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RECENT ADVANCES IN PROCESSING OF Ag-CLAD Bi-2223 SUPERCONDUCTORS*

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DISCLAIMER

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ABSTRACT

Enhancements in the transport current properties of long lengths of multifilament Ag-sheathed $(Bi,Pb)_2Sr_2Ca_2Cu_3O_y$ (Bi-2223) superconducting tapes were made as a function of increased packing density of precursor powder, improved mechanical deformation, and adjusted cooling rate. Improved processing parameters had a pronounced effect on the transport critical current (I_c) of the superconducting tapes. At 77 K and zero applied magnetic field, an I_c of 60 A was obtained in short length samples (4 cm), an I_c of 54 A in a 164 m length, and 18 A in a 1,260 m length. These enhancements were based on the increase in packing density accompanied with improved mechanical deformation and cooling schedule. Maximum critical current values were two to three times higher in slow-cooled tapes than in fast-cooled tapes.

INTRODUCTION

Continuing as the most promising approach for fabricating wires and tapes is the powder-in-tube (PIT) process. The critical current density (J_c) of Ag-sheathed $(Bi,Pb)_2Sr_2Ca_2Cu_3O_y$ (Bi-2223) superconducting tapes is the most important factor for practical applications. The Ag-clad Bi-2223 tapes now being used in demonstrations of a prototype HTS motor, transmission cable, and fault current limiter are performing reasonably well.[1,2]. However, their applicability in large electrical equipment is presently limited to the temperature range of <30 K because of their low overall J_c and susceptibility to magnetic fields.

Within the past three years, several research groups reported that in Ag-sheathed Bi-2223 superconducting tapes, the supercurrent is transported in a very thin region at the silver superconductor interface.[3-12] The bulk of the superconductor core does not contribute to the total critical current (I_c). Very thin layers (≈2-3 μm) of superconductor in a processed tape were able to support a transport current that translated into a J_c value > 10^5 A/cm^2 at 77 K.[3-5] Furthermore, tapes were produced with the same superconductor total cross sectional area but different lengths of interface with the Ag sheath.[6] The I_c was shown to be directly proportional to the relative amount of superconductor/Ag interface and was expressed as a linear function of the interface perimeter length (IPL). These results were consistent with observations that <10% of the 2223 superconductor transports the supercurrent in the silver-sheathed superconducting tapes.[7-12] Therefore, low overall J_c values can be expected to increase by improving the processing parameters.

Experimental results for J_c as a function of temperature and applied magnetic field in BSCCO/Ag wires and tapes showed that J_c was very anisotropic.[13-15] In Bi-2223 tapes, for the same average J_c value, the effective pinning energy (U_{eff}) for H perpendicular to 'c' is two orders of magnitude higher than that for H parallel to 'c'.[15] Effort is currently focused on circumventing the problem of flux creep by adopting various metallurgical techniques, for example, precipitating secondary phases and introducing fine-scale microstructural defects.[16-18]

Parrel et al.[19] observed that changing the cooling rate had a significant effect on transport critical current. The partial decomposition of the Bi-2223 phase during the slow cooling was used as the basis for rationalizing the results. The 2212 phase ($Bi_2Sr_2CaCu_2O_x$) formed by decomposition had a very different morphology than that of the residual 2212 phase and affects the connectivity of the core. Tetenbaum and Maroni[20] showed that slow cooling increases the oxygen content of the Bi-2223 phase. This increase in oxygen content may contribute to the enhanced critical current density observed during slow cooling. In a postannealing study, Nomura et al.[21] observed that the J_c values of tapes increase with an increase in oxygen content. In our previous study,[22] changing the cooling rate showed a pronounced effect on the transport current of Bi-2223 superconducting tapes. The thin layer of superconductor adjacent to the Ag sheath was under compression during fast cooling, and the compressive stress caused microcracking and affected the interconnectivity of superconductor grains in the thin layer next to the silver sheath. This changed the current path through the high-critical-current-density region in the superconductor.

EXPERIMENTAL PROCEDURE AND RESULTS

In the first step before the mechanical processing, packing density of the precursor powder was varied. The second step was to improve the mechanical processing of multifilament tapes. The third step was related to improving the heat treating schedule. A series of experiments was designed to study these factors. Multifilament Ag-sheathed Bi-2223 tapes were made by the PIT technique with precursor powders having the overall stoichiometry of Bi-2223. The precursor powder contained 2212 (Pb added), Ca_2PbO_4, and alkaline earth cuprate phases. Before packing into Ag tubes, the powder had an average particle size of $\approx$3-5 μm. Packing density in the Ag tubes was varied by using precursor powder, as well as precursor powder prepressed into billets, that was then placed in the silver tubes. The precursor powder was packed into the silver tubes at a density of $\approx$2.25 g/cm^3, while the precursor rods were prepressed into billets of $\approx$3.5 g/cm^3 (low-packing-density precursor rod) and $\approx$4.5 g/cm^3 (high-packing-density precursor rod). As seen in Figure 1, the higher packing density resulted in higher I_c values when heat treated at 820°C. These higher I_c values were maintained uniformly over a length of 1.45 m (see Figure 2).

After packing, the tubes were drawn and rolled to a tape that was $\approx$ 200 μm thick. The mechanical deformation schedule was also varied. The cross-sectional area of each sample was observed by scanning electron microscopy (SEM); compositional analysis was accomplished by energy-dispersive spectroscopy (EDS). Figure 3 is a composite of low-magnification SEM images showing the effect of mechanical deformation on the cross sections of two multifilament tapes. Improved mechanical processing of the high-density precursor rod showed a pronounced effect on the uniformity of silver/superconductor interface. The standard mechanical processing consisted of > 10% reduction per pass, while the improved mechanical processing reduced the rate of mechanical deformation to

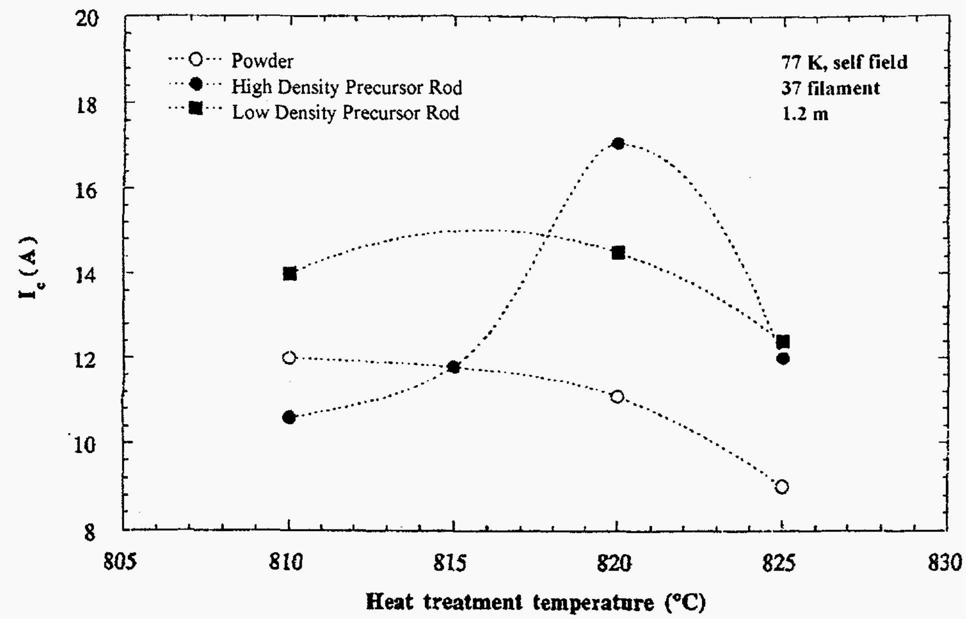


Figure 1. Transport critical current (I_c) as a function of heat treatment temperature for 1.2-m-long tapes with various precursor packing densities.

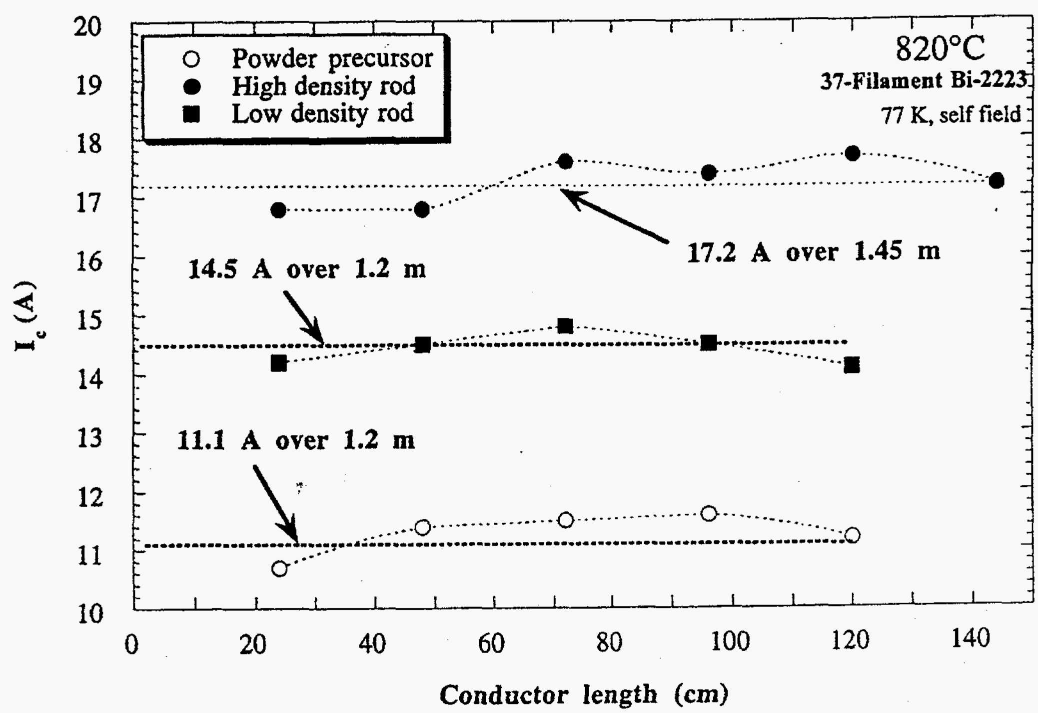
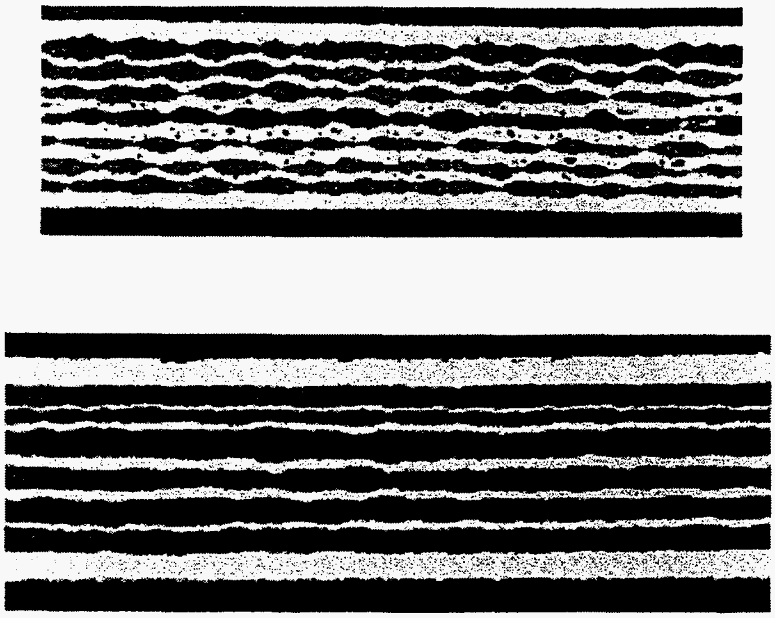


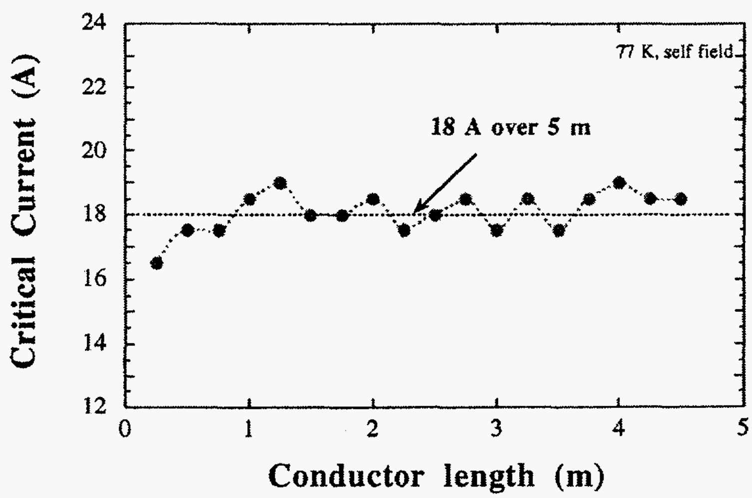
Figure 2. I_c along 1.2 - 1.45-m-long tapes with various precursor packing densities.



Consolidated Precursor Rod
Standard Mechanical Processing
Ic = 18 to 20 A

Consolidated Precursor Rod
Improved Mechanical Processing
Ic = 36 A

Figure 3. SEM photomicrographs of multifilament tapes showing the effect of improved mechanical processing. SEM photomicrograph of tapes processed under standard mechanical deformation is also shown for comparison.



Consolidated Precursor Rod
Standard Mechanical Processing

Figure 4. Uniform I_c values along a 5-m-long tape fabricated with consolidated precursor powder rod in the silver tube.

< 10% reduction. Again, the I_c values were quite uniform, as shown in Figure 4 for a 5-m length of tape. The tapes were heat treated in reduced oxygen partial pressure under the following schedule:

1. Heating to ≈820°C at a rate of ≈2°/min,
2. Holding at 820°C for 50 h, and
3. Cooling: standard cool (1-2°C/min), slow cool from 820 to 725°C, and slow cool from 820 to 790°C.

The transport critical current I_c (77 K, self-field, 1 μV/cm criterion) was measured by a conventional four-probe method. Figure 5 shows the effect of cooling rate on the I_c value for 1.2-m-long samples. Table 1 summarizes the best transport critical current values achieved for the multifilament tapes.

Slow cooling improved the transport current properties by a factor of 2 to 3 over that of the previous standard cooling rate. The faster cooling rate played a dominant role in reducing the current-carrying capacity of samples. During fast cooling, the thin layer of superconductor next to the silver sheath is subjected to thermal stresses. The thermal gradient between the central core of superconductor and the silver sheath tends to exert compression on the thin layer next to the silver sheath. This affects the alignment and interconnectivity of 2223 grains in this region and changes the current path through the superconductor. Misaligned c-axes and bent or curved grains increase the percolative path for current flow,[22] and weak links along the "a-b" planes force the current to flow along the c-axis of the 2223 phase. In extreme cases, compression caused by a thermal gradient can cause microcracking in this layer, which is detrimental to current transport. Control of present processing parameters results in consistent I_c values for long lengths of superconducting tape. This can be seen in Figure 6 for 17 manufacturing runs of 100 to 150-m lengths of Bi-2223 tapes with I_c values above 20 A.

CONCLUSIONS

Improvements in the transport current properties in long lengths of multifilament Ag-sheathed $(Bi,Pb)_2Sr_2Ca_2Cu_3O_y$ (Bi-2223) superconducting tapes were made by varying mechanical and thermal parameters during tape processing. The packing density of precursor powder, improved mechanical deformation, and cooling rate were all parameters that had a pronounced effect on the critical transport current (I_c) of the superconducting tapes. At 77 K and zero applied magnetic field, an I_c of 60 A was obtained in a short sample (4 cm), an I_c of 54 A was seen in a 164-m length, and 18 A was observed in a 1260-m length. These enhancements were based on the increase in packing density, accompanied by an improved mechanical deformation and cooling schedule. Maximum critical current values were two to three times higher in slow-cooled tapes than in fast-cooled tapes.

ACKNOWLEDGMENTS

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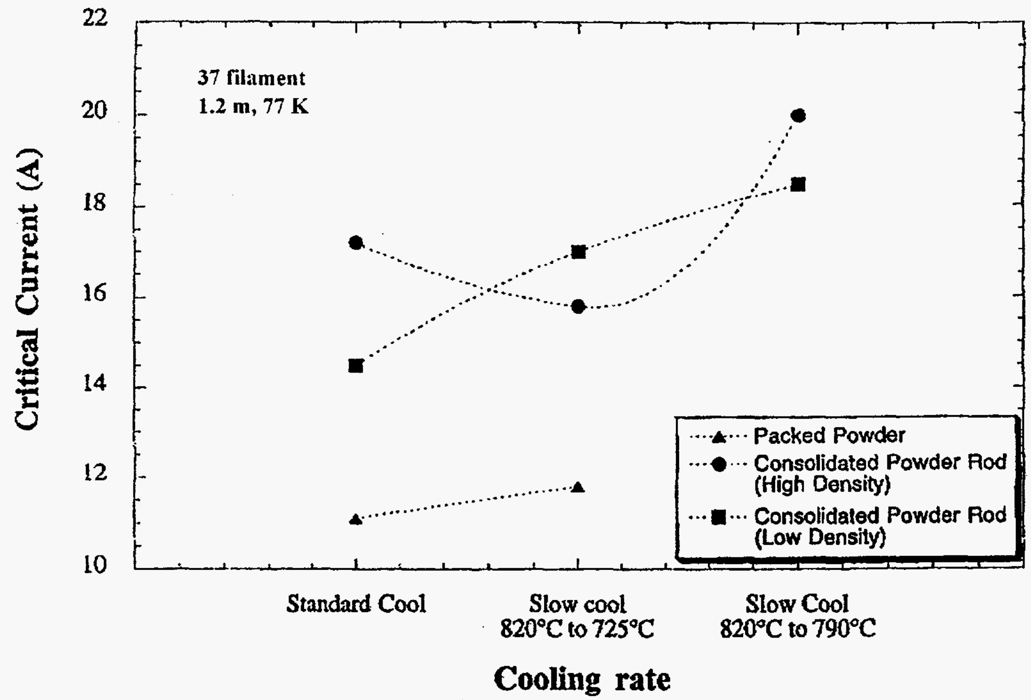

Figure 5. Transport critical current along a 1.2-m-long tape as a function of cooling rate and precursor powder packing density.

TABLE 1. Transport critical current, I_c; engineering critical current density, J_e; and critical current density, J_c; for multifilament tape as a function of conductor length.

Conductor Length (m)	I_c (A)	J_e (A/cm^2)	J_c (A/cm^2)
0.04	60	6,400	25,000
164	54	6,000	24,000
1260	18	3,500	12,000

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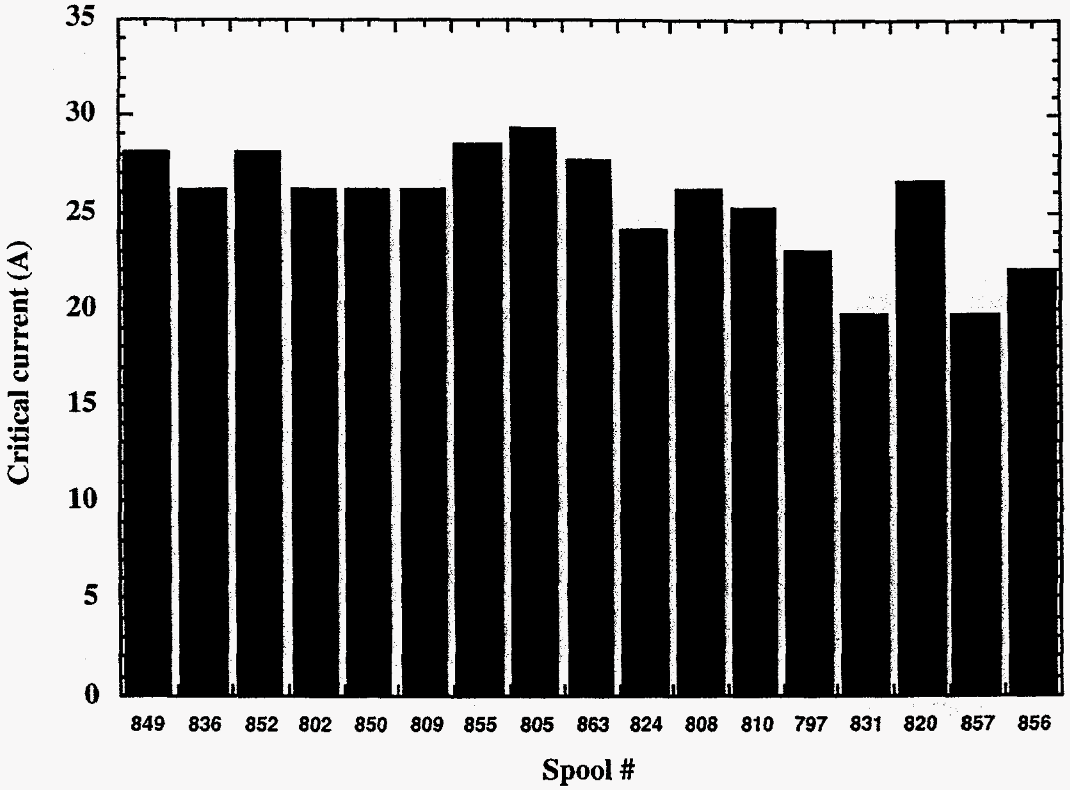

Figure 6. Distribution of I_c values for 17 different manufacturing runs of 100 to 150-m-long tapes.

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