Low-temperature mechanical properties of MgB_2 bulk fabricated by hot isostatic pressing

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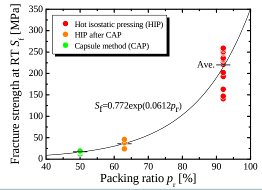
Introduction

Understandings of mechanical properties such as fracture strength and fracture toughness of superconducting bulks are indispensable because superconducting bulks are subjected to electromagnetic force and thermal stress in the superconducting devices. However, mechanical properties of MgB_2 bulk have not been understood extensively. In our previous study, packing ratio of an MgB_2 bulk fabricated by hot isostatic pressing (HIP) was higher than those of conventional MgB_2 bulks fabricated by capsule method [1]. The fracture strength of the former MgB_2 bulk was excellent at room temperature (RT) [1]. Evaluations of the mechanical properties at cryogenic temperature are informative for the practical application of superconducting bulks. In the present study, fracture strength and fracture toughness of an MgB_2 bulk fabricated by HIP were evaluated at 77 K through bending tests for specimens cut from the bulk. The fracture strength at very low temperature was estimated from the bending test results at 77 K and RT.

[1] A. Murakami et al., Physics Procedia accepted.



Conclusion

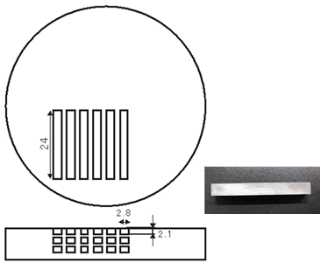
Fracture strength and fracture toughness in an MgB_2 bulk with the packing ratio of 92 % fabricated by hot isostatic pressing were evaluated at 77 K through bending tests for specimens cut from the bulk. The average fracture strength of the MgB_2 bulk at 77 K (257 MPa) was higher than that at room temperature (220 MPa). The fracture strength at 77 K of the MgB_2 bulk was also higher than that of a high-density RE-Ba-Cu-O bulk. Considering the experimental results, the fracture strength at 77 K of ideal MgB_2 bulk, whose packing ratio is 100 %, is estimated to be around 419 MPa. The fracture strength at 4.2 K of the HIP MgB_2 bulk (Packing ratio: 92 %) is estimated to be around 269 MPa.

Bulk sample & Specimens

MgB_2 bulk sample

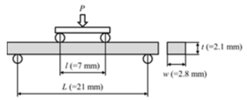
MgB_2 bulk sample with 70 mm in diameter was prepared by HIP. HIP pressure, temperature and time were 98 MPa, 1173 K and 3 h, respectively. The packing ratio of the MgB_2 bulk, which was measured by Archimedian method, was 92 %.

Bending test specimens



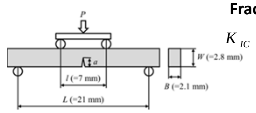
Bending test specimens with the dimensions of 2.8 x 2.1 x 24 mm³ were cut from the MgB_2 bulk.

Bending test procedures



Fracture strength

$$\sigma_f = \frac{3P(L-l)}{2wt^2}$$

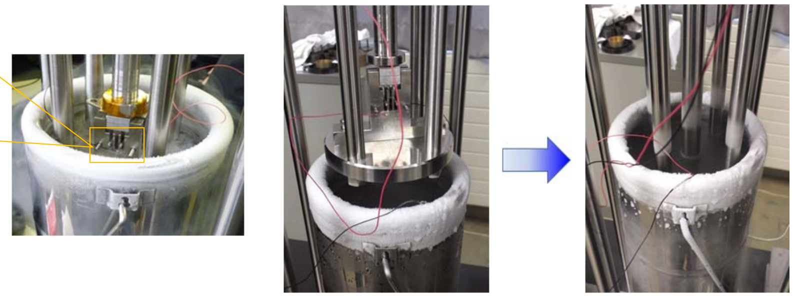


Fracture toughness

$$K_{IC} = \sigma\sqrt{\pi a}\,F(a/W)$$

$$\sigma = \frac{3P(L-l)}{2BW^2}$$

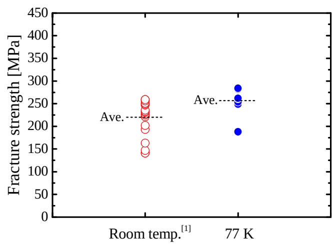
$$F(a/W) = \sqrt{\frac{2W}{\pi a}\tan\left(\frac{\pi a}{2W}\right)}\;\frac{0.923+0.199\left(1-\sin\frac{\pi a}{2W}\right)^4}{\cos\frac{\pi a}{2W}}$$



Specimen was placed on the four-point bending jig. After that, the specimen was immersed into the liquid nitrogen bath, together with the jig.

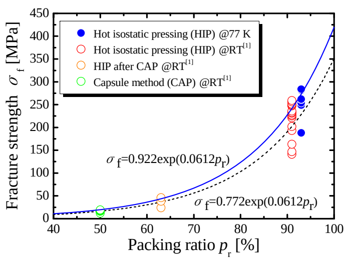
Results

Fracture strengths at 77 K and RT



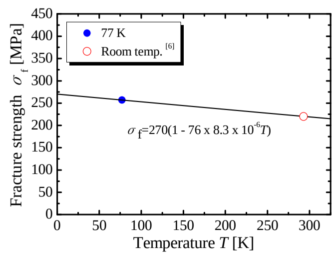
Fracture strength at 77 K is higher than that at RT. Improvement of the fracture strength by cooling is mainly due to the decrease of inter-atomic distance. The fracture strength at 77 K of the MgB_2 bulk (188-284 MPa) is higher than that of a high-density RE-Ba-Cu-O bulk (99-132 MPa).

Fracture strength and packing ratio



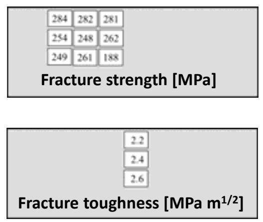
Dependence of the fracture strength at 77 K on the packing ratio is expressed as shown by the blue solid line. The fracture strength at 77 K of ideal MgB_2 bulk, whose packing ratio is 100 %, is estimated to be around 419 MPa.

Fracture strength and temp.



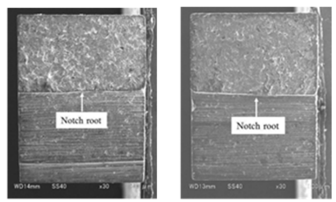
By using the average fracture strengths (257 MPa at 77 K and 220 MPa at RT) and coefficient of thermal expansion (8.3 x 10⁻⁶ K⁻¹), temperature dependence of the fracture strength is expressed as shown in the figure. The fracture strength at liquid helium temperature (4.2 K) is estimated to be around 269 MPa.

Distribution



The maximum fracture strength value is observed for the region near the surface. The minimum fracture strength value is observed for the inner region. There is no significant difference in the fracture toughness value between the regions near the surface and inner.

Fracture surfaces



Max. toughness **Min. toughness**

V-notched specimens

Fracture surfaces of the specimens cut from the inner region are slightly rough in comparison with those of the specimens cut from the region near the surface of the bulk. It is thought that one of the reasons for the rough fracture surfaces is existence of sintering defects. The fracture strength is degraded by the sintering defects because the sintering defects can be an origin of the fracture. On the other hand, it is deduced that the fracture toughness is not degraded by the sintering defects because the fracture of the V-notched specimens is caused at the V-notch.