# §16. 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)]

Fig. 1 shows a sub-scale superconductor for demonstrating the fabrication process and the performance of the conductor. Nine flat cables were stacked and twisted into a rectangular cross-section. Cabling pitches of the flat cable and the final rectangular cable are 35 mm and 55 mm, respectively. Because all the strands are fully and regularly transposed, irregular current distribution due to coupling currents can be avoided. The cable was then heat-treated and embedded into the U-shaped jacket. Finally the cover of the jacket was welded to the U-shaped jacket by FSW. After a conditioning process, 1-m-long superconductors were fabricated and tested in an 8-T split magnet.

We succeeded in carrying 19 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 4.4 K and the bias field. 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 72 (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 the critical current was approximately 15%. We propose two possible reasons for this. One might be non-uniform current distribution inside the cable due to non-uniform resistance between the strands and the copper terminal at both ends of the sample. The other could be strain effects of $Nb_3Sn$ due to the jacketing process, thermal contraction and electromagnetic force. 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 only 3~5% at 8 T, the other effects should be considered.[3)] In both cases, this degradation is less severe for practical use and can be reduced by further investigation.

As the next step, we will develop a long sub-scale conductor and a test coil with the conductor. The conductor will be wound after the heat treatment, which is called a "react and wind" process. Further investigation will be required to develop manufacturing processes of the conductor and the coil without degradation of superconducting properties.

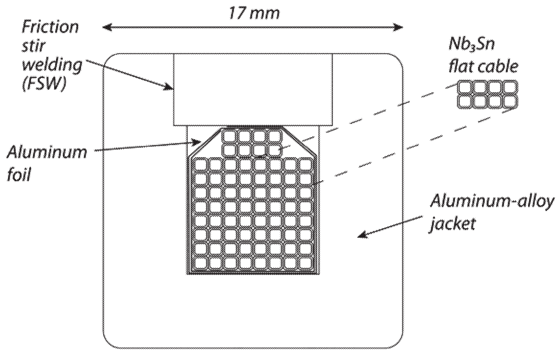


Fig. 1. 10-kA-class sub-scale superconductor developed for demonstration of aluminum-alloy jacketed conductors.

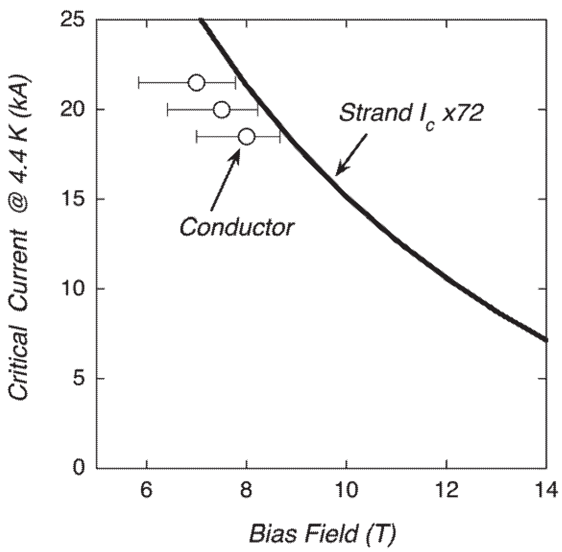


Fig. 2. Critical currents of the sub-scale superconductor.

Reference

1) Mito, T., et al., Fusion Eng. Des. 81 (2006) 2389
2) Dawes, C.J., Thomas, W.M. , Welding Journal 75 (1996) 41
3) Summers, L.T., et al., IEEE Trans. Magn. 27 (1991) 2041