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Effect of polymeric and metal substance impregnation on the magnetic properties of YBCO bulk superconductor

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The cylindrical type of YBCO bulk superconductor was fabricated by top-seeded melt growth (TSMG) process. The 10 mm diameter of hole was mechanically drilled at the center of YBCO bulk, parallel to the c-axis. Then the mechanically drilled YBCO bulk was impregnated by epoxy resin or indium in order to elucidate the effect of impregnation on the trap field distribution depending filler materials. The trap fields of plain YBCO and YBCO with hole at 77 K under 0.33 T were 2.77 kG and 2.705 kG, whereas the trap fields of YBCO filled with resin or indium were 2.695 kG and 2.682 kG, respectively, which is relatively lower than plain YBCO without any impregnation. Based on our preliminary results of magnetic field mapping, the trap field shows the tendency of decrease even after impregnation by resin and indium into YBCO hole.

Key words: YBCO bulk, Trap field, Impregnation, Hole, Levitation force.

Introduction

Improvement of progress in the top-seeded melt growth (TSMG) skills has permitted the fabrication of large single grain bulk superconductors with large critical current density (Jc) [1]. For industrial applications, the stronger levitation force, higher critical current and stronger mechanical strength are expected for the better performances of YBCO bulks. Especially field trap capability is importance of a magnetic levitation system for a various engineering applications, such as magnetic bearing, superconducting flywheel energy storage (SFES), load transport, levitation, and trapped field magnets [2, 3].

It is well known that the critical current density (Jc) depends predominantly on the microstructural characteristics in the melt processed bulk superconductor [4, 5] and critical current density (Jc) and trapped field remarkably increase with cooling temperature [6].

Recently, researches targeted to enhance trapped field capacity of high temperature superconducting (HTS) bulks by artificial holes have been conducted by a few research groups [7-10]. The results of the researches have proved that the presence of artificial holes in the YBCO bulk superconductors benefit to prevent cracking by thermal and magnetic stresses occurred during cooling cycle or magnetization. And resin impregnation has been found to be one of effective ways in improving the mechanical properties of bulk superconductor. However, many works have not been studied the effect of the filler on the magnetic properties of YBCO until now.

In this work, the trapped flux distribution and the levitation force of YBCO have been systematically investigated in terms of different filler materials and compared with the magnetic properties before and after impregnation by epoxy resin or indium, respectively.

Experimental

The circular type of $Y_1Ba_2Cu_3O_{7-y}$ (YBCO) bulk samples were manufactured by the top-seeded melt growth (TSMG) method. Typical dimensions were 28 mm in diameter and 10 mm in thickness. And then 10 mm diameter of hole, parallel to the c-axis, was mechanically drilled at the center of YBCO bulk. Following after, epoxy resin and indium were filled into hole respectively. Magnetic flux mapping trapped field (MF), levitation force (LF) and attractive force (AF) were measured on the different samples with various fillers and compared to estimate the influence of fillers on the magnetic properties of YBCO superconductor at 77 K. Fig. 1 shows photographs of the plane YBCO bulk sample or with hole and impregnated by epoxy resin or by indium, respectively. Epoxy resin used in the experiment was composed of Stycast 2850 FT and Catalyst 24 LV as a hardener. These compounds were mixed in a weight ratio of 100 and 5. Also, indium of 99.99% purity was impregnated by melting process. Table 1 shows general features of four different YBCO bulk samples.

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Fig. 1. The melt processed YBCO bulk; (A) without hole, (B) with hole, (C) impregnated by epoxy resin, and (d) impregnated by indium.

Table 1. Typical specifications of YBCO bulk.

sample	diameter and thickness	hole size	impregnated material
(a)		no hole	none
(b)		10 mm	none
(c)	28 × 10 mm^2	10 mm	resin with STYCAST
(d)		10 mm	indium : purity: 99.99% grains: 3-6 mm

To measure the trapped magnetic field distribution, samples were cooled down in a bath of liquid nitrogen at 77 K with a permanent magnet of a surface field of 0.33 T. After the external magnetic field was removed, the trapped magnetic field distribution of the magnetized YBCO bulk was measured by scanning a Hall probe sensor attached on the sample surface. The magnetic levitation forces at 77 K were estimated from force-distance hysteresis curves of melt-textured YBCO samples under the field cooling condition using Nd-B-Fe permanent magnet of 30 mm with a surface field of 0.51 T. The bulk superconductor was cooled with liquid nitrogen at 77 K in the absence of field for about 10 min, and then the permanent magnet was approached toward the sample surface to measure the repulsive force between YBCO and permanent magnet.

Results and Discussion

Fig. 2 and Fig. 3 represent the 2 and 3-dimensional surface magnetic field distributions on the top surface of the plain YBCO at 77 K under 0.33 T. All the field profile shows the similar deformation of the contour lines measured in the field cooled mode. Fig. 2 and Fig. 3 show the single corn patterned in the all samples indicating a single-domain structure. The single grain sample represents one large maximum peak progressed at the center of the sample. The maximum trapped magnetic field distributions of the plain YBCO measured at 77 K shows almost symmetrical field distribution with the peak value of (a) 2.771 kG, (b) 2.752 kG, (c) 2.765 kG and (d) 2.757 kG, respectively. This suggests that the bulk samples were well formed as single domain with no fatal cracks or defects. Fig. 4 and Fig. 5 represent the 2 and 3-dimensional surface magnetic field distributions for the top surface of

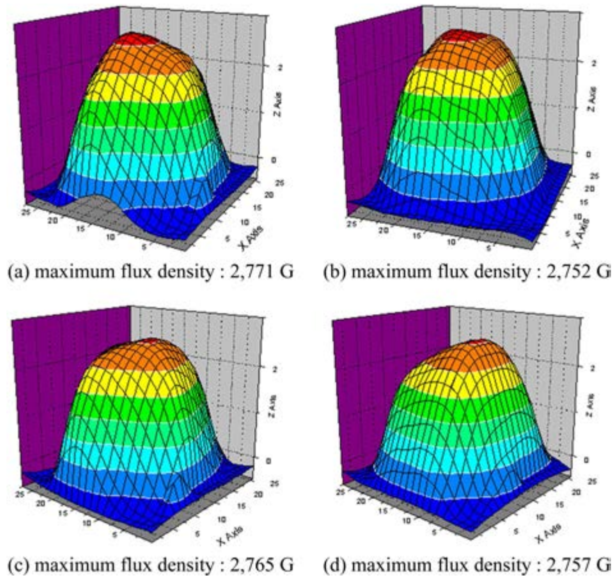

Fig. 2. The 3-dimensional surface magnetic field distributions measured on plain YBCO bulk by permanent magnet at 77 K under 0.33 T.

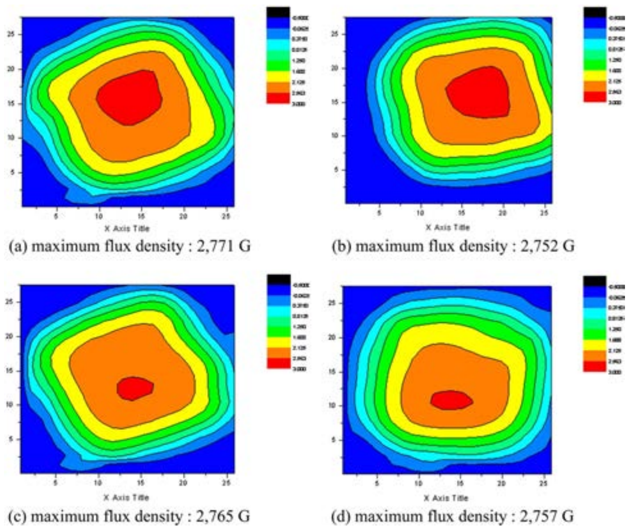

Fig. 3. The 2-dimensional surface magnetic field distributions measured on plain YBCO bulk by permanent magnet at 77 K under 0.33 T.

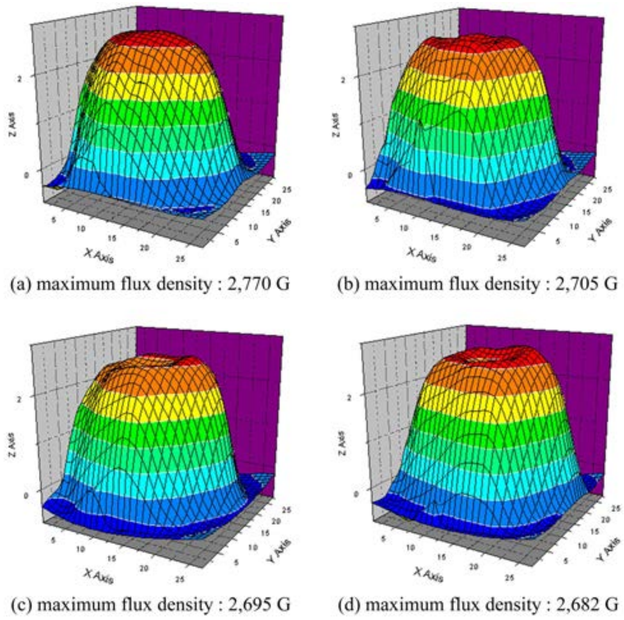

Fig. 4. The 2 and 3 dimensional surface magnetic field distributions measured on different shapes of YBCO bulk by permanent magnet at 77 K and 0.33 T; (a) without hole, (b) with hole, (c) filled with resin and (d) filled with indium.

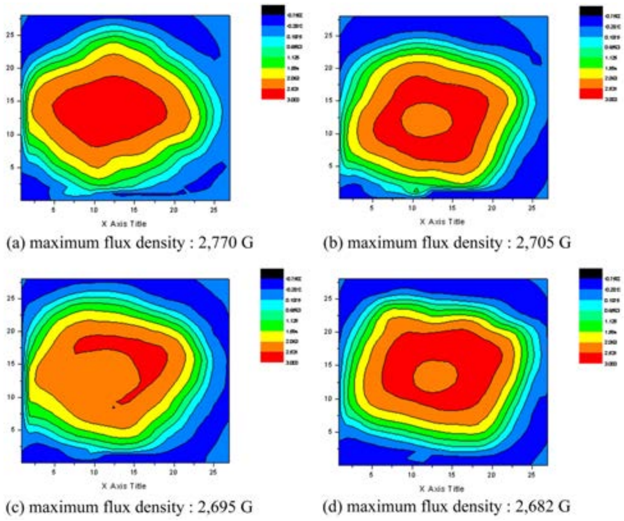

Fig. 5. The 2-dimensional field mapping profiles of YBCO bulks; (a) without hole, (b) with hole, (c) filled with epoxy resin, and (d) filled with indium.

YBCO measured at 77 K after formation of hole and then impregnated with (c) epoxy resin or (d) indium into hole, respectively. According to the measurements, the maximum magnetic flux densities of the plain sample and with hole were 2.77 kG and 2.705 kG while the maximum magnetic flux densities of the sample filled with epoxy resin and indium were 2.695 kG and 2.682 kG, respectively. This result indicates that trapped magnetic field of impregnated by epoxy resin or indium was lower than that the plain YBCO with and without hole. Also the trapped magnetic field of impregnated YBCO with indium is a little bit lower than that filled by epoxy resin. It seems

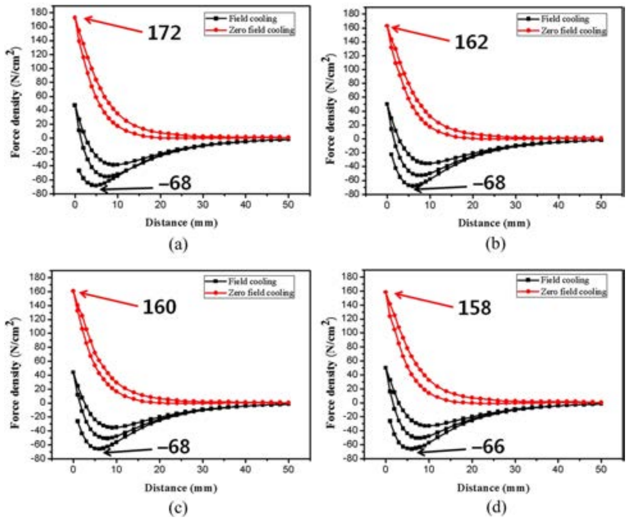

Fig. 6. The levitation and repulsive force in terms of different filler materials in YBCO samples measured at 77 K under ZFC or FC conditions; (a) without hole, (b) with hole, (c) filled with resin and (d) filled with indium.

that polymeric material influences more than that of metal substance in magnetic flux density. These results well agree with the tendency of the levitation and attractive forces shown in Fig. 6. Fig. 6(a) - (d) show the plots of the repulsive force versus the distance between sample surface and the permanent magnet at 77 K. It was known that the levitation force is dependent on many parameters, such as the critical current density and grain size, grain radius, grain orientation, etc. [10]. The maximum attractive and repulsive forces of the pure YBCO without hole under ZFC and FC were 172 N/cm^2, and - 68 N/cm^2 while the maximum attractive and repulsive forces of the YBCO impregnated by resin measured at ZFC and FC were 160 N/cm^2, and - 68 N/cm^2, respectively. The attractive forces of the plain sample and with hole at 1 mm interval between sample and the permanent magnet under ZFC were about 172 N and 162 N, whereas the attractive forces of those impregnated by epoxy resin or indium under ZFC were 160 N and 158 N, respectively. From the results taken from levitation force measurement, we confirmed that plain YBCO or with hole exhibit higher magnetic properties as compared with YBCO impregnated by any other substances. Also the levitation force of YBCO with polymeric resin was somewhat higher than that impregnated by metal substance of indium. The results on levitation force measurement shown in Fig. 6 represent the similar implication of the magnetic field mapping measurement, indicating the tendency of decrease after impregnation by epoxy resin and indium. The small variation of levitation force of the individual sample was due to the reduction of the sample's volume comparing with that entire single-domain bulk sample. Particularly the relative levitation force variations in drilled hole and impregnated materials are presumably related to the effect of additional cracks generated during the drilling process. Therefore it can be conclude that magnetic properties of infiltrated YBCO with resin or indium relatively decreased as compared with the plain YBCO or with hole, even though impregnation has been found to be one of effective ways in improving the mechanical properties of bulk superconductor.

Conclusions

The YBCO bulk was mechanically drilled on parallel to the c-axis and impregnated by epoxy resin and indium. The 2, 3-dimensional surface magnetic field distributions and the maximum levitation force were measured at 77 K on the samples with different substance impregnation. By applying 0.33 T using permanent magnet, the trapped fields of YBCO without or with hole exhibit 2.77 kG and 2.705 kG, while those of YBCO filled with epoxy resin or impregnated with indium represent 2.695 kG and 2.682 kG, respectively. This results show that the trap field of mechanically drilled YBCO was lower than that of pure YBCO. Also the levitation forces of plain YBCO or with hole in ZFC were 172 N and 162 N whereas the sample impregnated by epoxy resin or indium were 160 N and 158 N, respectively. We confirmed that the magnetic properties of YBCO bulk with or without hole were somewhat higher than that by impregnated by polymeric or metal substance. The trapped magnetic field and levitation force were found to decrease regardless impregnated substance.

Acknowledgements

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