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INFLUENCE OF OPERATION FREQUENCY ON THE TEMPERATURE DISTRIBUTION IN MATERIALS DURING INDUCTION BRAZING

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Abstract: *The paper deals with the numerical simulation of brazing process of components for solar collectors from dissimilar copper-brass materials by means of brazing solder CuP7 applying induction heating. The main aim of the paper is on the base of coupled numerical analysis of electromagnetic and thermal fields by the program code ANSYS to assess the influence of current frequency in induction coil on the temperature distribution in solder and brazed components. The obtained results confirmed that using suggested arrangement of induction heating it is possible to attain solder melting and development of a good joint by increased frequencies during the shorter heating times without undesirable overheating of brazed components or surface melting of brass flange.*

Key words: *brazing, induction heating, coil design, numerical simulation, ANSYS*

1. INTRODUCTION

Design of induction heating processes is in most cases performed on the basis of long-time practical experience and trial/error approaches with the aim to attain the desired parameters of heating (temperature distribution, heating rate) and the subsequent micro-structural characteristics and material properties of the treated materials. In general, experimental setting of suitable inductor shape, number of windings, position and operational parameters is a costly and time consuming task.

Due that reason, in design, analysis and optimization of induction heating, computer modeling based on the solution of a coupled electro-magnetic and thermal tasks, is ever more applied. Majority of the elaborated models is based on finite elements method (FEM) or combination of this method with the method of boundary elements (Rudnev, 2003).

The presented contribution deals with numerical simulation and analysis of induction heating at brazing copper with brass using the program code ANSYS 10.0. The main aim of the paper is to assess the influence of the operation frequency on the temperature distribution during brazing parts of solar collectors made of combined metallic materials Cu – brass.

2. BRAZING TECHNOLOGY

The Department of Welding at the Institute of Production Technologies (IPTE) of the Faculty of Materials Science and Technology in Trnava deals with the topic of brazing components for solar collectors, namely the parts of collecting pipe. The copper tube with the inner diameter of 16.4 mm (Fig. 1a) and the outer diameter of 18 mm should be brazed to a brass flange by the use of CuP7 brazing alloy and the flux type SUPERAN H1. The brass solidus temperature is 880 °C(***, 2009, 2010). The interval between solidus and liquidus for the CuP7 brazing alloy is from 710°C to 793 C (***, 2010). Brazing clearance (Fig. 1b) varies within 0.1 and 0.5 mm, in order to attain a good running of brazing alloy and thus also sufficient joint strength.

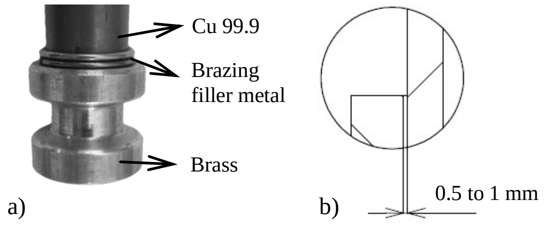

Fig. 1. Brazed components of solar collectors, a) copper tube and brass flange, b) brazing clearance

3. MATHEMATICAL AND SIMULATION MODEL

As well known, the induction heating is physically based on three main phenomena: electro-magnetic induction, skin effect and heat convection (Rudnev, 2003, Haimbaugh, 2001). The induced currents and subsequently the generated heat are not uniformly distributed over the cross section of the heated material. Approximately 63% of induced current and 87% of the generated heat is concentrated in the surface zone of heated body, designated by the term "penetration depth" (Rudnev, 2003). The penetration depth decreases with increasing frequency.

The basis equations describing the time variables of electro-magnetic fields during induction heating process can be derived from classical Maxwell´s equations (Langer, 1979). In case of axisymmetric harmonic electromagnetic fields, the final partial differential equations in cylindrical coordinates for the conductive and non-conductive environment attain the forms

$$\frac{\partial^2 A}{\partial r^2}+\frac{1}{r}\frac{\partial A}{\partial r}-\omega\sigma\mu A=0 \tag{1}$$

$$\frac{\partial^2 A}{\partial r^2}+\frac{1}{r}\frac{\partial A}{\partial r}+\omega^2\varepsilon\mu A=0 \tag{2}$$

where A is the vector potential, σ - the specific electric conductivity and ω - the angular frequency.

The transient heat conduction in solid bodies is described by the Fourier-Kirchhoff´s partial differential equation (Incropera& DeWitt, 1996). For the heat transfer in isotropic material at axi-symmetric conditions, it takes in cylindrical coordinates the following form

$$c\rho\frac{\partial T}{\partial t}=\lambda\left(\frac{\partial^2 T}{\partial r^2}+\frac{1}{r}\frac{\partial T}{\partial r}\right)+q_v \tag{3}$$

where ρ is the density, c - the specific heat capacity, λ - the thermal conductivity and q_v - the volume density of internal heat sources, i. e. the heat generated in unit volume per unit time.

Numerical simulation of technological process of brazing applying induction heating was considered as a coupled electromagnetic and thermal problem (Behulova, 2007). For the electromagnetic analysis, the axisymmetric geometrical model was developed using the program code ANSYS (Fig. 2). The model consists of a copper pipe, a brass flange, brazing alloy, a water cooled induction coil and surrounding air. The flange was modeled simplified without construction details (radii, bevels,…). The thermal analysis took into account only the brazed components. The finite element mesh was generated

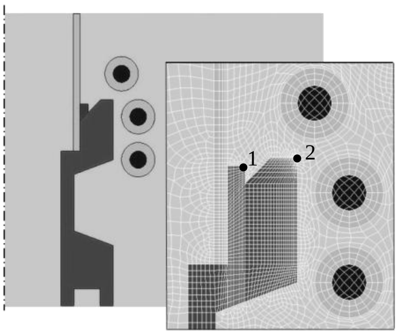

Fig. 2. Axisymmetric geometrical model for electromagnetic analysis with a detail of the mesh in the area of joint development

in compliance with the exponential decay of current density from the surface of components toward the rotational axis. Material properties of brass, copper and brazing alloy were considered to be temperature dependent (***, 2010, ***, 2009). As the brazed materials are non-magnetic, their relative permeability was set to $\mu_r = 1$. The initial temperature was supposed to be 20 °C. Symmetry conditions were applied in the rotational axis. A perfect electric and thermal contact on the boundary of materials was supposed. Heat removal from the surface of heated parts by the mechanisms of convection and radiation was neglected in the initial numerical analyses. Current frequency in induction coil was selected parametrically from the interval from 1 kHz to 25 kHz at current density of $6.8{\times}10^7$ A.m^{-2}.

4. RESULTS AND DISCUSSION

Using the developed simulation model, the initial computations were performed applying the operation frequency of 25 kHz with the aim to define the current density in induction coil necessary for the formation of a good joint. Based on the obtained results, the current density of $6.8{\times}10^7$ A.m^{-2} can be recommended for the investigated brazing process. The following simulations were focused on the evaluation of the influence of operating frequency from the interval from 25 kHz to 45 kHz on the temperature distribution in brazed components.

As it follows from numerical simulations, the time needful to heat the brazing solder to its working temperature (from 30 °C to 50 °C above the liquidus temperature of 793 °C) is shorter (Fig. 3). The heating rate enhances with the frequency increase. On the other hand, the increase in frequency leads to the reduction of skin depth and consequently to the rise of temperature of the brass flange. The maximal temperatures of the brass flange at the moment when the solder attains the liquidus temperature are from 820 °C for the frequency of 25 kHz to 837 °C for the frequency of 45 kHz. The temperature fields in the brazed components in the time of reaching the temperature of solder melting are illustrated in Fig. 4 for the frequency of 25 kHz, 30 kHz and 45 kHz and the current density of $6.8{\times}10^7$ A.m^{-2}. Applying the selected parameters of induction heating, the computed temperatures did not exceed the solidus temperature of copper pipe and also the brass solidus temperature. The increase of the frequency from 25 kHz to 45 kHz results in reduction of heating time from 20.04 seconds to 13.4 seconds. Of course, the application of higher frequencies requires very accurate parameters setting to avoid the possible material overheating in the area of brass flange surface.

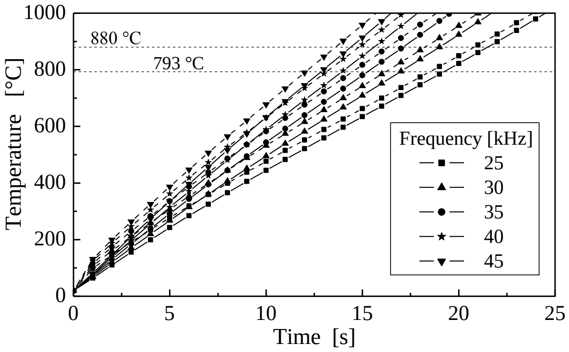

Fig. 3. Time dependence of solder temperature in the node 1 (solid line) and the maximal temperature of the brass flange in the node 2 (dashed line) at considered frequencies

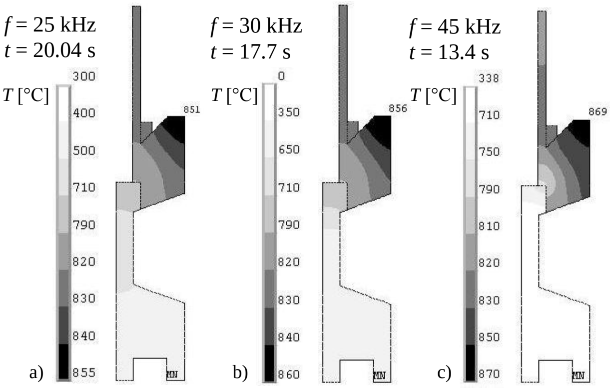

Fig. 4. Temperature fields in brazed components

5. CONCLUSIONS

In the paper, the simulation model and initial results of numerical simulation of electromagnetic and temperature fields developed during brazing of components of solar collectors from combined materials using induction heating are presented. According to the parameters of available laboratory equipment, the frequency of the source current of 25 kHz was considered and compared with results of temperature distribution obtained for higher frequencies up to 45 kHz.

For higher applied frequencies of current in induction coil, the heating rate increases. At the same time, the maximal temperatures of brass flange enhance as a consequence of the decrease in the skin depth. However, it can be concluded that using the suggested arrangement of induction heating with higher frequencies it is possible to attain melting of brazing solder in shorter time without the undesirable overheating of brazed components.

6. ACKNOWLEDGEMENTS

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