Brazing Aluminum Tubes with Induction Heating

The solar energy belongs to very popular and frequently applied renewable power sources. The solar system actively utilizes the solar energy and transforms it to the thermal energy. Collector, connecting tubing and heat consumer (absorber plate) constitute the basic components of any solar equipment. The absorber plates are usually made from aluminum alloy while connecting tubes are fabricated mostly from copper. In connection with requirements laid on the cost reduction, aluminum alloys have started to be exploited for manufacturing of connecting tubing as well. Flame and induction brazing are commonly used to join the connecting tubes and connecting tubes with collection tubes. The induction brazing seems to be very perspective as the induction heating represents a fast, clean, accurate and very efficient method of material heating [1,2].

The novel applications areas of induction heating require analyzing the temperature distribution inside the heated components taking into account the corresponding structures and the material properties. The finite element method (FEM) provides a powerful tool to perform such analyses and optimization of induction heating processes through coupled electromagnetic and thermal numerical analyses and simulations.

The main aim of this contribution is to indicate the possibility of application of the proper, sophisticated and efficient induction brazing technology for the manufacturing of solar collectors based on numerical simulation and performed experiments.

Problem description

This work deals with the design of components for solar collectors suitable for brazing process, namely the parts of collecting tubing (Fig. 1a). Tubes are made from the Al alloy of the AW 3000 type with the chemical composition given in the Table 1. For brazing, the alloy of Al 104 type is used (Table 2) together with the flux Braze Tec 32/80 which residues are non-corrosive. The temperature interval between solidus and liquidus temperatures for the Al 104 brazing alloy ranges from 575 °C to 585 °C. The solidus temperature of the tube material is 650 °C.

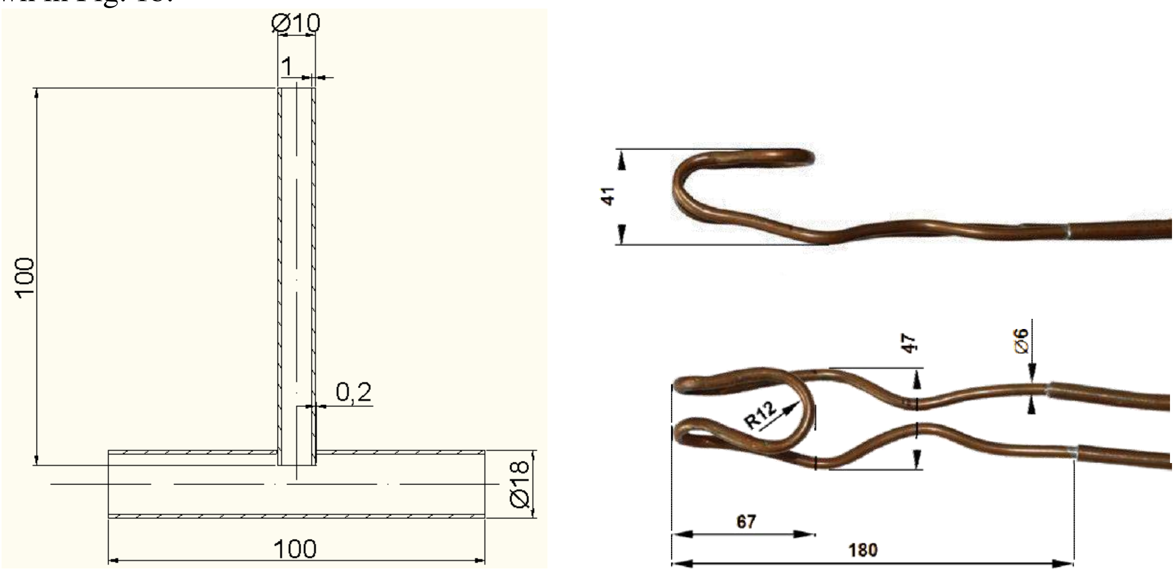
Table 1 Chemical composition of AW 3000 alloy [wt. %]

Si	Fe	Cu	Mn	Mg	Zn	Cr	Al
0.05-0.15	0.06-0.35	max. 0.1	0.3-0.6	0.02-0.20	0.05-0.3	max. 0.25	balance

Table 2 Chemical composition of the brazing alloy of the Al 104 type [wt. %]

Si	Fe	Cu	Mn	Mg	Zn	Ti	Al
11-13	0.6	max. 0.3	0.15	0.1	0.2	max. 0.15	balance

The brazing process supposes the application of induction heating. It is necessary to design the system of induction heating in such a manner that brazing temperatures should be achieved in the joint zone (brazed metals – brazing alloy) in the same time. From this viewpoint, a proper selection of induction coil, its geometry and operation parameters (mainly the frequency and the source current) is very important. The shape and dimensions of the designed copper water-cooled induction coil are shown in Fig. 1b.



(a) (b)

Fig. 1 Dimensions of components a) brazed tubes, b) inductor

The effect of relevant parameters of induction heating on the temperature distribution in the brazed parts was assessed using the numerical simulation of induction heating applying the program code ANSYS 10.0.

Simulation model

In accordance with the methodology of solution of coupled electromagnetic and thermal problems by FEM using the ANSYS 10.0 software [3-5], the simulation model of induction heating process for brazing was developed including geometrical, physical, and initial and boundary conditions. The main aim of numerical simulation was to define the optimum parameters of induction heating (the frequency and the source current) to achieve the required temperature distribution in the zone of joint formation.

Suggested 3D-model (Fig. 2) for electromagnetic analysis consists of the model of tubes, brazing alloy, water-cooled induction coil and surrounding air (not shown in Fig. 2). In the thermal analysis, only the tubes and brazing alloy were considered. A detail of the mesh generated from the linear, 8-node elements in the zone of joint formation is illustrated in Fig. 2b.

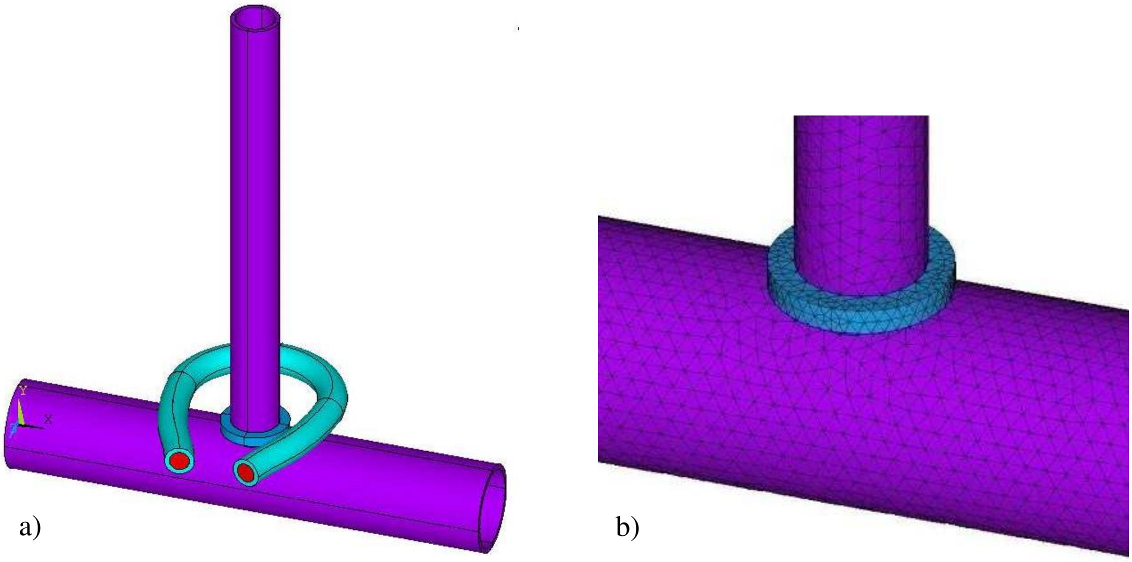
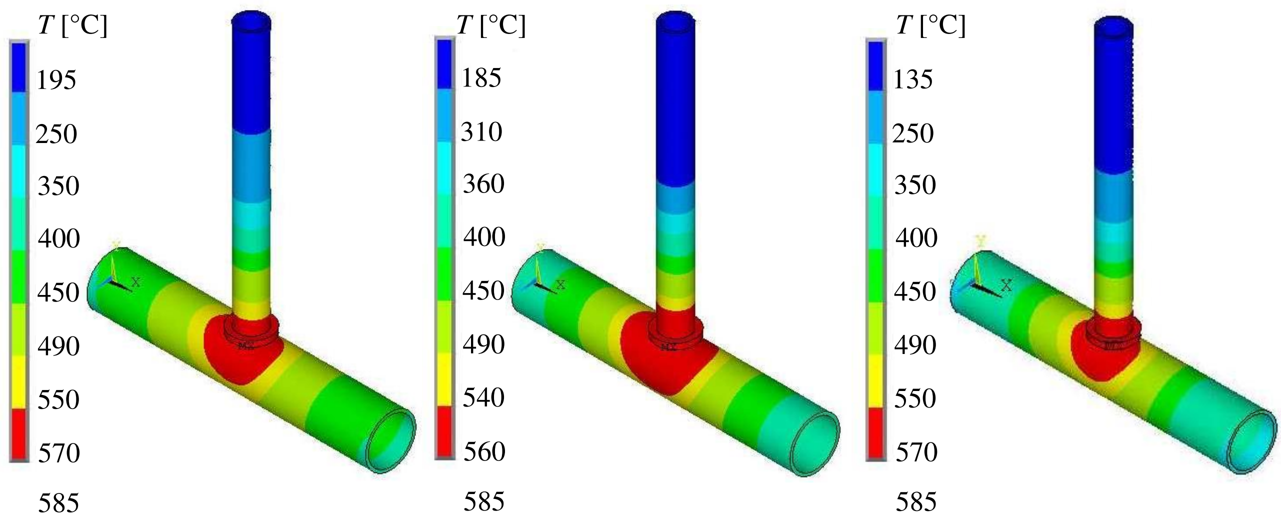


Fig. 2 a) Geometrical model for electromagnetic analysis without surrounding air and b) detail of the 3D mesh generated in the zone of joint formation

The temperature dependences of electric and thermal properties of AW 3000 alloy and Al 104 brazing alloy were obtained using JMatPro software [6]. Following from the fact that the applied materials are non-magnetic, their relative permeability $\mu_r = 1$.

The initial temperature of brazed materials was 20 °C. Perfect electric and thermal contacts on the boundary surfaces of materials were supposed. The frequency of the source current in the induction coil was supposed to be 350 kHz. The value of the source current was defined from the interval from 600 A to 700 A. Cooling of the brazed tubes by free convection and radiation to the air with the temperature of 20 °C was taken into account. Combined heat transfer coefficient dependent on the surface temperature of brazed parts was defined. In Fig. 3, the temperature distribution in brazed components after the achievement of required temperatures in the joint zone are shown for chosen values of applied source currents in induction heating coil. The time of 36 seconds using the source current of 600 A seems to be quite long. The fast heating applying the source current of 700 A cannot be sufficient for the melting of the Al 104 brazing alloy. In this reason the source current approximately of the level of 620 A to 640 A is recommended leading to the brazing times from 25 to 27.5 seconds.



a) $t = 36$ s b) $t = 27.5$ s c) $t = 18$ s

Fig. 3 Temperature distribution in brazed components after the achievement of required temperatures for the source currents of a) 600 A, b) 620 A and c) 700 A

Experimental

The results of numerical simulation of induction brazing were verified using the real experiments. High frequency induction heating equipment HRF 15 was used for fabrication of brazed joints. Surface impurities and oxides were removed from the surfaces of brazing joints and subsequently degreased. The appropriate amount of Braze Tec 32/80 flux was than deposited onto surfaces of brazed parts. Tubes were placed and fixed in the proper position inside the induction coil. Series of brazed joints were produced using the suggested frequency of 350 kHz and the power supply from 9.5 kW to 10.1 kW. Brazing time was changing in dependence on applied equipment power from 24 seconds to 36 seconds.

Brazed joint produced with 9.5 kW power and 36 sec. brazing time is documented in Fig. 4a. Advanced erosion at the surface of the base material was found by visual inspection. The erosion could be associated with the longer brazing time or high temperature. The 9.9 kW power was used for fabrication of the next joint (Fig. 4b), brazing time was 26 sec. Based on visual inspection it can be stated that no visible surface defects were observed in brazed joint.

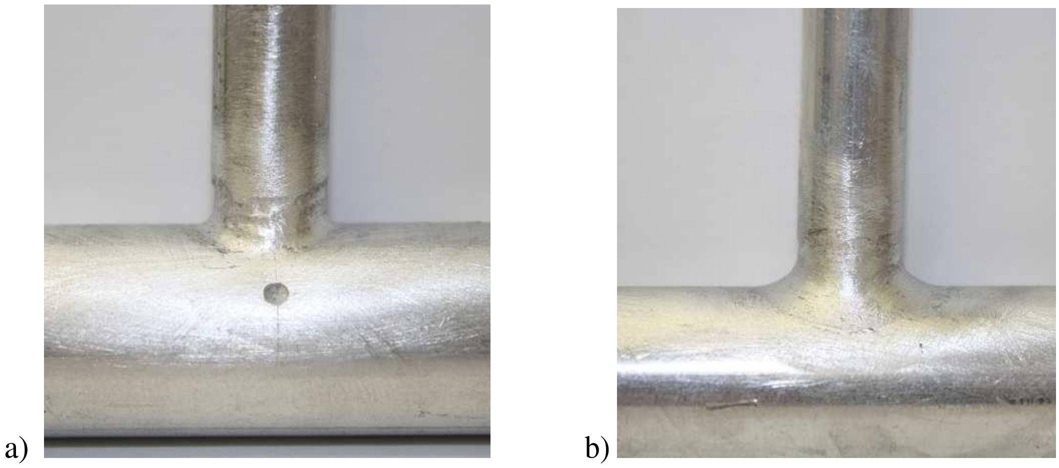


Fig. 4 Brazed joints of collecting tubing

Sufficient filling of the brazed joint clearance with brazing alloy is shown in Fig. 5a where isolated pores were observed. Microstructure of the joint interface is given in Fig. 5b. The presence of voids was observed in brazing alloy used.

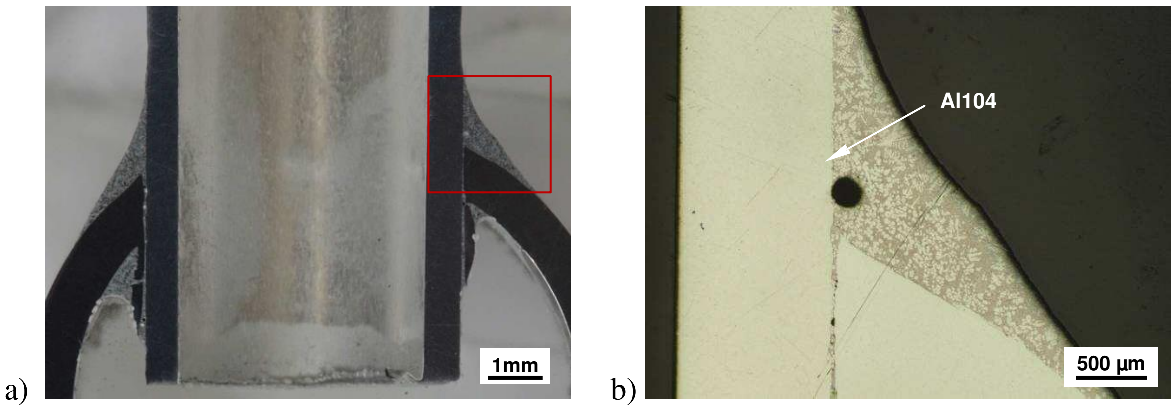


Fig. 5 a) Macrostructure of brazed joint, b) void present in the joint area

This may be caused by the affect of entrapped air, which could not escape in time from the joint zone. No visible inhomogeneities were found in the brazed joint. Tiny porosity does not exert any effect on the joint quality. The brazed joint will not be dynamically loaded and thus it will be suitable for the specified purpose.

Summary

The contribution deals with the design of a suitable technology of brazing for the joining parts of solar collectors, as a substitution for the utilized flame brazing technology. Very important is also the question of the finding of a suitable alternative material for copper from which the manifolds of solar collectors have been made. The Al alloy of the AW 3000 type was suggested as the possible material for the collector tubes.

In order to increase the efficiency and to reduce the thermal effect of metal heating, the induction brazing technology is proposed. Advantage of this technology consists mainly in exact location of heating supplied to the brazed joints. Based on the results of numerical simulation it was then possible to design the parameters necessary to achieve brazing temperatures in the desired time. The aim was to minimize this time to avoid an undesired thermal effect on the metals during metallurgical joining. The results of numerical simulation revealed that increasing the current frequency resulted in concentration of maximum temperatures in surface areas of joined metals. With increasing current, the reduction of time required for reaching the brazing temperature was observed.

The problem of surface oxides was solved by mechanical removal and selection of a suitable flux. Series of brazed joints with the use of Braze Tec F32/80 flux and Al 104 solder was fabricated. Visual inspection, optical microscopy and EDX microanalysis were used for quality control of the brazed joints. The aim of optical microscopy was to assess the presence of discontinuities (voids, pores) and detection of leaking in the brazing alloy. It was found out that longer time caused erosion of the base material with brazing alloy.