Preparation of cylindrical Bi-2223 sintered bulk composed with nickel meshes for current lead

S Yoshizawa¹,* , M Sakamoto², Y Hishinuma³, A Nishimura³, S Yamazaki² and S Kojima²

¹Department of Environmental Systems, Meisei University, 2-1-1, Hodokubo, Hino, Tokyo 191-8506, Japan
²Department of Electrical Engineering, Kogakuin University, 2665-1, Nakano, Hachioji, Tokyo 192-0015, Japan
³Fusion Engineering Research Center, National Institute for Fusion Science, 322-6, Oroshi, Toki, Gifu 509-5202, Japan

E-mail: yoshizawa@es.meisei-u.ac.jp

Abstract. In order to improve the superconducting property and mechanical property of Bi-2223 sintered bulk, Ni wire meshes were added in the bulk. The mesh concentration was 18 x 18 meshes/cm² using Ni wires of 0.25 mm in diameter. The Ni meshes were plated with Ag by 0.03 mm in thickness. We prepared the cylindrical sintered bulk, 27 mm in outer diameter 2 mm in thickness and 50 mm in length using a cold isostatic pressing (CIP) method. The samples were sintered at 845 °C for 50 h. Critical current density ($J_c$) of the samples was estimated at 77 K under self-field. By composing with the Ni meshes the $J_c$ property was improved compared with the samples without the mesh. It is mentioned that the $J_c$ increase of the Bi-2223 bulk by adding with the Ni meshes is attributed from formation of the Bi-2223 plate-like grains in the vicinity of the Ag-plated Ni wires.

1. Introduction
Sintered bulk of Bi-2223 has a critical temperature of over 77 K and low thermal conductivity. It has been used as a current lead for the liquid He-free cryocooler-cooled magnet and a current limiter. However, Bi-2223 bulk has some restrictions that limit the application field. One of the typical limitations is that the critical current density ($J_c$) of the bulk materials is much smaller than that of the wire and tape materials. And another is that the sintered bulk is fragile because Bi-2223 bulk is a ceramic material.

We prepared Bi-2223 bulk including metal silver (Ag) sheet, analogous to the tape and wire materials, which improved the $J_c$ property [1]. This is because highly c-axis oriented and densely structured Bi-2223 plate-like grains could be formed along the Ag sheet. We also reported that the mechanical property was improved by addition of Ag and Ag-alloy wires showed by a three point bending test [2-4]. Moreover, it was found that the composite did not rupture but only fine cracks were induced after the maximum bending stress, and although the current value was not large, a superconducting current flows in the fine-cracked sample [5]. Bi-2223 and Ag-plated nickel (Ni) wires composite bulk was developed, which has good superconducting and mechanical property [6]. Recently Bi-2223/Ni wire meshes composite bulk was prepared [7]. By adding metal meshes into the
sintered bulk, it can be expected that the mechanical property of the composite is strengthened for bending stresses from various directions.

In this study, we prepared cylindrical Bi-2223 sintered bulk samples composed with Ag-plated Ni meshes, 27 mm in outer diameter, 2 mm in thickness and 50 mm in length. It has to be mentioned that, preparing a cylindrical large sample, the sample is easy to produce compared with the sample composed with addition of a lot of wires.

2. Experimental Procedure

2.1. Sample preparation
Cylindrical Bi-2223 bulk composed with Ni wire meshes was prepared. The mesh concentration was 18 x 18 meshes/cm² using Ni wires of 0.25 mm in diameter. The Ni meshes were plated with Ag by 0.03 mm in thickness. Figure 1 shows cylindrical sample and cylindrical Ni meshes. A vinyl tube of 39 mm in inner diameter and a brass rod of 24 mm in diameter was used as a mold. The Ni meshes were centered between the mold, and calcined powder (Dowa Mining Co., Ltd.) of the constant mass of 27 g were molded using an isostatic cold pressing (CIP) method applying 2 tons for one minute. The molded sample was sintered at 845 °C for 50 hours in air. The sample size was 27 mm in outer diameter, 2 mm in thickness and 50 mm in length.

---

Figure 1. (a) Cylindrical Bi-2223 sintered bulk and (b) added Ag-plated Ni meshes.

Figure 2. XRD pattern of surface of the cylindrical sintered bulk.

Figure 3. Temperature dependence of magnetic susceptibility of the cylindrical bulk.
2.2. Measurement
We measured superconducting transport critical current ($I_c$) at 77 K under self field. $J_c$ was obtained from $I_c$ and cross-section area of the oxide subtracting the area of the Ni meshes. $T_c$ was measured by temperature dependence of the magnetization. Crystalline characteristics were studied by x-ray diffraction (XRD) method. Microstructures of the interface region between the oxide and Ni meshes were observed by means of Scanning Electron Microscope (SEM).

3. Results and Discussion
Figure 2 shows the XRD pattern measured on the sintered bulk. It was observed that mainly (00$l$) peaks of Bi-2223 phase were obtained indicating the $c$-axis oriented structure, and in addition we found some peaks originated from Bi-2212 phase.

Evaluating the effect of added Ni meshes into the sintered bulk with respect to the superconductivity, we estimated the $T_c$ and the $J_c$ values of the composites. From the magnetization curves in figure 3, it is observed that there is a transition in the curve of the sample and the $T_c$ (on-set) and the $T_c$ (off-set) are determined at 108 K and ca. 95 K, respectively. These results suggest that the sample consists of a mixture of phases with high and low temperature transition.

![Figure 4](image4.png)

**Figure 4.** Increase of $J_c$ by composing with Ni meshes. 1; without Ni meshes and 2, 3, 4; with meshes.

![Figure 5](image5.png)

**Figure 5.** SEM photographs of the cross section in the vicinity of interface between Bi-2223 oxide and Ag-plated Ni meshes in the cylindrical sample.
$J_c$ of the samples, 5 mm in width, 22 mm in length and 2 mm in thickness, cut out from the cylinder is shown in figure 4. The measured small pieces of the composite were cut from three cylinders. The $J_c$ values improve twice by composing with Ni meshes. It has to be mentioned that the $J_c$ values are low because the superconducting phase is not single Bi-2223 phase. It is expected, therefore, that high $J_c$ of the composite bulk is obtained with intermediate pressing and succeeding sintering [8].

Results of cross sectional SEM observations in the vicinity of the interface between the Bi-2223 oxide and Ag-plated Ni meshes in the cylindrical sample are shown in figure 3. We found dark thin layers between Ag layer and Ni metal, which was assigned to NiO by SEM-EDX. The black NiO layer 0.01 mm in thickness is formed between Ni wire and plated Ag layer during the heat treatment process. Highly $c$-axis oriented and densely structured Bi-2223 plate-like grains are formed around the Ag-plated Ni wires. It has to be mentioned that the $J_c$ increase of the Bi-2223 bulk by composing with Ni meshes is attributed to the formation of the Bi-2223 plate-like grains.

4. Conclusions
Cylindrical Bi-2223 sintered bulk composed with Ag-plated Ni meshes was prepared for application as a current lead. The mesh concentration was 18 x 18 meshes/cm$^2$ using Ni wires of 0.25 mm in diameter. Size of the cylinder was 27 mm in outer diameter 2 mm in thickness and 50 mm in length using a cold isostatic pressing (CIP) method. The samples were sintered at 845 °C for 50 h. $J_c$ of the samples was estimated by 77 K under self-field. By composing with the Ni meshes the $J_c$ property was improved to 150 A/cm$^2$ compared with the samples of 70 A/cm$^2$ without the mesh. It is mentioned that the $J_c$ increase of the Bi-2223 bulk by adding with the Ni meshes is attributed from formation of the Bi-2223 plate-like grains in the vicinity of the Ag-plated Ni wires.

Acknowledgment
The present work was partially supported by the National Institute of Fusion Science, NIFS04KFRF007.

References
[1] Yoshizawa S, Hishinuma Y, Nemoto S, Tezuka I, Haseyama S, Yamazaki S and Nakane H 2000 Applied Superconductivity 1999 (Institute of Physics Publishing) pp 255-258
[2] Matsunaga K, Nishimura A, Hishinuma Y, Nemoto S, Yoshizawa S, Satoh S and Motojima O 2000 Cryogen. Eng. 35 292-297
[3] Hishinuma Y, Yamamoto R, Hirano S, Yoshizawa S, Matsunaga K, Nishimura A, Matsumoto A and Kumakura H 2001 IEEE Trans. Appl. Superconductivity 11 3916-1919
[4] Hirano S, Wakasa Y, Saka A, Yoshizawa S, Seimiya Y, Hishinuma Y, Nishimura A, Matsumoto A and Kumakura H 2003 Physica C 392-396 458-462
[5] Nishimura A, Hishinuma Y and Yoshizawa S 2003 Supercond. Sci. Technol. 16 980-983
[6] Hirano S, Yoshizawa S, Hishinuma Y and Nishimura A 2004 Applied Superconductivity 2003 (Institute of Physics Publishing) pp 2465-2470
[7] Hirano S, Yoshizawa S, Hishinuma Y and Nishimura A 2004 Physica C 412-414 734-738
[8] Yoshizawa S, Hirano S, Hishinuma Y and Nishimura A 2005 IEEE Trans. Appl. Superconductivity 15 2495-2498