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Investigation of soldered low-resistance joints for coated conductors

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Abstract

The experimental investigation of resistance and thermal impacts stability of coated conductor joints has been carried out. We measured resistances of solder layers with the thicknesses ca. 10, 20, 30 and 40 μm and additionally studied their stability against thermal impacts. The obtained results show a high quality of this joints and their applicability, e.g., for design of current leads in various superconductive energy applications.

Keywords: coated conductors, low-resistance joints

1. INTRODUCTION

Nowadays, one of the important problem for development of electrical power applications based on coated conductors (CC) is the fabrication of joints both of individual tapes and current leads modules. The requirements to these joints are very strong, and one of them is the low resistance (30-50*10^{-9} Ohm/cm^2 at 77 K) combined with the high uniformity of thickness and width of the solder layer and stability under mechanical loads and repetitive thermal impacts [1-5]. It helps to avoid local overheating of the tapes, subsequent decreasing of transport current and normal zone propagation [6-9].

The obtained experimental results showed that developed soldered joints had demonstrated high quality and stability under thermal impacts. We have investigated two types of 2G HTSC CC – 4 mm wide tape manufactured by SuperPower Inc. (USA, NY) and 12 mm wide tape by SuperOx (Russia, Moscow) [4]. Both of these CC's were stabilized by copper with thickness of 20 μm.

2. SAMPLES AND FABRICATION OF JOINS

The soldering procedure was then performed by using of a simple tool (Fig. 1) with controlled pressure force (up to 15.0 MPa during to 120 seconds). The surfaces of both types of CC`s were preliminarily cleaned by neutral organic solvents. Then, they were coated by soldering alloys with using of standard soldering iron (Fig. 2b). For SuperPower tapes we used the indium-tin solder POIN-52 (In 48%, Sn 52%, t_{melt}=120^{0}C) at their allowable heating temperature 165^{0}C, for SuperOx tapes we used lead-tin solder POS-61 (Sn 61%, Pb 39%, t_{melt}=190^{0}C) at 205^{0}C. Note that the low temperature resistivity of POS-61 is significantly lower than of POIN-52. Two overlapped tapes pressed together at a certain length then subsequent heating up to the desired temperature controlled by a thermocouple and then were cooled down to room temperature. The schematic illustration of the soldering procedure, photography of two soldered tape and optical micrographs of cross-section of the samples are shown in Fig. 2 and Fig. 3, respectively.

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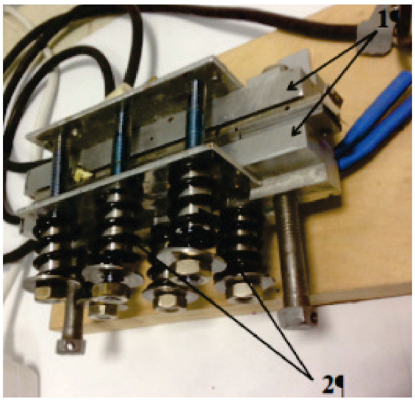

Fig. 1. Photography of the tool that used for fabrication of joints (1-metallic heater which clamps the CC samples; 2-springs which provide compressive force).

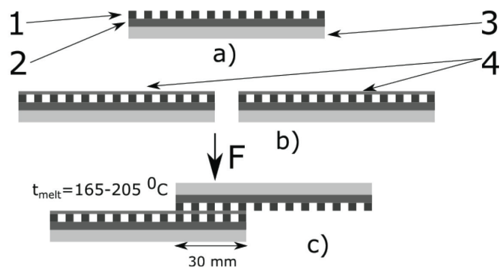

Fig. 2. Schematic illustration of the soldering procedure of the two tapes (1-Copper stabilizer layer, 2-YBCO layer, 3-buffer/substrate, 4-thin solder layer).

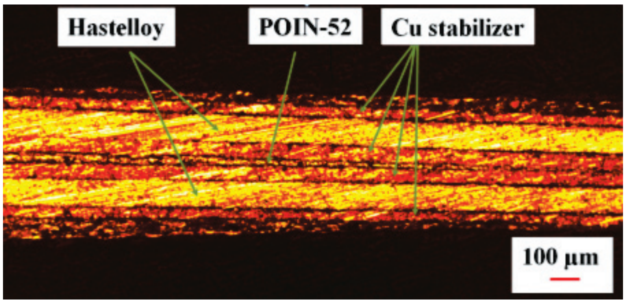

Fig. 3. Optical micrographs of the cross-section of the soldering samples.

3. EXPERIMENTAL TECHNIQUE

The measurements of voltage-current characteristics (VCC) of the soldered CC joints were performed using traditional four-probe method.

We used two units of HP 6031A power supply source connected in parallel and having low ripple level and high current stability to generate the transport current in the sample. The maximum current is 240 A with controllable current ramp rate (dI/dt) up to 2 A/s. The typical dI/dt we used in all experiments was 0.4 A/s. Transport current (voltage on the reference shunt U_e) and voltage on the sample were measured by the HP 3474A digital multimeter and Keithley 181 nanovoltmeter, respectively. The sample voltage taps were located as far as possible from the current leads at least 150 mm to avoid any interference which could affect the measurements.

4. RESULTS AND DISCUSSION

The typical VCC of the soldered SuperPower joint is shown on Fig. 4. The critical current (I_c) of the soldered SuperPower CC joints was the same that one previously measured for the single tapes - 99 A, the n-index of VCC is equal to 26, and also matches to the value for the single tape.

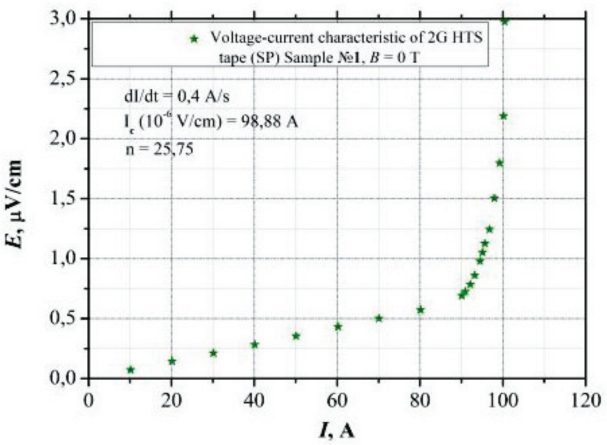

Fig. 4. VCC of the soldered SuperPower CC join at the temperature T=77.3 K.

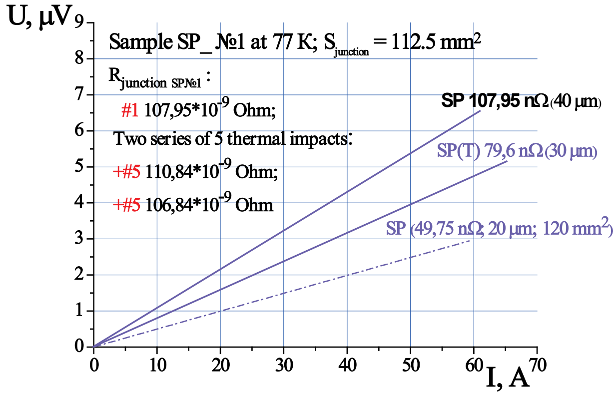

Fig. 5. The results of soldered joint resistance measurements for SuperPower CC tapes.

The results of the resistivity measurements for two soldered SuperPower CC joints (the solder layer thickness is 40 µm) after first cooling down in liquid nitrogen (LN2) are shown on Fig. 5. It was equal to $107.9 \cdot 10^{-9}$ Ohm. Then the sample was subjected to 2 series of 5 similar thermal impacts (it means that tape immersed into LN2 then take out and was heated by industrial heat gun ($t=80^0$C) to room temperature, then process repeated), and the resistance was $110.8 \cdot 10^{-9}$ and $106.8 \cdot 10^{-9}$ Ohm, respectively, which is an obvious indicator of the high stability of these joints under thermal impacts and that our soldering procedure has been done.

Then joint was put in our soldering tool again and then was heated up to 165^0C and pressured to 30 µm thickness of the solder layer. In this case the resistance was $79.6 \cdot 10^{-9}$ Ohm. The calculated value of the joint resistance with the solder thickness of 20 µm was about $49.75 \cdot 10^{-9}$ Ohm, this value is in a good agreement with the results of [10, 11].

In Fig. 6 demonstrates the results of investigations of the SuperOx tapes (S=12.0×67.0 mm^2 and S=12.0×77.0 mm^2). In this figure the resistivity of all tapes interfaces and soldered joints are presented. We can see that the joints were stable under thermal impacts: the difference in total resistances after the first thermal impact ($\Sigma R\#1 = 20.95 \cdot 10^{-9}$ Ohm) and the third one ($\Sigma R\#3 = 21.67 \cdot 10^{-9}$ Ohm) did not exceed 3.5%. soldered joints are

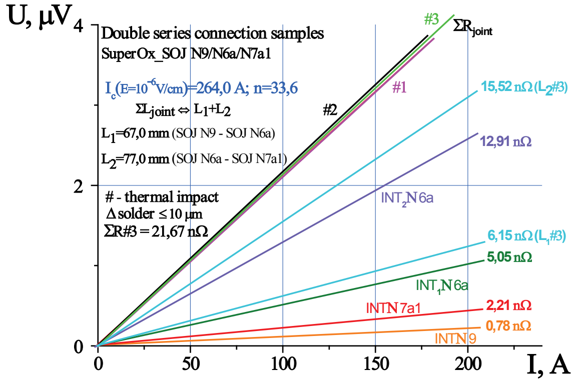

Fig. 6. The results of soldered joint resistance measurements for SuperOx CC tapes.

TABLE I
THE RESISTANCE MEASUREMENT RESULTS FOR SUPERPPOWER AND SUPEROX CC SAMPLES.

Type of sample	Number of thermal impacts	Area of joint, mm^2	Thick-ness of joint, µm	Value of resistivity $*10^{-9}$, Ohm
Super Power	0	30*4	40	107.95
	5	30*4	40	110.84
	5 (after first 5)	30*4	40	106.84
	0	30*4	30	79.6
	0	30*4	20 (calculation)	49.75(that is in a good agreement with the results of [5, 6])
SuperOx	1	12*67	10	$20.95*10^{-9}$
	3	12*67	10	$21.67*10^{-9}$

presented. We can see that the joints were stable under thermal impacts: the difference in total resistances after the first thermal impact ($\Sigma R\#1 = 20.95*10^{-9}$ Ohm) and the third one ($\Sigma R\#3 = 21.67*10^{-9}$ Ohm) did not exceed 3.5%.

5. CONCLUSION

The experimental investigations of soldered joints of various 2G HTSC tapes had been performed. The joints were fabricated by simple tool which allowed controlling heating up and pressure forcing. The obtained results confirm high quality of these joints. The joints had relatively low resistivity level and demonstrated high stability under repetitive thermal impacts and potential for further decreasing of the solder layer even after the tests in liquid nitrogen. Table 1 summarizes the results of resistance measurement for SuperPower and SuperOx CC samples.

The fabricated joints can be used in electrical power systems e.g. in current leads.

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