COPPER ACCELERATING STRUCTURE FABRICATION WITH CONTROLED Cu-Ag JOINING CONDITIONS

V. Danielyan†, V. Avagyan, S. Nagdalyan, T. Mkrtchyan, V. Dekhtyarov, A. Simonyan, V. Vardanyan, CANDLE SRI, Yerevan, Armenia
A. Tsakanian, Helmholz Zentrum Berlin (HZB), Berlin, Germany

Abstract

The paper is devoted to the development of technological processes of copper accelerating structure fabrication from oxygen-free copper. The experimental setup for vacuum brazing of long accelerating structures, with optimal Cu-Ag joining conditions, is described. The experimental results of precise machining and subsequent vacuum brazing of Ag-Cu eutectic are presented.

INTRODUCTION

A research review in the field of advanced copper accelerating structures manufacturing has shown that their need in technology has significantly increased in recent years [1]. A large amount of experimental material on the formation regularities for joints of copper accelerating structures has been accumulated [2-4]. These structures must have the following properties: high-precision of surface machining, high strength, ductility, vacuum hermeticity, preservation of the original dimensions.

However, in spite of the important achievements in this filed, many issues have not been studied yet, particularly the positioning between separate elements of accelerating structures before joints, the scientific justification for the selection of optimal methods of heating source and characteristics of its thermal field. The problems of joining methods determination have not been solved yet: diffusion welding or vacuum brazing [2-4] and also heating load.

During diffusion, the welding joint is formed as a result of closing up of contact surfaces at the expense of local plastic deformations at high temperatures. During brazing the formation of joints is realized by heating the connected materials below their melting temperature, by solder wetting, by solder wicking into the gap and its crystallization [5]. As a heating type, for connecting accelerating structures - the induction heating has advantages here as compared with the radiation one. The aim of the work is to determine the optimal parameters of technologies for the accelerating structure fabrication by means of brazing process with the cooper-silver solder.

CALCULATIONS

For distribution and temperature control analyses, during the brazing of lengthy accelerating sections, a computer modelling was carried out. The calculations were realized for a maximum quantity of structures. For the initial stage, the maximum heating time was 2700 s. As a result, the data of temperature field distribution along column height were received.

The data analysis shows, that for a small exposure time (100 s and 200 s) the warming-up of subsequent structures on the upper ones is minor and is distributed up to 9-14 cells. But there is a certain point in time at which the temperature penetration intensity along the column height is significantly reduced and practically does not change with time increase. From Fig. 1 it is seen, that such a moment in time is the interval within the exposure time of 900 s and 1000 s. At heat exposure, more than 1000 s, the column warming-up process can be regarded as static, and at the same time the gradual heating of lower structures up to 60-100 0C temperature is not taken into account.

One of the most important tasks of brazing process is to set the inductor movement rate through the column to receive uniform heating over the entire height. To solve this problem, we use the received data of temperature distribution along the column height.

For different exposure times, Q/t heat transfer velocities are received in each specific case. As well as it is necessary to add the ΔQ/t heat transferring velocity to the calculations at the expense of thermal conductivity. The above-mentioned factors allow to get equations [Eq. (1)] for calculating the velocity of inductor movement, depending on exposure degree:

$$V_{Ind} = \frac{L}{\dfrac{Q'}{n \cdot c_{cu} \cdot \Delta T \cdot \dfrac{m_{cu}}{t}}} + \frac{Q^{max} - Q_{n+1}}{3}. \qquad (1)$$

Where L is the effective inductor length, n is the quantity of simultaneously heated structures, ccu is the copper heat capacity, mcu is the weight of simultaneously heated structures, t is the exposure time, Q' is the amount of heat required to heat each subsequent cell, Qmax is the maximum amount of heat required to heat a cell from the minimum temperature to the one set, Qn+1 is the amount of heat generated from the thermal conductivity.

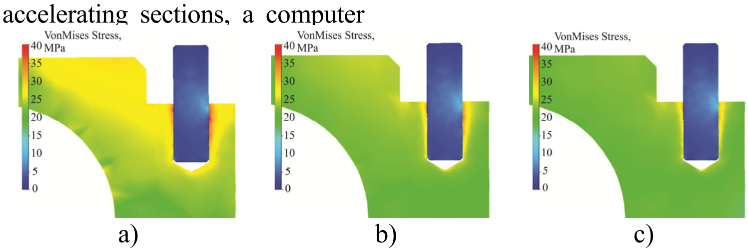


Figure 1: Stress fields on copper structure: a – 200 s heat, b – 700 s heat, c – 2700 s heat.

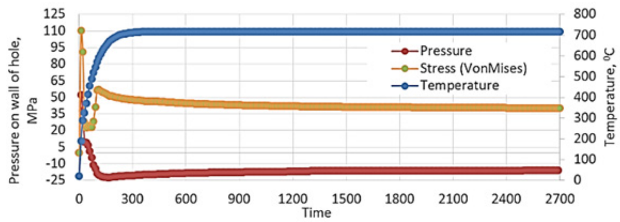


Figure 2: Diagram of temperature and pressure changes on the surface of the hole.

To solve the problem for the positioning of structures, which are relative to each other during brazing, as well as to avoid their mutual movement, the usage of structural element pinning is suggested. For preventing geometry violations, it is proposed to place the pins on planes for brazing. The pins are of 304L stainless steel with a diameter of 3 mm. To position each pair of accelerating structures, 2 pins are applied. At the expense of different thermal expansion coefficients, fields of compression stresses emerge between elements, which can cause irreversible shape distortions at sufficiently large values.

For determining stress fields, which appear at the point of pin and accelerating structure contact, a computer simulation was carried out by the method of finite elements. In view of significantly smaller sizes of the pin, as compared to the accelerating structure, the mutual influence of pins on each other can be neglected. The calculations were performed for a single pin at complete accelerating structure heating. In this case, the results obtained for a single pin, will be similar for the other two.

The analysis was performed for a definite warm-up period of the accelerating structure, which was 2700 s. At the same time, the final temperature reached 700 0C. At 700 0C temperature copper turns into a soft material, resulting in a reduced stress on the surface of the hole.

The stress pattern on the inner surface of copper structure in different time periods, is shown in Figure 1.

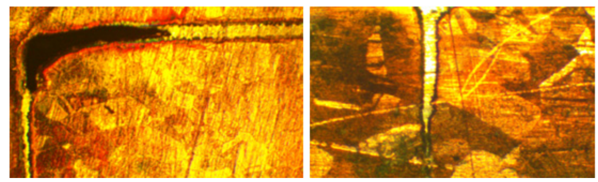
As can be seen from the figure, after being heated for 700 s, the stress pattern is only slightly changed. It is also worth mentioning that the stress localization is close to the hole and does not extend deep into the metal. The results of stress distribution on surfaces of pin holes are shown in Figure 2.

As can be seen from Figure 2, the effect of pin temperature expansion starts after 30 s of heating. The stress positive value points to the hole expansion as a result of heating, but the subsequent stress transition into the negative region indicates surface compressions. The surface compression starts after 60 s from the structure heat and continues till its end. At the same time, the intensity of surface compression first increases and then decreases. In the final heating stage, the stress on the surface practically remains unchanged and gradually decreases. It should be noted that the results obtained can be extended by using different boundary conditions for this problem, as well as by heating speeds of the structure.

EXPERIMENTS

For brazing with Ag72Cu28 solder, samples of M1 copper, with 25 mm diameter, were made. The research was conducted in two ways: 1. A foil of 50μm was set between the surfaces, 2. In the corners of brazed copper elements a groove and a gap for solder flow were made.

In the first variant, the silver foil usage was necessary, to apply a little pressure for plastic deformation localization; in that case the excessive solder goes into the working volume of the components, which is undesirable.



a) b)

Figure 3: The Microstructure of brazed cooper cells (x200).

In the second variant, the more the tilt angle is, the more the void around the groove is (Fig. 3, a). The investigations have shown that in our case the optimal gap for solder flow is 0.07 mm (Fig. 3, b).

The brazing of items and the location of grooves for soldering were developed according to the principle of groove fabrication for the inner solder, where the embedded solder rapidly flows into the tapering gap [6], since the filling pressure increases at a reduced gap width, the items are collected with a specific gap, which tapers in the direction of solder flow.

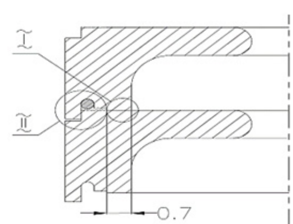


Figure 4: Joint of brazed cooper cells.

In Figure 4 the manufactured joint of cooper cells is presented, which is conditionally divided into two parts: the first part serves as a barrier for the liquid solder, to flow into the working area of the accelerating structure, and the second one ensures silver soldering without cooper component deformation, since there is no external pressure.

In the process of accelerating structure brazing the relim-inary compression of elements for obtaining quality products plays a decisive role. The load value determines a complete closure of lock 1, which prevents the solder from getting into the inner space of the accelerating structure. The force choice for compression is an actual issue in accelerating structure obtainment matters.

To provide quality brazing and final cell structures, a preliminary compressive force between brazed elements should be made for a complete closure of zone I (Fig. 4). To identify the force value, a mathematical analysis, based on FEA, was applied. The change of force parameters (Fig.

ISBN 978-3-95450-182-3

5) and mutual displacement between the cells were analyzed for the whole period of modelling.

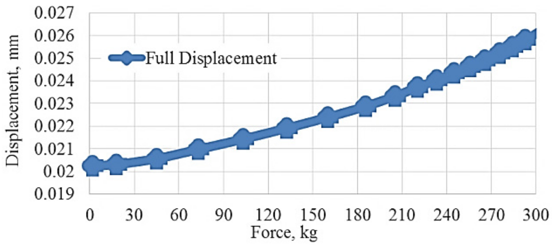
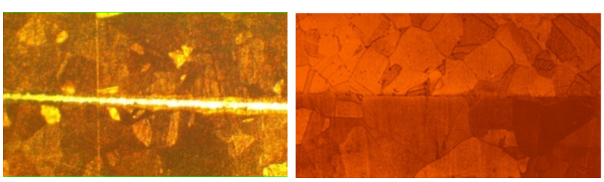


Figure 5: The dependence of mutual displacement and compression force.

As is seen in Figure 5, the deformation process at the contact point between the two cells can be divided into two phases: elastic displacement and plastic displacement. There are specifications seen on the curve line for every phase. Before the value of 185 kg, the force proportionally varies to displacement (straight line segment), that corresponds to elastic deformation. After the value of 185 kg, plastic deformation starts, which is proved by no proportional change between force and displacement (curvilinear line segment).

Therefore, it is reasonable to carry out the brazing process with compression force, which does not exceed 185 kg. This will enable keeping the inner geometrical parameters of the accelerating structure after brazing, due to elastic unload.



a) b)

Figure 6: The Microstructure of brazed cooper cells (x50).

The brazing of copper accelerating sections was realized in P=$1{,}3*10^{-5}$ vacuum, with silver solder (Ag72Cu28), under 0.45kg/mm^2 compression pressure, along the whole area of brazing cells to ensure the necessary contact. The brazed accelerating structures change their original size for almost 16 μm. Figure 6 shows the metallographic structure for the joint zone in region 1, the total closure of the lock and the stopping point of the melted solder are seen (Fig. 6, a). It is necessary to mention, that at compression pressure increase, till silver solder (Ag72Cu28) melting, a diffusion welding occurs at sector 1 (Fig. 6, b). It is seen from the figure that the section border is preserved and a general formation of grains is observed.

In Figure 7 an installation for soldering the accelerating structure, 1.2 m in length, is presented [7].

The developed machine allows to ensure optimum brazing regimes at the junction of every two cells along the entire length of the accelerating structure. The pressure constancy is provided by the pneumatic cylinder control system, which decreases the load as the heater moves from top to bottom; the permanent time constancy of brazing process and heating temperature is provided by the inductor thermal field movement, according to the thermal conductivity of copper.

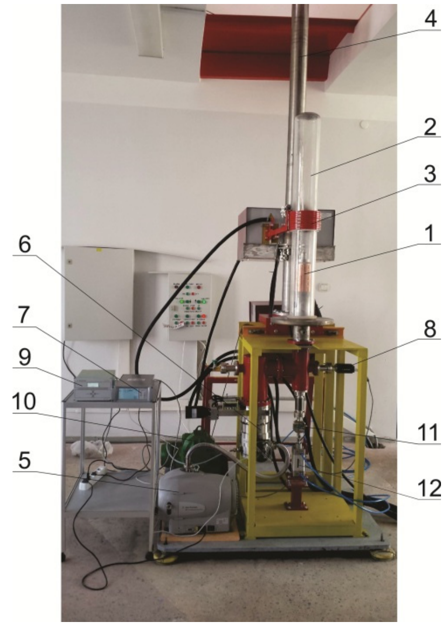


Figure 7: Installation for vacuum soldering of accelerating cooper structures (1. Accelerating structure, 2. Quartz chamber, 3. Inductor, 4. Directive, 5. Fore vacuum pump, 6. Turbomolecular pump, 7. Vacuum gauge controller, 8. Vacuum gauge, 9. Turbomolecular pump controller, 10. Redactor for inductor displacement, 11. Dynamometer, 12. Pneumatic cylinder).

It should be noted that the already conducted researches in paper [3], for a similar machine, had some shortcomings, which are as follows; the electromagnetic field of the inductor distorts the parameters from the potentiometer and accordingly, the parameters of the electromagnet are changed.

CONCLUSION

1. The dependency for inductor movement calculation while accelerating structure soldering is achieved, to preserve a constant thermal field along the entire column height.

2. A mathematical modelling of accelerating structure heating process by a positioning pin usage has been carried out. The stress fields on the hole surface in accelerating structure have been determined. It is shown that the stress intensity does not exceed the yield range and does not affect the inner surface of the product for the given dimensions of the assembly.

3. Experiments have been carried out on the formation of connections among structures at soldering process.

4. Analytical calculations for the determination of compressive force amount while accelerating structure soldering process have been performed, to ensure that the solder does not flow into the inner area of the product. It is determined, that at the given accuracy of accelerating structure fabrication, the compressing force intensity does not exceed 185 kg, to ensure the quality of the final product.

REFERENCES

[1] V.A. Danielyan, Development of the Vacuum Brazing Process of Copper Accelerating Structures, Proceedings Of Engineering Acadeny Of Armenia. 2016, V0LUME 13, N 2, pp.304-307.

[2] Juwen Wang, X-band Accelerator Structures R&D at SLAC SLAC/LLNL Discussion, March 5, 2011.

[3] Avagyan V. Development of technology for brazing and diffusion welding of copper accelerating structures, Phys. Rev. Special Topics- Accelerator and Beams, 2006, v.9, pp. 083501- 083507.

[4] J. W. Elmer, J. Klingmann, and K. Van Bibber Diffusion bonding and brazing of high purity copper for linear collider accelerator structures, Phys. Rev. ST Accel. Beams 4, 053502 – Published 23 May 2001.

[5] Lashko S.V., Lashko N.F. Brazing of metals - 4th edition, Recycling and add.-M.:Machine building, 1988.- P.7.

[6] Ruge U. Welding Technology: Directory. Pub. V2.- N.1.Materials, Translated from German.-M.: Metallurgy, 1984.- p. 552.

[7] Avagyan V. Sh, Danielyan V. A., Dekhtiarov V. S., Mkrtchyan T. H., Nagdalyan S. A., Simonyan A. S., Vardanyan V.V., “Apparatus for Vacuum Brazing”, Intellectual Property Agency of the Republic of Armenia, N 3025A, AM20160022, 16.06.2016.