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Fabrication and Properties of Silver and Silver-Sheathed BSCCO Conductors

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ABSTRACT

Significant progress has been made in the development of silver-sheathed BSCCO conductors for potential electric power and high-field magnet applications. High critical current density (J_c) has been achieved in mono- and multifilament conductors fabricated by the powder-in-tube technique; J_c up to 12,000 A/cm^2 has been observed at 77 K, in an 1,260-m-long multifilament conductor. A high-T_c magnet generated a self-field of $\approx$ 3.2 T at 4.2 K. A 0.25 KVA high-T_c transformer has been developed with the use of a racetrack-wound solenoid. Strain tolerance of the conductors was evaluated by in-situ tensile and bending tests. Tensile testing indicated that multifilament conductors have better strain tolerance than monofilament conductors and are able to retain 90% of their initial current (I_c) at a strain of $\geq$1%. Effect of superconducting/Ag ratio on bending characteristics of the conductors was also evaluated; preliminary results indicate that the irreversible strain limit of the monofilament conductor increases with decreasing superconductor/Ag ratio.

KEYWORDS : Powder-in-tube (PIT) technique, multifilament conductor, high-T_c magnets, high-T_c transformer, strain tolerance

INTRODUCTION

Significant effort has been made over the past few years in the development of superconducting wires and tapes, through use of the powder-in-tube technique for possible electric power and high-field magnet applications. Several research groups have demonstrated high critical current density (J_c) in short-length Ag-clad BSCCO tapes fabricated by the powder-in-tube (PIT) technique [1-7]. The tapes were fabricated in a series of uniaxial pressing and heat treatment schedules. Because this technique cannot be adopted for fabricating high-quality long-length conductors a modified processing technique was required. 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 of up to several hundred meters [4,8-9]. These conductors have been cowound into prototype pancake- and racetrack-shaped coils. While the former has been used in fabricating high-T_c superconducting magnets, the latter was used in a 0.25 KVA transformer. During fabrication and service, the tapes are subjected to axial and tensile stresses that could have detrimental effects on transport properties. Currently, research is underway to improve the mechanical properties of the tapes by alternative sheath materials such as AgMgNi, AgMg, Ag-10 at.% Cu, or AgAl, and by developing multifilament conductors [10-13]. Details of the magnet and transformer, along with the mechanical properties of the conductors, will be discussed in the present paper.

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 rolled to a thickness of ≈0.1 mm. Multifilament conductors containing 37 and 61 filaments were fabricated by stacking monocore wires in a larger Ag tube and then drawing and rolling them to final size.

Short lengths of tapes were cut and heat treated at ≈850°C in air with intermittent uniaxial pressing. After each thermomechanical step, the tapes were characterized by X-ray diffraction (XRD), scanning electron microscopy, and critical current measurements. Transport properties of the resulting tapes were measured by the four-point probe technique, with a 1 μV/cm criterion. Long-length mono- and multifilament conductors were fabricated by implementing a carefully designed two-step rolling and heat-treatment schedule. Figure 1 shows winding of the long-length conductor onto a spool. These conductors were cowound in parallel to form pancake coils and racetrack-shaped solenoids. High-T_c magnets were fabricated by stacking together and connecting in series a set of pancake coils. The magnets were characterized at various temperatures and applied magnetic fields.

A high-T_c transformer, with an iron core and capable of operating at liquid nitrogen temperature, was developed by using the racetrack-shaped solenoid. Axial strain tolerance of mono- and multifilament conductors containing 61 filaments was evaluated by subjecting the tapes to an in-situ tensile test. I_c retention as a function of applied strain was measured at 77 K and in applied fields of 0 and 0.5 T. In-situ bend characteristics of the conductors were determined with a custom-designed test fixture. The tape was fixed between two movable arms mounted on a lead screw. The tapes were bent in a bath of liquid nitrogen by moving the arms toward each other by a crankshaft mechanism. Correlation between the number of turns of the crankshaft and radius of curvature to which the tapes were bent was preestablished at ambient temperature. Bend strain (ε) was determined from the relation

$$\varepsilon = t/2R \qquad (1)$$

where t is the total thickness of the tape and R is the radius of curvature. The irreversible strain limit, ε_{irr}, is defined as that strain beyond which the decrease in the critical current is irreversible. Bend testing was conducted on both mono- and multifilament conductors containing 61 filaments at 77 K and zero applied field. Additionally, the effect of superconductor/Ag ratio (also known as superconductor fill factor) on the bend characteristics of monofilament conductor was also studied. Monofilament conductors with 23, 30, and 38% fill factor were used.

RESULTS AND DISCUSSION

High I_c values in short samples have been achieved by a combination of uniaxial pressing and heat treatments. I_c values above 40 A were typically attained at 77 K, with the highest being 51 A, in short samples subjected to three or four cycles of uniaxial pressing and heat treatment. For fabricating long length conductors, however a more practical approach such as rolling has been adopted. Table 1 summarizes the transport current properties, at 77 K, of both short and long mono- and multifilament conductors. At 77 K, core J_c values of $\approx 1.2 \times 10^4$ A/cm^2 have been achieved in a 114-m-long monocore conductor.

Figure 2 shows I_c along the length of a 1,260-m-long multifilament conductor containing 37 filaments. The I_c was 18 A, corresponding to a J_c of $\approx 1.2 \times 10^4$ A/cm^2. These results indicate that considerable progress has been made in the development of Ag-clad BSCCO superconductors by the PIT technique. Pancake coils and racetrack shaped solenoids were fabricated from long Ag-clad BSCCO conductors. High-T_c magnets were fabricated by stacking the pancake coils and

Fig. 1. Winding of long-length conductors onto a mandrel.

Table 1. Summary of transport current properties of short and long mono- and multifilament Ag-clad BSCCO conductors.

Conductor	Length (m)	I_c (A)	Core J_c (A/cm^2)	Overall J_c (A/cm^2)	Fill Factor (%)
Monofilament					
Short Pressed	0.03	51	45,000	9,000	20
Short Rolled	0.03	51	29,000	7,800	27
Long Length	70	23	15,000	3,500	24
Long Length	114	20	12,000	3,200	27
Multifilament					
Long Length	20	42	21,000	6,800	32
Long Length	90	35	17,500	5,600	32
Long Length	850	16	10,500	2,500	24
Long Length	1,260	18	12,000	3,500	30

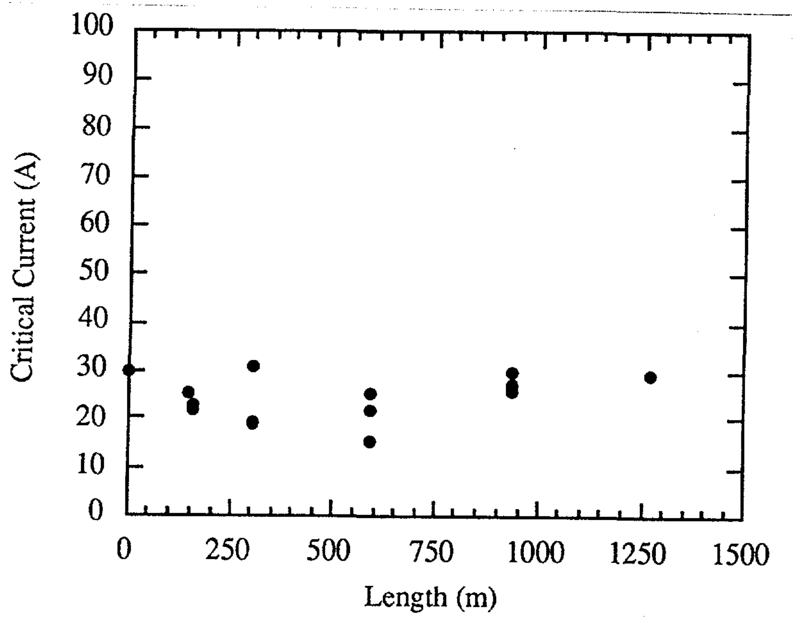

Fig. 2. I_c vs. length at 77 K of multifilament conductor containing 37 filaments. J_c of ≈1,260-m-long conductor was ≈1.2 x 10^4 A/cm^2.

connecting them in series. A test magnet (Fig. 3) fabricated by stacking 20 pancake coils generated a self-field of ≈3.2 T at 4.2 K and zero applied field. Total length of the conductor in the magnet was 2400 m. The outer and inner winding diameters of the coil were 0.203 and 0.04 m, respectively. Ampere turns at 4.2 K were >250,000. Another test magnet fabricated with eight double-pancake coils, with each coil containing three 16-m lengths of BSCCO conductors cowound together, generated a field of 1 T at 4.2 K and 0.6 T at 27 K, in a background field of 20 T. Total length of the conductor in the magnet was 770 m. The racetrack-wound solenoid was used in developing a 0.25 KVA high-T_c superconducting transformer (Figure 4) with an iron core and capable of operating at liquid nitrogen temperatures. The primary end of the transformer had about 85 m of high-T_c conductor and the secondary had 31 m. Turns in the primary and secondary winding were 140 and 40, respectively.

In-situ tensile testing indicates that multifilament conductors (61 filaments) conductors to have better strain tolerance than the monofilament conductors, retaining more than 90% of their initial I_c at ≥ 1% strain. While ε_{irr} for the multifilament conductor was ≈1%, that for the monofilament conductor was ≈0.2%. Preliminary results on the bend characteristics of the conductors indicate that the drop in I_c is more profound in monofilament conductors than in multifilament conductors (61 filaments) as bend radius decreases. Figure 5 shows the effect of fill factor on the bend characteristics of monofilament conductors. The plot shows that ε_{irr} for the monofilament conductor increases as the superconductor fill factor decreases. These results are encouraging because they show that further improvement in mechanical properties can be achieved without compromising transport current properties.

SUMMARY

High quality mono- and multifilament conductors up to several hundred meters in length have been successfully fabricated by the PIT technique. These conductors have been used to develop high-T_c superconducting magnets and transformers. A high-T_c magnet containing 20 pancake coils generated a self-field of ≈3.2 T at 4.2 K. Strain tolerance of the conductors indicate that multifilament conductors have better strain tolerance than do monofilament conductors. The irreversible strain limit of the monofilament conductor increases with decreasing superconductor fill factor.

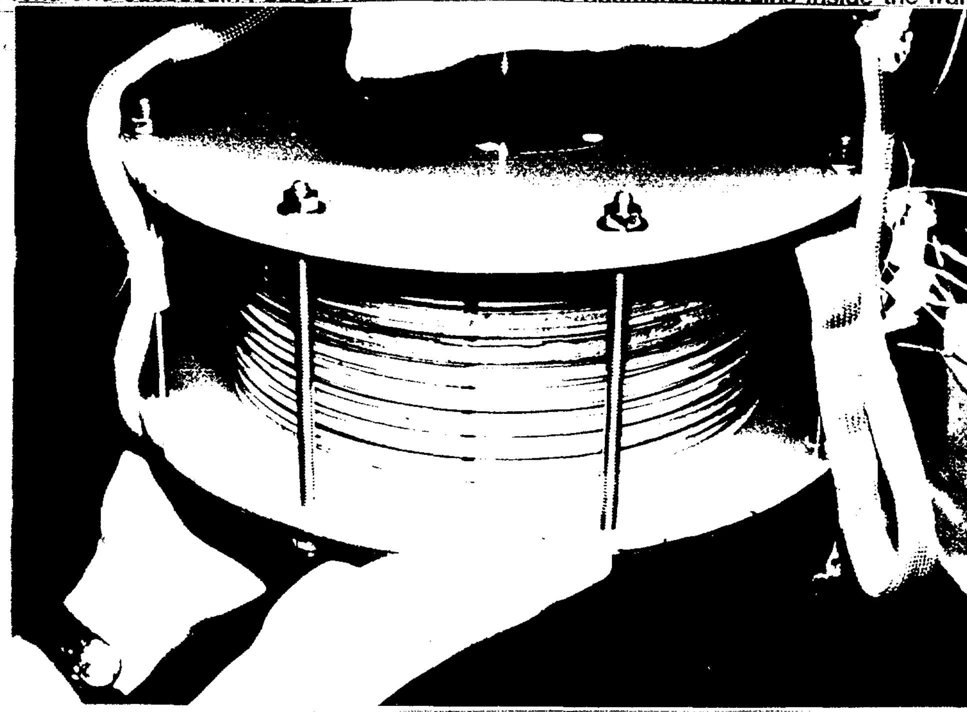

Fig. 3. Test magnet that generated a field of ≈3.2 T at 4.2 K and zero applied field.

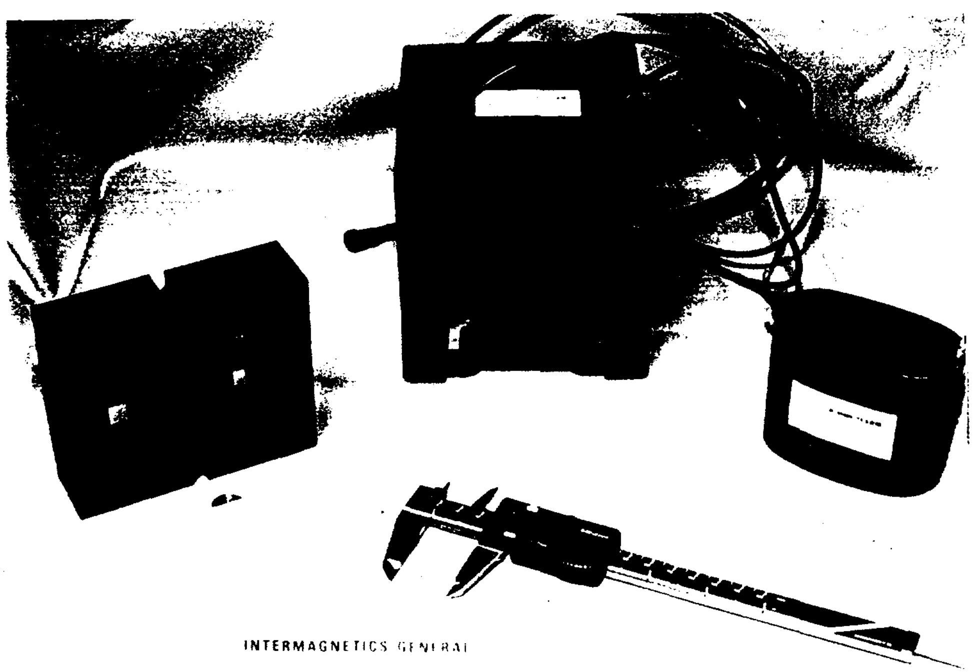

Fig. 4. Photograph of 0.25 KVA high-T_c superconducting transformer shown with its iron core.

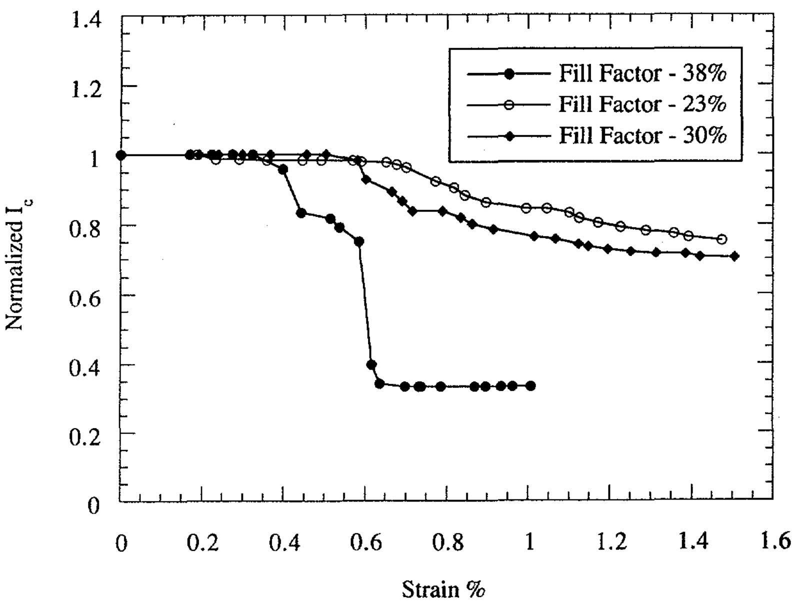

Fig. 5. Normalized I_c vs. bend strain of monofilament conductor of three different superconductor fill factors.

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