonic joining was obtained for sample 3, using the parameters presented in Table 4. Macroscopic aspect of the sample number 3 obtained after welding, for the experiment type A, is shown in Figure 5.

In Figure 6 the representative curves (corresponding to samples 3 and 6 with and without embossment) to characterize the breaking strength and tensile strength according to elongation at break are presented. The tensile tests were obtained by using the device Zwick Roell Proline 500 with pneumatic flat grips, in accordance with ISO 14273:2000 standard.

Results and discussion

The tensile tests performed on the piece batch without embossment (experiment type A), presented in Table 3, revealed that although the best results were obtained for the sample 6 (Table 2), the welded joint is not a qualitative one. This is presented in Figure 4 where it can be seen that, at the contact between the sonotrode and the sample (Figure 4a) the fingerprinting is very strong and does not meet the conditions required, and at the interface between the two joined materials (Figure 4c and 4d) the welding is insular, in points.

The experimental tests performed on samples with embossment (experiment type B), shown in Table 4, revealed improved values of the breaking force (F_r) and of tensile strength (R_m) reported to the active surface at the interface of materials to be welded. A joint quality was obtained for the sample number 3 by using the parameters presented in Table 4.

The macroscopic analysis of sample 3, presented in Figure 5, shows that the contact area of the sample with the sonotrode (Figure 5a) corresponds to the quality conditions required and at the interface between the two joined materials (Figure 5c and 5d) it can be seen the welded zone. The results of the breaking force obtained are in complying with the minimum imposed by the beneficiary, 675N.

A comparison of the tensile tests results, highlighting the variation of the breaking force and tensile strength calculated based on the active surface area is presented in Figure 6. It is observed that for the variant without embossment, the highest value of the tensile strength (R_m = 50MPa) is obtained for sample 6 (Table 3, Figure 6d), using a more aggressive regime compared to the welded joint with concentrator (embossment) at that the highest values of the tensile strength (R_m = 253MPa), calculated as a function of the active area at the interface level was obtained for sample 3 using a welding regime presented in Table 2.

From the analysis of the breaking force - elongation curves is observed that the fracture of the samples without concentrator (embossment) occurs without a prior elongation of the joint. This

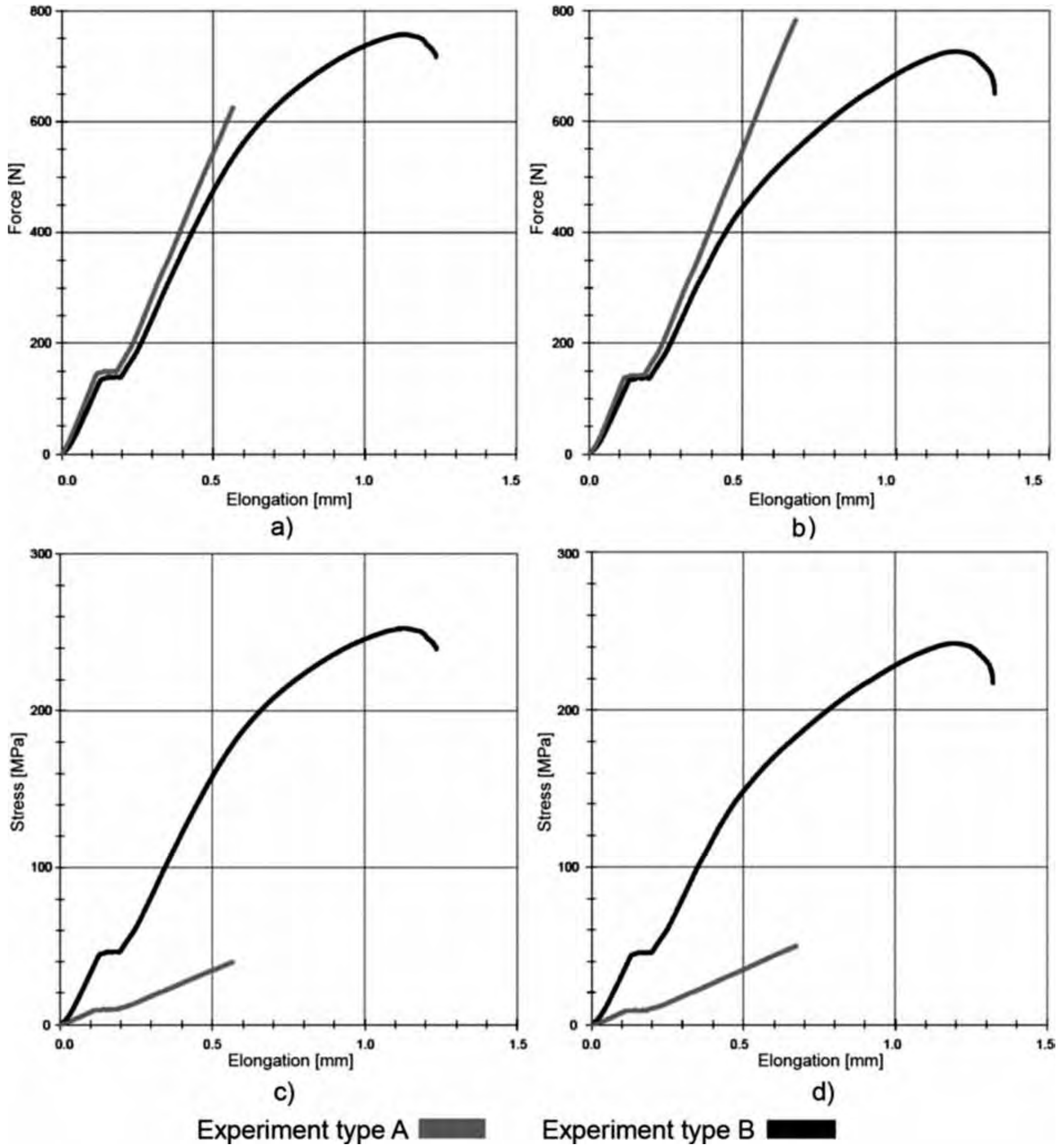

Figure 6. The variation diagrams of the breaking force according to elongation at break (a, b) and tensile strength according to elongation at break (c, d).

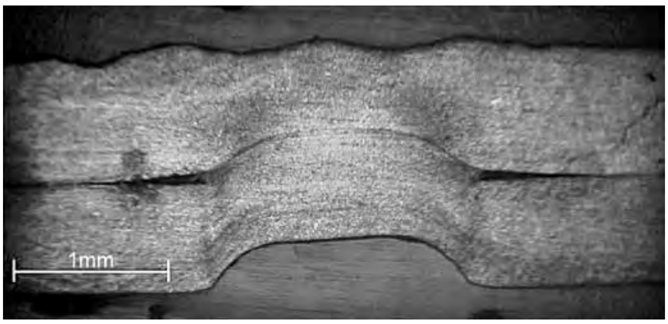

Figure 7. Microscopic analysis of the experiment characteristic type B (with embossment).

confirms that the solution without embossment does not ensure a proper joint according to the technical documentation of the product.

The results described above are reinforced by the microstructural tests performed for the experiment B shown in Figure 7.

Conclusion

The surface geometry of the welded samples plays a key role in the ultrasonic welding process of Cu 95.99, with a thickness of 0.7 mm. By using a concentrator type embossment it was obtained a qualitative and resistant joint.

The use of a concentrator type embossment in the experiment B, led to an increase of the tensile strength calculated as a function of the active surface at the interface lever more than 10 times, from 20MPa to 253MPa.

The use of a concentrator type embossment is the optimal solution in achieving qualitative ultrasonic joints joint of non ferrous materials, characterized by the repeatability of mechanical, electrical and aspect properties.

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