Progress in superconductivity Vol.1, No.2 pp 141-145 29 February 2000

Twisted Multifilamentary BSCCO 2223 Tapes by Using High Resistive Sheath

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Received 7 February 2000

Abstract

Different twist pitches of multifilamentary BSCCO 2223 tapes using high resistivity sheath were fabricated to investigate the effect of twist pitches on the microstructure and critical current property. A conductor with a high resitstivity matrix is possible to allow larger twist pitch for reducing ac losses and reduce eddy current losses simultaneously. The J_{ct} values of 10 mm and 5 mm twisted tapes drop faster than that of untwisted and 20 mm twisted tapes under increasing magneticfield, especially in low field regime (0 ~ 0.03 T). It suggests that weak links in the former are more serious than in the latter, which is in accordance with the microstructure analysis.

Keywords : BSCCO 2223, Sheath alloys, Weak link

I. Introduction

Enormous progress in the production of long lengths (> 1 km) of Ag sheathed BSCCO 2223 tapes with high J_C has generated much interest in the practical application of such tapes in electric power systems, like transformers, power cables, motors and magnets. For use in such power applications low AC losses is one of the major requirements to these conductors and much attention has been directed recently to understanding and measuring the losses in BSCCO 2223 tapes [1-3]. AC losses have been investigated extensively in low temperature superconductors (LTS). It is generally recognized that AC losses associated with multifilamentary LTS arise from (1) hysteretic losses within the superconducting filaments, (2) eddy current losses within the normal metal matrix surrounding the filaments, and (3) filament coupling losses through the normal metal matrix. It has been reported that hysteretic losses in the superconducting core were found as dominating factor [1]. Filament coupling losses can be mitigated by twisting the filaments in the order of 10 mm twist pitch and less, and eddy current losses are reduced by a strongly increased electrical resistivity of the matrix compared to Ag.

However, twisting the filaments severely will damage the microstructure, the evolution of texture, and eventually decrease the critical current. In this regard the alternative way to reducing twist pitches will be increasing the matrix resistivity. Some of the theoretical study of AC losses in tape conductors suggested that a conductor with a high resistivity matrix will allow larger twist pitch and reduces coupling losses at the same time [4,5], nevertheless experimentally not proven yet. Therefore, effective approach to both retaining critical current and reducing AC losses will be applying the modest twist pitches with high resistivity matrix. There are many reports that one of the effective methods to increase electrical resistivity is alloying the Ag with Au or Pd

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[6,7]. Our previous results also presented that the electrical resistivity of Ag alloy at 77K can be significantly increased and 10 times higher than that of pure Ag by alloying small amounts (2.5 atomic %) of Au [8].

In this study, different twist pitches of multifilamentary BSCCO 2223 tapes using high resistivity sheath were fabricated to investigate whether a high resistivity sheath will allow larger twist pitch, as well as to study the effect of different twist pitches on the microstructure and critical current property.

II. Experimental procedure

$Ag_{0.97}Au_{0.025}Mg_{0.005}$ and other Ag alloys were prepared in a high frequency induction furnace and cold-rolled into the thickness of 0.5mm plates. The electrical resistivity measurements of the alloys were made by a standard 4-wire technique and the hardness was measured with Matsuzawa Seiki DMH-1 instrument with a 50 gram weight for 20 seconds.

For PIT process, $Ag_{0.97}Au_{0.025}Mg_{0.005}$ alloys were extruded into hollow tubes of O.D: 12.7 mm and I.D 9.5 mm using specially designed extrusion die. Precursor powders were prepared by spray drying appropriate amounts of Bi, Pb, Sr, Ca, and Cu nitrate so that the cation ratios of the compound become Bi:Pb:Sr:Ca:Cu = 1.8:0.4:2:2.2:3. The calcined powders were loaded in the $Ag_{0.97}Au_{0.025}Mg_{0.005}$ alloys tube. After swaging and drawing, the hexagonally drawn 61 wires were bundled into a same Ag alloys tube.

After similar deformation to wire diameters of 2.0 mm, wires were twisted to various twist pitches using a simple torsional deformation technique. These wires were then flat-rolled repeatedly until the tape became a desired final thickness of 0.30 mm, width of about 3.0 mm. The thermomechanical treatment conditions employed are as follows: initially annealed at 839 °C for 70h, pressed, and repeated this procedure again. The four probe method was employed to determine the critical current of these tapes, as a function of magnetic field intensity, and orientation at 77 K.

III. Results and discussion

Both the Au and Pd are ideal candidates for alloying with Ag since they are completely solid soluble to Ag, and raise the melting temperature and Increase the electrical resistivity when added to Ag. Moreover, Au and Pd have less affinity to oxygen than the Ag and any elements in the BSCCO, so that no detrimental effect on superconducting properties is expected. Mg is also solid soluble to Ag to some amount but tends to form strong oxide almost instantaneously when exposed to oxygen. Considering the high permeability of oxygen in Ag, any Mg in solution in Ag is expected to form MgO which can act as dispersion hardening precipitates.

Table I lists Vickers hardness, electrical resistivities of several air annealed alloys after rolling. The resistivity of the Ag-Au-Mg and Ag-Pd-Mg alloys was strongly affected, and noticeably increased by the additions of Au and Pd, respectively, particulary at the low temperature (77 K). The resistivity of the $Ag_{0.999}Mg_{0.001}$ alloy, however, was only slightly higher than that of pure Ag.

TABLE I
VICKERS HARDNESS, AND ELECTRICAL RESISTIVITY AT T=77K AND T=298K FOR VARIOUS AIR ANNEALED ALLOYS AFTER SEVERAL ROLLING

Sample	Hardness, H_V (kg/mm^2)	ρ77K ($\mu\Omega$-cm)	ρ298K ($\mu\Omega$-cm)
Pure Ag	33	0.45	2.45
$Ag_{0.999}Mg_{0.001}$	79	0.62	2.23
$Ag_{0.96}Au_{0.04}$	39	4.23	6.62
$Ag_{0.974}Au_{0.025}Mg_{0.0001}$	73	3.85	6.15
$Ag_{0.970}Au_{0.025}Mg_{0.005}$	106	3.89	6.21
$Ag_{0.965}Au_{0.025}Mg_{0.01}$	118	3.97	6.31
$Ag_{0.95}Au_{0.025}Mg_{0.025}$	173	4.04	6.36
$Ag_{0.935}Pd_{0.06}Mg_{0.005}$	89	6.26	8.84
$Ag_{0.92}Pd_{0.06}Mg_{0.02}$	148	6.42	9.02
Ag-5wt% ZrO_2	95	—	—

It is well known that, in order to reduce AC losses, the twist pitch L_p must satisfy [9]:

$$L_p << \sqrt{\frac{e \rho_m \pi J_c}{\nu \mu_0 H_0}} \quad (1)$$

where e is the tape thickness, ν is the current, frequency, ρ_m is the matrix resistivity. Meanwhile, the eddy current losses [W/m^3], for an infinite slab, can be given by [9]:

$$P_e = \frac{(2\pi \nu e \mu_0 H_0)^2}{6\rho_m} \bullet \frac{e(1-\lambda)+2w(1+\lambda)}{e(1+\lambda)}$$

Table II. Critical current results after repeated thermomechanical treatments (press & annealing) under air atmosphere at 839 °C for 70hrs

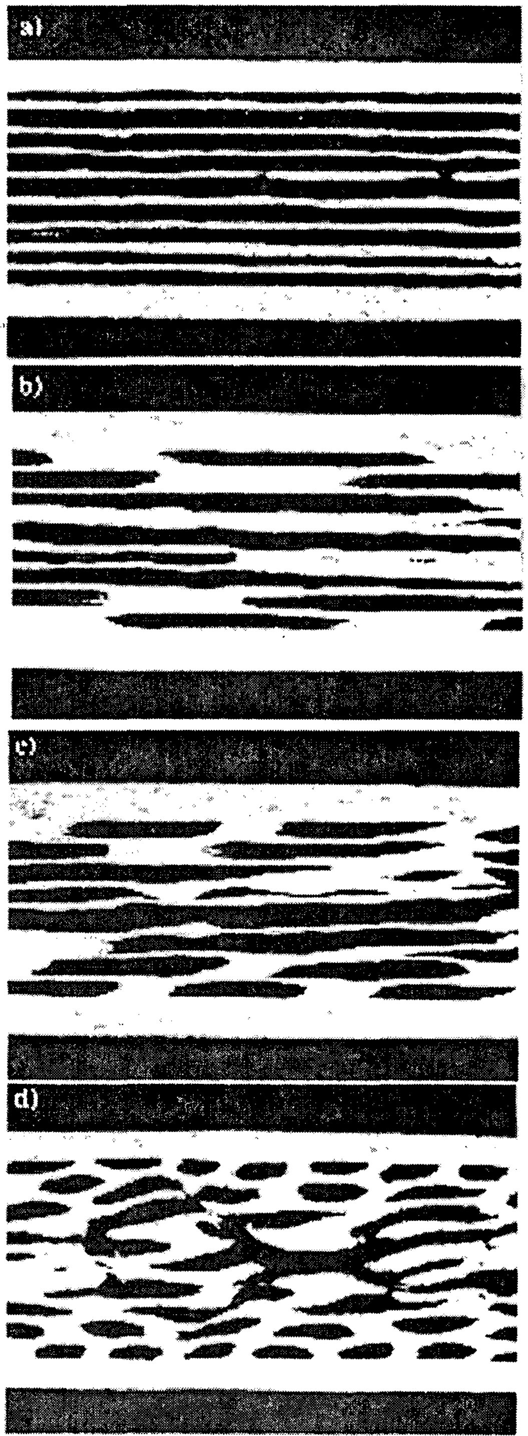
Sample	1st	2nd	3rd
Twist Pitch, $L_P = \infty$ (untwisted)	5.7 A	17.4 A	-
Twist Pitch, L_P=20	7.0 A	20.0 A	-
Twist Pitch, L_P=10	0.2 A	5.6 A	11.0 A
Twist Pitch, L_P=5	0.19 A	4.6 A	13.2 A

where w is the external matrix thickness and λ the superconducting material fraction in the slab. It can be found that a conductor with a high resitstivity matrix can allow larger twist pitch and reduce eddy current losses simultaneously. Therefore, these Ag-Au-Mg, Ag-Pd-Mg alloys are expected to allow larger twist pitch and decrease the eddy current losses by a factor of 10 since the loss is in inverse proportion to the resistivity.

Fig. 1 presents optical micrographs of polished longitudinal cross sections of wires with twist pitches (L_p) of (a) ∞ (untwisted), (b) 20 mm, (c) 10 mm, and (d) 5 mm, respectively. All of these samples were polished after twisting and before the first heat treatment. For scale, the diameter of these samples is 2 mm. It is observed that the spatial paths traced out by the filaments in the twisted tapes are very different from that in the untwisted tape.

With the decrease of twist pitch, twist angles of the filaments will increase, and then the superconducting core seems to become discontinuous on the polished longitudinal cross section. Since the portions of the filaments near the edges of the wire receive the most strain in the process used to fabricate twisted tapes, it is generally believed that defects such as cracks are localized in these portions, potentially resulting in superconductor that is weakly linked in the edge regions other than the central part of the wire. However, if the twist pitch is too small, very high torsional strain will be put on most filaments, which leads to cracks, sausaging and bridging in the twisted wire. This can be seen obviously in Fig. 1(c) and (d).

Table II gives transport critical current (I_c) results for untwisted and twisted tapes. The highest I_c value



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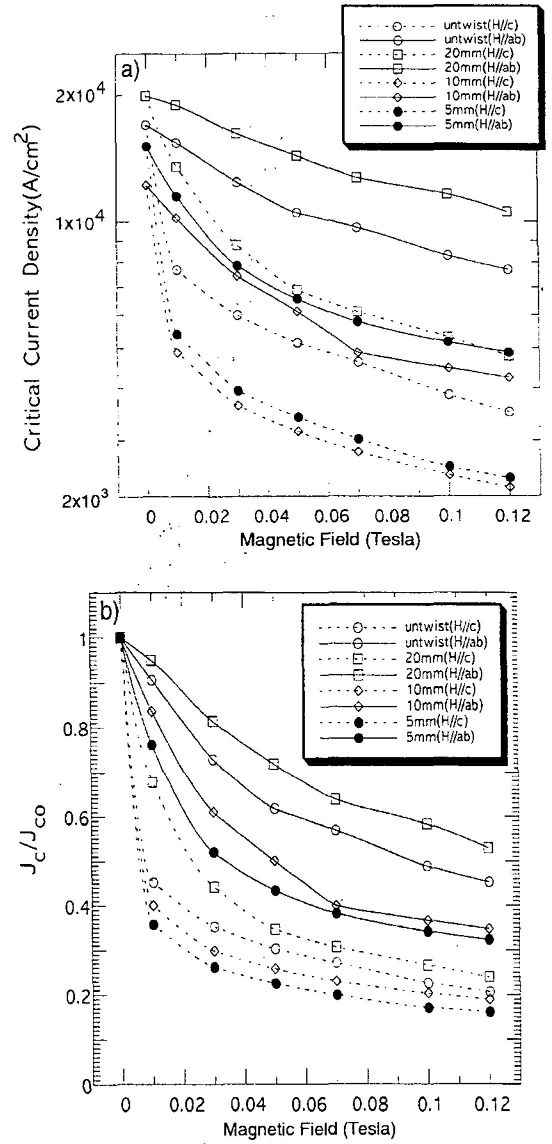

Fig. 2. Field dependence of (a) the critical current densitie and (b) J_c/J_{co} of BSCCO tapes using $Ag_{0.97}Au_{0.025}Mg_{0.00}$ alloy sheath for different twisting condition (twist pitche ∞ :untwisted, twist pitches 20 mm, twist pitches 10 mm twist pitches 5 mm)

is 20 A obtained in the twisted tape with a twist pitch of 20 mm after second heat treatment. The samples with smaller twist pitches show relatively low I_c values after the first heat treatment, compared to the sample with larger twist pitch. Furthermore, after the third annealing, the I_c values are still only 11 A (L_p= 10 mm) and 13.2 A (L_p= 5 mm), respectively. As mentioned before, high torsional strain will induce cracks and other defects, and degrade the texture degree during the annealing process. Therefore, weak links will be greatly enhanced, which is inevitably detrimental on the current transport properties of samples.

Fig. 2(a) shows the transport critical current density (Jct) in magnetic field for untwisted and twisted tapes at 77 K for two field orientations: parallel and perpendicular to c-axis. Fig. 2(b) shows the normalized Jct-B curves for the samples. The Jct values of 10 mm and 5 mm twisted tapes drop faster than that of untwisted and 20 mm twisted tapes, especially in low field regime (0 ~ 0.03 T).

It suggests that weak links in the former are more serious than in the latter, which is in accordance with the microstructure analysis. It is quite interesting that the slightly twisted tape (20 mm twisted tapes) has better Jct-B curves than that of untwisted tapes. Further investigation is needed for developing twisted multifilamentary BSCCO 2223 tapes accrding to larger twisting pitches, defects, and evolution of microstructure.

At this stage work on the measurements of AC losses of these conductors is in progress. Further experiments such as AC losses measurements by both magnetization methods and transport technique will be made soon in order to clarify the role of high resistivity matrix and twist pitches on AC losses of BSCCO 2223 tapes.

Acknowledgement

This work is supported by Ministry of Science and Technology of Republic of Korea.

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