Joining of copper alloys and low-carbon steels by electrical resistance spot brazing

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ABSTRACT: The general problems related to electrical resistance brazing of various metals were considered in this paper. In brazing different electrodes and technological parameters are used. For experimental purposes, electrodes were made of highly alloyed tungsten steel and of copper with graphite and tungsten inserts, so the symmetrical temperature field was obtained. Success of brazing was determined by testing the mechanical properties, micro hardness and microstructure of the brazed joint. Hardness measurement results suggested the strain hardening of the steel thin sheets, what imposed necessity of recrystallization annealing. It was necessary to apply both the flux and the silver solder for joining, since copper and iron are poorly mutually soluble. When the metallurgy problems were solved and the optimal brazing parameters selected, the optimal mechanical properties were achieved, which were experimentally confirmed.

1 INTRODUCTION

Due to low solubility of copper-based alloys' and steel's basic components, i.e., copper and iron, brass and steel are difficult to join by the welding procedures. This problem can be solved by inserting the inter-layer made of the third metal, which is soluble both in copper and in iron. In this case, that is the silver solder in the form of a foil with addition of the flux in the form of the thin coating. To enable successful joining of those alloys it was necessary to perform numerous tests to obtain mechanical properties, micro hardness and microstructure of the brazing joint. Hardness measurements results have shown hardening of the steel thin sheet, due to action of the compressive force during the brazing, what imposed the necessity for recrystallization annealing of the joint for the purpose of improving the structure and the mechanical properties.

2 EQUIPMENT FOR ELECTRIC RESISTANCE BRAZING OF THE TWO ALLOYS

Electric resistance spot brazing is done on the devices for the spot welding with energy of the alternate current, with voltage less than 20 V. The power of the apparatus ranges between 5 and 200 kVA, while electrodes material's characteristics are given in Table 1.

Electrodes for brazing are different from the welding electrodes. The most applied are the electrodes made of the strain hardened copper alloys, as well as of sintered alloys Cu-W and W-Mo. Besides the metal electrodes, the graphite electrodes are also used. They are characterized by relatively higher own electric resistance (0.01 to 0.06 Ωmm, depending on the graphite type) and by the lower thermal conductivity, what allows for brazing with the lesser intensity current Kianersi et al. (2014). For joining of materials with different thermal conductivity, electrodes made of different materials are applied; the metal with higher thermal conductivity comes to contact with electrode with the higher electric resistance.

Table 1. Characteristics of the electrodes' materials

Electrode type	Electrode material	Own electric resistance Ωmm	Thermal conductivity W/mK	Hardness HB	Softening temperature ºC
Metal	Hardened Cu	0.000019	394.0	95	150
	Hardened Cu alloys	0.000021	-	110÷150	250÷450
	Sintered Cu-W alloys	0.000056	-	200÷280	1000
	Tungsten	0.000055	201.0	450÷500	> 1000
	Molybdenum	0.000057	146.5	150÷190	> 1000
Graphite	Soft graphite	0.010	150.6	-	-
	Medium hard graphite	0.018	50.2	-	-
	Hard graphite	0.061	33.5	-	-

To make the soldering process successful, one must apply fluxes. It is deposited in the form of the water or alcohol solution, immediately prior to soldering, to prevent the flux evaporation. The amount of flux must not be too large, since it soils the working surfaces and thus slows the heating process. Recommendation related to soldering of the copper and steel parts are that the copper parts need to be silver coated, while the steel parts should be zinc coated, either by the electroplating or by immersion. During the soldering, copper is alloyed by zinc due to heating, thus, by composition the joint point corresponds to brass. This type of soldering is widely applied in electronics, Radomski and Ciszewski (1985), ASM-Metals Handbook (1979), JMM Brazing materials and applications (1967).

3 EXPERIMENTAL TESTING OF THE EXECUTED JOINTS

3.1 *Base metals properties and equipment used for soldering*

Experimental tests were conducted to determine soldering parameters and technology (current intensity, time, force, type of solder and flux, etc.), so the joints would correspond to required pressure characteristics. Tests were done on the stable apparatus for the spot welding TA-60. In Figure 1 is presented the schematics of soldering used in experiments.

Tests were conducted by soldering the brass thin sheet CuZn37, of dimensions 100×20×3 mm and the steel DC01 thin sheet of dimensions 100×20×1 mm, with application of the silver solder Castolin 1802 of 0.25 mm thickness. The graphite insert at the bottom side plays the role of an electrode, which is placed in the hollow copper holder (Fig. 1). Electrode with the graphite insert has the increased electric resistance since the brass is far better heat conductor than steel (Table 2). Special electrodes were produced for the needs of this experiment, made of copper alloys with graphite and tungsten inserts, as well as electrodes of highly alloyed high-speed steel HS 18-0-1 (0.75% C, 1.1% V, 18% W and the rest Fe) (Table 2).

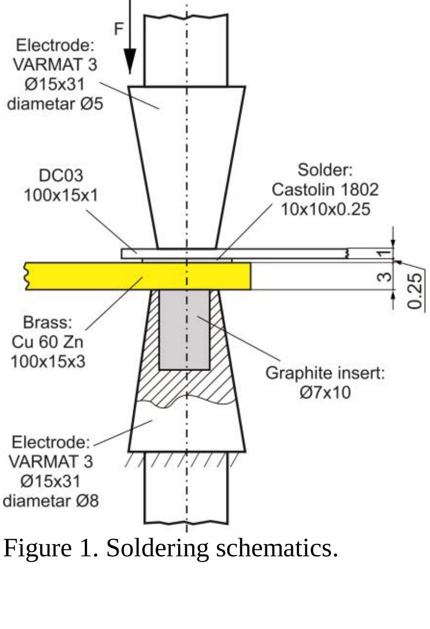

Figure 1. Soldering schematics.

The purpose of built-in inserts is to increase the specific resistance of electrodes. Considering that the solder in the electric circuit – the brazing zone has the lowest melting point, only the solder would melt, while the thin sheets are being heated, though remaining in the solid state. This is why the lower intensity current is needed for soldering than for welding. It is possible to control the process of electric resistance brazing by optimal combination of current intensity and time, Spitza et al. (2015).

Table 2. Characteristics of the electrodes' materials

Electrode type	Electrode material	Own electric resistance Ωcm	Thermal conductivity W/mK	Hardness HB	Softening temperature ºC
Metal	Hardened Cu	0.0000019	394.0	95	150
	Hardened Cu alloys	0.0000021	-	110÷150	250÷450
	Sintered Cu-W alloys	0.0000056	-	200÷280	1000
	Tungsten	0.0000055	201.0	450÷500	> 1000
	Molybdenum	0.0000057	146.5	150÷190	> 1000
Graphite	Soft graphite	0.0010	150.6	-	-
	Medium hard graphite	0.0018	50.2	-	-
	Hard graphite	0.0061	33.5	-	-

3.2 *Brazing parameters*

Base metals taken for practical tests were the steel and brass thin sheets (melting temperatures T_{tst} = 1525°C and T_{tbr} = 920°C, respectively), while the solder was CASTOLIN 1802 (T_{tsol} = 550°C). The brazing parameters are being selected in such a way that the current intensity and the compressive force would be lower than for welding, while the brazing time should be as long as possible. The two regimes (Table 3) were selected that provided for the brazed joints of satisfactory carrying capacity.

Table 3. Basic brazing parameters of steel and brass

Brazing parameters	Electrode tip diameter d_e mm		Current intensity I_z	Brazing time b_t		Compressive force F_z
	Copper	With graphite insert	A	per	s	daN
Regime 1	5	8	5700	12	0.24	280
Regime 2	5	8	5070	12	0.24	280

4. ANALYSIS OF TEST RESULTS

Checking of the brazed joint, and indirectly the validity of the selected brazing regimes, was done for all the joints, first by visual inspection of the samples' and electrodes' surfaces, then by tearing tests and finally, by macro inspection of the fractured joints and metallographic investigations. Mechanical investigations were done by tearing of the brazed samples, with comparison of obtained results to mechanical characteristics of the base metals (Table 4).

Table 4. Stresses and the tearing forces of the brass and steel samples

Material	Cross-section dimensions mm	Cross-section area mm^2	Tensile strength R_m MPa	Yield stress R_{eH} MPa	Force at yield F_{eH} kN
CuZn37	20×3	60	300-380	max 200	max 12
DC01	20×1	20	280-420	250	≈ 5

By reviewing the results presented in Table 4, one can notice that the force of 5 kN corresponds to the yield stress of steel, i.e., the beginning of the plastic deformation. That force can serve as an indicator for quality estimates of the executed brazed joints.

Results of the shear tests, obtained by testing ten samples are presented in Table 5. It shows that even the average values of the shearing force of the brazed joints were exceeding the limiting force that corresponds to the yield stress of the steel thin sheet. In the other words, the permanent deformation of the steel thin sheet would occur before the shearing of the brazed "spot", i.e. the nugget. Macro inspections of the destroyed nuggets showed that melting of the total volume of the solder did not occur in any of the cases, but only in the middle portion around the electrode. It was not possible to determine precisely the nugget diameter since it varied between 5 and 7 mm for regime 1 and between 4 and 6 mm for regime 2.

Table 5. Values of the tearing forces of the brazed joints

Sample number		1	2	3	4	5	6	7	8	9	10	Average
Force kN	Regime 1	5.45	5.82	5.46	5.60	5.71	5.32	5.48	5.38	5.65	5.60	5.55
	Regime 2	5.42	4.58	5.34	4.79	5.18	5.02	5.10	5.35	5.25	5.31	5.13

For the purpose of the more precise analysis of the brazed joints, metallographic investigation of one joint executed by each of the regimes 1 and 2 was performed. The slits were ground from each joint in such a way that samples were cut longitudinally through the center of the brazed joint and casted into the same plastic (Fig. 3). On certain steel sheet samples micro hardness measuring was performed (Fig. 4).

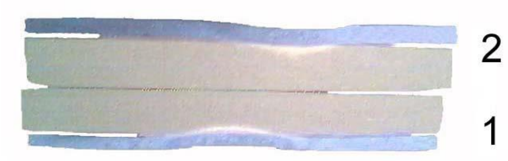

Figure 3. Slits for metallographic investigations: 1 – Brazed joint - regime 1; 2 – Brazed joint - regime 2.

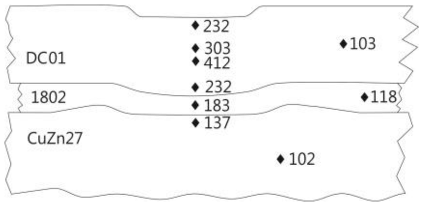

Figure 4. Hardness HV0.2 distribution within the brazed joint.

5. CONCLUSION

Possibilities for electric resistance spot brazing of metals and alloys, that are insoluble in the solid state, i.e., which cannot be welded by melting, were investigated in this paper, theoretically and experimentally. Within the experimental part it was shown that joints executed in laboratory conditions have complied with all the requirements related to mechanical properties of the brazed joints. Results of these voluminous investigations could serve as a basis for manufacturing application of resistance brazing of different metals.

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