§15. Studies on Advanced Superconductors for Fusion Device

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i) Fabrication of New Nb₃Sn Superconductors for High-Field Use

The bronze-processed Nb₃Sn with small amount of Ti addition is being widely used for high-field generation, however, a superconducting magnet capable of generating fields over 20T at 4.2K has not yet been realized. A new process to fabricate Nb₃Sn conductor has been developed starting from Nb₆Sn₅ intermediate compound powder. The Nb₆Sn₅ fine powder can be synthesized by the melt diffusion process of Sn using Nb and Sn powders. The Nb₆Sn₅ intermetallic compound powder is mechanically mixed with Nb powder, and then tape conductors are fabricated using mixed powder of Nb/Nb₆Sn₅ encased in a Ta tube. The fabrication can be performed without intermediate annealing. Fig. 1 shows the cross-section of the specimen with outer layer of Cu stabilizer.

![Fig. 1. Cross-section of the present Nb₃Sn specimen.](image)

The upper critical field $B_{c2}$ of present Nb₃Sn reaches 24.7T at 4.2K, which is nearly 5T higher than that of bronze-processed pure Nb₃Sn. The normal state resistivity $\rho_n$ of the present Nb₃Sn is about three times larger than that of bronze-processed Nb₃Sn which may be account for the high $B_{c2}$ in the present Nb₃Sn. In this study the effect of small amount of Ge addition to the Nb₃Sn conductor fabricated by the new process has been studied. The Ge is added to Nb₆Sn₅ compound at the time of the melt diffusion.

The SEM structures taken on the cross-section of the specimen indicate that the small amount of Ge addition appreciably reduces the grain size of Nb₃Sn after the heat treatment. Fig. 2 illustrates the critical current $I_c$ and critical current density $J_c$ at high magnetic fields for different specimens heat treated at quoted conditions. The Ti addition to Nb₃Sn improves high-field performance as described in the last report. The small amount of Ge addition produces more significant enhancement in $J_c$ at high fields than the Ti addition does. The optimum amount of Ge addition is found to be 0.5-1.0wt%. The composition slightly richer in Sn, i.e. Nb₂.₉Sn, is more favorable to obtain improved high-field performance. The composition slightly richer in Sn yields the increase in $\rho_n$ value of Nb₃Sn. The significant enhancement in $J_c$ at high-fields seems to be attributed to the grain refinement of Nb₃Sn by the Ge addition described above. A $J_c$ value of over 30000A/cm² has been realized at 21T and 4.2K by the Ge addition. The present result is much encouraging for the development of Nb₃Sn conductor capable of generating fields over 20T at 4.2K.

![Fig. 2. $I_c$ and $J_c$ at 4.2K in fields of 21, 22 and 23T for different specimens. NS:Nb₃Sn.](image)
ii) Investigation on the Present Status of Advanced Metallic Superconductors other than Nb$_3$Sn.

A comprehensive report on the development of Nb$_3$Sn was published as NIFS-MEMO-20 in last year$^4$). Present study covers the progress so far achieved in the research and development of advanced metallic superconductors other than Nb$_3$Sn$^5$). Among different A15 crystal-type compounds, Nb$_3$Al has been fabricated into cables with large current-carrying capacity referring its smaller sensitivity to mechanical strain than Nb$_3$Sn. Other high-field A15 superconductors, e.g. V$_3$Ga, Nb$_3$Ge and Nb$_3$(Al,Ge), have been also fabricated through different novel processes. Meanwhile, B1 crystal-type NbN and C15 crystal-type V$_2$(Hf,Zr) superconductors are characterized by their excellent tolerance to mechanical strain and neutron irradiation. Chevrel-type PbMo$_6$S$_8$ compound has gained much interests due to its extremely high $B_{c2}$ value. In addition, this study includes the recent progress in ultra-fine filamentary Nb-Ti wires for AC use, and that in Nb-Ti/Cu magnetic shields necessary in the application of high magnetic field. The data on the decay of radioactivity in a variety of metals relating to fusion superconducting magnet are also included. This report might contribute substantially as a useful reference for the planning of fusion apparatus of next generation.

References