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核融合マグネットの分割製造のためのインジウムを用いたREBCOラップ接合の曲げ捻り特性評価

Evaluation of Bending and Twisting Characteristics of REBCO Lap Joint with Indium for Segment-fabrication of Fusion Magnets

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1. Introduction

Bridge-type mechanical lap joint of simply stacked Rare-Earth Barium Copper Oxide (REBCO) conductors with indium foil insertion has been proposed for segment-fabrication of high-temperature superconducting (HTS) magnets especially for a heliotron-type fusion reactor FFHR-d1 [1]. Previous studies have investigated straight mechanical joints of STARS conductors [2]. On the other hand, segment-fabrication of helical shaped coil ideally needs bent and twisted joint parts, therefore, the evaluation of bending and twisting characteristic of the lap joint is necessary. There are two procedures to fabricate the joint parts, 1) joint, twist, and bend (JTB), and 2) twist, bend and joint (TBJ) procedures. In this study, joint and bend (JB), and joint and twist (JT) testing were performed to evaluate critical strain for the former as well as bend and joint (BJ), and twist and joint (TJ) testing for the latter. In previous research [3] the JB testing was performed but no pickling process [4] was applied to improve joint characteristic.

2. Sample preparation

For joint samples 4-mm-wide REBCO tapes were used, whose critical current is 98 A at 77 K, self-field. As joint interface material, 100-μm-thick indium foil was used. We applied the pickling process [4] and heat treatment at 90°C [5] to complete fabricating process of the joint to reduce joint resistance. Evaluated joint resistivity (= product of joint resistance and joint area) for the single lap joints was 20-30 nΩcm^2 at 77 K, self-field. In samples prepared for JB testing, Samples J1 with joint length, L_J, was 5, 8 and 20 mm, J2 and J3 with L_J = 8 mm are lap joints of REBCO tapes showed in Fig. 1. In JT testing, Sample J1 with L_J = 5 mm and used the twist jig with 5 MPa pressure to apply torsion strain to the joint. In BJ and TJ testing, the tape was fixed on bend or twist jig then joining and L_J was 5 mm.

3. Result and Discussion

In JB testing, critical current deteriorated at a bending strain larger than 0.6%, which is induced at REBCO layer inside the REBCO tape. Since the irreversible strain of REBCO tape was reported to be 0.6% [6], the result is reasonable. For evaluating joint resistance, the bending strain of interface of REBCO tape and indium foil, ε_{b_int} needs to be considered. ε_{b_int} is calculated by the following equation,

$$\varepsilon_{b\_int} = i/(2r + 2t + i) \quad (1)$$

where t is thickness of the sample, and r is bend radius of bend jigs, i is thickness of indium foil. Fig. 2 shows results in JB testing. By comparing with a previous study [3], the joint resistivity decreased from 42 nΩcm^2 to 20-30 nΩcm^2 by using pickling process. The joint resistivity increased when bending strain, ε_{b_int} = 0.2% with L_J = 5 mm, ε_{b_int} = 0.4-0.6% with L_J = 8 mm and no increase until ε_b = 0.2% with L_J = 20 mm. In a previous study [3], the joint resistivity started to increase at about ε_{b_int} = 0.17-0.26% with L_J = 5 mm and ε_{b_int} = 0.52-0.61% with L_J = 10 mm. The result indicates critical bending strain for joint resistivity depends on the joint length but not on whether the pickling process is performed. In a previous study [3], samples with higher joint resistivity showed lower critical bending strain, but in JB testing there is no significant impact when joint resistivity is lower than 40 nΩcm^2. In JT testing, no increase in joint resistivity and no decrease on critical current were confirmed at torsional strain lower than 0.26%. In the evaluation of the actual FFHR-d1 conductor, it can be found that the bending and torsional strain of the conductor is much smaller than the critical strain. In the BJ, and TJ testings for TBJ procedure, the joint resistivity equivalent to that of the straight joint sample was obtained. No increase in joint resistivity or decrease in critical current was observed at 10-100 mm bending radius and 50-350 mm twist pitch. The TBJ procedure can also be applied not only to FFHR-d1 but also to smaller and more complex coils.

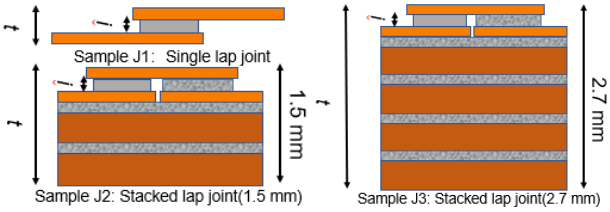

Fig. 1 Test samples in JB testing

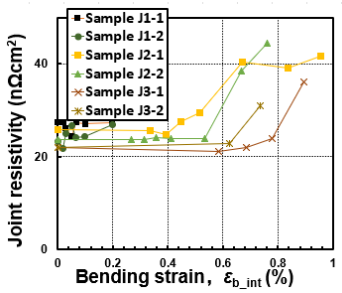

Fig. 2 Joint resistivity of bending strain for Samples J1, J2, J3 (L_J = 8 mm)

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