Highly Strengthened Superconducting Magnet for a 40 T Compact Hybrid Magnet(Magnet Technology)

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Highly Strengthened Superconducting Magnet for a 40 T Compact Hybrid Magnet *

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A 16 T outer superconducting magnet for a 40 T compact hybrid magnet is investigated. A highly strengthened superconducting magnet with a 360 mm room temperature bore can be made using newly developed $(Nb,Ti)_3Sn$ wires with Cu-Al_2O_3 reinforcing stabilizer. The coil weight is outstandingly reduced by as much as 70 %.

KEYWORDS : Nb_3Sn superconductor, reinforcement, Cu-Al_2O_3 stabilizer, high field, large bore superconducting magnet

1. Introduction

In a wide bore superconducting magnet, the electromagnetic force at the windings increases with the strength of a field. The critical current of Nb_3Sn wires without reinforcement degrades easily under the large stress. Practically reinforced superconducting wires have been realized by means of an external reinforcement. Heat-treated and fully reacted Nb_3Sn wires are surrounded with housings of cold-worked hard Cu[1] as shown in Fig. 1. Since Cu stabilizer with a large cross section must be utilized as housings to overcome the huge stress, the average current density of the coil is extremely reduced. As a result, high field superconducting magnets with a wide bore become larger. From the aspects of manufacturing and operating costs, such a large scale superconducting magnet system is undesired.

In order to reduce the coil weight and size, a very compact superconducting magnet has to be developed. This paper describes a remarkably light 16 T superconducting magnet with a large bore using $(Nb,Ti)_3Sn$ superconducting wires reinforced with Cu-Al_2O[2].

2. $(Nb,Ti)_3Sn$ Wires with Cu-Al_2O_3 Reinforcing Stabilizer

Figure 2 shows cross sectional views of newly developed multifilamentary $(Nb,Ti)_3Sn$ wires with Cu-Al_2O_3 reinforcing stabilizer. The $(Nb,Ti)_3Sn$ wire reinforced with Cu-Al_2O_3 has a 1.0 mm outer diameter, 52 μm filament diameter, 132 filaments, and Cu/Cu-Al_2O_3/non-Cu ratio of 0.94/0.86/1. It is important to know the resistivity of the reinforcing materials used instead of Cu stabilizer. Figure 3 shows the magnetoresistances of the stabilizer materials measured in high fields at 4.2 K after the heat treatment. Cu-0.4 at.%Al_2O_3 composites exhibit the low magnetoresistivity of 0.15 μΩ·cm at 16 T and 4.2 K, which is slightly higher than that of Cu stabilizer. Therefore,

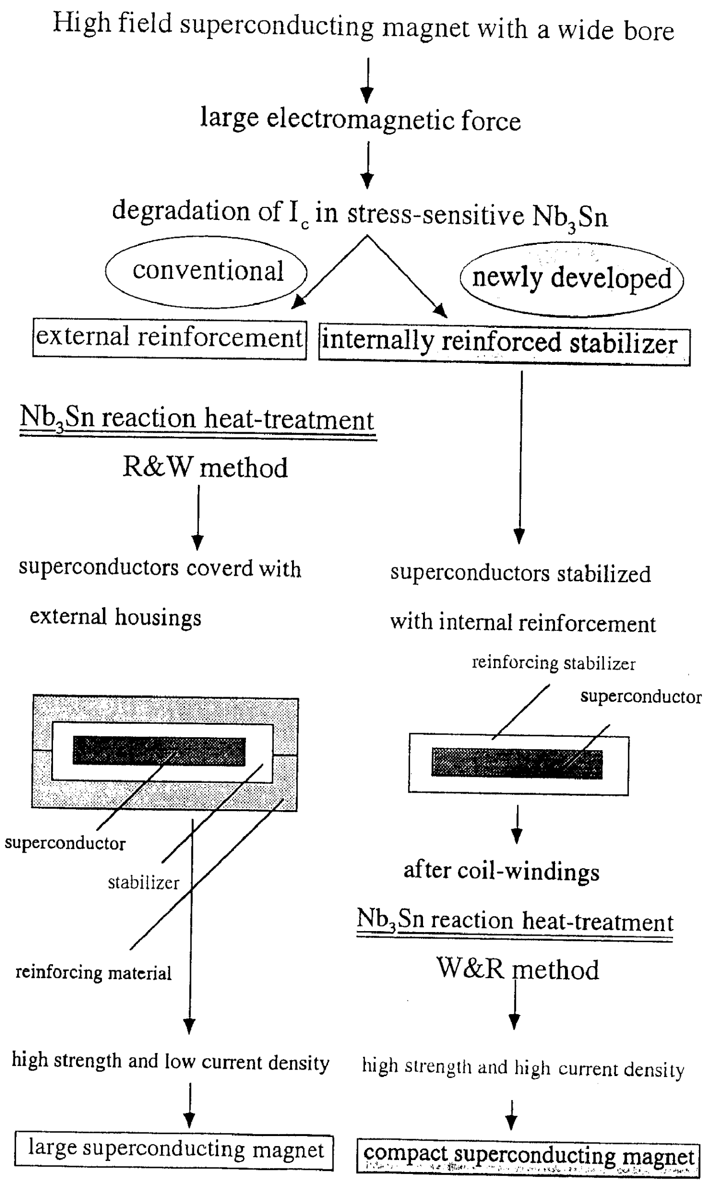

Figure 1 Comparison of highly strengthened $(Nb,Ti)_3Sn$ wires between ordinarily external reinforcement and newly developed internal reinforcement.

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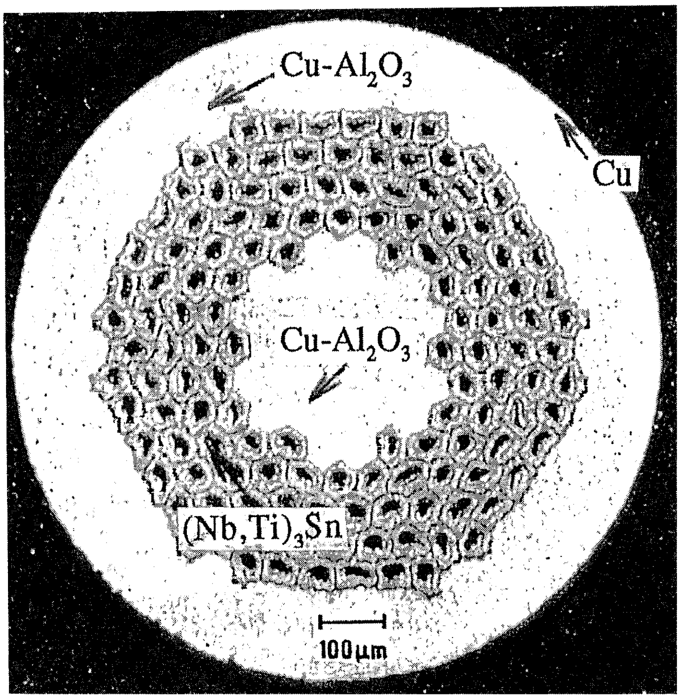

Figure 2 Nb-tube processed multifilamentary $(Nb,Ti)_3Sn$ wire with Cu-Al_2O_3 reinforcing stabilizer.

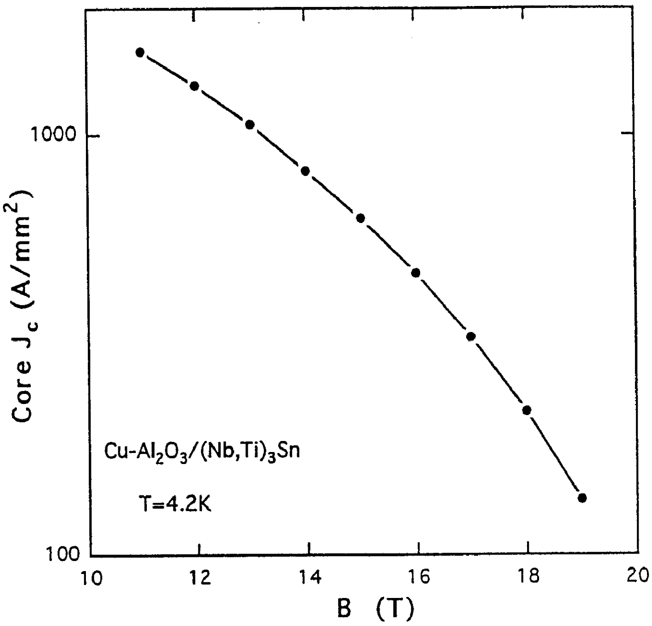

Figure 4 Core J_c at 4.2 K in high fields for Cu-$Al_2O_3/(Nb,Ti)_3Sn$.

these reinforcing materials are expected to play a role of stabilizer. The heat-treatment to form A15 compounds was carried out at 720 ℃ for 50 hours. Reinforcing $(Nb,Ti)_3Sn$ superconducting wires give characteristic points such as mechanically strong properties and electrically good conductivity after heat-treatment at about 700℃. From the stress-strain curve measured at 4.2 K, it was found that the yield stress defined as the 0.2 % proof stress is more than 300 MPa at 4.2 K. When these value are compared with that of ordinary $(Nb,Ti)_3Sn$ wires without reinforcement, it is clear that the strength of such reinforced $(Nb,Ti)_3Sn$ wires is twice as high as that of ordinary ones.

Figure 4 exhibits the core critical current densities in high fields at 4.2 K for the highly strengthened multifilamentary $(Nb,Ti)_3Sn$ wires. In an applied strain state due to the Lorentz force, the critical current density becomes closer to the J_c properties in a strain free state, since the residual compressive strain decreases with increasing the

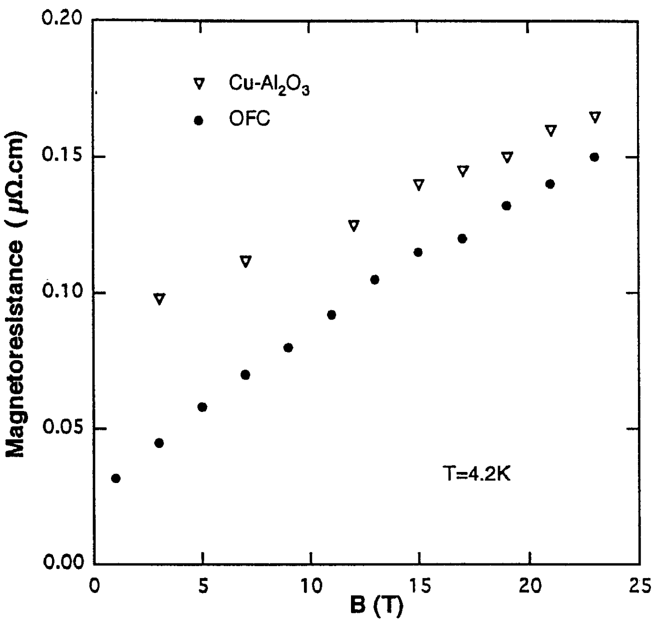

Figure 3 Magnetoresistance as a function of magnetic field at 4.2 K. Oxygen free copper (OFC) and Al_2O_3 dispersion copper (Cu-Al_2O_3) were annealed at 720 ℃ for 50 hours.

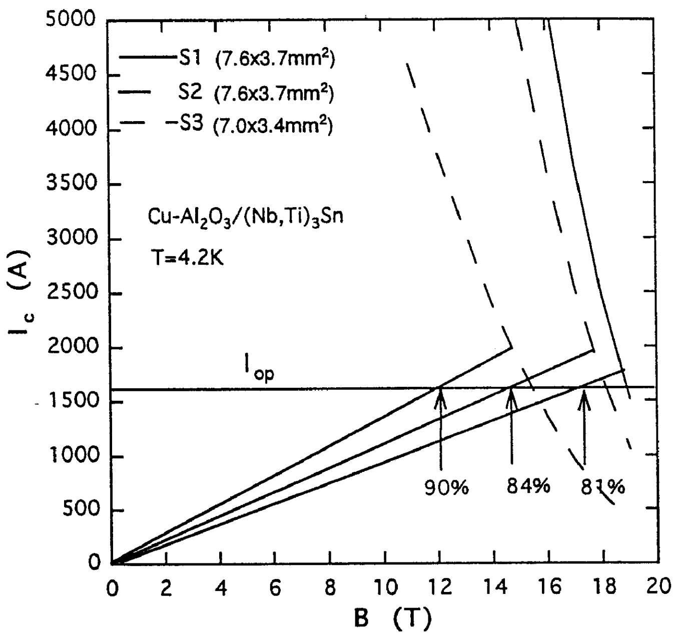

Figure 5 I_c-vs-B properties for Cu-$Al_2O_3/(Nb,Ti)_3Sn$ superconducting wires, and the load lines of a 16 T superconducting magnet.

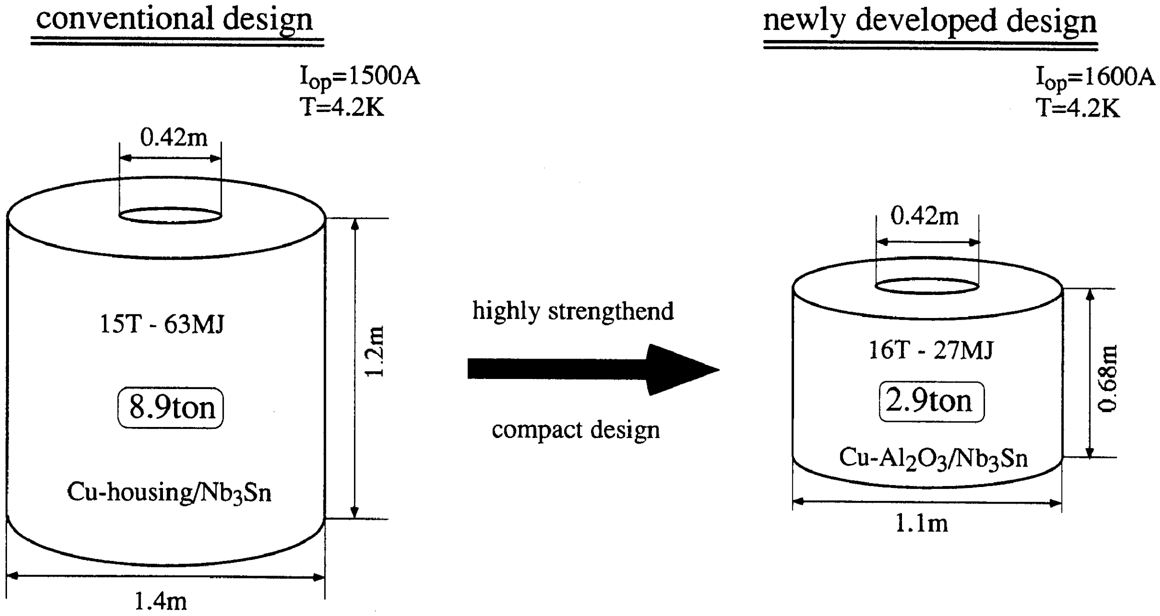

Figure 6 Comparison of the coil weight and size for large bore high field superconducting magnets.

electromagnetic tensile strain axially applied to the wire. For Cu-Al_2O_3/$(Nb,Ti)_3Sn$ wires, the residual strain at 4.2 K was about $\varepsilon \approx 0.3$ %. The overall J_c values show the good performance even in 0.3 % prestrain state. From these results, Cu-Al_2O_3/$(Nb,Ti)_3Sn$ wires are considered to have an enough potential for the highly strengthened superconducting magnets.

3. Highly Strengthened Superconducting Magnet

In order to perform an outstanding design of a new 16 T superconducting magnet with a 360 mm room temperature bore, we adopt the advanced conditions as follows :

1) The superconducting magnet may quench, if the insert resistive magnet fails.
2) The mechanical properties are extended to be less than 250 MPa for a tangential tensile stress of the coil and less than 100 MPa for a transverse stress of the coil.
3) The coil weight is as light as about 3000 kg.

The conceptual design parameters are presently obtained, although the magnet design is not optimized yet. This magnet consists of four grades coils which are designated S1, S2, S3, and T1 from the inside out. The S coils are wound using highly strengthened multifilamentary $(Nb,Ti)_3Sn$ superconducting wires, and the T coil employs a conventional NbTi superconducting wire. Figure 5 shows the load lines for S1, S2, and S3 coils of the 16 T superconducting magnet. The innermost coil experiences the maximum field of 17 T at 4.2 K at the windings. As a safety margin, the hoop stress is 200 MPa. This stress value gives a lower strain value than that of the strain free state of 0.5 % in highly strengthened $(Nb,Ti)_3Sn$ superconducting wires. It is worthy of note that the total conductor weight employed in this design is less than about 2,900 kg. This results in the large reduction of magnet size and weight, as compared in Fig. 6. According to the conventional design using $(Nb,Ti)_3Sn$ wires with external reinforcing housings, the total conductor weight reaches about 9,000 kg. Therefore, an extremely compact high field superconducting magnet with a wide bore whose weight is about 1/3 in comparison with the ordinarily made magnet can be realized.

4. Conclusion

A high field and wide bore superconducting magnet without external housing reinforcement can be made by developing multifilamentary $(Nb,Ti)_3Sn$ superconducting wires with reinforcing stabilizer Cu-Al_2O_3. A very compact superconducting magnet with the large over-all current density is realized, and the weight of a 16 T superconducting magnet with a 360 mm room temperature bore is reduced to about 1/3 in comparison with the ordinarily made magnet.

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