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Effect of Indium Addition on Matrix of MgB_2 / Al Composite Materials

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MgB_2 has the higher critical temperature of superconducting transition (T_C=39K) in the intermetallic compound superconductive material, however, is that MgB_2 is hard for practical use because of its unworkable and lower critical current density (J_C) in a high magnetic field than Nb-based superconductive materials. We have developed the original method of three-dimensional penetration casting (3DPC) to fabricate the MgB_2/Al composite materials. In the composite material we made, MgB_2 particles dispersed to the matrix uniformly. The T_C was determined by electrical resistivity and magnetization to be about 37～39K. In this work, we change the matrix from pure Al to Al-In alloy. Critical current density (J_C) of composite material with the matrix of Al-In alloy was calculated from the width of the magnetic hysteresis based on the extended Bean model. The result was better than that MgB_2/Al composite material without In. Microstructures of these samples have been confirmed by SEM method.

Keywords: *composite material, MgB_2, aluminum, superconductivity, critical current density*

1. Introduction

As has been known, MgB_2 is the Type II superconductor, and its superconducting transition temperature (T_C) is 39 K which is higher than Nb-based superconductor and no orientation dependence of crystalline [1]. Studies on MgB_2 has focused on the application for superconducting magnets as well as Nb-based intermetallic compounds [2], and many projects for fabrication of wires and/or sheets are actively being pursued [3]. There is a problem to be turned MgB_2 into actual utilization. MgB_2 is intractable to compare the superconductive materials of Nb-series. In our previous studies, we fabricated composite materials formed from Al or age-hardenable Al alloys matrix reinforced by ceramics particles such as Al_2O_3, SiC, and TiC, and investigated their hardening behaviors, microstructures, and aging properties [4]. Our special technique for fabricating composite materials (3DPC) method can disperse particles in the matrix homogenously without any aggregation and control their volume fractions within the range of 4 – 50 %, even when particle size is less than 1μm. Thus, these composite materials can be processed by machining, extrusion and rolling. MgB_2 dispersed in Al matrix composite materials was made by 3DPC method. We reported that MgB_2/Al composite materials had superconductive behavior and succeeded in extruding MgB_2/Al composite billet to 10mmϕ rod and 3mmϕ wire [5]. In addition, in a high magnetic field, MgB_2 has low critical current density. It is reported that Indium improves J_C in high magnetic fields of MgB_2 [6]. In the present work, we added Indium in an aluminum matrix for the purpose of improving J_C in high magnetic fields of the MgB_2/Al composite material. Microstructures of these samples have been confirmed by SEM method. The superconducting properties of the samples were evaluated from magnetization.

2. Experimental

MgB_2 powders (Kojundo Chemical Laboratory Co., Ltd.,) with purity higher than 99%, and size smaller than 40μm are used in this work. Initially, a preform was fabricated using compacted powders with 30mm diameter and 42mm length. This preform was set in the bottom of steel mold. Indium was added in molten aluminum with 0.05, 0.1, and 0.2wt.%. Molten metal at about 1173 K was poured in to this steel mold and the molten Al was pressed in the preform by a pressing machine. This method was referred to the 3-dimensional penetration casting (3DPC) method. After cooling, the billet was removed from the steel mold by cutting. The volume fraction (V_f) can be controlled to 10 – 50% by this method. The V_f of MgB_2 powders in the obtained billet was about 50 % (the high V_f sample).

Superconductivity was measured by Physical Property Measurement System (PPMS, Quantum Design, Co., Ltd.). Samples for the measurement were cut from composite material to 1mm cubes. Electrical resistivity was measured by a DC 4-terminal method, at a direct current of 1.0 mA. The range of temperature employed for measurement of electrical resistivity, thermal conductivity, and magnetization was from room temperature to 4.2 K, and cooling rate was 0.003 K/s. Magnetization was measured by SQUID (Quantum Design, Co., Ltd.) using an applied magnetic field of 100 G.

The microstructures of composite materials were observed by a scanning electron microscope (SEM). Samples for microstructure were simply cut from composite materials and polished using conventional polishing papers. The SEM observation was taken by S-3500H (Hitachi, Co., Ltd.) operating at 20 kV, and Mg and Al maps were obtained from a sample by energy dispersive X-ray spectroscopy (EDS).

3. Results and discussion

Figure 1 shows a longitudinal cross section of the MgB_2/Al–0.1%In composite material billet. No remarkable shrinkages, cracks, large aggregations of powders or any other defects are observed. Gray and bright contrasts appear in this figure and correspond to a reinforced region and pure Al region without particles, respectively. The region of Al also exists at the bottom side of the steel mold, indicating that the molten Al sufficiently penetrates to the bottom side through the preform of MgB_2 and can be turned back to the preform by the applied pressure. Fig.2 shows the longitudinal cross section of the composite materials made with Al and Al–In. These images show homogeneous distribution of particles respectively in the matrix, and no cracks between particles and the Al matrix at this magnification.

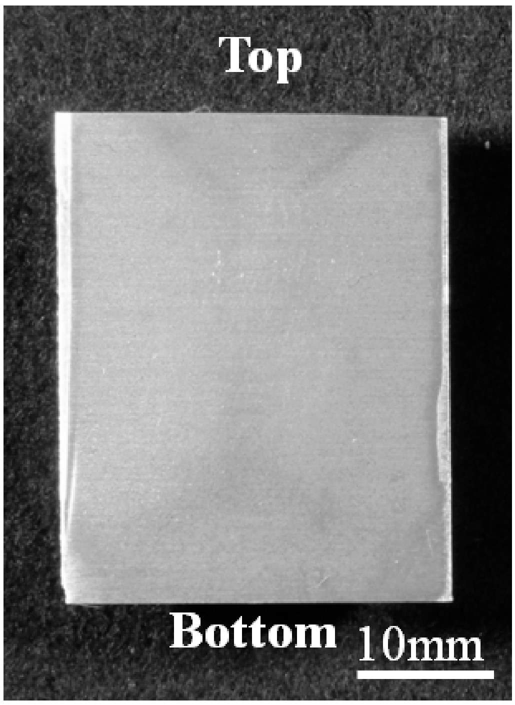

Fig.1: Outlook of MgB_2/Al-In composite material billet.

Temperature dependence of magnetization rate in Fig.3 shows that superconducting onset temperatures (T_c) are around 37.7K for the samples with Al matrix, and around 38K for those with Al–0.05wt.%In, Al–0.1wt.%In, Al–0.2wt.%In. Magnetization curves at 5K under applied fields from −7T to +7T. It can be seen that $M(H)$ loop of MgB_2/Al composites is expanded by adding Indium. The critical current density $|J_c(H)|$ of pristine and composites are estimated from the $M(H)$ loop, by using equation of an extended Bean critical state model [7] of $|J_c(H)| = 20\Delta M / a(1-a/3c)$, where ΔM is the width of the $M(H)$ loop in emu/cm^3 at a given field and temperature. The MgB_2/Al–In composites cause the increasing tendency of J_c compared with MgB_2/Al composite, moreover, the $J_c(H)$ of MgB_2/Al–0.1wt.%In is the highest among MgB_2/Al–In composite.

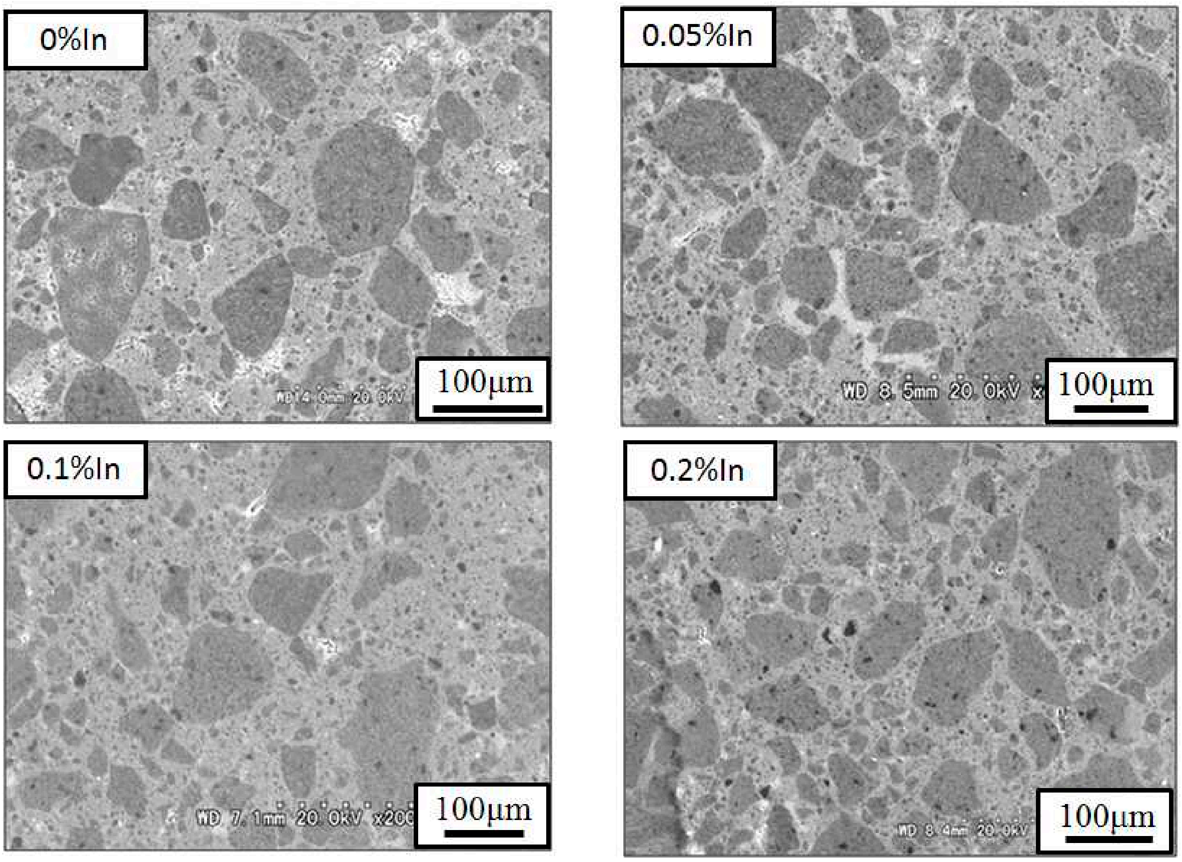

Fig.2 : SEM images of shows the longitudinal cross section of the composite materials made with Al and Al–In.

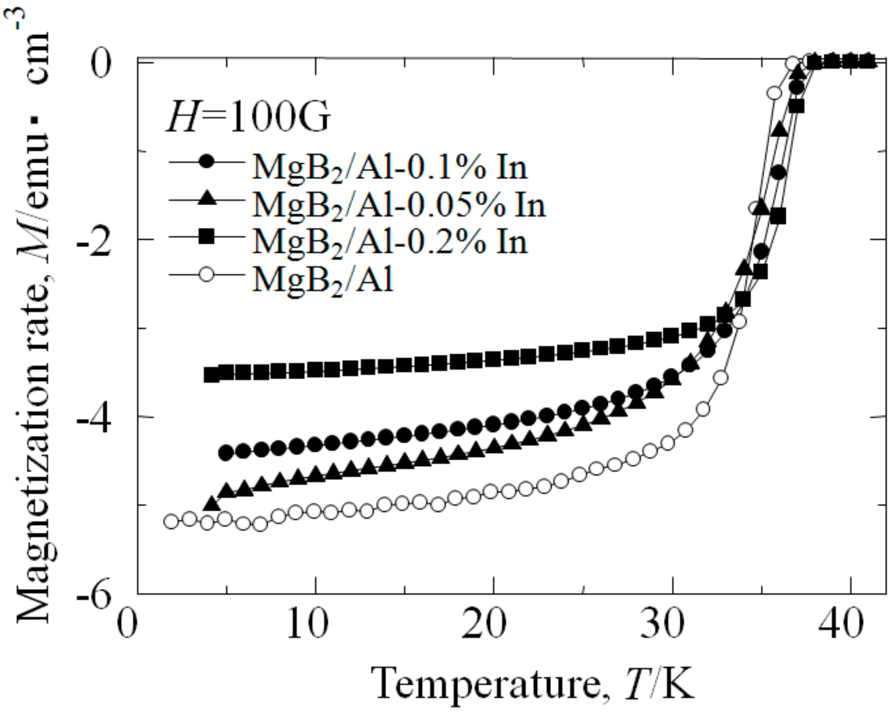

Fig.3 : Temperature dependence of magnetization rate (M) obtained for MgB_2/Al and MgB_2/Al-In composite materials.

4. Summary

Al or Al-In based MgB_2 composite materials could be fabricated by the three-dimensional penetration casting method. A longitudinal cross section of the MgB_2/Al and MgB_2/Al–In composite material billets showed no remarkable shrinkages, cracks, large aggregations of powders or any other defects. All the composite materials were found to have similar T_c(~38K) to that of MgB_2 intermetallic compound. The critical current density $|J_c(H)|$ of pristine and composites are estimated from the $M(H)$ loop by using equation of an extended Bean critical state model. The MgB_2/Al–In composites cause the increasing tendency of J_c compared with MgB_2/Al composite, moreover, the $J_c(H)$ of MgB_2/Al–0.1wt.%In is the highest among MgB_2/Al–In composite materials.

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