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Significantly enhancement of critical current density properties of mechanically alloyed Nb_3Al superconductor by hot-pressure sintering route

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ABSTRACT

A series of Nb_3Al bulks were prepared to study the effects of sintering pressure on superconducting properties of mechanically alloyed (MA) Nb_3Al. The results suggest that hot-pressure (HP) sintering can significantly improve the critical current density (J_c) and superconducting transition temperature (T_c) of MA Nb_3Al. Comparing to the Nb_3Al with atmosphere pressure (AP) sintering, the $T_{c,\ onset}$ and J_c at 8 K, 7 T for HP Nb_3Al with a milling time of 2 h increase up to 15.7 K and 6.03×10^4 A/cm^2 from 15.1 K and 0.56×10^4 A/cm^2, respectively. Improvements in reducing porosity and grain connectivity are thought to be mainly responsible to the J_c-enhancement of HP Nb_3Al superconductor.

1. Introduction

Nb_3Al is thought as a good alternative to Nb_3Sn in high-field application due to its better J_c and strain tolerance properties. Generally, high-J_c Nb_3Al wires are prepared by using the multifilamentary Nb_3Al precursor wires and Rapid Heating, Quenching and Transformation (RHQT) heat-treatment [1–3]. However, application of Nb_3Al superconducting wire is still limited due to the complicated RHQT process.

It was thought that the mechanical alloying (MA) method, combining with powder in tube (PIT) way, may be an effective route to develop practical Nb_3Al wire with simple fabrication process. In our previous works, the phase formation and superconducting properties of Nb_3Al prepared by high-energy ball milling method had been systematically studied, and PIT Nb_3Al wires and tapes were also successfully prepared [4–6]. However, the J_c of the MA Nb_3Al superconductors are still insufficient maybe because of their porous microstructure and weak grain connectivity. Hot-pressure treatment is effective to enhance the density and inter-granular coupling of powder-sintering superconductors, like MgB_2, $Bi_2Sr_2CaCu_2O_x$ and others [7–9]. However, up to now the effects of hot-pressing sintering on MA Nb_3Al superconductor still have no studies.

Based on the above motivation, we prepared a series of Nb_3Al bulk superconductors with different sintering pressure and ball milling time in this work. The results suggest the method that combing with the MA and PIT is strongly promising to develop practical Nb_3Al superconducting wires.

2. Experimental

Niobium (99.9%) and aluminum (99.8%) powders with a nominal composition of Nb-26at.% Al were ball milled in a SPEX Mixer-Mill with steel vial and balls for all the samples. The powder mixture with a milling time of 1–5 h were pressed into the cylinders with 5 mm in height and 10 mm in diameter. After that, these cylinders were put in a graphite die and positioned into the furnace. Then the samples were sintered at 950 °C for 3 h in vacuum with a uniaxial pressure of 0, 10, 20 and 30 MPa, respectively.

AP-2 and AP-3 have no sintering pressure and a milling time of 2 and 3 h, respectively. HP-2-10, HP-2-20 and HP-2-30 are with the same 2 h milling time and 10, 20 and 30 MPa sintering pressure, respectively. Similarly, HP-1-30, HP-3-30 and HP-5-30 have 30 MPa sintering-pressure and a milling time of 1, 3 and 5 h, respectively. All the data of these Nb_3Al samples, like as milling time, sintering pressure, annealing conditions, onset and middle T_c, superconducting transition width (ΔT_c) and J_c at 8 K and 7 T,

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Table 1
The data of the milling time of powders, sintering pressure, annealing conditions, T_c and J_c at 8 K and 7 T for all Nb_3Al samples.

Samples	Milling time	Sintering pressure	Annealing conditions	$T_{c,\ onset}$	$T_{c,\ mid}$	ΔT_c	J_c (A/cm^2) at 8 K, 7 T
AP-2	2 h	0 MPa	950 °C/3 h	15.1 K	14.16	1.21	0.56×10^4
AP-3	3 h	0 MPa	950 °C/3 h	14.6 K	13.37	1.18	0.20×10^4
HP-2-10	2 h	10 MPa	950 °C/3 h	15.6 K	14.97	0.80	3.95×10^4
HP-2-20	2 h	20 MPa	950 °C/3 h	15.7 K	14.90	0.83	4.90×10^4
HP-1-30	1 h	30 MPa	950 °C/3 h	15.5 K	14.52	1.43	0.68×10^4
HP-2-30	2 h	30 MPa	950 °C/3 h	15.7 K	15.04	0.78	6.03×10^4
HP-3-30	3 h	30 MPa	950 °C/3 h	15.6 K	14.63	0.62	6.70×10^4
HP-5-30	5 h	30 MPa	950 °C/3 h	14.6 K	13.31	1.29	0.20×10^4

are shown at Table 1. The J_c was calculated from the width, ΔM, of the magnetization loops (M-H) by using the Bean model.

3. Results and discussion

Fig. 1 shows the effects of the sintering pressure and ball milling time on the Nb_3Al phase formation. As shown in Fig. 1(a), XRD patterns of all the samples are almost same and the main peaks of Nb_3Al phase are clearly appeared. However, the content of Nb_2Al impurities seems to be higher at AP-2 than that at the HP. In Fig. 1(b), the peaks of Nb_2Al and Nb phases could be detected in HP-1-30, suggesting that the Nb and Al atoms not completely solid solution. The XRD patterns of HP-2-30 and HP-3-30 are very similar and very little of Nb_2Al phase exist in these samples, suggesting high-quality $Nb(Al)_{ss}$ solid solution formed during the ball milling process. The content of Nb_2Al seriously increases in HP-5-30, which is attributed to the formation of the amorphous phase during the milling.

Fig. 2(a) shows the M-T curves of Nb_3Al samples for AP-2, HP-2-10, HP-2-20 and HP-2-30. They have a same ball milling time of 2 h. From the Fig. 2(a), it can be seen that the onset and middle T_c of Nb_3Al at HP-2-10, HP-2-20 and HP-2-30 are much higher than

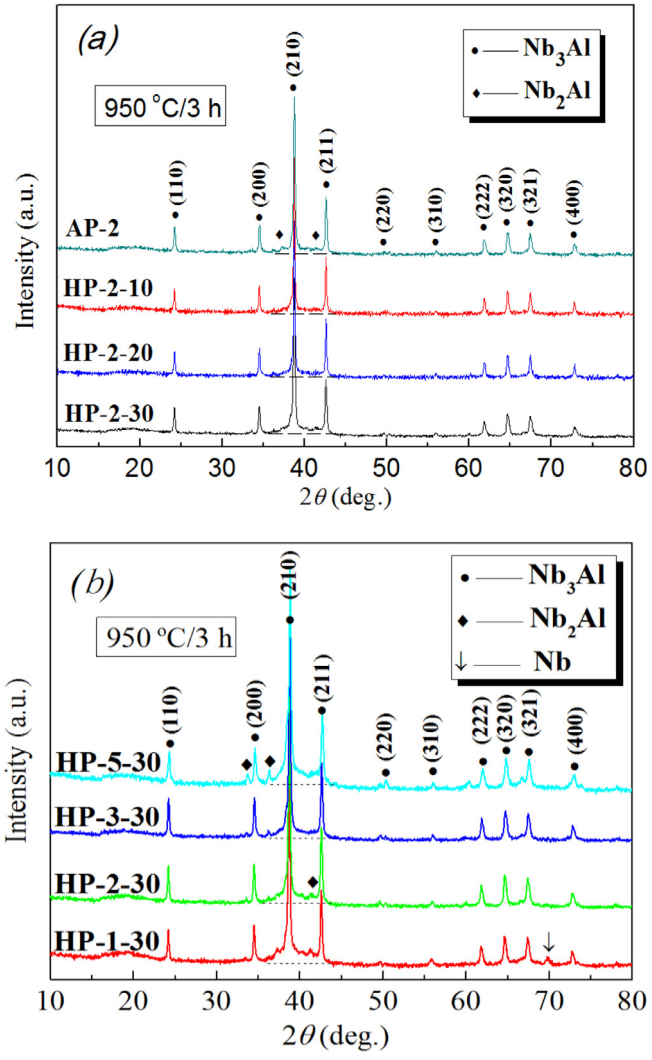

Fig. 1. XRD patterns of the Nb_3Al samples sintered at 950 °C for 3 h with different (a) sintering pressure (0, 10, 20 and 30 MPa) and (b) ball milling time (1, 2, 3 and 5 h).

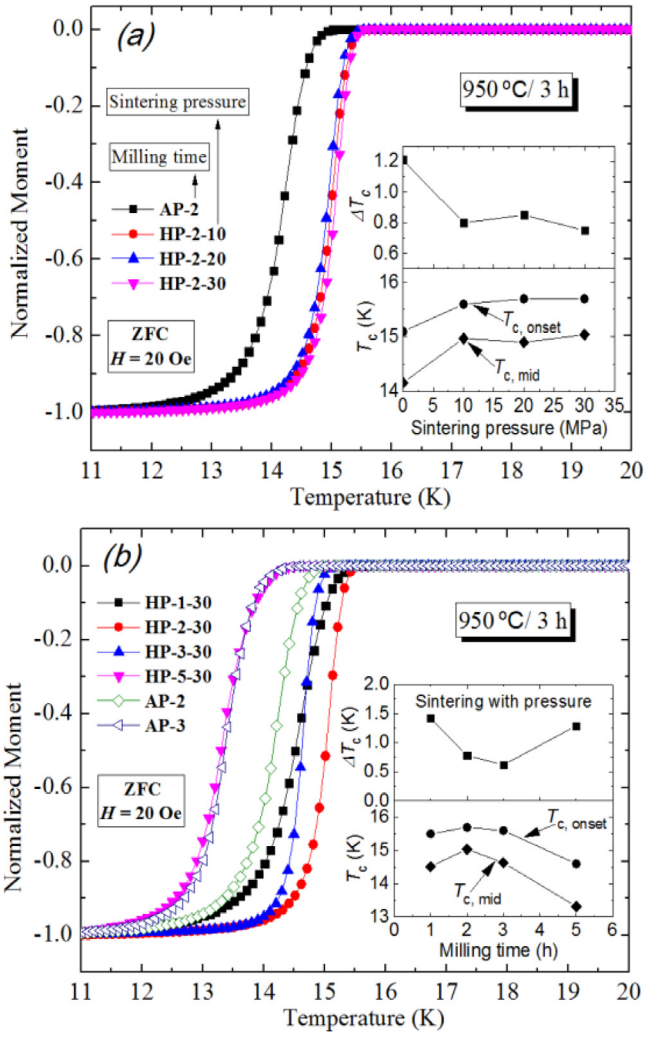

Fig. 2. M-T curves of the Nb_3Al samples sintered at 950 °C for 3 h with different (a) sintering pressure (0, 10, 20 and 30 MPa) and (b) ball milling time (1, 2, 3 and 5 h).