

Critical current density and flux pinning characteristics of powdered MgB_2 specimens

Y. Matsumoto^{a,b,1}, I. Shigeta^b, T. Abiru^a, Y. Terasaki^a, T. Akune^c, N. Sakamoto^c

^aDepartment of Electrical Engineering, Fukuoka University, 8-19-1 Nanakuma, Fukuoka 814-0180 Japan

^bAdvanced Materials Institute, Fukuoka University, 8-19-1 Nanakuma, Fukuoka 814-0180 Japan

^cDepartment of Electrical Engineering, Kyushu Sangyo University, 2-3-1 Matsukadai, Fukuoka 813-8503, Japan

Abstract

Field and temperature dependence of magnetization and also time dependent magnetization (flux creep) of powdered MgB_2 specimens have been measured by using SQUID magnetometer in the temperature range of $4.5 \leq T \leq 37$ K and under the field up to 1 T. Scaling plots of normalized pinning force density $F_p/F_{p\max}$ as a function of normalized flux density B/B_{\max} in the temperature range of $25 \leq T \leq 37$ K showed that a two dimensional pinning is dominant for the flux pinning of the specimens. Another distinct feature is that a linear reduction of J_c with increasing temperature at temperatures lower than 30 K and a quadratic decrease at higher temperatures than 35 K have been observed.

Key words: MgB_2 ; Magnetization; Critical current density; Flux pinning

1. Introduction

Magnesium diboride, MgB_2 , is a newly discovered superconductor [1] and is an interesting material for superconducting wire fabrication, because it has a high critical current density even at 20 K. Recently, some research groups have reported the J_c characteristics and other physical properties for the MgB_2 wires fabricated by the powder in tube (PIT) method, where a commercially available MgB_2 powder was used [2,3]. It is important, therefore, to examine the flux pinning mechanism of the powder. Our object is to elucidate the flux pinning characteristics of the powder.

2. Experimental

The particle size of MgB_2 powder (produced by Alfa Aesar Co., phase purity 98%) was selected by using

two kinds of sieve with mesh size of 50 μm and 63 μm . Selected powder was mixed with epoxy resin and was solidified in order to reduce connection between particles. DC magnetization of thus fabricated samples was measured by SQUID (Quantum Design Co.) at temperatures of $4.5 \leq T \leq 40$ K and under magnetic field of $|B| \leq 1$ T.

3. Results and discussion

Superconducting transition temperature T_c of the specimen was 38.5 K. Hysteresis loops of the magnetization M were measured at temperatures $4.5 \leq T \leq 37$ K. They showed symmetric behavior to the $M = 0$ line which means the measured magnetization gives the bulk feature.

The critical current density was determined from the hysteresis width of the magnetization using Bean model, where the diameter of the powdered specimen was estimated to be 56.5 μm . The irreversibility field

¹ E-mail: matumoto@fukuoka-u.ac.jp

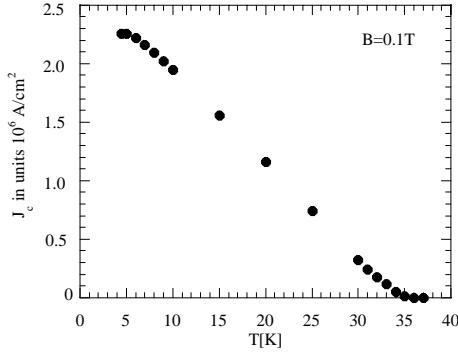


Fig. 1. Temperature dependence of J_c for $B = 0.1$ T.

was determined as a field at which the J_c becomes 1×10^2 A/cm 2 .

Temperature dependence of J_c under a field of 0.1 T is shown in Fig. 1. Almost experimental points except those at temperatures lower than 5 K and those at temperatures higher than 35 K lie on a straight line. Such linear decrease of J_c with increasing temperature has been already reported [4]. Concave behavior of J_c in high temperature region may come from a flux creep effect. In our flux creep measurements, the creep rate, $d|M|/d \log t$, abruptly increases at temperatures higher than 30 K. Such behavior can be explained by Kim & Anderson model. According to the model,

$$J_c(T) = J_{c0}(T) \left[1 - \frac{k_B T}{U_0(T)} \log \frac{t}{t_0} \right],$$

is obtained, where

$$U_0(T) = U_0(0) \left[1 - \left(\frac{T}{T_c} \right)^2 \right]^{\frac{3}{2}}.$$

If we neglect $(T/T_c)^2$ term compared to T/T_c , then a quadratic feature of J_c on temperature can be deduced.

The reduced pinning force density $F_p/F_{p\max}$, where $F_{p\max}$ means the maximum value of the pinning force density F_p , was plotted as a function of reduced magnetic field $b = B/B_{\max}$. B_{\max} is the field at which the F_p becomes its maximum. The experimental results were compared with three kinds of theoretical curves. If we describe the pinning force density as $f(b)$, then following expressions are well known [5];

$$f(b) = 3b^2 \left(1 - \frac{2b}{3} \right) \text{ for } \Delta\kappa \text{ pinning,}$$

$$f(b) = \frac{9}{4}b \left(1 - \frac{b}{3} \right)^2 \text{ for normal point pinning and}$$

$$f(b) = \frac{25}{16}\sqrt{b} \left(1 - \frac{b}{5} \right)^2 \text{ for surface pinning.}$$

The experimental results at $T = 25$ K is shown in Fig. 2, where the expected three theoretical curves are

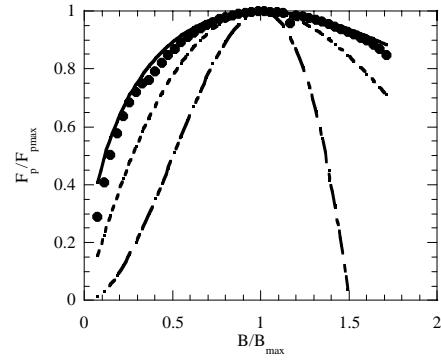


Fig. 2. Reduced pinning force density vs reduced field at 25 K. Solid circles are experimental points. Solid line, dotted line and dot-dashed line show curves from the surface pinning, the normal point pinning and the $\Delta\kappa$ pinning, respectively.

also shown. It is obvious that the experimental points are most fitted to the curve from the surface pinning. The fact means that the flux pinning mechanism of the sample comes from a two-dimensional surface pinning. SEM observation showed the used MgB₂ powder consists of tiny grains with the size less than 0.1 μm . It suggests that the specimen contains so much grain boundaries.

Another scaling of pinning force density was accomplished. If we plot the $F_p/F_{p\max}$'s versus $h = H/H_{\text{irr}}$, where H_{irr} means the irreversibility field, the experimental points for $T = 30 \sim 35$ K are well fitted to a curve calculated by an equation $F_p/F_{p\max} = h^\gamma(1 - h)^\delta$, $\gamma = 0.65$ and $\delta = 2.0$. The value of $\delta = 2.0$ means that the pinning force density has a saturating characteristic like as the case of Nb₃Sn.

As a conclusion, a concave behavior of $J_c(T)$ at temperatures higher than 30 K is caused by the flux creep. Flux pinning of measured MgB₂ specimen mainly comes from surface pinning which may be attributed to grain boundaries. The experimental points at temperatures higher than 30 K are well fitted to an universal curve represented by $F_p/F_{p\max} = h^{0.65}(1 - h)^{2.0}$, if we scale a magnetic field by the irreversibility field.

References

- [1] J. Nagamatsu, N. Nakagawa, T. Muranaka, Y. Zenitani, J. Akimitsu, *Nature* **410** (2001) 63.
- [2] H. Fujii, H. Kumakura, K. Togano, *Physica C* **363** (2001) 237.
- [3] C. Beneduce, H. L. Suo, P. Toulemonde, N. Musolino, R. Flukiger, preprint
- [4] J. R. Thompson, M. Paranthaman, D. K. Christen, K. D. Sorge, H. J. Kim, J. G. Ossandon, *Supercond. Sci. Technol.* **14** (2001) L19.
- [5] T. Higuchi, S. I. Yoo, M. Murakami, *Phys. Rev. B* **59** (1999) 1514.