4MP7-13

STU MTF

SLOVAK UNIVERSITY OF TECHNOLOGY IN BRATISLAVA
FACULTY OF MATERIALS SCIENCE AND TECHNOLOGY IN TRNAVA

INDUCTION SOLDERING OF CC HTS TAPES WITH LEAD-FREE SOLDER ALLOYS

Marián Drienovský, Eva Michalcová, Marcela Pekarčíková, Marián Palcut, Ľubomír Frolek, Peter Gogola, Igor Jančuška, Jozef Mišík, Fedor Gömöry

ABSTRACT

In the present work, the joints of rare earth barium copper oxide (REBCO) high temperature superconducting (HTS) tapes, with surrounding copper stabilizer were prepared by induction heating. The HTS tapes with the overlap of 35 mm were joined by using two types of Sn-Ag-Cu solder alloys: near eutectic (Sn-3.0Ag-0.5Cu, element concentrations given in wt. %) and hypoeutectic (Sn-0.3Ag-0.7Cu). The soldering temperatures were controlled by thermocouples. The pressure on the joint area was constant.

The quality of the joints has been studied by measuring the room-temperature current-voltage curve, from which the joint electrical resistance, critical current and *n*-value were determined. The electrical characterization has been followed by microstructural investigation of the solder tape interface by using the scanning electron microscopy. The chemical composition of the solder alloys influenced the joint quality. Furthermore, there is a notable decrease in joint resistivity for induction soldered joints in comparison with the near-eutectic solder alloy.

INTRODUCTION

(RE)BCO coated conductors (CC) are expected to be promising for some specific superconducting applications, such as the insert coil of nuclear magnetic resonance (NMR) device, or the resistive fault current limiters (FCL). These applications, however, require several kilometres of superconductor wire in a typical unit. At present, standard length of 100 to 300 m are typically available [1], as it is hard to produce such long CC tape with high and uniform critical current density. Because of these drawbacks the joining of the CC tapes is still essentially needed for manufacturing of superconducting devices. In general, there are three possible joining techniques, including super-conducting joints, diffusion joints and non-superconducting joints using a low melting point soldering materials. Previous study [2] has shown, that the overlapped joints prepared by the diffusion technique exhibit very low contact resistivity. Nevertheless, it is necessary to remove the Cu stabilizer and joining has to be realized in N_2 or O_2 atmosphere. In this regard, the overlap joining with suitable solder alloy [3-5] still remains the alternative for large scale industrial manufacturing as it has a limited number of involved procedures and a moderate temperature range. A relatively new approach in soldering technology is the soldering via induction heating [6, 7]. The potential of the induction heating has not been fully explored in this area yet despite the advantage of the intrinsic induction, i.e., the heat is generated directly in the metallic workpiece and the non-metallic parts are only minimally affected by heat. In non-magnetic metals the heat is generated by eddy currents only. Nevertheless, these currents can not be readily generated in thin metallic tapes. That means they are generated mostly in the solder alloy which is initially in the form of solder balls or wire. In this work we show that the soldered joints of HTS tapes can also be produced by induction heating.

REFERENCES

[1] http://www.superpower-inc.com/content/2g-hts-wire (9.9.2017)
[2] G. Celentano et al., IEEE Trans. Appl. Supercond., vol. 20, no. 3, June 2010
[3] J. Zheng et al., IEEE Trans. Appl. Supercond., vol. 27, no. 5, August 2017
[4] N. Bagrets et al., IEEE Trans. Appl. Supercond., vol. 26, no. 4, June 2016
[5] E. Michalcová et al., IEEE Trans. Appl. Supercond., vol. 26, no. 3, April 2016
[6] M. Yang et al., J. Mater. Processing Technol. 236 (2016) 84–92.
[7] M.X. Chen et al, Sci. China Tech. Sci. 53 (2010) 1252–1257.

ACKNOWLEDGMENT

The authors wish to acknowledge the support from the Grant Agency VEGA under contracts No. 1/0811/14, 1/0068/14 and 1/0151/17 and to project "Inkubátor nových nápadov a myšlienok č. 1371".
This contribution is the result of the project implementation: Centre of excellence for development and application of advance diagnostic methods in processing of metallic and non-metallic materials, ITMS:26220120048, supported by the Research and Development Operational Program funded by the European Regional Development Fund.

CONTACT

Slovak University of Technology in Bratislava
Faculty of Materials Science and Technology in Trnava

Address: Jána Bottu 25, 917 24 Trnava, Slovakia
email: marian.drienovsky@stuba.sk
web: www.mtf.stuba.sk

EXPERIMENTS

Superconducting tape SCS4050-AP with surrounding copper stabilizer (SuperPower) was used for testing the solderability by electrical and microstructural investigations. The width of the tape was 4.1 mm and its overall thickness was 95 µm. The self-field critical current measured in liquid nitrogen was 141 A. Pieces about 80 mm long were cut from the tape and used to prepare the overlap joints. The tape pieces were soldered face-to-face using the lead-free solders Sn-3.0Ag-0.5Cu (SAC305) and Sn-0.3Ag-0.7Cu (SAC0307) specified in Tab 1. The flux was a resin-isopropyl alcohol mixture.

The induction soldering was performed in a plastic mould made from polytetrafluorethylene (PTFE). The mould was used to fix the precise positions of soldered HTS tapes. The solder was heated by a pancake type inductor made of Cu tube (outer diameter 5 mm). The Rajmont HFR15 induction device (Fig. 1) was the source of high frequency (300 kHz) electromagnetic field. After the melting, the mould with the soldered sample was moved to cold water to ensure a high cooling rate.

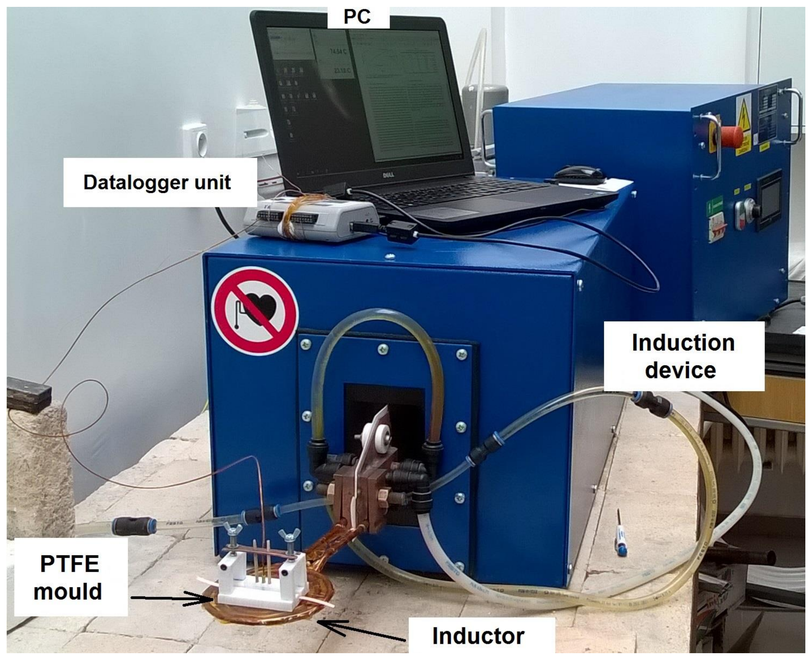

Fig. 1. Experimental setup for soldering by induction heating

Tab. 1 Chemical composition (in wt.%) and melting temperatures of utilized solder alloys

Solder alloy	Sn	Ag	Cu	Melting temp. (°C)
SAC305	96.5	3.0	0.5	217.5 – 221.0
SAC0307	99.0	0.3	0.7	217.5 – 228.0

During soldering a time-temperature reflow profiles were recorded with a fine K-type thermocouple. Two time-temperature profiles are given in Fig. 2. The blue curve represents the induction soldered sample while the red curve shows the sample soldered by electrical resistance heating [5]. Both reflow profiles were recorded with periodicity of 250 milliseconds by the help of the datalogger module OM-DAQ-USB-2401. Although the temperature measurements with thermocouple are problematic at induction heating, the results show that the time of soldering was less than 20 seconds.

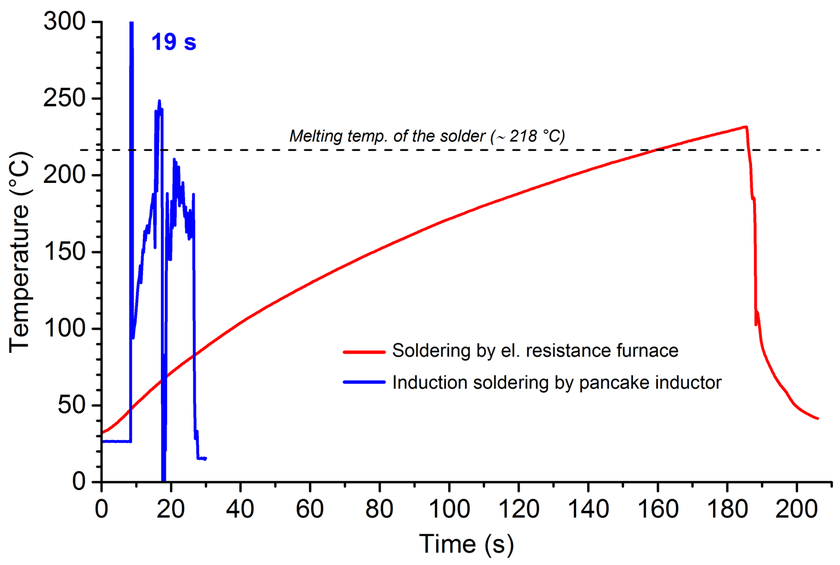

Fig. 2 Temperature profiles recorded during soldering

RESULTS

Electrical properties of soldered specimens were measured at 77 K in a liquid nitrogen bath. The four probe method was used to record the voltage-current curve. The results of the measurements are presented in Fig. 3 and summarized in Table 2. The present data are compared with data from our previous study [5]. The cross-sections of the samples were prepared by laser-cutting. The tape was cut along its width (cross-section was perpendicular to long-length of tape) and polished with Ar ions using the cross-section polisher device JEOL SM-09010. The microstructure of solder joint was investigated by scanning electron microscope JEOL JSM7600F and the chemical composition was estimated with coupled energy dispersive X-ray spectroscopy (EDX).

The microstructure of the overlap joints consisted of Sn-rich matrix containing Cu_6Sn_5 (SAC0307, Fig. 4 a) and Ag_3Sn intermetallic particles (SAC305, Fig. 4 b). At the interface between the Cu stabilizer and the solder two intermetallic layers of Cu_6Sn_5 and Cu_3Sn were found. The average thickness of the soldered area including intermetallic layers was 15 µm in case of hypoeutectic SAC0307 solder and 8 µm in case of near-eutectic SAC305 solder. The thickness of the joint was probably influenced by physical and technological properties of the used alloys (wetting, spreading, surface tension, etc.).

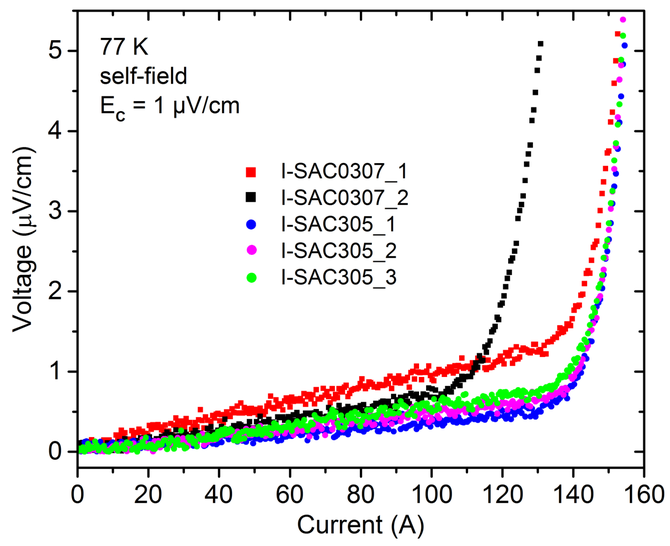

Fig. 3 Voltage – Current curves of investigated joints

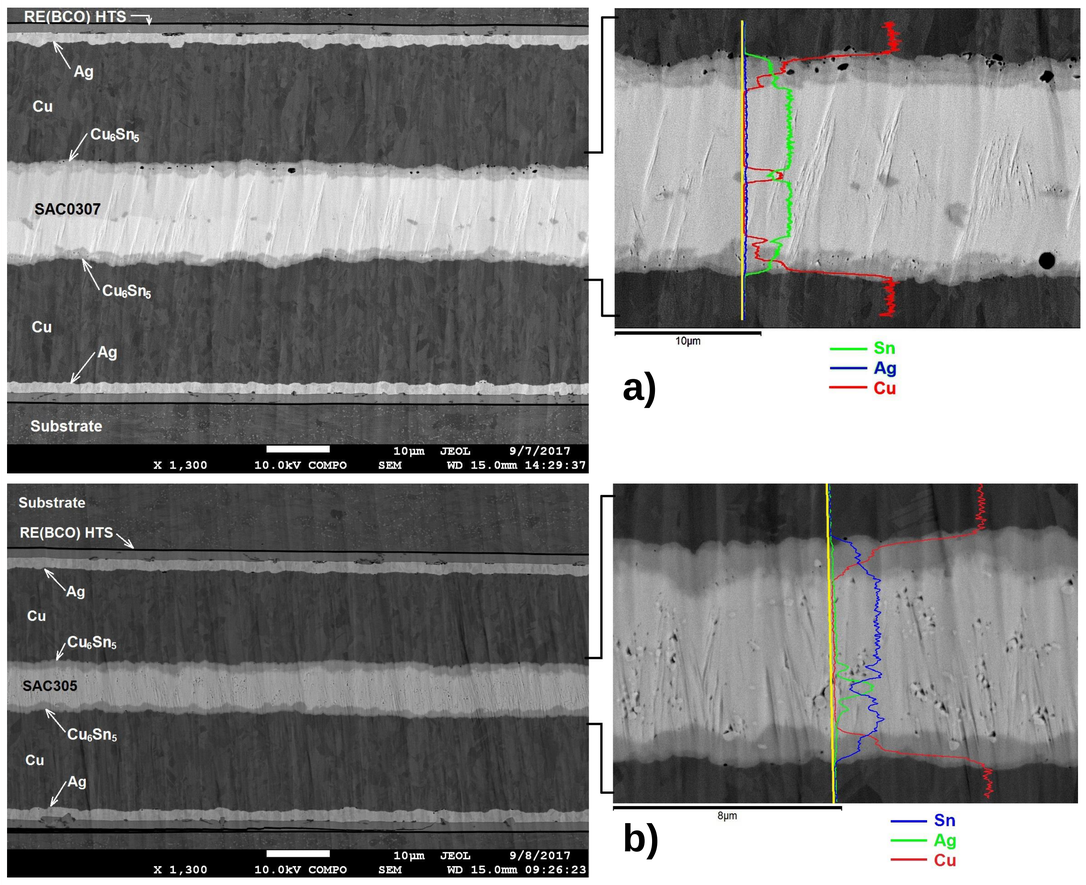

Fig. 4 SEM-EDX micrographs of overlapped joints soldered with SAC0307 (a) and SAC305 lead-free solders (b)

Tab. 2. The electrical characteristics of jointed samples. Prefix I – induction soldered by pancake inductor and R – reflow soldered by hot-plate furnace

Sample	Joint resistivity (nΩ.cm²)	I_C / I_{Cref} (A)	n_0 / n_{0ref}
I-SAC0307_1	81.2	136.6 / 141.0	14.4 / 27.6
I-SAC0307_2	57.7	113.9 / 141.0	11.8 / 27.6
I-SAC305_1	40.6	143.4 / 141.0	21.5 / 27.6
I-SAC305_2	47.4	143.7 / 141.0	23.8 / 27.6
I-SAC305_3	49.5	142.6 / 141.0	20.8 / 27.6
R-SAC305_1 [5]	71.0	407.3 / 395.0	27.2 / 31.0
R-SAC305_2 [5]	70.0	393.9 / 395.0	21.9 / 31.0
R-SAC305_3 [5]	67.0	385.7 / 395.0	17.8 / 31.0

SUMMARY

In this work, the soldered joints of 2G HTS tapes were successfully produced via induction heating. The joint characteristics of each sample were investigated by electrical measurements in LN2 as well as by microstructural observation. It was found that the quality of the joint is influenced by both, chemical composition of the solder alloy and the soldering technology. The induction-soldered joints with near-eutectic solder alloys (SAC305) exhibited the best joint resistivity and I_C/I_{Cref} ratio. Moreover, the number of the voids between the solder – Cu stabilizer interface was notably smaller. The reasons of these findings will be discussed in a related manuscript.