§1. Research on Mechanical Properties of MgB_2 Superconducting Bulk Materials

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Large superconducting bulk materials are required for the development of high performance devices. RE-Ba-Cu-O (RE: rare-earth elements) is commonly used for the superconducting bulk applications. However, RE-Ba-Cu-O bulk materials have to be a single-grain fabricated by using a seed crystal. It is difficult to obtain large bulk pieces due to undesirable nucleation at positions away from the seed crystal. Although the critical temperature of MgB_2 is lower than that of RE-Ba-Cu-O, high performance MgB_2 bulk materials would be obtained by just sintering. Thus, MgB_2 is promising for the large bulk pieces. Sintering of a MgB_2 bulk is commonly carried out under ambient pressure. The packing ratio (relative density) of the MgB_2 bulk is commonly low (around 50%). Low packing ratio causes declination of the mechanical properties. Since superconducting bulk materials are subjected to the electro-magnetic force and thermal stress in the superconducting devices, improvement of the packing ratio of a MgB_2 bulk is required. In this study, high packing ratio MgB_2 bulk samples by HIP (Hot Isostatic Pressing) and SPS (Spark Plasma Sintering) are prepared, and the effects of the improvement of the packing ratio on the mechanical properties of the MgB_2 bulks are investigated.

Four MgB_2 bulk samples were prepared. Mechanical properties were evaluated through four-point bending tests at room and liquid nitrogen temperatures (293 and 77 K) for specimens cut from the bulk samples. The specimens were immersed into a liquid nitrogen bath, together with the bending test jig, for 77 K tests.

Fig. 1 shows the relationship between the average fracture strength at room temperature and packing ratio of the MgB_2 bulk samples. The packing ratio and fracture strength of the usual MgB_2 bulk fabricated by CAP (capsule method: sintering under ambient pressure) were 50% and 20 MPa, respectively. The packing ratio and fracture strength were improved by HIP, which were 92% and 220 MPa, respectively. Further improvements were achieved by SPS. The packing ratio and fracture strength of the SPS bulk were 98% and 315 MPa, respectively. Stress-strain behaviors of the high packing ratio MgB_2 bulks fabricated by HIP and SPS were almost linear until their fractures. Such linear behavior is typical to brittle materials. On the other hand, stress-strain behavior of the usual MgB_2 bulk fabricated by CAP was not linear. It is deduced that vacancies cause the non-linear behavior. The packing ratio was not improved by HIP after CAP. The relationship between the fracture strength and packing ratio of the MgB_2 bulks can be approximated by using the exponential function.

Fig. 2 shows the fracture strength of the specimens cut from the MgB_2 bulk fabricated by SPS at 77 and 293 K. The facture strength is improved by cooling, which is mainly due to the decrease of the interatomic distance. Since the critical temperature of MgB_2 is lower than 77 K, the fracture strength at lower temperature was estimated by using the fracture strength data at 77 and 293 K and coefficient of thermal expansion. The fracture strength at 20 K was estimated to be around 425 MPa.

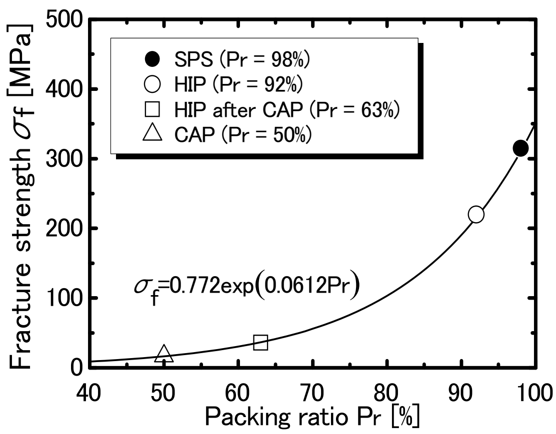

Fig. 1. Relationship between average fracture strength at room temperature and packing ratio of MgB_2 bulks.

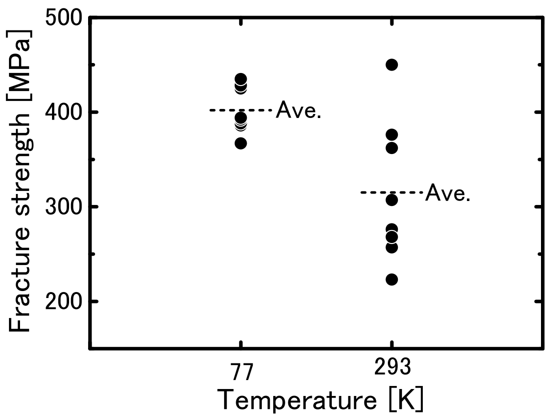

Fig. 2. Fracture strength at 77 K and room temperature (293 K) of MgB_2 bulk fabricated by SPS.