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Fracture toughness of Dy123 low porosity bulks at liquid nitrogen temperature

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ABSTRACT

In order to evaluate the fracture toughness of $DyBa_2Cu_3O_x$ (Dy123) low porosity bulks, bending tests of V-notched specimens cut from the bulks were carried out. Fracture toughness evaluations of a conventional Dy123 bulk which had pores were also carried out and effects of elimination of pores on the fracture toughness were investigated. Fracture toughness values at 77 K of the low porosity bulks were higher than those of the porous bulk. These fracture toughness values at 77 K were higher than the values at room temperature. Fracture toughness of the low porosity bulk was improved by Ag addition.

1. Introduction

Improvements of the mechanical properties such as fracture strength and fracture toughness of $RBa_2Cu_3O_x$ (R123, where R is yttrium or rare-earth elements) superconducting bulks are important because R123 bulks are subjected to the electromagnetic force and thermal stress in the superconducting devices. Conventional R123 bulks fabricated in air or under low O_2 atmosphere have pores which cause degradation of the mechanical properties. It has been reported that R123 bulks fabricated by heating precursors in O_2 atmosphere had few pores [1–9] and the fracture strength values at room and cryogenic temperatures of the R123 low porosity bulks were higher than those of conventional R123 bulks which had pores [1,4–9]. Since R123 bulks have inherent brittleness, fracture toughness evaluations are also important as well as fracture strength evaluations. Fracture toughness values of Dy123 low porosity bulks at room temperature have been reported by the present authors [4,6,10]. However, the fracture toughness of R123 low porosity bulk at cryogenic temperature has not been evaluated. In the present study, the fracture toughness of Dy123 low porosity bulks and that of a conventional Dy123 bulk which had pores were evaluated at liquid nitrogen temperature (77 K) through bending tests of V-notched specimens cut from the bulks and effects of elimination of pores on the fracture toughness at 77 K were investigated.

It is well-known that Ag addition is effective in improving the mechanical properties of R123 bulks [1,7,11,12]. In the present study, effects of Ag addition on the fracture toughness at 77 K were also investigated for the Dy123 low porosity bulks.

2. Experimental procedure

Dy123 single-grain bulk samples fabricated by Nippon Steel Corporation were tested. Specifications of the bulk samples are shown in Table 1. These bulk samples are denoted as Dy0P, Dy0LP and Dy10LP, respectively. While the Dy0P was fabricated in air, the Dy0LP and the Dy10LP were fabricated by heating precursors in O_2 atmosphere. Details of the fabrication processes for these bulk samples are reported elsewhere [6]. Optical micrographs of the bulk samples are shown in Fig. 1. Few pores are observed for the Dy0LP and the Dy10LP.

Fracture toughness evaluations were carried out at 77 K through bending tests of V-notched specimens cut from the bulk samples. Specimens with the dimensions of $2.8 \times 2.1 \times 24$ mm^3 were cut from the as-grown bulk samples Dy0P, Dy0LP and Dy10LP as shown in Fig. 2. Oxygen annealing was conducted for the specimens at 723 K for 100 h. One V-notch was introduced to the center of the longitudinal direction of the specimens as shown in Fig. 3. Razor and diamond paste were used to obtain sharp V-notch with the notch root radius of about 20 μm. Reduced notch depth (notch depth/height of the specimen) was 0.24–0.37.

Each V-notched specimen was placed on a bending test jig as shown in Fig. 3 and then immersed in the liquid nitrogen bath. Four-point bending load was applied to the specimen in the liquid nitrogen bath at a crosshead speed of 0.1 mm/min by means of INSTRON 4464 testing machine equipped with a 2 kN load cell.

Fracture toughness value K_{IC} was calculated by the following equations [13].

$$K_{IC} = \sigma_{max}\sqrt{\pi a}F(a/W) \quad (1)$$

$$\sigma_{max} = \frac{3P_{max}(L-l)}{2BW^2} \quad (2)$$

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Table 1
Specifications of Dy123 bulk samples.

Sample name	Dy211 (mol%)	Ag (wt.%)	Pt (wt.%)
Dy0P (porous)[a]	25	0	0.5
Dy0LP (low porosity)[b]	25	0	0.5
Dy10LP (low porosity)[b]	25	10	0.5

[a] Dy123 porous bulk fabricated in air.
[b] Dy123 low porosity bulks fabricated by heating precursors in O_2 atmosphere.

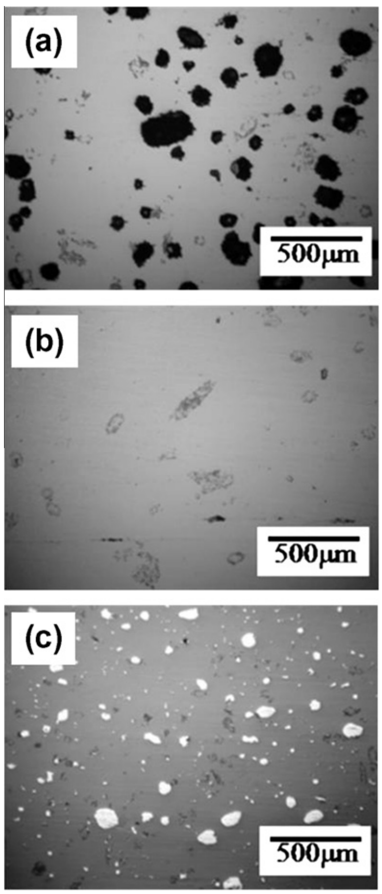

Fig. 1. Optical micrographs of Dy123 bulk samples: (a) Dy0P, (b) Dy0LP and (c) Dy10LP. Black parts of (a) are pores and white parts of (c) are Ag particles.

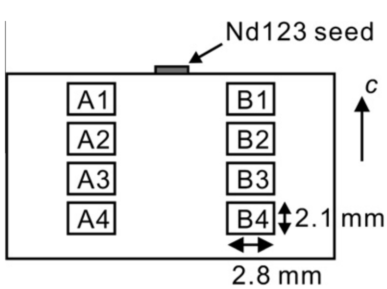

Fig. 2. Cutting out of fracture toughness test specimens.

$$F(a/W) = \sqrt{\frac{2W}{\pi a}\tan\left(\frac{\pi a}{2W}\right)}\frac{0.923 + 0.199(1 - \sin\frac{\pi a}{2W})^4}{\cos\frac{\pi a}{2W}} \quad (3)$$

where P_{max} is the maximum load applied, a is V-notch depth, L is outer supporting span, l is upper loading span, W and B are height and thickness of the specimen, respectively.

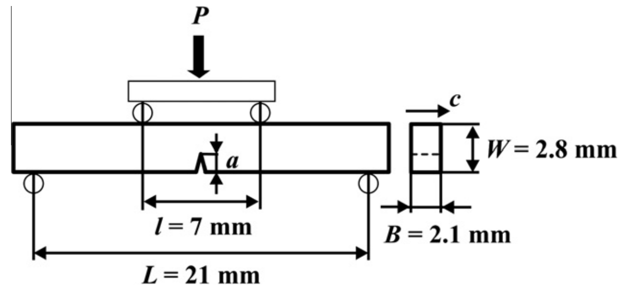

Fig. 3. Schematic illustration of fracture toughness test.

After the fracture toughness tests, fracture surface observations were carried out by using a scanning electron microscope. Optical micrographs of polished side surfaces of the fractured specimens were also obtained as shown in Fig. 1. Area fraction and the average size of pores and Ag particles were measured through image analysis.

3. Results and discussion

3.1. Relationship between fracture toughness at 77 K and porosity

Fracture toughness values at 77 K of the Ag-free bulks Dy0LP and Dy0P are shown in Fig. 4. Fracture toughness values at room temperature (RT) of an Ag-free Dy123 low porosity bulk [4] and an Ag-free Dy123 porous bulk [14] reported elsewhere are also shown for reference. Scatter of the fracture toughness data of the porous bulk Dy0P was larger than that of the low porosity bulk Dy0LP. One of the reasons for it is significant difference in the porosity among the specimens of the porous bulk Dy0P as mentioned in the followings. Fracture toughness values at 77 K of the low porosity bulk were higher than those of the porous bulk as well as the fracture toughness at RT. The average fracture toughness value at 77 K of the low porosity bulk was 1.88 MPa $m^{1/2}$, which was 20% higher than that of the porous bulk 1.57 MPa $m^{1/2}$. It is deduced that such an improvement of the fracture toughness by eliminating pores is attributable to that the net cross-sectional area of the Dy0LP is 12–16% larger than that of the Dy0P as mentioned in the followings (see Fig. 5). The average fracture toughness value of the low porosity bulk at 77 K was 25% higher than that at RT and

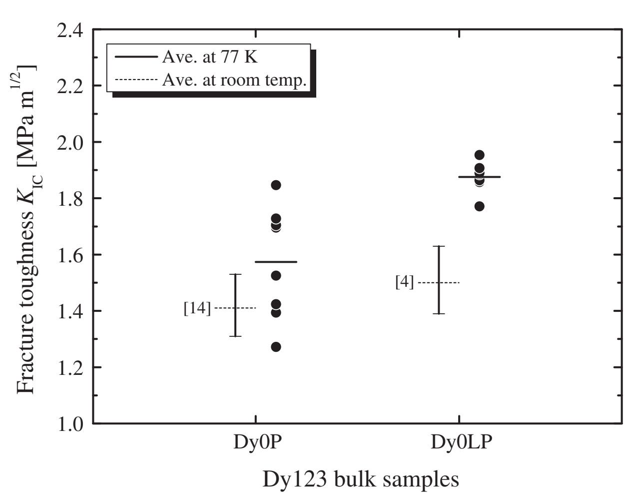

Fig. 4. Fracture toughness values at 77 K of specimens cut from Ag-free bulks Dy0LP and Dy0P. Fracture toughness values at room temperature of an Ag-free Dy123 low porosity bulk [4] and an Ag-free Dy123 porous bulk [14] reported elsewhere are also shown for reference.