§12. Analysis of $j_c$ Properties in High Magnetic Fields for Low Activation Superconducting Wires

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It is necessary to consider the neutron irradiation effect on superconducting magnets of an advanced fusion reactor beyond the ITER project. V-based compound and alloy may be applied for a future fusion magnet because they have shorter decay time of induced radioactivity compared with Nb-based superconductor. We approach V$_3$Ga compounds as V-based low activation and high magnetic field superconducting materials for fusion application.

V$_3$Ga compounds have high upper critical magnetic fields ($H_{c2}$) above 20 T and better mechanical property than Nb-based compound. And then, the commercial processing of Nb$_3$Sn such as “Bronzed process” was developed by diffusion process of the V$_3$Ga wire. Although V$_3$Ga compound was older material compared with Nb-based material, we think that V$_3$Ga will have high potential performances for the fusion application. However, critical current density ($J_c$) properties of V$_3$Ga compound are lower than that of Nb-based superconductors and are insufficiency for the fusion magnet. No substitution effects of V$_3$Ga compound such as Ti substitution into the Nb$_3$Sn phase will be mainly caused by the lower $J_c$ property. In order to improve superconducting property of V$_3$Ga compound, we have developed the new processing using high Ga content Cu-Ga compound and metal V matrix. In this study, we measured the superconducting properties under the high magnetic field using various High-Field Superconducting Magnet systems in Tsukuba Magnet Laboratory of National Institute for Materials Science (TML-NIMS).

V$_3$Ga compound mono-cored and multifilamentary wires were prepared by the high Ga content Cu-Ga compound (Ga:30at%–64at%) powder (filament) and metal V tube (matrix) through the Powder-In-Tube (PIT) process. These Cu-Ga compound powders were packed into V tubes, and then these precursors were cold-drawn to wire having 1.0mm diameter. The multifilamentary wires were also made by the restacking of mono-cored wire into V tube and restacked precursors were cold-drawn to wire having 1.0mm diameter. These wires were sintered in a vacuum. The thicker V$_3$Ga phase compared with conventional process was formed along the interface between V matrix and Cu-Ga powder filament.

Fig.1 shows that the magnetic field dependence of critical temperature ($T_c$) property in the Cu-30at%Ga/V mono-cored wire. From the results of $T_c$ measurements, optimum heat treatment condition of mono-cored wires was 700°C for 50h and maximum $T_c$ value was obtained to be about 15 K which was same property compared with conventional process. It was known that $H_{c2}$ value was estimated by the formula shown in Fig.1 in the case of A15 phase. $H_{c2}$ value was obtained to be 22.8 K and this value was 1.5 T higher than that of conventional process without substitution. Fig.2 shows that $J_c$-B performances of various high Ga content V$_3$Ga wires. In generally, $H_{c2}$ value was shown by the extrapolation of Kramer plot ($J_cB^{1/2}$). $H_{c2}$ property was depended on the Ga content into the precursor wires. And optimum Ga content was 50 at%Ga. These results suggested that the new processing using high Ga content Cu-Ga compound powder was one of the effective methods to improve superconducting property of V$_3$Ga compound wires. We thought that V$_3$Ga compound had clear possibility of candidate materials for Nb-system superconductor though the progress of further process optimization.

Fig. 1 The relationship between critical temperature and applied magnetic field on the Cu-30at%Ga/V mono-cored wire.

Fig.2 $H_{c2}$ properties of the V$_3$Ga multifilamentary wires using various high Ga content compound estimated by Kramer formula.