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Electrical resistance spot brazing of two different alloys

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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, which made possible selection of the soldering parameters, which gave the needed mechanical properties of the brazing joint. Besides that, it was also necessary to check the micro hardness and microstructure of the joint. Hardness measurements results 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 improving the structure, namely the mechanical properties and the corrosion resistance.

Electric resistance brazing is the process of joining metals where the Joule's effect – RI^2 is used as the heat source. There are three methods of electrical resistance brazing: *spot wise*, used for joining steel and brass thin sheets, for joining parts in electronics, etc.; *seam wise*, used for making the box-like parts where the hermetic joints are required and *butt brazing*, used for brazing the sintered cutting platelets onto the steel holder of the cutting tools, Radomski and Ciszewski (1985), AMS-Metals Handbook (1979), JMM Brazing materials and applications (1967).

Heat amount (Q), released within the closed power circuit of the total electric resistance (R), through which flows the electric current (I), during the time (t), amounts to $Q = RI^2t$. The released heat amount is not the same in all the parts of the circuit, but it is proportional to the electric resistance within particular part. This is why one can obtain, by construction measures and selection of the electrode material, the highest resistance at the thin sheets overlap. Since it is not possible to prevent completely the heating of the rest of the circuit, it has to be reduced by water-cooling of the electrodes. Electrodes material's characteristics are given in Table 1.

Table 1. Characteristics of the electrodes' materials.

Electrode type	Electrode material	Own electric resistance Ωmm	Thermal conductivity W/mK	Hardness HB	Softening temperature °C
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	–	–

2 ELECTRIC RESISTANCE SPOT BRAZING-ELECTRODES AND DEVICE

Electric resistance spot brazing was done on the devices for the spot welding. Energy for the resistance brazing is the alternate current, with voltage less than 20 V. The power of the apparatus ranges between 5 and 200 kVA.

Electrodes for brazing are different from the welding electrodes. The most applied are the electrodes made of the strain hardened copper alloys which posses very high electrical conductivity, Agapiou and Perry (2013), as well as of sintered alloys Cu-W and W-Mo. Sintered alloys Cu-W are especially convenient for brazing of copper and its alloys, since they possess relatively higher ohm resistance and lower thermal conductivity, what creates very favorable conditions for heating. Additional advantage of those electrodes is their significantly higher thermal stability with respect to copper electrodes. Besides the metal electrodes, the graphite electrodes are also used for electric resistance brazing. 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. Sometimes, the brazing electrodes are made of carbon or stainless steels (Cr-Ni steel – has higher electric resistance), 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.

To make the soldering process successful, one must apply fluxes. The flux is being 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, i.e., 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), JMM Brazing materials and applications (1967).

3 SOLDERING PARAMETERS AND TECHNOLOGY

3.1 *Soldering equipment and base metals properties*

Experimental investigations were conducted with the aim to determine soldering parameters and technology (current intensity, time, force, clearance, 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 general schematics of soldering used in experiments.

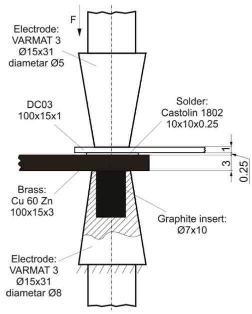

Figure 1. Soldering schematics.

Table 2. Characteristics of the electrodes' materials.

Electrode type	Electrode material	Own electric resistance Ωcm	Thermal conductivity W/mK	Hardness HB	Softening temperature °C
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	–	–

Tests were conducted by soldering the brass thin sheet CuZn37, of dimensions 100 × 20 × 3 mm and the steel DC 01 thin sheet of dimensions 100 × 20 × 1 mm, with application of the silver solder Castolin 1802 of 0.25 mm thickness. Prior to soldering the contact surfaces of samples were degreased and ground with the sand paper 3M of granulation P180, to remove dirt.

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, what is convenient, from the aspect of thermal balance, since the brass is far better heat conductor than steel (Table 2). The electrode with the graphite insert should always be placed at the bottom side, to prevent graphite crumbling and reducing the contact surface between the electrode and the working piece. The compressive force should not be too large, so that the molten solder would not be squeezed out and the thin-walled copper holder.

3.2 *Electrodes for resistance brazing*

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 (Table 2). The purpose of built-in inserts is to increase the specific resistance of electrodes, i.e., when the current flows through the electrode the larger amount of heat is to be released, with respect to the case when there are no inserts on 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 energetically the process of electric resistance brazing by optimal combination of current intensity and time, Spitza et al. (2015).

Shapes and materials of electrodes used in this experiment are shown in Figure 2. At position 1 is presented the VARMAT 3 (Cu-Cr-Zn) alloys, which has the highest specific resistance of 17.2 μΩmm. The total electric resistance of an electrode is increased by built-in insert made of

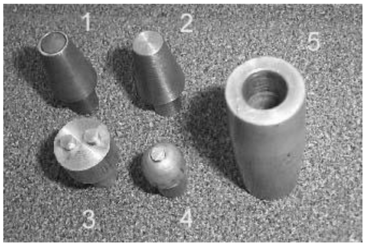

Figure 2. Various forms of used electrodes: 1 – copper electrodes with graphite insert, 2 – electrode of steel HS 18-0-1, 3 and 4 copper electrodes with tungsten inserts, 5 – copper holder of the lower electrode.

Table 3. Basic brazing parameters of steel and brass.

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

graphite EG01, with specific electric resistance of 10000 μΩmm. Electrodes at positions 3 and 4 in Figure 2 with the tungsten inserts are constructed according to the same principle.

Tungsten has specific resistivity of 55 μΩmm, which is significantly higher than that of the VARMAT 3 alloy, but still for another order of magnitude lower with respect to graphite, so the tungsten electrodes are scarcely used in these experiments.

To avoid problems related to manufacturing the electrodes with inserts, electrodes made of pure graphite or the highly alloyed tungsten steels are used sometimes. In this case, the electrode made of the steel HS 18-0-1 (0.75% C, 1.1% V, 18% W and the rest Fe) was used, Figure 2, position 2.

3.3 *Energetic parameters for resistance brazing*

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 (with $T_{tsol} = 550°C$). Since the solder's melting temperature is significantly lower than the melting temperatures of both base metals, there is no danger of zinc evaporation from the brass. The brazing energetic parameters are being selected in such a way that the current intensity (driving energy) would be lower than for welding, while the brazing time should be as long as possible. The compressive force, i.e., the clamping force of the working pieces, must also be lower than for welding. Taking all the aforementioned into account and since there are no empirical expressions for selecting the brazing regime, the brazing parameters were determined based on numerous practical trials. The two regimes (Table 3), with different current intensity were selected that provided for the brazed joints of satisfactory carrying capacity.

3.4 *Results of experimentally executed joints*

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. The trace of the electrodes indentation was checked by visual inspection, as well as the depth of the imprint, deformation of the thin walled copper electrode holder, etc. Results of those investigations enabled successive corrections of the brazing parameters during the brazing experiments. 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 the yield point F_{eH} kN
CuZn37	20 × 3	60	300–380	max 200	max 12
DC01	20 × 1	20	280–420	250	≈5

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

Sample number		1	2	3	4	5	6	7	8	9	10	Average value
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

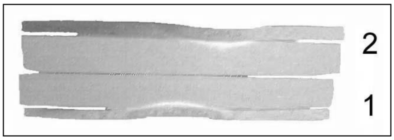

Figure 3. Slits for metallographic investigations: 1 – Brazed joint realized according to regime 1, 2 – Brazed joint realized according to regime 2.

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. In the ideal case of rational design, it is assumed that the carrying capacity of the brazed joint should correspond to that of the weaker of the two materials. However, usual request is that the brazed joint strength should somewhat supersede the strength of the weaker material.

Results of the shear tests, obtained by testing ten samples are presented in Table 5.

From Table 5 one can see 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 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's diameter since it varied between 5 and 7 mm regime 1 and between 4 and 6 mm for regime 2.

3.5 *Metallographic analysis of brazed joints*

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, Figure 3. The light zones beneath the imprints (dents) on the steel thin sheet represent the brazing points. The electrode imprint on the steel thin sheet, in the case of regime 2, has uneven profile due to worn tip. The compressive force caused deformation, not only the steel thin sheet, but the brass thin sheet as well. The thickness of the solder was variable, from the initial thickness of 0.25 mm, to just 0.074 mm, at the end.

On certain samples on steel sheet was performed micro hardness measuring (Fig. 4). Change of hardness in the zone of the pressure action, with respect to the unchanged base metal is very prominent, especially in the middle portion of the sheet. This increase of hardness is a consequence of the cold plastic deformation of the steel thin sheet. Homogeneous hardness distribution and

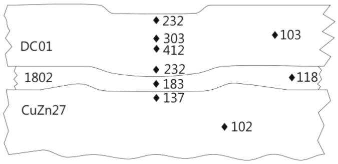

Figure 4. Hardness HV0.2 distribution within the brazed joint.

uniform size of metal grains are obtained by the recrystallization annealing at temperature that does not jeopardize the brazed joint (T < 550°C). Increased hardness, for over 50%, was noticed in the solidified solder that was completely molten during the brazing process.

4 DISCUSSION OF RESULTS AND CONCLUDING REMARKS

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, the possibility for brazing of brass and steel was investigated. 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.

Advantages of the resistance brazing, with respect to other brazing procedures, mainly consist of: fast heating of the joining zone, high productivity of the process, high quality of joints, possibility for easy regulation of temperature and heating time, possibility for monitoring the process flow, process simplicity, lower price, etc. The basic disadvantage of the electric resistance brazing is that it could be done only on parts of smaller dimensions, of a simpler shape and with application of costly silver solder.

Further research directions, for the purpose of improving this joining method, would be in proper selection of the brazing parameters, use of graphite inserts of the higher electric resistance and application of a solder in the form of a foil with thickness less than 0.1 mm. Additionally one must consider application of special auxiliary tools for controlling the optimal clearance between parts that are being brazed.

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