§11. Conceptual Design of Advanced Superconducting Magnet with Aluminum Stabilized Nb_3Al Conductor for FFHR

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Conceptual design of FFHR is underway aiming a future LHD type nuclear fusion reactor. Since a peak field in a superconducting helical coil for FFHR will reach 13 T or higher, application of advanced superconductors replacing NbTi technology should be necessary. In terms of a coil cooling scheme, an indirect cooling, which can significantly simplify the system rather than a force-flow cooling suffering very complicated joint work at ends of Cable in Conduit Conductors (CICC), will be a promising candidate. Therefore, the new advanced superconductor for FFHR should fulfill the requirement regarding not only critical current density at high field but also thermal conductance and mechanical rigidity.

An Nb_3Al superconductor with a rapid heating/quenching and transformation (RHQ) process can be a baseline material due to its stress/strain endurance and higher critical current densities than an Nb_3Sn bronze wire for ITER. On the other hand, large scale magnets utilizing indirect cooling have been successfully demonstrated in many facilities by using aluminum stabilized NbTi superconducting cable, which fulfilled both requirement of high RRR (=thermal conductivity) and high yield strength. Therefore, we have aimed the RHQ-Nb_3Al superconductor with aluminum stabilizer for FFHR and have being carried out the elementary development.

We have proposed RHQ-Nb_3Al cable conformed in aluminum stabilizer for FFHR. As a reference, a cross-sectional picture of aluminum stabilized NbTi Rutherford cable is shown in Fig. 1. Since the melting point of aluminum is about 660 °C which is much lower than the heat treatment temperature of 800 °C for the RHQ-Nb_3Al, the cable should be reacted in advance of conforming process. Even though the RHQ-Nb_3Al superconductor shows better mechanical endurance, certain degradation of the performance is anticipated after the conforming. Therefore, we firstly attempted to develop the RHQ-Nb_3Al wire having higher non-copper critical current densities, non-Cu J_c.

A cross-sectional picture of the RHQ-Nb_3Al wire developed for this study is shown in Fig. 2 and main parameters are listed in Table I. This wire successfully demonstrated non-Cu Jc beyond 1000 A/mm^2 at 13 T, which is higher than Nb_3Sn for ITER. It was also confirmed that suffering of instability at low field with niobium matrix was significantly improved by tantalum matrix. Furthermore, we succeeded to fabricate a 20 m long Rutherford type cable comprised of 28 RHQ-Nb_3Al wires, as shown in Fig. 3.

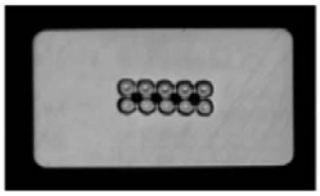

Fig. 1 A cross-sectional picture of aluminum stabilized NbTi Rutherford cable (15 mm wide, 8 mm thick).

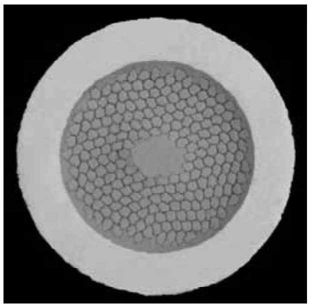

Fig. 2 A cross-sectional picture of the RHQ-Nb_3Al wire with a diameter of 1 mm.

Table I Main parameters of RHQ-Nb_3Al wire

Wire Diameter	1.0 mm
Non-Copper Diameter	0.7 – 0.73 mm
Area Reduction	~70 %
Filament Diameter	35 mm
Barrier Thickness	4 - 6 mm
Twist Pitch	45 mm
Piece Length	~ 1 km

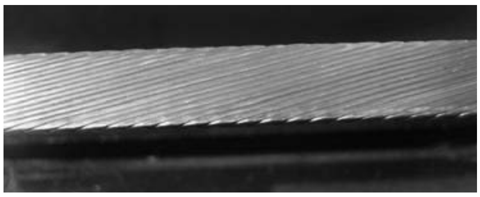

Fig. 3 RHQ-Nb_3Al Rutherford cable.

Secondly, we developed the material of aluminum stabilizer. To fulfill both a good thermal conductance at cold and a mechanical rigidity, we adopted pure aluminum materials with ~100 ppm dopant of copper or magnesium and the final mechanical rigidity is given by cold-work after the conforming process. The target specification was empirically set to be RRR of 450 and 0.2 % proof stress of 50 MPa at 300 K. As a result of development, RRR of 460 and proof stress of 70 MPa were successfully achieved.

For the future development, demonstration of aluminum conforming with RHQ-Nb_3Al cable is necessary.