§23. Development of 100-kA Indirectly Cooled Superconductor for FFHR

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A 100-kA indirectly cooled superconductor has been designed and optimized for the heliotron fusion power reactor FFHR-d1. To date, large-scale Nb_3Sn conductors have been developed that include a Rutherford cable and an aluminum-alloy jacket[1–7]. A Rutherford cable avoids irregular current distributions due to coupling currents, because all the strands are regularly transposed. An aluminum-alloy jacket not only supports the electromagnetic force, it also diffuses the heat generated by the nuclear heating in the conductor because the thermal conductivity of the aluminum alloy is thirty times higher than that of stainless steel. The manufacturing process is unique in that the jacketing process is performed after a reaction heat treatment of the Nb_3Sn cable. We term it a “react-and-jacket” process. This process improves the critical current I_c because the compressive strain induced in the Nb_3Sn filaments by thermal contraction of the jacket is reduced[1].

Figure 1 schematically shows a cross section of the conductor optimized for FFHR-d1. It has a critical current of approximately 200 kA at 12 T, double the operating current of 100 kA. The Rutherford cable consists of 216 (6×36) Nb_3Sn wires with diameters of 1.6 mm, along with 36 copper wires. The heat-treated cable and low-melting-point metal fillers are embedded in an aluminum-alloy jacket with a high filling factor. Two 2-mm-thick strips made of high-purity aluminum reduce the hotspot temperature during a quench. The two jacket halves are bonded by friction stir welding (FSW) which does not damage the cable. Using Nb_3Sn wires with a non-copper critical current density (J_c) of 1000 A/mm^2 leads to a critical current (I_c) of 200 kA.

We are presently developing a superconducting wire having a high critical current of 1 kA and a diameter of 1.6 mm, corresponding to a non-copper J_c of 1000 A/mm^2. Because this wire has much larger diameter than conventional products with a diameter of about 1 mm, the filament diameter and heat-treatment conditions have been optimized from scratch. Figure 2 shows a photograph of the bronze-route Nb_3Sn wire developed in FY2014. The wire is reinforced with Nb filaments in copper stabilizer. The bronze matrix includes 30,000 Nb_3Sn filaments with a diameter of 3.4 μm. Figure 3 shows I_c measurements. I_c of the as-reacted wire was approximately 900 A at 12 T. In addition, the multiple bent (pre-bent) treatment improves I_c by about 30% at 14 T. Therefore, the target, 1 kA at 12 T, should be achieved, even though I_c of the pre-bent sample could not be measured at 12 T because of the capability of a sample holder. The next step of the project is to fabricate a conductor with this wire and to demonstrate its performance in a high-field magnet.

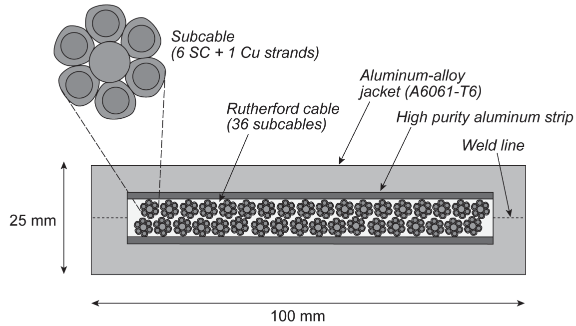

Fig. 1. Conductor for the fusion reactor FFHR-d1.

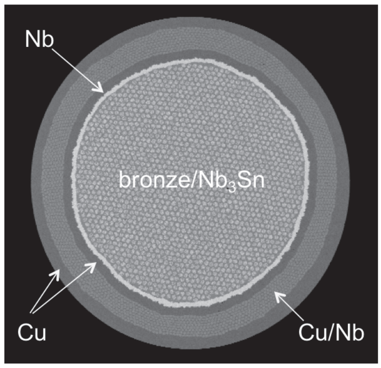

Fig. 2. Photograph of the developed bronze-route Nb_3Sn superconducting wire with a diameter of 1.6 mm.

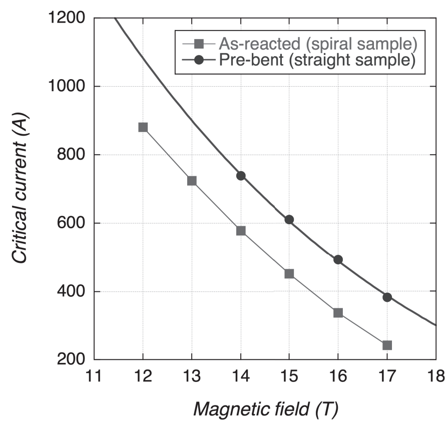

Fig. 3. Critical currents of as-reacted and pre-bent superconducting wires.

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