§15. Aluminum-alloy-jacketed Nb_3Sn Superconductor for the LHD-type Fusion Reactor FFHR

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We have studied a conceptual design of the superconductor and coil for the LHD-type fusion reactor FFHR superconducting magnet. One option is to use an aluminum-alloy jacketed Nb_3Sn superconductor and indirect cooling using cooling panels inside the coil.[1)] Commercial Nb_3Sn wires can be used because they are widely used at 13 T, the maximum field of the FFHR. The aluminum-alloy jacket, which has higher thermal conductivity than stainless steel, promotes elimination of steady-state nuclear heating. The use of an aluminum-alloy jacketed superconductor is, however, novel because the melting point of aluminum (933 K) is a little lower than the heat treatment temperature of Nb_3Sn wires (~1000 K). Therefore the jacketing must be performed after the heat treatment of the wires. We developed a conductor fabrication process using a recently developed friction stir welding (FSW) technique that uses friction heating.[2)]

In the previous paper, we report the development of a sub-scale superconductor (dimension: 17 mm x 17 mm) for demonstrating the fabrication process and the performance of the conductor.[1)] We succeeded in carrying 19 kA at 8T through 1-m-long conductors. Then we start development of the next step to fabricate a long sub-scale conductor and to develop a demonstration coil using the long conductor. The conductor will be wound after the heat treatment, which is called a "react and wind" process. Therefore further investigation will be required to develop manufacturing processes without degradation of superconducting properties.

Fig 1 shows the developed superconductor. The 18-strand Rutherford cable was heat-treated and embedded into the U-shaped jacket. Finally the cover of the jacket was welded to the U-shaped jacket by FSW. The dimension is 17 mm x 5 mm. After a conditioning process, 1-m-long superconductors were fabricated and tested in an 8-T split magnet. We succeeded in carrying 9 kA at 8 T.

Fig. 2 shows the experimental results of current-carrying capacity tests. Open circles indicate the critical currents (I_c) of the test conductor at 4.3 K and the bias field. In order to develop the demonstration coil, the conductors must be bent. We then investigate the effect of bending. Open triangles indicate I_c of the sample that were bent with a curvature radius of 150 mm and straightened. The criterion for the I_c definition was 1 μV/cm. Error bars represent the maximum and the minimum magnetic fields inside the conductor. The self field was generated by the current through the conductor. The solid line indicates the product of 18 (the strand number) and I_c of the strand, of which the criterion for the definition was also 1 μV/cm.

The experiments indicate that the degradation of I_c was approximately 5%. The additional residual strain due to the difference in thermal contraction between the cable and the jacket is estimated to be about -0.08% (in compression) when the conductor is cooled from 300 K to 4.4 K. Because this strain corresponds to the degradation of 3~5% at 8 T, the observed degradation can be explained by the thermal contraction.[3)] After bending, I_c slightly increased. We also observed that the critical current of the strands increased by pre-bending. In addition, the pre-bending effect has been reported by previous papers.[4)] These results confirm that the developed conductor can be applied to the demonstration coil.

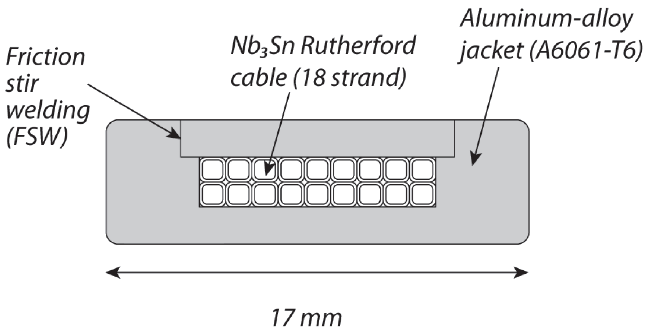

Fig. 1. Sub-scale superconductor developed for demonstration of aluminum-alloy jacketed conductors.

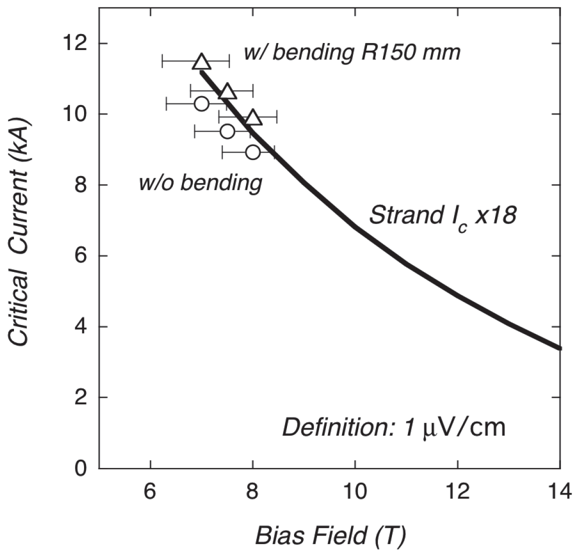

Fig. 2. Critical currents of the sub-scale superconductor.

1) Takahata, K., et al., Fusion Eng. Des. 82 (2007) 1487
2) Dawes, C.J., Thomas, W.M. , Welding Journal 75 (1996) 41
3) Summers, L.T., et al., IEEE Trans. Magn. 27 (1991) 2041
4) Awaji, S., et al., Fusion Eng. Des. 81 (2006) 2473