Effects of uniaxial constant pressures on the joint properties of REBCO coated conductors

Nobuyuki Mori¹, J. Yoshida¹, T. Maebatake¹, R. Teranishi¹, M. Mukaida¹, K. Yamada¹, M. Miura², M. Yoshizumi², T. Izumi²

¹Kyushu University, 744 Motooka, Nishi-ku, Fukuoka, Fukuoka 819-0395, Japan
²Superconductivity Research Laboratory (SRL) - ISTEC, 1-10-13 Shinonome, Koto-ku, Tokyo 135-0062, Japan

E-mail: mori-ny@zaiko.kyushu-u.ac.jp

Abstract. We studied the effects of uniaxial constant pressures by using some weights on the properties of the diffusion joints using Ag stability layers of REBa₂Cu₃O₇−ₓ (REBCO, RE=Y, Gd) coated conductors. Two tapes were stuck in a face to face manner with Ag surfaces in contact, and were pressed uniaxially during the joining under a constant pressure at 673K in a pure oxygen atmosphere. The Ag area at the joint was 6x5 mm² for YBCO coated conductors produced by modified metal-organic deposition (MOD) process using precursor solution of trifluoroacetates (TFA) for Y and Ba and F-free salt for Cu. A very low resistance of about 10 nΩcm² across the joint was achieved by the diffusion joining under the pressure of 10 MPa. The relations between the joint resistance, the joint structure and the joint pressure were investigated.

1. Introduction

REBCO (REBa₂Cu₃O₇−ₓ, RE=Y, Gd) coated conductor (CC) is proposed for superconducting power apparatuses. Since it is hard to make long CC tape with uniform high critical current density, the joint techniques for the tapes are essential for their practical applications and should be investigated. Among the joint processes, although soldering is a simple joint technique, resistance across the joint is high because it includes resistance of a soldering material, Ag layer and contact resistance of their interfaces. On the other hand, diffusion joining using Ag stabilizing layers, in which an Ag surface is put over the other in a face to face manner, can reduce the resistance across the joint without resistance of a soldering material [1-6]. Since some parameters in the Ag diffusion joint process may influence joint resistance, it is necessary to know about factors of the diffusion joint process. In this paper, we studied the effects of joint pressures on the joint properties of REBCO coated conductors

2. Experimental

YBCO coated conductor (CC) tapes fabricated by modified metal-organic deposition (MOD) process using precursor solution of trifluoroacetates (TFA) for Y and Ba and F-free salt (MOD-YBCO), which were stacked Ag, YBCO, buffer layer (CeO₂, Gd₂Zr₂O₇ (GZO) etc.) on the Hastelloy were used to make the joint as shown in Figure 1(a). Figure 1(b) shows experimental apparatus (with heater and loading apparatus) of the joint experiment. Iₓ of the tapes measured in liquid nitrogen before the joint process were over 150A. The tapes were set in a Inconel holder with the state that Ag surfaces were stuck together in a face to face manner with an
Then, they were held to make the diffusion joint in the experimental apparatus under a load between 2 ~ 40 kg (pressure=0.7 ~ 13 MPa for the joint area of 6x5 mm$^2$) at the temperature of 673K in pure oxygen gas flow for 1 h and cooled in the apparatus to room temperature. The $V$-$I$ properties across the joint after joining were measured in liquid nitrogen by four-probe method. The resistance (and the resistance area product) was obtained from the initial slope of the $V$-$I$ curve. Further, GdBCO CC tapes fabricated by pulsed laser deposition (PLD-GdBCO) were also used to make the joint, and the joint properties were measured.

3. Results and discussion

MOD-YBCO tape was joined using diffusion of Ag stabilizing layer under a pressure between 0.7 and 13 MPa in an oxygen atmosphere. Figure 2 shows the relations between the resistance ($\Omega$cm$^2$) of the joint and the joint pressure (MPa). The joint resistance decreased with increase in pressure until it reaches about 10MPa. The resistance of about 10 n$\Omega$cm$^2$ was obtained at 10MPa. However, the resistance seems to increase again, when the pressure increased over the above pressure. Further, the lowest resistance of about 6-7n$\Omega$cm$^2$ for SRL specimen [6] is shown in the figure, which means that more improvement in joint resistance is possible.

Figures 3 (a) and (b) show microstructures of the sectional areas of joints. In the fig.3 (a) for the specimen joined at the pressure of 0.7 MPa, some interface-like lines can be seen at the joined central position of Ag layers. This means that insufficient joint was produced by insufficient joint pressure. On the other hand, in the fig.3 (b) for the specimen joined at 13 MPa, almost uniform Ag layer was created. Fig.3 (c) also shows uniform Ag microstructure of SRL specimen joined at 10 MPa. Further, when the surface of Ag stabilizing layer was polished beforehand, the diffusion process is promoted effectively, and the low resistance across the joint was achieved [6].

It is known that Ic of joined specimen is reduced substantially when the joint pressure is above 30 MPa, and this result was attributed to the cracks in the joint [1, 5]. So, in the case of high pressure, some cracks and/or some defects may form in the YBCO layer in the joint, and Ic may decrease and the resistance may increase because of decrease in the contact area. The above phenomena to increase the joint resistance may be also increased by the unevenness of the joint tapes and the holders, as shown in figure 4 (a). Such unevenness enhances the unevenness of the pressure distribution. Figure 4 (b) shows even pressure distribution (deep red part indicates high pressure region) at the contact area of the joint, and fig.4 (c) shows uneven pressure distribution, which was occurred when the substrate tape has uneven shape formed by the cutting of the tape.

Fig.1 Schematic drawing of experimental apparatus and specimen. (a) CC tapes for the joint, (b) joint apparatus with heater and loading weight.

overlapped area of 6x5 mm$^2$. 

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By the way, it is known that the resistance was 96 nΩcm$^2$ in the case of the sample joined using a soldering material, which was larger than that for the diffusion joint. [5]

![Graph showing the relationship between joint resistance and joint pressure for YBCO tapes joined at 673K in pure oxygen gas. (SRL: Superconductivity Research Laboratory)](image1)

**Fig.2** Relations between joint resistance and joint pressure for YBCO tapes joined at 673K in pure oxygen gas. (SRL: Superconductivity Research Laboratory)

![Images of microstructures of the sectional areas of joints. (a) Specimen joined at the pressure of 0.7 MPa, (b) Specimen joined at 13 MPa, and (c) SRL specimen joined at 10 MPa.](image2)

**Fig.3** Microstructures of the sectional areas of joints. (a) Specimen joined at the pressure of 0.7 MPa, (b) Specimen joined at 13 MPa, and (c) SRL specimen joined at 10 MPa.

![Images illustrating unevenness of substrate, affecting pressure distribution and joint defect/property distribution. (b) Even pressure distribution at a joined part, (c) Uneven pressure distribution.](image3)

**Fig.4** (a) Unevenness of substrate, which affects pressure distribution and joint defect/property distribution. (b) Even pressure distribution at a joined part, (c) Uneven pressure distribution.

From the above results, we can show the factors affecting the joint resistance of YBCO tapes, as shown in figure 5. The joint resistance decreases with increase in pressure by the improvement of diffusion joining of Ag, and this can be enhanced by surface cleaning and/or proper joining temperature and time. On the other hand, the joint resistance increases with increase in pressure by the degradation of YBCO caused by uneven deformation of Ag because of unevenness of substrate and/or holder, and this can be decreased by using even substrate and/or even holder.

Joints of GdBCO tapes (PLD-GdBCO) were also fabricated under the pressure of 10 MPa, and their
resistances were measured to be about 50-60nΩcm$^2$. To improve the joint structure and property, we need some changes of the above factors.

4. Conclusions
REBCO coated conductors (RE=Y,Gd) were joined by diffusion joining using Ag stabilizing layer under some constant pressures, and the joint resistances were measured by four-probe method in liquid nitrogen.

(1) Joint resistance of joined YBCO tapes decreased with increase in pressure until it reaches about 10MPa. The resistance of about 10 nΩcm$^2$ was obtained at 10MPa. However, the resistance had tendency to increase again, when the pressure increased over the above pressure.

(2) The above decrease in joint resistance with increase in pressure was attributed to the improvement of diffusion joining of Ag, and this was able to be enhanced by surface cleaning and/or proper joining temperature and time. On the other hand, the increase in resistance with increase in pressure was because of the degradation of YBCO caused by uneven deformation of Ag and unevenness of substrate and/or holder.

(3) Joint resistance of GdBCO tape was also measured, and was about 50-60nΩcm$^2$. This result needs more improvement by the change of the above factors.

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