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**PROCESSING AND PROPERTIES OF LONG-LENGTHS OF Ag-CLAD BSCCO
SUPERCONDUCTORS AND HIGH-T_c MAGNETS***

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PROCESSING AND PROPERTIES OF LONG-LENGTHS OF Ag-CLAD BSCCO SUPERCONDUCTORS AND HIGH- T_c MAGNETS*

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ABSTRACT

Long lengths of Ag-clad mono- and multicore BSCCO tapes were fabricated by the powder-in-tube technique. The critical current density (J_c) of 125-m-long monocoil tapes was $\approx 12,000 \text{ A/cm}^2$ (critical current, $I_c \approx 20 \text{ A}$) at 77 K. A 230-m-long 37-filament tape carried an I_c of 14 A (corresponding to a J_c of $\approx 10,000 \text{ A/cm}^2$). Pancake-shaped coils were formed from long-length conductors by the wind-and-react approach. High- T_c magnets were then assembled by stacking the pancake coils and connecting them in series. The magnets were tested as a function of applied magnetic fields at 4.2, 27, 64, and 77 K. A magnet containing 480 m of high- T_c tape generated a record-high field of 2.6 T at 4.2 K. Another magnet assembled with $\approx 770 \text{ m}$ of tape generated a field of $\approx 1 \text{ T}$ at 4.2 K and $\approx 0.6 \text{ T}$ at 27 K, both in an applied background field of $\approx 20 \text{ T}$. Strain tolerance of high- T_c tapes was evaluated by measuring J_c retention as a function of applied strain in an 0.5 T applied field at 77 K.

INTRODUCTION

Potential commercial applications of bulk high- T_c superconductors include motors, generators, and transmission cables. For the success of such applications, high- T_c superconductors, which are brittle oxide ceramics, must be fabricated into useful shapes such as wires or tapes. Conventional techniques like sinter forging, hot isostatic pressing, and tape casting have resulted in samples with low transport properties. However high quality Ag-clad Bi-Sr-Ca-Cu-O (BSCCO) conductors have been successfully fabricated by the powder-in-tube (PIT) technique [1-5]. Though several research groups have reported high critical current density (J_c) values for short length samples subjected to a series of uniaxial pressing and heat treatment cycles, the process is not appropriate for fabricating long-length conductors [1-3,5-6]. Using a more practical approach such as rolling, Intermagnetics General Corporation of Latham, NY, in collaboration with Argonne National Laboratory, has fabricated mono- and multifilament BSCCO conductors in lengths up to several hundred meters. At 77 K J_c values of $\approx 1.2 \times 10^4$ A/cm² has been achieved in a 125-m-long monocoil tape. A 230-m-long 37-filament tape carried a critical current (I_c) of 14 A, corresponding to a J_c of $\approx 1 \times 10^4$ A/cm². These conductors have been cowound into prototype pancake-shaped coils by the "wind and react" approach. High- T_c superconducting magnets have been fabricated by stacking the pancake-shaped coils and connecting them in series.

During fabrication and service the tapes are subjected to axial, bending, and electromagnetic hoop stresses which could have detrimental effect on the transport properties of the tapes. Currently research is underway to improve the mechanical properties of the tapes either with alternative sheath materials such as AgMgNi, AgMg, Ag-10 at% Cu or Ag-Al₂O₃ or by developing multifilament conductors

[2,5,7,8-11]. With the improvement in current carrying capabilities and mechanical properties, various commercial products using high- T_c superconductors can be envisaged.

EXPERIMENTAL PROCEDURE

Partially reacted precursor powder for the PIT process was prepared by a solid-state reaction of high purity oxides and carbonates of Bi, Pb, Sr, Ca, and Cu. The powder was then packed into Ag tubes, swaged, drawn through a series of dies, and then finally rolled to a final thickness of ≈ 0.1 mm. Transport properties of the tapes were measured by the four-point probe technique and with $1 \mu\text{V}/\text{cm}$ as the criterion. Long length conductors were fabricated by implementing a carefully designed two-step rolling and heat treatment schedule. Test magnets were fabricated by stacking together and connecting in series a set of pancake-shaped coils. The magnets were characterized at 4.2, 27, 64, and 77 K and in background fields up to 20 T. Multifilament conductors were fabricated by stacking circular monocoil wires in an Ag tube and drawing them to a size of ≈ 2.5 mm. Finally, with a special shape-forming technique, the wires were rolled to a final thickness of ≈ 0.5 mm. Strain tolerance of mono- and multifilament conductors containing 61-filaments at 77 K were evaluated by measuring I_c as a function of applied strain at 0 and 0.5 T.

RESULTS AND DISCUSSION

Rolling and heat treatment have been successfully used to fabricate long lengths of mono- and multifilament conductors. The I_c of a 125-m-long monocoil conductor was ≈ 20 A, which corresponds to a J_c of $\approx 1.2 \times 10^4 \text{ A}/\text{cm}^2$. A 230-m-long 37-filament conductor carried an I_c of 14 A. Figure 1 shows I_c along the length of a

850-m-long multifilament conductor containing 37-filaments. The I_c of the conductor was 16 A, which corresponds to a J_c of 1.2×10^4 A/cm², at 77 K and zero applied field. Consistent transport property results, as shown in Figure 1, indicate that considerable progress has been achieved in fabricating multifilament conductors. Test magnets were fabricated by stacking the pancake-shaped coils and connecting them in series. A prototype test magnet fabricated by stacking 10 pancake coils, with each coil containing three 16-m lengths of BSCCO-2223, generated 2.6 T at 4.2 K and zero applied field. At 27, 64, and 77 K, the generated fields were, respectively, 1.8, 0.53, and 0.36 T. Total length of conductor used in the magnet was ≈ 480 m. Recently another test magnet (Figure 2) was fabricated with 8-double pancake coils. Each coil contained three-16 m lengths of BSCCO conductor cowound together. Total length of conductor used was ≈ 770 m. The magnet generated a field of 1 T at 4.2 K and ≈ 0.6 T at 27 K, in a background field of 20 T. Such high- T_c superconductor magnets can be used as inserts to form hybrid magnets with low- T_c magnetic coils, already in commercial use, to generate higher fields. This opens up the possibility of high- T_c magnets being used for field sensitive applications such as magnetic resonance imaging.

Strain tolerance of mono- and multifilament BSCCO conductors containing 61-filaments, was evaluated at 77 K by measuring I_c retention as a function of applied field at 0 and 0.5 T. Figure 3 shows normalized I_c of both the conductors as a function of applied strain. Multifilament conductors appear to have better strain tolerance than monofilament conductors, retaining more than 90% of their initial I_c at $\geq 1\%$ strain. The irreversible strain limit for the monofilament conductor was $\approx 0.2\%$.

SUMMARY

Long lengths of high quality mono- and multifilament conductors were fabricated by the PIT process. High- T_c magnets were fabricated by forming pancake-shaped coils and connecting them in series. A magnet containing 770 m of tape generated a field of ≈ 1 T at 4.2 K and ≈ 0.6 T at 27 K. Multifilament conductors appear to have better mechanical properties, as compared to monocoil conductors, retaining 90% of their initial I_c under strain. Consistent and steady improvement in transport and mechanical properties of these conductors has been achieved over the past few years brightening the prospects for commercial applications.

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LIST OF FIGURES

Fig. 1. Critical current vs. length at 77 K of multifilament conductor containing 37 filaments.

Fig. 2. Test magnet that generated a field of 1 T at 4.2 K in a background field of 20 T.

Fig. 3. Normalized critical current vs. strain for mono- and multifilament conductors at 77 K and 0.5 T applied magnetic field.

FIG. 1

FIG. 2.

FIG. 3