§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[1–6]. 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].

Fig. 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. A zero-dimensional calculation suggests that the temperature can be kept less than 150 K for a current decay time constant of 20 s. 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 of 200 kA.

We are presently developing a superconducting wire having a high critical current 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. Fig. 2 shows a photograph of the bronze-route Nb_3Sn wire developed in FY2013. The filament diameter is 2.5 μm. Fig. 3 shows the measurements of the non-copper critical current density of the wire. The non-copper J_c was approximately 700 A/mm^2 at 12 T. Even though the target cannot be achieved, the non-copper J_c was improved by 30% compared with the previously developed wire with the filament diameter of 6.7 μm[6]. To achieve the target, further optimization will be conducted in FY2014.

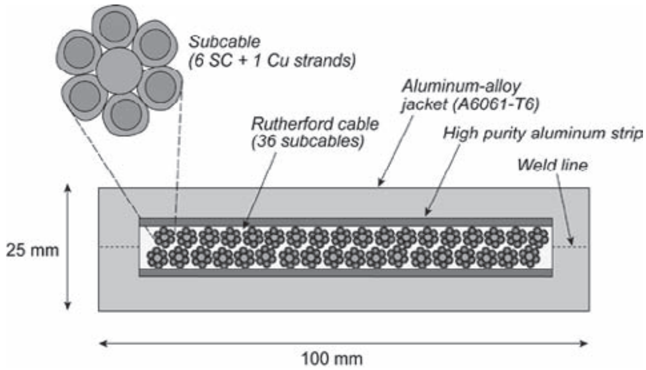

Fig. 1. Conductor for the fusion reactor FFHR-d1.

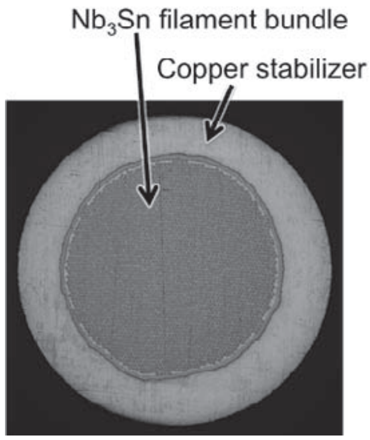

Fig. 2. Photograph of the developed bronze-route Nb_3Sn superconducting wire with a diameter of 1.6 mm.

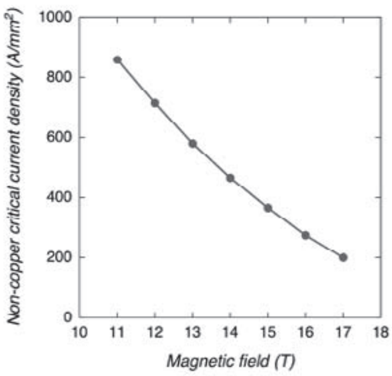

Fig. 3. Non-copper critical current density of the developed superconducting wire.

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