§17. Study on Effects of Bending Strain to Critical Current Characteristics of Nb_3Al CIC Conductors

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Nb_3Al conductor has the advantage in less degradation of critical current against the bending strain, which has been observed in previous R&D works. This attractive feature has a strong advantage in the coil winding process and in the operation window of conductor. Operation window will be widely extended towards higher magnetic field. In winding process, so-called react-and-wind (R&W) method can be adopted, which considerably reduces a manufacturing cost and a time schedule.

In previous investigation on the bending strain dependence of Nb_3Al conductor[1], the critical current, I_c, did not decrease up to 0.4% in bending strain and slightly decreased when bending strain exceeded 0.4%. The I_c at the maximum bending strain of 0.55% showed 96% of I_c without bending.

In this work, a sample with a smaller void fraction of 25% is newly fabricated. Strands in the new sample are hard to move compared to the previous sample with a void fraction of 36%. The detail of the sample and the experimental procedure is shown in Ref.1. Figure 1 shows the dependence of the I_c on the bending strain in the external magnetic filed of 11.3 T. Self field is not taking into account. The decrease of I_c of lower void fraction sample (closed circle) is smaller than that of larger void fraction sample (open circle). Thus, the reason of smaller degradation of I_c of larger void fraction sample is possibly attributed to the strand movement. However, the conduit volume of each sample is different, so that the thermal strain is different. The further analysis is required to discuss the results in detail.

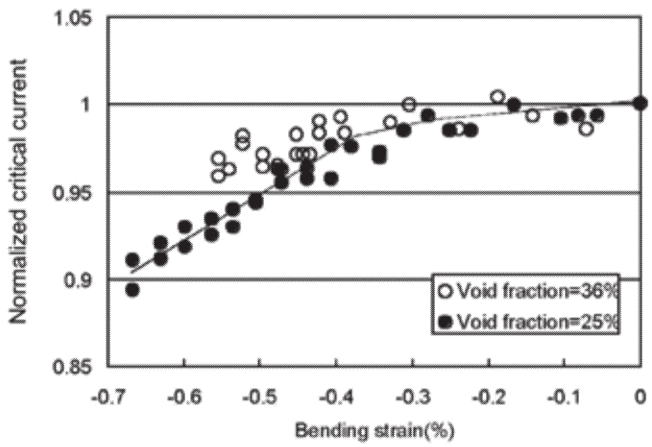

Fig. 1. The strain dependence of normalized critical current.

The application of the measured results to the DEMO TF coil fabrication is considered. When the cable with the curvature radius of R_1 is wound into the circular arc of R_2 in curvature radius, the bending strain, ε_b, is written as

$$\varepsilon_b = d/(2R_2) - d/(2R_1), \quad (1)$$

where d is the cable diameter.

For a case study of large superconducting coil, a large D-shaped coil like the ITER TF coil is considered. A D-shaped coil consists of one straight part at inboard leg and several circular arcs. Generally, adjacent arcs of the straight part referred as the 1st arc have the minimum curvature radius. From Eq. (1), the bending strains at the straight part (ε_{bs}) and the 1st arc (ε_{ba}) are written as

$$\varepsilon_{bs} = d/(2R_h), \quad (2)$$

$$\varepsilon_{ba} = d/(2R_a) - d/(2R_h). \quad (3)$$

The R_h and R_a are the curvature radius at the heat treatment and that of the 1st arc, respectively. The ε_{bs} and ε_{ba} have to be smaller than the allowable bending strain.

Figure 2 shows three different circular sizes allowable during heat treatment for a D-shape coil which depend on the acceptable strain. The height of winding, the curvature radius of innermost turn at the 1st arc and the cable diameter is assumed to 13.3 m, 1998 mm and 40.2 mm, respectively. Applying Eq (2), it is possible to calculate bending strains of 0.4, 0.6 and 0.8% corresponding to three different shapes during the heat treatment. The diameter of the heat treatment shape ($2R_h$) is 10.05 m for 0.4%, 6.7 m for 0.6% and 5.025 m for 0.8%. The minimum R_a from Eq. (3) for 0.4, 0.6 and 0.8% are 2512.5, 1675 and 1256.25 mm, respectively. Since the minimum R_a of 0.6% in bending strain is smaller than 1998 mm, R&W method can be applied on the fabrication of this coil. For the case of wind-and-react (W&R) method, the furnace of heat treatment with 13.3 m is required. On the other hand, for the case of R&W method with allowable bending strain of 0.6%, furnace size becomes half of W&R method.

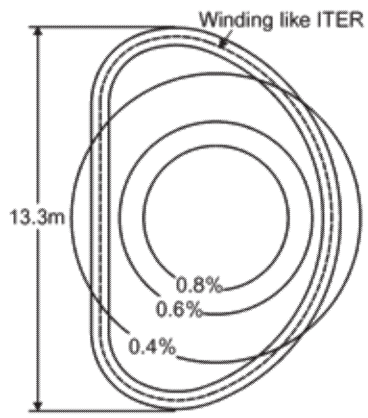

Fig.2. The size comparison between D-shaped coil like the ITER winding and heat-treatment for R&W method with allowable bending strain of 0.4%, 0.6% and 0.8%.

Reference
1) Tamai, H. *et al.*, Ann. Rep. NIFS (2005-2006) 230.