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Fabrication and superconducting property of MgB_2 tape with Al metal powder addition

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***Abstract*--** **The sub micron sized spherical MgB_2 powders were synthesized by spray reaction method. MgB_2 tapes with Al addition were fabricated by Powder in Tube (PIT) method. The superconducting property and microstructure of Al doped MgB_2 tapes were characterized by X-ray diffraction, *optical microscopy and transport measurement* under magnetic field. The J_c value of MgB_2 tapes was increased with 10 vol.% Al addition. The J_c value of 5,500 A/cm^2 and 11,000 A/cm^2 at 4.2 K and 5 T were obtained for the MgB_2 tape and 10 vol. % of Al added MgB_2 tape without heat treatment, respectively. The J_c value of 8,000 A/cm^2 and 33,000 A/cm^2 at 4.2 K and 5 T were obtained for the MgB_2 tape and 10 vol. % of Al added MgB_2 tape with heat treatment, respectively. The J_c-B curves show enhancement in J_c (B), which suggests that the microstructure and transport properties of MgB_2 tapes have been improved with Al addition.**

1. INTRODUCTION

In January 2001, a new superconducting material, MgB_2 compound was discovered, which is superconducting up to 39 K [1]. This material can be fabricated into a useful long length, low cost wire that can operate at the desired temperature range of 20-35 K for several potential applications such as Magnetic Resonance Imaging (MRI) Magnet, Transformer and Fault Current Limiter (FCL)..

Many magnetization and transport measurements show that MgB_2 does not exhibit weak-link electromagnetic behavior at grain boundaries [2] or fast flux creep phenomena [3], which limit the performances of high-T_c superconducting cuprates. Recently, MgB_2 tapes with high transport currents using Ni, Cu and stainless steel sheath were obtained without any heat treatment [4-7]. This is a very convenient process for a practical application. Considering superconductivity at 39 K, one of possible applications of MgB_2 compound is a crycooler-cooled magnet operated at 20 K. In view of practical applications, superconducting parameters such as upper critical field, H_{c2}, critical current density, J_c, and irreversibility field, H_{irr}, are very important factors. The upper critical field, H_{c2} of MgB_2 at 20 K is about 12 -14 T, which is higher than that of Nb-Ti wire at 4.2 K [8]. The enhancement in H_{c2} of MgB_2 films through the oxygen and nano SiC doping is reported [9-10]. The field which limits the range of practical applications, the irreversibility field, H_{irr}, is approximately 7 T at 4.2 K, significantly lower than that of Nb-Ti(10 T) [11] and that of Nb_3Sn(~20 T) [12]. The critical current density J_c(B) at 20 K of MgB_2 is still low, which does not reach to the practical level and H_{irr} at 20 K is also not high enough for magnet applications. The enhancement in J_c with metal powder addition or doping is reported [13-14].

In this study, we report transport property of Al powder added MgB_2 tape under magnetic field at liquid helium temperature and propose the possibility of enhancement in transport properties under magnetic field.

2. EXPERIMENTAL

The spray reaction system used in this work is schematically shown in Fig. 1. It mainly consists of three parts. The first is the ultrasonic spray zone which consists of the mist-generating system of liquid source with an ultrasonic nebulizer (ultrasonic power of mist generator is about 100 W, 2.56 MHz) and the mist- droplet- carrying

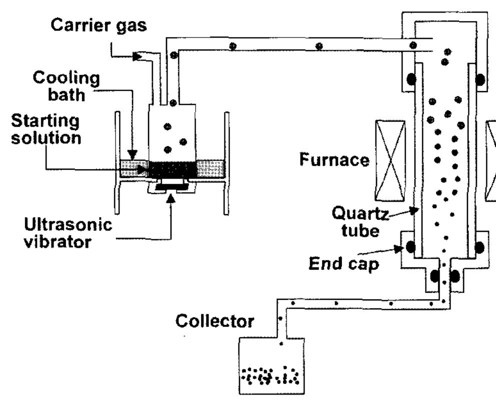

Fig. 1. Schematic diagram of the spray reaction system utilized to prepare MgB_2 powders.

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system with H_2/Ar mixed carrier gas. The second is the heating zone in which the misted droplet is pyrolyzed in a pre-heated chamber. And the last is the pumping zone which consists of pumping the evaporated/decomposed gases and trapping the produced powders. The total precursor concentration of 0.05, 0.1, 0.2 and 0.5 mol/ℓ were tested. The furnace temperature tried was between 800 and 900 °C.

The synthesized MgB_2 powder with various amounts (1, 3, and 10 vol.%) of Al metal powder was packed into stainless steel (SS) tubes. These tubes were drawn and rolled into tapes. The final size of tapes was about 4 mm in width and about 0.4 mm in thickness. Some tapes were heat treated at 200 °C for 30 minutes. These tapes were cut into short pieces with a length 4-5 cm, and current leads and voltage taps were directly soldered to the sheath materials of the tapes. A magnetic field was applied parallel to the tape surface. The critical current I_c was measured by a standard four-probe resistive method at 4.2 K in magnetic fields with a 1 μV/cm criterion. The detailed experimental procedures are shown in Fig. 2. The microstructure of the specimens was also studied using an optical microscope.

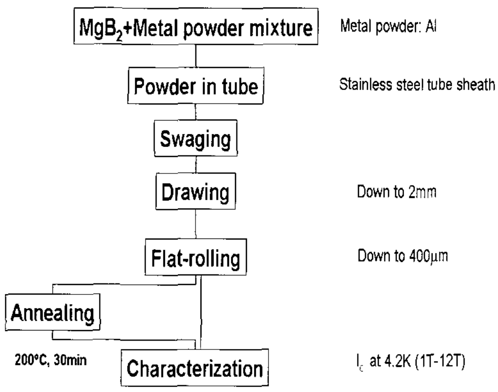

Fig. 2. Experimental procedure for MgB_2 tapes by PIT process.

3. RESULT AND DISCUSSION

Fig. 3 shows SEM micrographs of the MgB_2 powder with different solution concentration. It follows, from the images, that the MgB_2 particle size was decreased with dilution of solution concentration. Other important characteristics of the powders obtained by this method were that the aggregation-free particles had a narrowly size distribution around 100 nm.

The temperature dependent magnetization for the MgB_2 powder synthesized from a solution of 0.1 mol/ℓ (Fig. 4) was measured. The onset of superconducting transition temperature was around 36 K. It seems likely that superconductive volume fraction in the sample synthesized is not high (Fig.5). The process condition will be optimized for higher superconductive volume fraction.

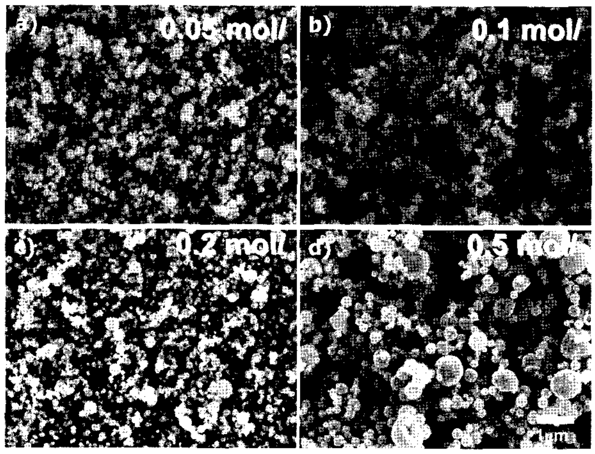

Fig. 3. SEM micrographs for MgB_2 powder obtained from a) 0.05 mol/ℓ solution, b) 0.1 mol/ℓ solution, c) 0.2 mol/ℓ solution and d) 0.5 mol/ℓ solution, at 900 °C.

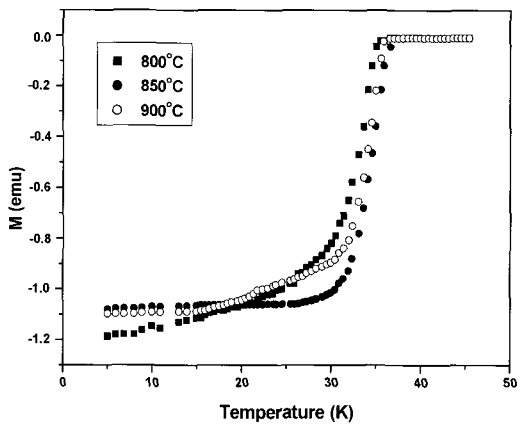

Fig. 4. Diamagnetic transition of MgB_2 superconductor produced by this experiment in zero-field cooled states is around 36 K (Reaction temp. : 850 °C, Solution conc. : 0.1 mol/ℓ).

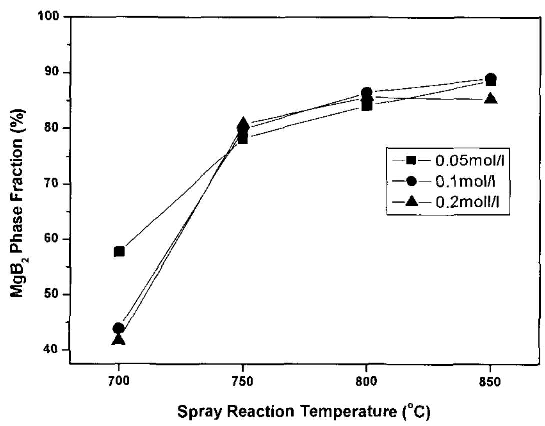

Fig. 5. MgB_2 phase fraction calculated from XRD peak intensity with spray reaction temperature and solution concentration.

Fig. 6 shows the X-ray powder diffraction patterns for Al added MgB_2 tape. Comparing Al peaks with MgB_2, it is obvious that the peak intensity of Al is higher than that of MgB_2. Insufficient MgB_2 intensity can be an indication of small crystallite size or high sample absorption.

Fig. 7 shows the typical cross section of the stainless steel sheathed MgB_2 tape. Densified microstructure was obtained without any heat treatment. For stainless steel sheathed tapes with pure MgB_2 powder, in comparison with 10 vol. % Al MgB_2 tape, many microcracks were observed.

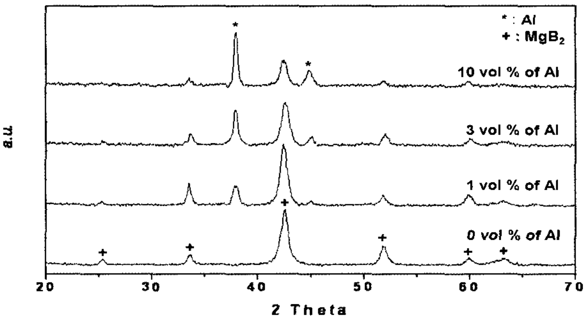

Fig. 6. X-ray powder diffraction patterns for Al added MgB_2 extracted from as-rolled tape.

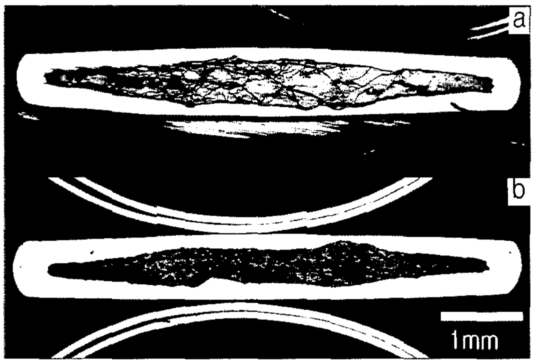

Fig. 7. Optical micrograph of cross section for MgB_2 tape (a) MgB_2, (b) 10% Al.

Fig. 8 shows J_c versus magnetic field curves of both the MgB_2 tape and Al metal powder added MgB_2 tapes, before or after annealing. The J_c values of Al added MgB_2 tapes were much higher than that of the MgB_2 tape under magnetic field. The J_c value in 5 T of MgB_2 was about 5,500 A/cm^2 and 11,000 A/cm^2, irrespective of initial SS tube dimension, for 10 vol. % of Al added MgB_2 tape without heat treatment, respectively. The J_c value of 8,000 A/cm^2 and 33,000 A/cm^2 at 4.2 K and 5 T, irrespective of initial SS tube dimension, were obtained for the MgB_2 tape and 10 vol. % of Al added MgB_2 tape with heat treatment, respectively. Enhancement in J_c under magnetic field for Al metal powder added MgB_2 tape can be explained by the high packing density of MgB_2 with soft metal powder addition associated with the hard sheath material. Thus the improvement in grain connectivity seems to be the probable origin for the enhancement in J_c by Al addition.

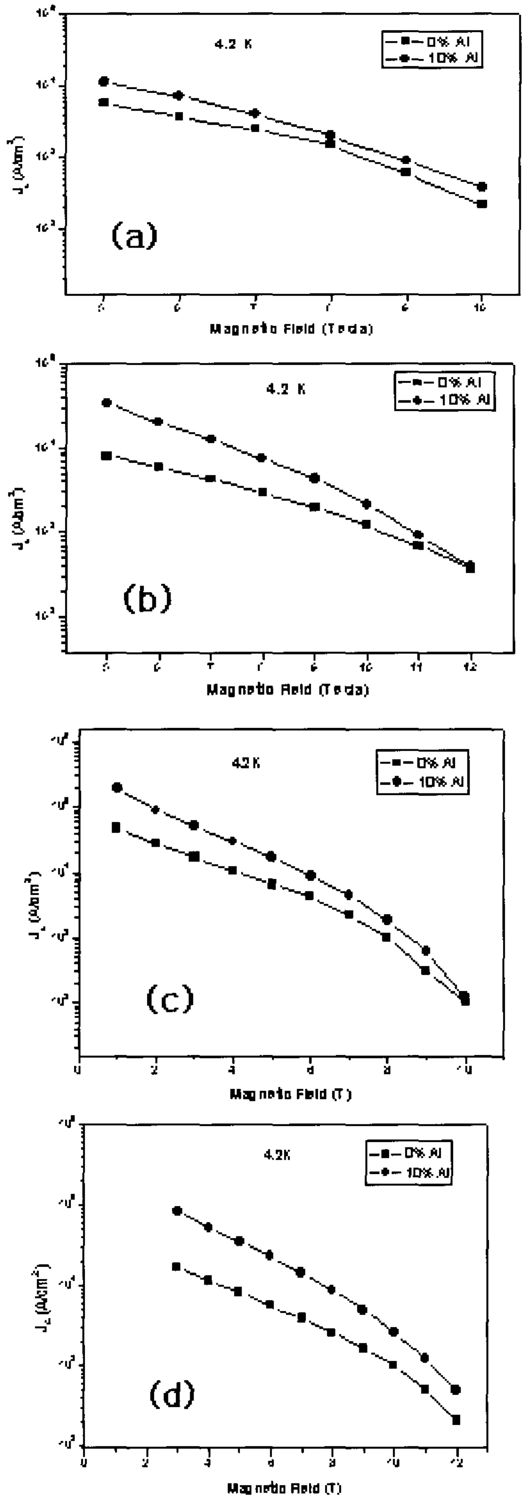

Fig. 8. (a) J_c-B characteristics at 4.2 K of MgB_2 tapes with 10% Al metal powder (OD: 6mm, ID: 4mm, SS tube, before heat treatment). (b) J_c-B characteristics at 4.2 K of MgB_2 tapes with 10 % Al metal powder (OD: 6mm, ID: 4mm, SS tube, after heat treatment 200 ℃, 30 mins). (c) J_c-B characteristics at 4.2K of MgB_2 tapes with 10 % Al metal powder (OD: 8mm, ID: 4mm, SS tube, before heat treatment). (d) J_c-B characteristics at 4.2K of MgB_2 tapes with 10 % Al metal powder (OD: 8mm, ID: 4mm, SS tube, after heat treatment 200℃, 30 mins).

4. CONCLUSIONS

We synthesized MgB_2 powders by spray reaction and fabricated Al metal powder added MgB_2 tapes by PIT method without and with heat treatment. The J_c value of 5,500 A/cm^2 and 11,000 A/cm^2 at 4.2 K and 5 T were obtained for the MgB_2 tape and 10 vol. % of Al added MgB_2 tape without heat treatment, respectively. The J_c value of 8,000 A/cm^2 and 33,000 A/cm^2 at 4.2 K and 5 T were obtained for the MgB_2 tape and 10 vol. % of Al added MgB_2 tape with heat treatment, respectively. The J_c-B curve shows enhancement in J_c under magnetic field, which suggests enhancement in workability and grain connectivity with Al metal powder addition.

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