Available online at www.sciencedirect.com
ScienceDirect
Physica C 456 (2007) 196–202
PHYSICA C
www.elsevier.com/locate/physc

Review

Fabrication and properties of powder-in-tube-processed MgB_2 tape conductors

H. Kumakura *, A. Matsumoto, T. Nakane, H. Kitaguchi

National Institute for Materials Science, 1-2-1, Sengen, Tsukuba, Ibaraki 305-0047, Japan

Received 6 December 2006; received in revised form 26 December 2006; accepted 28 December 2006
Available online 9 January 2007

Abstract

MgB_2 tapes are now fabricated by two powder-in-tube (PIT) methods. One is an *in situ* method, in which a powder mixture of Mg and B is used as a starting material. The other is an *ex situ* method, in which reacted MgB_2 powder is used. Here, we report the recent progress of our PIT-processed MgB_2 tapes. The superconducting properties of PIT-processed MgB_2 tapes are sensitive to the quality of the starting powder, the porosity of the MgB_2 core, the heat-treatment temperature, and impurity additions. In the case of the *in situ* method, a sub-micrometer Mg starting powder is quite effective for enhancing J_c. Some kinds of carbon compound additions to the starting powder introduce a carbon substitution for boron in MgB_2 crystal and enhance B_{irr}. At 20 K, B_{irr} reached ~10 T, a value which is nearly equal to that of commercial Nb–Ti at 4.2 K. This result clearly indicates that MgB_2 tapes are promising as conductors of cryogen-free magnets. In general, *ex situ*-processed MgB_2 tapes show lower J_c than *in situ*-processed tapes. The key factor to obtain a high J_c for an *ex situ* tape is the high quality of the MgB_2 starting powder. Recently, we succeeded in the fabrication of high J_c *ex situ* MgB_2/Fe tapes using MgB_2 cores removed from *in situ* MgB_2 tapes. Furthermore, the J_c of this *ex situ*-processed tape was less sensitive to the magnetic field than that of the *in situ* tape because of the higher B_{irr} of the *ex situ* tape. Al-sheathed *ex situ*-processed tapes are interesting due to their light weight and the high thermal stability of conductor. By improving the tape fabrication process mentioned above, we have obtained a large increase of J_c values. The highest J_c values obtained so far are 27 kA/cm^2 at 4.2 K and 10 T and higher than 10 kA/cm^2 at 20 K and 5 T. However, these J_c values are still below a practical level. Further improvement of the processing of MgB_2 tapes is essential in order to obtain a practical level of J_c values.

Keywords: Microstructure; Upper critical field; Critical current density

Contents

* Corresponding author. Tel.: +81 29 859 2327; fax: +81 29 859 2301.
E-mail address: KUMAKURA.Hiroaki@nims.go.jp (H. Kumakura).

0921-4534/$ - see front matter
doi:10.1016/j.physc.2006.12.017

1. Introduction

Because the superconducting transition temperature, T_c, of MgB_2 is much higher than that of conventional metallic superconductors, MgB_2 is expected to be a promising candidate for practical applications. The lower material costs of Mg and B than of Nb are additional advantages of MgB_2. T_c values of ~40 K suggest that MgB_2 can be used with a convenient cryocooler as a conductor for a cryogen-free magnet at elevated temperatures of ~20 K. For this reason, many studies have already been reported on the fabrication and properties of MgB_2 tapes and wires. Canfield et al. first fabricated dense MgB_2 wires by exposing tungsten-core boron filaments to Mg vapor and obtained good superconducting properties [1]. However, most of the MgB_2 tapes and wires are now fabricated by the powder-in-tube (PIT) method [2–5]. There are two methods for fabricating MgB_2 tapes and wires when using the PIT method. One is to use a mixture of Mg and B powder with a stoichiometric composition [6], and the other is to use MgB_2-reacted powder [7]. Many experiments were performed for both methods in order to enhance superconducting properties of PIT processed tapes and wires. However, the critical current density, J_c, of MgB_2 tapes and wires does not yet reach a practical level. In this paper, we report our recent systematic investigation on the T_c, upper critical field, B_{c2}, irreversibility field, B_{irr}, and J_c of single-core MgB_2 tapes fabricated by both *in situ* and *ex situ* techniques.

2. In situ method

2.1. Fabrication of MgB_2 tapes

In situ MgB_2 tapes are fabricated by using a mixture of Mg powder and B powder. However, it is difficult to obtain high J_c values using commercial Mg and B powder. This is probably because the surface of commercial Mg powder has already been oxidized. Thus, a pre-treatment of the starting powder seems to be important. Ball milling the Mg + B powder mixture under an inert gas atmosphere is a well-known pre-treatment method [8–10]. Ball milling the Mg powder alone is also effective for improving the J_c values, while ball milling the B powder alone is not effective for increasing the J_c values. This suggests that ball milling removes the oxide layers on the surface of the Mg powder and, thus, accelerates the reaction between the Mg and B powders. MgH_2 as a substitute for Mg powder is also effective in promoting the reaction and enhancing the J_c values [11]. In our tape fabrication procedure, a ball-milled Mg and B powder mixture or an MgH_2 + B powder mixture is put into an Fe tube, and the tube is cold-rolled into a tape without any intermediate annealing. A typical tape is 4 mm wide and 0.5 mm thick. The tapes are heat-treated at 600–900 °C for 1 h under an argon gas atmosphere. The heat-treatment temperature of 600 °C is not high enough to finish the reaction between Mg and B powder if ball milling is not applied. However, a complete reaction is obtained for a ball-milled powder mixture or a MgH_2 and B powder mixture for this heat-treatment temperature.

The use of nanometer-size Mg powder prepared under a high-purity argon gas atmosphere by the thermal plasma method [12] or the arc plasma method [13] is effective for obtaining smaller MgB_2 grain size and increasing the J_c values.

Concerning the composition of the Mg + B starting powder, a slightly Mg-rich composition from stoichiometry is usually used in order to optimize the J_c values because some amount of Mg is vaporized during the heat-treatment. However, Jiang et al. reported that the best J_c values in high fields are obtained for a slightly Mg-deficient composition because the Mg-deficient tape shows smaller grain size than Mg-excess tapes due to the reduced growth of the MgB_2 grains [14].

For MgB_2 superconductors, various impurity additions are reported to be effective in enhancing the B_{c2} and J_c values. Especially, carbon or carbon compound additions, such as carbon nanotube [15], SiC [16], B_4C [17], and hydrocarbon [18] additions, are effective for improving the J_c values in a high magnetic field region. We tried various impurity additions, including ~20 nm SiC [19] and several hydrocarbons, in order to improve the J_c–B property.

2.2. Superconducting properties

Fig. 1 shows the heat-treatment temperature dependence of the T_c values and the full width at half maximum (FWHM) values of the (101) X-ray diffraction peak from the MgB_2 core for pure and 10 mol%SiC-added MgB_2 tapes. T_c was defined as the midpoint temperature of resistive transition in a zero magnetic field. For both pure and

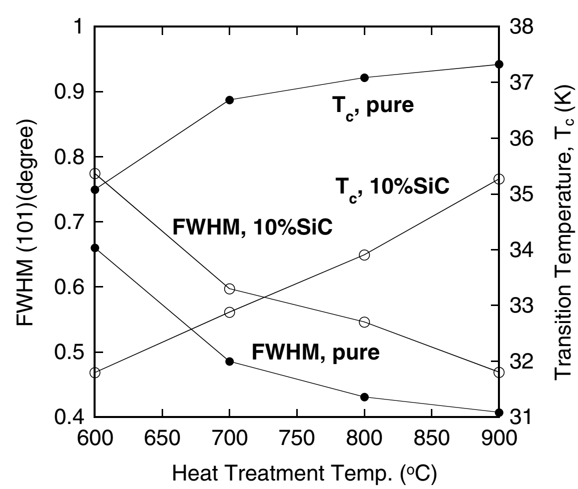

Fig. 1. Heat-treatment temperature dependence of the full width at half maximum (FWHM) of the (101) X-ray diffraction peak and transition temperature for pure and 10 mol%SiC-added tapes.