RAPID PUBLICATION

Superconducting Properties of Nb₃(Sn, Al) Wire Prepared by an Infiltration Method

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Nb₃(Sn, Al) wire has been fabricated by an infiltration method, and its superconducting properties, especially the critical current density, J_c at high applied magnetic fields up to 23 T, have been investigated.

Optimization of the heat treatment conditions on the Nb₃(Sn, Al) wires has been studied in detail and it has been demonstrated that a three-stage heat treatment enhanced the J_c property appreciably. Obtained values are the transition temperature, T_c of 17.5 K and the critical current density, J_c of 9.8×10^7 A/m² at 4.2 K and 20 T. The upper critical field, H_{c2} of more than 24 T at 4.2 K is extrapolated by Kramer-plotting.

Those values indicate that Nb₃(Sn, Al) wire has a potential to be used for high field applications.

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Keywords: superconducting property, Nb₃(Sn, Al) wire, critical current density, transition temperature, upper critical field, infiltration method

I. Introduction

The replacement of small amounts of Sn in Nb₃Sn by Al has been found to raise the superconducting transition temperature, T_c by several tenths of a degree⁽¹⁾⁻⁽³⁾. The bronze processed Nb₃(Sn, Al) wire has been reported to exhibit the critical current density, J_c of 4.4×10^8 A/m² at 4.2 K and 16 T⁽⁴⁾. However, no data have been available on the J_c -property of Nb₃(Sn, Al) wires at the applied magnetic fields higher than 16 T. It is very important for high field applications to investigate J_c properties at high applied magnetic fields.

In this paper, we present a study of superconducting properties of the Nb₃(Sn, Al) wire prepared by the infiltration method⁽⁵⁾⁽⁶⁾ focusing on the J_c properties at high applied magnetic fields up to 23 T. The infiltration method is an attractive one owing to its capability of yielding high field performances superior to those of conventional bronze-processed Nb₃Sn.

II. Experimental Procedure

Niobium powder with a sieve range of $-200+250$ mesh (from 59 to 118 μ m) was isostatically compacted at a pressure of 180 MPa to produce porous rods (diameter of 11 mm, height of 30 mm). They were sintered for 600 s at 2523 K under a vacuum of the order of 10^{-3} Pa to pro-

vide the desired combination of porosity and ductility. For infiltration, the sintered rod was immersed in a Sn-3 mass% Al bath maintained at about 770 K. The infiltrated rod was clad with an annealed niobium tube, and the assembly was encased in a copper alloy tube for mechanical reduction to fabricate a fine composite wire by a combination of rod-rolling and wire drawing.

After etching away the sheathed copper alloy, the obtained fine wire of 100 μ m diameter was heat treated to form Nb₃(Sn, Al) and its superconducting properties were measured. T_c was taken as the midpoint in the normal-superconducting transition. The critical current, I_c was measured at a transverse magnetic field up to 23 T at 4.2 K using the 0.1 μ V/mm criterion. The overall J_c was calculated by dividing I_c by the cross-sectional area of the wire including the clad niobium tube. For comparison, a Nb₃Sn wire was also prepared by the same method, and its superconducting properties were measured.

III. Results and Discussion

1. Workability

The composite rods could be reduced to fine wires 100 μ m in diameter, and a reduction in cross-sectional area of 16900:1 was consistently obtained. Figure 1 shows a typical cross-section of the infiltrated porous niobium rod. The immersed alloy is solidified rapidly in the infiltration method⁽⁶⁾ and a fine structure of Sn-Al alloy is obtained as shown in Fig. 1. The alloy with such a fine solidified structure shows good workability, which promotes workability of the composite rod. The infiltration method has an advantage of refining the immersed alloy

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Fig. 1 Cross-section of sintered niobium rod infiltrated with Sn-3 mass% Al alloy.

structure in this manner.

2. Superconducting properties

Figure 2 shows the relationship between the heat treatment conditions and the J_c -values at 4.2 K and 14 T. The optimum holding time changes depending on the temperature; the lower the temperature the longer the optimum holding time, and it can be seen that the low temperature treatment gives the high peak value.

Figure 3 shows the J_c -properties of the two-stage heat-treated wires. Such a treatment gives higher J_c -property than the single-stage heat treatment does unless the temperature of the first step heat treatment is raised higher than 1273 K. Therefore, it is important to optimize the heat treatment condition carefully.

Figure 4 shows the J_c -properties of the Nb_3Sn and $Nb_3(Sn, Al)$ wires heat-treated under the respective optimum condition. The Nb_3Sn wire was heat-treated at

Fig. 2 Variations of J_c (at 14 T and 4.2 K) as a function of heat treatment conditions.

Fig. 3 J_c - H curves for two-stage heat-treated $Nb_3(Sn, Al)$ wires.

Fig. 4 J_c - H curves for $Nb_3(Sn, Al)$ wire and Nb_3Sn wire heat-treated under optimum conditions.

Fig. 5 Kramer plot of $J_c^{1/2} H^{1/4}$ versus B by using the data shown in Fig. 4.

1223 K for 240 s followed by 973 K for 86.4 ks. The heat treatment for the Nb₃(Sn, Al) wire was composed of three stages; the first one at 933 K for 605 ks, the second one at 1273 K for 60 s, and the last one at 1023 K for 345 ks. Compared to the single-stage heat treatment (Fig. 2) and the two-stage heat treatment (Fig. 3), the three-stage heat treatment enhances the J_c -property of Nb₃(Sn, Al) wire appreciably and gives J_c of 9.8×10^7 A/m² at 4.2 K and 20 T, and T_c of 17.5 K. However, the three-stage heat treatment for the Nb₃Sn wire does not enhance the J_c property. Figure 5 shows Kramer-plotting of data in Fig. 4, from which the upper critical field, H_{c2} more than 24 T can be extrapolated.

The obtained superconducting properties of Nb₃(Sn, Al) wires are comparable to those of (Nb, Ti)₃Sn wires, which have been used in a 20 T superconducting magnet system operated at 1.7 K⁽⁷⁾. Considering both their ex-

cellent superconducting properties and good workability, a Nb₃(Sn, Al) wire fabricated by the infiltration method is a promising superconducting material for high field applications.

IV. Conclusion

The Nb₃(Sn, Al) wire has been fabricated by the infiltration method to study the superconducting properties, especially the critical current density, J_c , at high applied magnetic fields up to 23 T. The present results demonstrate the transition temperature of 17.5 K and the critical current density of 9.8×10^7 A/m² at 4.2 K and 20 T. Moreover, the critical field of more than 24 T is extrapolated.

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