§3. Fabrication of HTS Low Porosity Bulks in Air and Evaluations of the Fracture Strength Properties

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Improvements of fracture strength of melt-processed $REBa_2Cu_3O_x$ (RE123, where RE denotes rare-earth elements) single-grain bulks are crucial for the development of RE123 superconducting current leads used for magnetically confined fusion reactors. Conventional RE123 bulks have pores which cause degradation of fracture strength. Such conventional bulks are melt-grown from precursors, which are prepared by cold isostatic pressing. It is deduced that pores in the precursors remain in the final RE123 bulks. In the present study, we try to fabricate Dy123 low porosity bulks by using precursors prepared through spark plasma sintering (SPS) process.

SPS temperatures were 650, 700 and 750 ℃. SPS pressure was 50 MPa. Precursors prepared through the SPS process were heated in air up to 1150 ℃, kept at that temperature for 1 h and then cooled down to 1040℃. After that, one Nd123 seed crystal was placed on each of them and they were gradually cooled down. These bulk samples are denoted as Sample 650, Sample 700 and Sample 750, respectively. Diameters of the samples were about 20 mm. Fracture strength was evaluated through the three-point bending tests for specimens cut from the bulk samples. The width and thickness of the specimens were 2.5 and 1.5 mm, respectively. The 1.5 mm direction of the specimens almost corresponded to the c-axis of the bulk samples. The fulcrum span of the bending test was 7 mm. Three-point bending load was applied at room temperature in the 1.5 mm direction. After the bending tests, fracture surfaces were observed by using scanning electron microscope.

Fig. 1 shows polished surfaces of the Dy123 bulk samples. Porosities for Samples 700 and 750 are lower than those of conventional bulks.

Fig. 2 shows magnified view of the polished surfaces. Although the Dy_2BaCuO_5 (Dy211) secondary phase particles of Sample 650 seem to be slightly coarse, fine Dy211 particles are dispersed for all samples.

Fig. 3 shows fracture strength of specimens cut from the Dy123 bulk samples. Improvement of the minimum fracture strength value is observed for Sample 750, which is presumably attributable to the increase of the net cross-sectional area caused by the reduction of pores. On the other hand, the maximum fracture strength values are similar between Samples 650 and 750. This is probably because Sample 650 also has low porosity region near the surface of the bulk. Fracture strength was improved by using a dense precursor as expected, but scatters of the fracture strength data of these bulks are relatively significant.

In order to investigate the reason for the large scatter of the fracture strength data, fracture surfaces of the bending test specimens were observed, as shown in Fig. 4. Steps parallel to the c-axis, which are presumably due to the pre-existing cracks (Fig. 4 (c)), and opening of a large macro-crack (Fig. 4 (b)) are observed as marked by arrows. It is deduced that scatter of the fracture strength data was caused by the distributions of pores and pre-existing cracks.

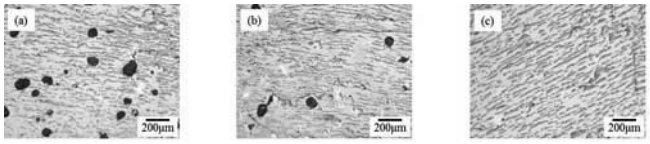

Fig. 1. Polished surfaces of Dy123 single-grain bulks fabricated from spark plasma sintered precursors. (a) Sample 650, (b) Sample 700 and (c) Sample 750. Black parts are pores.

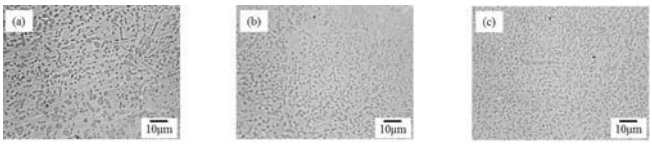

Fig. 2. Magnified view of polished surfaces. (a) Sample 650, (b) Sample 700 and (c) Sample 750. Fine secondary phase particles are observed.

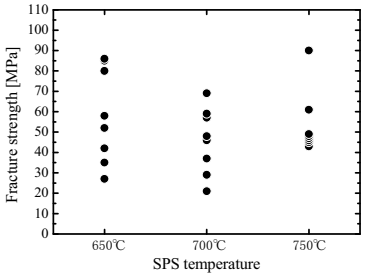

Fig. 3. Fracture strength of specimens cut from Dy123 bulk samples.

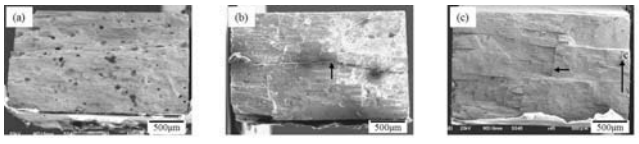

Fig. 4. Fracture surfaces of bending test specimens. (a) Sample 650, (b) Sample 700 and (c) Sample 750.