Ultra-thin A15 Superconducting Wires for Future High Field Accelerators

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The work herein described aims at reducing high field accelerator magnet cost by producing ultra-thin A15 superconducting wires that would be suitable to produce magnets through the React and Wind (R&W) technique as opposed to the Wind and React (W&R) process. In the current process, coils made of either Nb_3Al or Nb_3Sn are heat treated at high temperature and inert atmosphere after winding. In the proposed method, the Rutherford cable is heat treated before using it to wind the coils. The requirement for smaller ovens would save considerable capital cost, and the fabrication risk for magnets would be greatly reduced. For this purpose, flexible and strain tolerant new superconducting strands and cables are needed.

The proposed work builds upon the multi-decade experience of NIMS, KEK and Japanese industry in the development of multifilamentary Nb_3Sn and Nb_3Al wires, and in the development of Nb_3Al Rutherford cables and accelerator magnet models in collaboration with Fermilab [1-12]. The work done so far within the U.S. Magnet Development Program [13] for high field accelerator magnets has shown that increases beyond 14 T of the magnet operational field, or increase of its aperture beyond 50-60 mm, will require designs with stress management concepts to manage excessive azimuthal and radial strains in the coil windings and prevent degradation of the current carrying capability of the conductor. Lorentz forces in the magnets are determined by the engineering current density in the coils. This means that the present limit for higher fields using Nb_3Sn is not its critical current density, but its strain sensitivity. A unique advantage of Nb_3Al is its strain tolerance [14], which is much larger than for Nb_3Sn.

The Nb_3Al multifilamentary wire developed in [1-10] was a breakthrough in that the copper could be added to the composite precursor after the rapid-heating, quenching and transformation (RHQT) process as a stabilizer, allowing it to be used in Rutherford cables and magnets models. However, the RHQT process increases the cost of the wire. Another limitation of the original wire was the challenge in reducing the filament size to the level required for field quality and to prevent magnetic instabilities in accelerator magnets. The proposed development of ultra-thin Nb_3Al wires processed by low temperature diffusion rather than by RHQT, would solve all of these challenges. More details on the work already performed and the work proposed for the future are given below.

Applying an intrinsic strain of 0.6%, Nb_3Al retains 95% of the superconducting performance, whereas Nb_3Sn loses 20%. Reducing the wire diameter and the superconducting filament size is a very effective way to decrease the mechanical strain. For example, the maximum bending strain of a 0.1 mm strand is 0.5% when it is bent around a 10 mm radius. So far, there are few reports on A15 superconducting strands having size smaller than 0.1 mm. In 2018, NIMS started an R&D on ultra-thin Nb_3Al strands in cooperation with Yuki Precision Co., Ltd. and Meiko Futaba Co., Ltd. [15]. Jelly-rolled Nb/Al lamination billets have been assembled in-house at NIMS, as well as at Yuki Precision. The wire drawing for the ultra-thin diameter is ongoing at Meiko Futaba, which are fabricating the pure electro-copper thin strands and braiding cables as their main products. In recent years, the rapid growth of the all and hybrid electric vehicles is increasing demand of pure electro-copper thin strands and cables. Meiko Futaba produces 1,800 tons of electro-copper wire annually. Our joint team is going to merge the independent technologies of both engineering fields of the electro-copper strands and the superconducting strands, and develop state-of-the art ultra-thin superconducting strands with A15 compounds. Recently, jelly-rolled Nb/Al mono filament strands with 50 μm in outer diameter and over 400 meters long have been successfully fabricated without wire-breakage. Some of them were additionally drawn down to 30 μm, which is much thinner than the diameter of typical human hairs showing in Fig. 1. Fig. 2 are microstructural images of the cross-sections of the jelly-rolled Nb/Al ultra-thin strand with 30 μm in diameter. (a) is an image for a horizontal direction and (b) is an image for longitudinal direction. The non-copper critical current density (J_c) is so far about 1,000 A/mm^2 at 4.2 K and 10 T, which is comparable to the diffusion processed Nb_3Al monolith strands. Of course, we need much improvement of the J_c in the future.

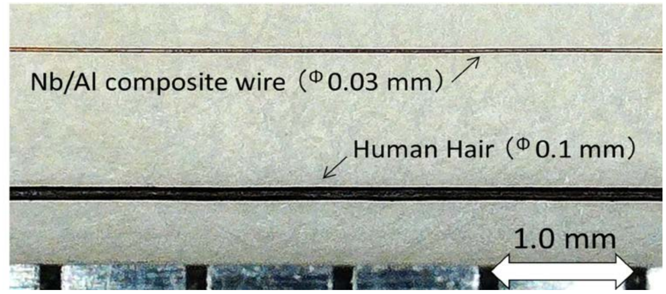

Fig. 1. Comparison of Nb/Al ultra-thin strand and human hair.

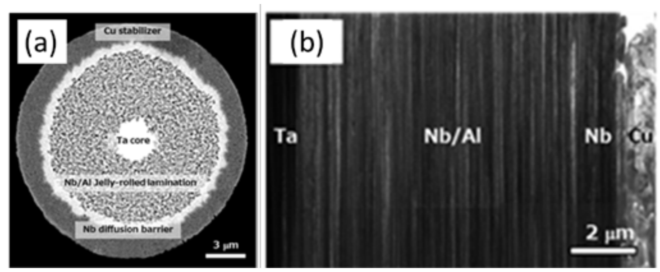

Fig. 2. The cross-sectional images of 30 μm Nb/Al strand for (a) horizontal direction, and (b) longitudinal direction, respectively.

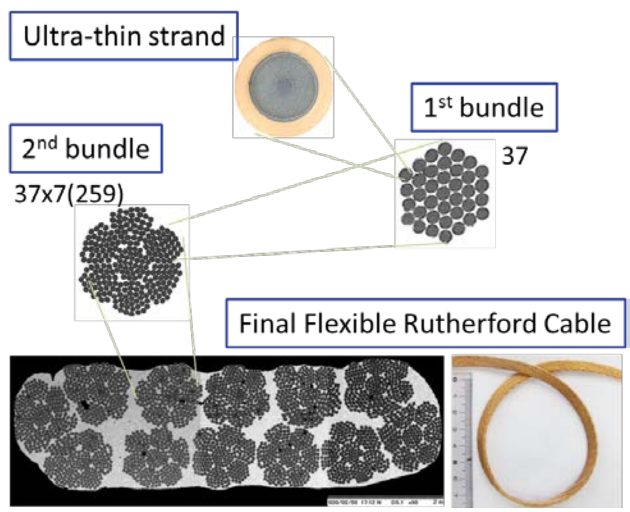

Fig. 3 Demonstrated new design of Rutherford cable using 0.05 mm ultra-thin strands.

Furthermore, we fabricated a novel Rutherford cable using 0.05 mm ultra-thin electro-copper strands as a feasibility study. As shown in Fig. 3, the 1st bundle is a 37-strand round cable and the 2nd bundle includes seven of the above cables in a six around 1 configuration. The total number of 0.05 mm copper strands is 259. The diameter of this 2nd bundle round cable is equivalent to 1.0 mm monolith strand. It showed no roping and no wire-breakage during cabling. This newly designed Rutherford cable shows extreme flexibility. We will develop ultra-thin strands not only for Nb_3Al but also for Nb_3Sn. In addition, we are planning to demonstrate flexible Rutherford cables by using Nb_3Al as well as Nb_3Sn ultra-thin strands in the near future.

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