ANALYSIS OF A BRAZED JOINT OF SILVER AND COPPER

Janez Tušek, Miro Uran

Institut za varilstvo, Ljubljana, Slovenia

Key words: solder joints, welding joints, metal-metal joints, brazing, electro-resistance brazing, Ag-Cu brazed joints of silver and copper, brazing filler metals, joint cross-sections, electric welding, electro-resistance welding, welding electric current, electric voltage drop, chemical analysis, contact elements, cost reduction

Abstract: The paper describes a practical application of resistance brazing to joining of a silver element and a copper element to make a contact element to be used in electrical engineering. First the two elements to be brazed are shown schematically. By means of an Auger electron spectrometer a chemical analysis of both surfaces to be joined by brazing, i.e. the copper-element surface and the surface of the filler metal placed at the surface of the silver element, is made. The experimental part schematically shows the principle of resistance welding and brazing, and diagrams show variations of current and voltage drop in both workpieces during brazing as a function of time. An analysis of the brazed joint included assessment of joint quality and of the occurrence of pores or other imperfections at the cross section of the joint. At individual locations of the joint, a chemical composition was analysed with a scanning electron microscope JEOL JSM with an energy disperse X-ray analyser. The conclusions drawn indicate that the technology applied to joining of silver and copper in the electrotechnical industry is quite suitable, although costly. From the points of view of technology and economy it would be reasonable to investigate a possibility of welding silver and copper, i.e. joining without the application of brazing filler metal.

Analiza spajkanega spoja srebra in bakra

Ključne besede: spoji spajkani, spoji varjeni, spoji kovina-kovina, spajkanje trdo, spajkanje elektrouporovno, Ag-Cu spoji srebro-baker spajkani trdo, spajke trde, preseki spojev, varjenje električno, varjenje elektrouporovno, tok električni varilni, padec napetosti električne, analiza kemična, elementi kontaktni, znižanje stroškov

Izvleček: V članku je prikazan praktični potek elektrouporovnega spajkanja elementa iz srebra in elementa iz bakra, ki se vgrajujeta kot kontaktni element v elektrotehniki. Najprej sta shematsko prikazana oba elementa, ki ju spajkamo, s spektrometrom Augerjevih elektronov pa je narejena kemična analiza ober površin, ki se med spajkanjem spojita. To sta površina bakrenega elementa in površina spajke, ki se že pred spajkanjem nahaja na površini srebrnega elementa. V okviru eksperimentalnega dela je shematsko prikazan princip uporovnega varjenja, v diagramih pa sta prikazana potek jakosti toka in padca napetosti v obeh spajkancih med spajkanjem v odvisnosti od časa. Pri analizi samega spoja smo na prečnem prerezu spoja ugotavljali kakovost spoja, prisotnost morebitnih por ali drugih napak. Na posameznih mestih pa smo z vrstičnim elektronskim mikroskopom JEOL JSM z energijskim disperzijskim analizatorjem rentgenskih žarkov analizirali kemično sestavo. Na koncu članka smo podali zaključke, ki pravijo, da je tehnologija spajanja srebra z bakrom za elektrotehnično industrijo popolnoma ustrezna, toda nekoliko draga. Z ekonomskega in tehnološkega vidika bi bilo smiselno raziskati tudi tehnologijo varjenja srebra in bakra, t.j. spajanje brez uporabe spajke.

1. Introduction

Increased demands for higher quality and productivity as well as cutting the production costs require introduction of up-to-date and reliable manufacturing technologies by manufacturers. Joining by welding and brazing processes may certainly be considered such advanced technologies. For example, in electrotechnical industry elements are often used which have to conduct electric current efficiently, show good strength and corrosion properties, and endure dynamic loads. By using an appropriate joining method for various elements made of different materials it is possible to produce a final product with the properties required. In numerous electric assemblies, elements can be found which were manufactured by welding or brazing of the same or different materials. The materials most often used for such applications are copper, brass, silver, and stainless steels.

The various materials can be joined in different ways. A special joining technology has to be elaborated for making each joint of two or more similar or dissimilar metals separately. Fusion welding can be used only under certain conditions, and only with certain similar or dissimilar materials. The different metals to be fusion welded should have the same or at least similar chemical, metallurgical, and physical properties. Highly different metals, however, can be joined permanently only by brazing with a brazing filler metal which melts in the course of the process and joins the two elements. It should be, however, taken into account that any joint made by fusion represents inhomogeneity between two metals. If the brazing filler metal is used, this inhomogeneity is even stronger. With electric elements it shows as an increased resistance during operation at room or elevated temperature.

2. Posing the problem

In manufacture of electotechnical elements very often a need arises to join a silver element and a copper element. In the literature practically no useful instructions or data on joining of silver and copper can be found. Indeed some general principles of welding and brazing of non-ferrous metals can be found in various publications /1-7/ but for such special cases as the one treated in the present paper, some experimental work had to be done.

Taking into account the size of series, resistance welding and brazing processes have established themselves as the

most cost-effective processes to be used with practical applications. Direct joining of silver to copper by welding without the application of filler metal shows numerous advantages over a brazed joint. They are higher homogeneity of the joint as a whole, more uniform characteristics of the entire element, which particularly concerns voltage drop in electric-current conduction. But the technology of welding pure silver-based and copper-based materials or alloys is extremely demanding due to high electric conductivity of the materials. Thus in many cases resistance brazing is preferred.

Figure 1 schematically shows copper and silver elements, a brazing filler metal, and the entire joint.

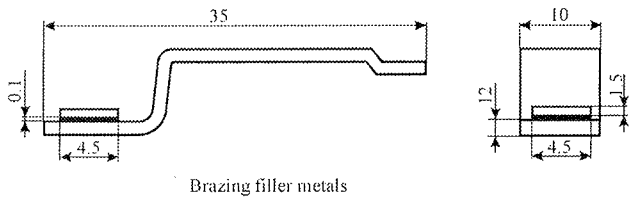

Fig. 1. Schematic representation of copper and silver elements including brazing filler metal, and the joint.

Lower energy required to produce the joint in particular is an advantage of resistance brazing over resistance welding. In brazing the parent metals will not melt but only heat up to the melting temperature of the brazing filler metal. In the course of brazing the filler metal will melt. The melting temperature of the filler metal is much lower than that of the parent metals, i.e. silver and copper, and a higher ohmic resistance and lower thermal conductivity, which makes it easier to produce the joint with Joule's heat. Resistance welding is based primarily on the principle of high contact resistance between two workpieces which is much higher than the resistance in the workpieces and that between the workpiece and the electrode. This principle is made use of in welding of all kinds of steel plates. In welding of non-ferrous metals with high electric conductivity, however, the contact resistance between the workpieces is comparatively low. Consequently, at the interface between the two metals low thermal energy is generated.

In general, contact resistance per unit area depends on the kind of the materials being in contact and on surface roughness. With most metals, their surface is contaminated by impurities and oxides, therefore, they show higher ohmic resistance than pure metals. In our case, the decisive role was played by the contact resistance between the copper element and the filler metal placed on the silver element. A chemical analysis of both surfaces was made. An Auger electron spectroscope (AES) was used. The primary static electron beam had an energy of 3 keV, a current of 0.8 μA, and a diameter of 40 μm. The two test pieces were etched at an area of 4.5 x 4.5 mm with two argon (Ar^+) ion beams with an energy of 1 keV at an angle of 47°. Velocity of ion etching was 2 nm/min. The concentration of the elements at the surface was calculated using sensitivity factors specified by the manufacturer of the apparatus. Figure 2 shows a through-depth profile of the chemical composition obtained with the copper element. The surface is covered by a thin contaminated carbon layer. It is estimated that the layer has a thickness of a few atom layers. The surface is mildly oxidised. Traces of chlorine were found as well.

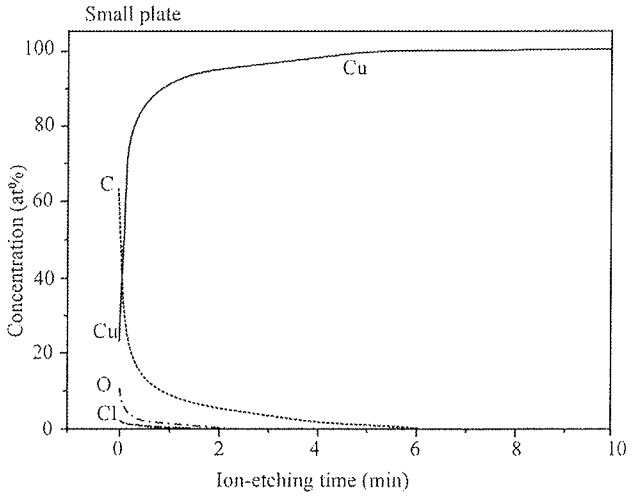

Fig. 2. Through-depth profile of chemical composition at the surface of copper element obtained with AES (velocity of ion etching: 2 nm/min)

Figure 3 shows results obtained with the silver element including the filler metal. The surface of the filler metal was analysed. The filler-metal layer at the surface of the silver element was 100 mm thick. At the surface of the filler metal some carbon and oxygen impurities were found. The composition of the filler metal was as follows: 74% Cu, 18% Ag, and 8% P. This is, however, the composition of the filler-metal surface. The composition of the filler metal itself differs very much from this composition.

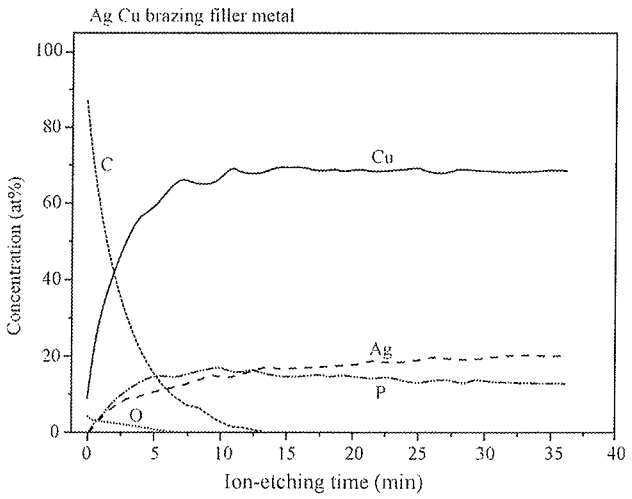

Fig. 3. Through-thickness profile of chemical composition at the surface of filler metal placed on the silver element (velocity of ion etching: 2 nm/min).

Both figures, i.e., Figs. 2 and 3, indicate that the contact surfaces to be brazed are covered by some impurities, but these layers are too thin to make contact resistance essentially increase. At both surfaces roughness was measured too. The measurements made showed that the surface of the copper element is much smoother than that of the filler metal placed on the silver element. Roughness at the filler-metal surface somewhat increases the contact resistance between the filler metal and the copper element, which makes brazing easier.

3. Experimental work

Experiments were made with a common resistance welding device and an alternating current with a frequency of 50 Hz. The principle of resistance spot brazing is shown in Fig. 4. Individual elements making the secondary part of the machine with a transformer such as electrode holders, clamping dies, electrodes, and the workpieces are shown. Materials for the electrodes and the lower-electrode clamping die are described. In resistance brazing and welding, particularly of non-ferrous metals, it is very difficult to select the right materials for the electrodes. The electrodes should conduct electric current efficiently, show high strength and hardness at room temperature as well as at elevated temperatures.

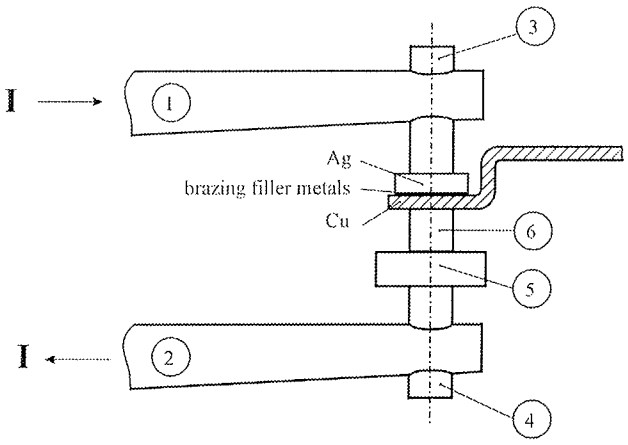

Fig. 4. Schematic representation of resistance spot brazing of silver to copper. 1 - upper-electrode holder; 2 - lower-electrode holder; 3 - upper electrode (silver); 4 - lower electrode (copper); 5 - connecting piece (copper); 6 - electrode (tungsten).

On the basis of experimental results, a copper electrode was selected to be positioned on the silver element and a tungsten electrode for the copper element (Fig. 4). As already mentioned. in brazing the brazing filler material should melt whereas the two elements should heat only up to the operating temperature.

Optimum brazing parameters were found experimentally. The most important brazing parameters are alternating-current intensity, electrode forces, and brazing time. The range of the optimum parameters is very narrow. This is particularly true of the brazing time and the brazing current intensity. In resistance brazing, current intensity is most often set in two steps. A rough setting is performed with a switch which includes different numbers of windings at the primary side of the transformer whereas a fine setting is performed with two thyristors acting as a switch at the primary side of the welding transformer as well. The optimum effective intensity of brazing current ranged between 6900 A and 7250 A, the optimum time between 180 ms and 220 ms, and the optimum electrode force between 430 N and 590 N.

Quality assessment of a spot joint obtained in resistance welding or brazing is a very difficult and time-consuming task. No efficient method has been found yet to make a reliable assessment of a spot weld based on the variation of welding and brazing parameters respectively. One of future methods which might provide appropriate results is measurement of the voltage drop in the entire joint in the course of welding and brazing respectively. Figure 5 shows a variation of voltage drop in spot brazing in duration of 200 ms with an effective current of 7100 A, and an electrode force of 480 N. It can be seen that the initial contact resistance was comparatively high. Immediately after the beginning of brazing it began falling and was falling for approximately 80 ms. After 80 ms of brazing, it was rising again till brazing was completed. Such a result could be expected. At the beginning of brazing the contact between the two surfaces was namely incomplete. This resulted in a high current density and, consequently, a strong voltage drop.

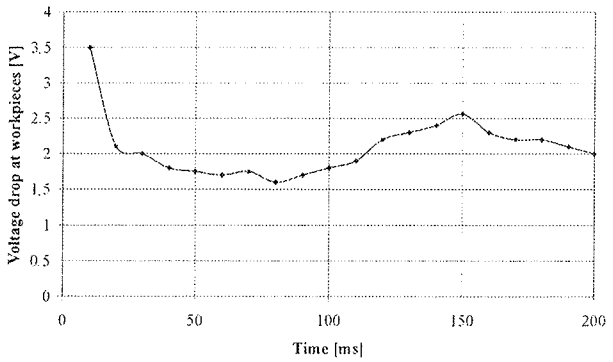

Fig. 5. Voltage drop at both workpieces as a function of time in resistance spot brazing of silver to copper: I = 7100 A, F = 480 N

Right after the beginning of brazing, the contact surface between the filler-metal surface and the copper-element surface increased due to Joule's heat and the electrode force. This produced the resistance and the voltage drop. After approximately 80 ms of brazing both workpieces obviously heated up so that the brazing filler metal started melting. As the resistance of a majority of metals increases at elevated temperatures, the voltage drop becomes stronger as well. In the last phase when the brazed joint finally is formed and the contact resistance between the electrodes

and the workpieces decreases, the voltage drop is again weaker.

Figure 6 shows a variation of the current during brazing. Right at the beginning of brazing the current intensity is a little lower since the contact resistance between the elements brazed is very high (see Fig. 5). After some ten milliseconds of brazing, a current of a stronger intensity flows which is then almost constant.

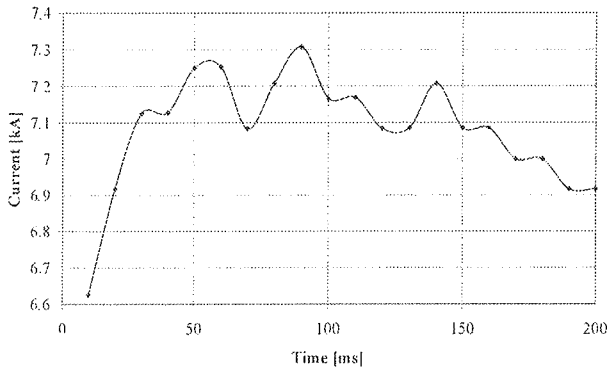

Fig. 6. Variation of current during brazing of silver to copper

4. Analysis of the brazed joint

Already during the study of the optimum parameters, macro specimens of the brazed joints were made, joint quality and dilution of the filler metal with the parent metal were studied, possible defects in the brazed joint were searched for, and individual macro specimens were compared with each other and with the brazing parameters. The brazing parameters of the joints of which the macro specimens fulfilled the stringent requirements for acceptance were taken as optimum parameters.

Figure 7 shows a cross section of the brazed joint of silver and copper. On the top the silver element is found, on the bottom the copper element, and in between a layer of the filler metal. The photo was magnified by 100 times, which means that 1 cm in the photo corresponds to 100 mm at the actual specimen.

Figure 8 also shows a cross section of the same brazed joint magnified by 600 times, which means that 1 cm in the photo corresponds to 17 mm at the actual specimen. In both figures (7 and 8) capital letters indicate eight different locations. At locations D, E, F, and G chemical analyses were made. For this purpose the scanning electronic microscope JEOL JSM 35 with energy-dispersion microanalyser of X-rays TRACOR TN 2000 was used. With the electronic microscope photos of the specimens were taken with secondary electrons emanating from bombardment of the specimen by an electron beam with an energy of 25 keV, current 0.2×10^{-10} A, and a beam diameter of 200 nm. Using the method of electron microanalysis the energy dispersive X-Ray (EDX) spectra were registered at the above-mentioned locations. The spectra obtained permitted the determination of the chemical compositions. This is an analytical method of determination of the composition of an around 1 mm thick layer.

In Table 1 the elements found at the point analysed are stated. It is estimated that the error may amount to around 2 wt-%.

Designation	Description	Ag (wt-%)	Cu (wt-%)	P (wt-%)
Location D	grain	84.5	15.5	0
Location E	grain	82.4	17.6	0
Location F	phase 1	3.6	96.4	0
Location G	phase 2	10.3	85.7	4
Location H	phase 2	11.5	84.5	4

Table 1. Compositions of the analysed locations at the specimen of the brazed joint in weight percentages. Locations are marked in the same way as in Fig. 8.

At the cross section of the silver plate two different zones were observed. In the upper zone (A in Fig. 7) dark pores were observed. The basic composition of the zone was silver. Traces of aluminium and copper, however, were found too. In the lower zone there was a 200 μm thick layer (B in Fig. 7) containing no dark pores. The chemical composition is the same as in the upper zone of the plate. A special layer is the layer of the filler metal (C in Fig. 7) which melted during brazing and partly diluted by the parent metal, particularly silver, and much less with copper. Prior to brazing the thickness of the filler-metal layer placed on the silver element was 100 μm (see Fig. 1).

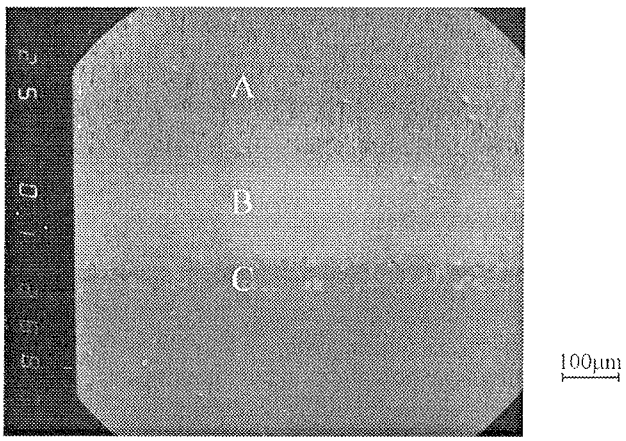

Fig. 7. Cross section of the brazed joint magnified by 100 times; brazing parameters: I = 7100 A, F =480 N

The layer formed during brazing was approximately 40 mm thick. It was composed of grains rich in silver and two intermetallic phases rich in copper. Some pores were found here too. The boundary between the filler-metal layer and the copper element was straight. This indicates that during

brazing there were no conditions for the formation of new phases or grains from the filler-metal elements or copper. Suitable conditions for such processes would be a longer brazing time or a higher energy input in the joint.

In Figure 8 capital letters D and E indicate the grains (in electronic microscope shots they are of light colour) containing 85 wt-% of silver and 15 wt-% of copper.

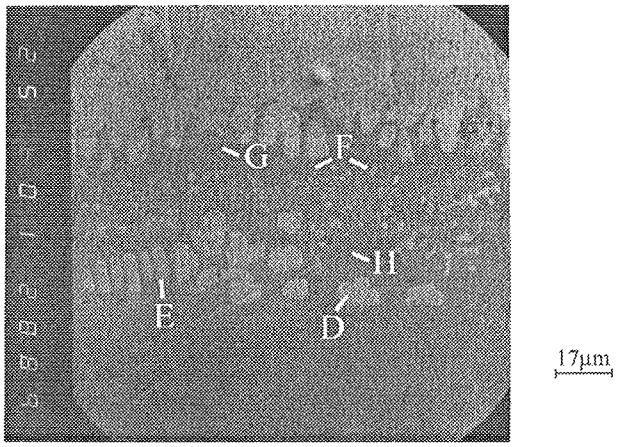

Fig. 8. Cross section of the brazed joint magnified by 600 times; brazing parameters (see Fig. 7).

Among these grains rich in silver and some pores in this layer there are also two phases both rich in copper but each having a different composition. The first phase consists of 96 wt-% of copper and 4 wt-% of silver and is round-shaped (F in Fig. 8). The second phase consists of 85 wt-% copper, 11 wt-% of silver, and 4 wt-% phosphor, and is fine-grained (G and H in Fig.8).

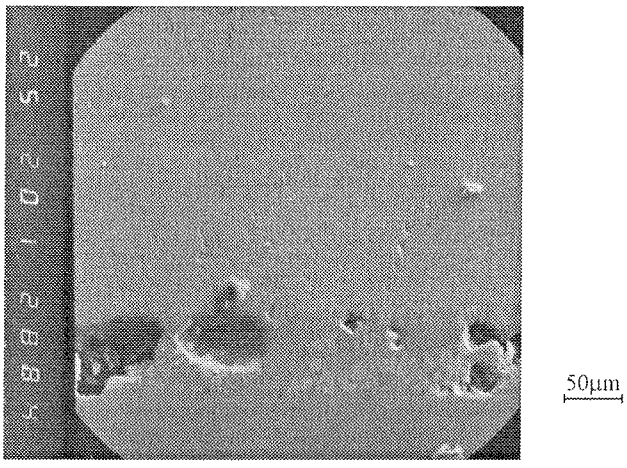

Fig. 9. Cross section of the brazed joint containing pores magnified by 200 times; brazing parameters: I = 6750 A, t = 300 ms, F = 480 N

In the case brazing was carried out with parameters beyond the range of optimum parameters, the joint obtained was not so homogeneous as the one shown in Figures 7 and 8. Figure 9 shows a cross section of the brazed joint containing pores with diameters ranging from 65 to 85 μm. The pores are found in the filler-metal layer and are relatively numerous, i.e., much more numerous as in the specimen shown in Figures 7 and 8. Quality of such a brazed joint is not acceptable. Consequently, such brazing parameters were excluded from the optimum range although the appearance of the brazed joint might be satisfactory and joint strength within the limits of acceptability.

5. Conclusions

The study of brazing of the silver element with the copper one showed that the comparatively low energy input permits the achievement of a quality joint and that the inhomogeneities at the brazing boundary, if brazed with the optimum parameters, are negligibly small. A difficulty encountered in the practical application of this technology is that the assessment of the quality of such a joint is very exacting. In spite of an excellent visual appearance of the joint and satisfactory joint strength it might happen that there are pores at the brazing boundary which will impair the characteristics of the brazed element, and they may be noticed only after a shorter or longer operation time.

6. References

/1/ *Welding Handbook, 7th ed. Vol. 4 Metals and their Weldability*. American Welding Society, Miami, Florida, 1982.

/2/ R. J. C. Dawson. *Fusion Welding and Brazing of Copper and Copper Alloys*. Butterworths, London, 1973.

/3/ S. Anik, L. Dorn. Metallphysikalische Vorgänge beim Schweissen von Kupfer und Kupferlegierungen - Werkstoffliche Grundlagen. *Schweissen und Schneiden*, vol. 39, no. 12, pp. 617-623, 1987.

/4/ V. Culcut, L. Brown. Joining of copper and copper alloys. *Welding & Metal Fabrication*, vol. 64, no. 6, pp. 232-235, 1996.

/5/ L. Brown. Joining of copper and copper alloys. *Welding & Metal Fabrication*, vol. 63, no. 1, pp. 18-21, 1995.

/6/ P. S. Sangha, D. M. Jacobson, A. T. Peacock. Development of the copper-tin diffusion-brazing process. *Welding Journal*, vol. 77, no. 10, pp. 432s-438s, 1998.

/7/ G. Flood. Ultrasonic energy welds copper to aluminium. *Welding Journal*, vol. 76, no. 1, pp. 43-45, 1997.

izr. prof. dr. Janez Tušek, univ. dipl. inž.
Miro Uran, univ. dipl. inž.
Institut za varilstvo
Ptujska 19, 1000 Ljubljana, Slovenija
tel: +386 01 436 77 00, fax: +386 01 436 72 22
e-mail: (janez.tusek, miro.uran)@guest.arnes.si

Prispelo (Arrived): 11.1.2002 *Sprejeto (Accepted): 26.2.2002*