Manufacturing and Applications of High Temperature Superconducting Bulk

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Superconducting technology is considered to be a promising technology for saving energy, while allowing for large currents and high magnetic fields, creating new functions and potentially helping to solve energy problems in the future. So far, advanced R&D has been carried out on superconducting materials and their application in developing new electrical equipment.

A high temperature superconducting substance (*1) whose critical temperature is higher than 30 K was discovered in the latter half of 1986. In several years that followed, superconducting substances (*2) with a critical temperature of 90 K to 100 K or higher were discovered one after another. There is a high level of expectation regarding the future application of these substances as new materials which would permit bringing about a superconducting state by using easy-to-handle liquid nitrogen (77 K) in place of liquid helium (4.2 K).

There are two different forms of superconducting materials. There is "wire", which has been used mainly in low-temperature, metal-based superconducting materials (*3) and "bulk", which was found to have excellent superconducting characteristics in the process of research and development on high-temperature superconducting materials.

In order to develop larger-sized superconducting bulks having better superconducting properties we have studied material manufacturing techniques, evaluated basic material properties and discussed the possibility of applying those bulks to practical applications (Table 1).

The candidate materials we used were silver (Ag)-added, Y-based superconductors (*4) and Ag-added, rare earth (RE) -based (*5) superconductors (*6).

Manufactured using a melt process, these superconductors have excellent superconducting properties at 77 K and are considered capable of generating high magnetic fields of tesla (T) order.

In the manufacturing of a superconducting bulk, the microstructure of the material varies markedly according to the raw material composition and heat treatment conditions. The reason why Ag is added to the composition is that this element is expected to improve both the microstructure and the mechanical and electromagnetic characteristics of the material, and that it permits the use of a lower heat treatment temperature.

Concerning the heat treatment conditions, we discussed the melting and solidification method in which, after the maximum temperature is reached, the temperature at which crystals grow and the degree of undercooling for heat treatment are kept constant (Fig. 1). Compared with the temperature gradient method in which the solidification temperature is lowered with the lapse of time, the method we adopted is considered to facilitate temperature control and promote the growth of crystals.

In the seeding process, which has to do with the starting point of crystal growth, we used an Nd-based thin-film seed in place of a single crystal or bulk crystal, which has been commonly used in the past. This thin film has a number of advantages—good crystallinity, stable composition, easy machining, less contamination of the material surface, etc. Since the effectiveness of the thin-film seed and the stable growth of crystals were confirmed, we made a Y-based bulk 40 mm in diameter and about 15 mm in thickness (Fig. 2 and Table 2).

*1: lanthanum (La)-based
*2: yttrium (Y)-or bismuth (Bi)-based
*3: NbTi (niobium titanium) etc.
*4: $YBa_2Cu_3O_X$
*5: samarium (Sm) etc.
*6: $RE_{1+X}Ba_{2-X}Cu_3O_X$

Table 1. Possible superconducting bulk applications in railways.

Applications	Basic functions
Superconducting permanent magnet	Magnetic field by trapping flux
Flywheels	Storing electricity by magnetic levitation (bearing)
Motors	Generating by trapping flux
Fault current limiter	Controlling transmission by current flow & normal resistivity
Actuators	Transferring from electricity to power by trapping flux
Magnetic Separation	Segregating by trapping flux
Magnetic shielding	Expelling magnetic field by diamagnetism or flux penetration
Current leads	Transmitting by current flow for equipment

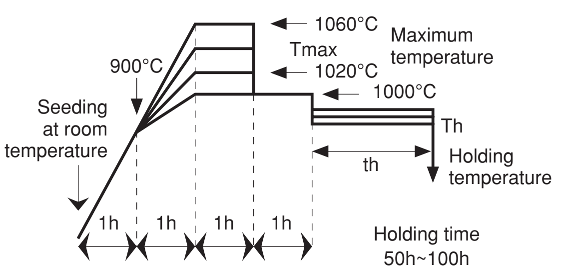

Figure 1. Heat treatment pattern discussed in the manufacturing of high-temperature Y-based superconducting bulk.

Table 2. Effects of high-temperature superconducting bulk manufacturing conditions applied in the present study

Manufacturing conditions	Effects
Y-based/rare earth element -based super conducting bulk (melt process)	Superior superconducting properties
Initial raw material composition with excess Y211 phase	Higher critical current density
Ag addition	Improved mechanical strength
Nd base/MgO substrate; thin-film seed (seeding at room temperature)	Improved homogeneity, stability and safety
Isothermal heat treatment (holding temperature at a constant undercooling rate)	Easier temperature control; possibility of mass production
Heat treatment in open air	Simple

Figure 2. Photograph of the surface of our Ag-added Y-based high-temperature superconducting bulk (maximum heat treatment temperature: 1,060 °C, undercooling temperature: 10 °C).