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MECHANICAL BEHAVIOR AND SUPERCONDUCTING PROPERTIES OF NANOSIZE MgO ADDED DIP-COATED $Bi_2Sr_2CaCu_2O_8$ SUPERCONDUCTING TAPE

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ABSTRACT

In this study, 3 to 8 weight percent of nanosize MgO particles was added to $Bi_2Sr_2CaCu_2O_8$ (Bi-2212) high-temperature superconductor to fabricate Bi-2212 superconductor elements with superior mechanical properties. The mechanical strength of the samples was studied by conducting the compression test at room temperature, and the addition of 5% nanosize MgO particles produced the highest strength when compared with other samples. The sample with 5wt% MgO addition also exhibited superior superconducting properties. The Bi-2212 powder with 5% nanosize MgO addition was used to fabricate Bi-2212 tapes through the dip-coating-then-stacking method. The fully processed tapes were investigated via dc electrical resistance measurements, XRD patterns, SEM micrographs, transport critical current density and tensile tests. The tensile tests were conducted at room and 77 K. Results of tensile tests and Young's modulus for the tapes showed that the Bi-2212 tapes with nanosize MgO addition recorded better mechanical property when compared to the non-added samples both at room and77 K. The double-core tape with 5% MgO addition recorded the highest failure point at 160 MPa. Beside the strengthening effect that was observed in the nanosize MgO added Bi-2212 superconductor tapes, superior superconducting properties were also observed in the tapes.

Keywords: BSCCO; stiffness; toughness;

INTRODUCTION

For practical applications of high-temperature superconductor materials in power engineering, where thermo mechanical and electromagnetically induced stresses are expected to occur, the high-temperature superconductor materials need to posses excellent superconducting properties and higher mechanical strength. Bismuth based high-temperature superconductors such as $Bi_2Sr_2CaCu_2O_8$ (Bi-2212) is one of the most promising materials due to its high critical current density, rapid phase formation and phase stability. Nevertheless the Bi-2212 superconductor, like other Bi-based high-temperature superconductors is generally has poor mechanical properties such as low stiffness, strength and toughness despite their excellent superconducting properties [1-4]. Low strength and low irreversible strain are among the factors that hindered the application of Bi-2212 superconductor in power industry. MgO fibers have been used to reinforce Bi-2212 superconductor and are able to improve the mechanical properties of the compounds [4,5]. Furthermore, the addition of nanosize MgO particles has shown to be an effective pinning center for Bi-2212/MgO compounds and samples with nanocrystalline microstructures are found to exhibit better plasticity under stress if compared with samples of larger grains [6-10].

In this paper we report on the superconducting and mechanical properties of dip-coated Bi-2212 superconducting tapes with nanosize MgO addition. The tapes were fabricated using the dip-coating-then-stacking (DIS) method [11].

EXPERIMENTAL PROCEDURE

The $Bi_2Sr_2CaCu_2O_8$ (Bi-2212) with nanosize MgO addition tapes were prepared through the DIS method. The silver foil that was used in the fabrication of the tapes was product of Alfa Aesar with 0.1 mm in thickness and 99.998% purity. In the process, slurry with an optimum composition was prepared before employing the dip-coated process. In preparation of the slurry, organic solution comprises of Span 85 or sorbitane trioleate ($C_{60}H_{108}O_8$), 1,3-propandiol ($C_3H_8O_2$), polyvinyl butyral and trichloroethylen (C_2HCl_3) were used. The Bi-2212 powder was then added with the solution in the ratio as shown in Table 1.

Table 1: Formulation of slurry used to fabricate dip-coated tapes

Component	Material	Fractions (Weight %)
Oxide powder	Bi-2212/ nanosize MgO	22
Solvent	Trichloroethylene	68
Binder	Polyvinyl butyral	6
spersant	Sorbitant triolate	4

The slurry was stirred for 24 hours to obtain a homogeneous solution before coating. The coated tape was then heated at temperature of 80˚C for 48 hour to remove any oxide layers before further heating at 500˚C in flowing oxygen for one hour to remove the organic materials. After heating, the tape was stacked and consequently rolled to increase the packing density of the oxide core before it is subjected to partial melt process.

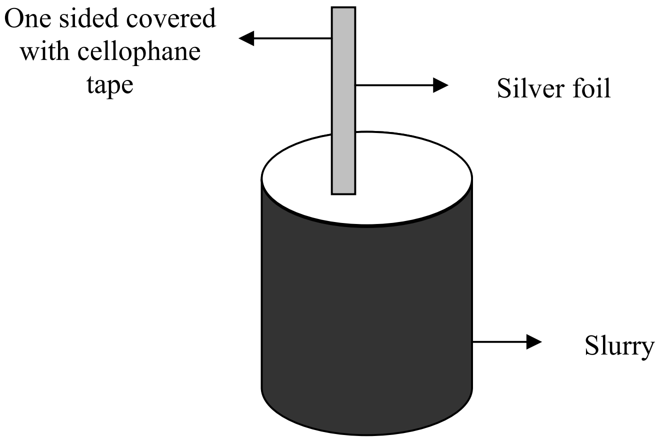

Figure 1: One-sided coating of silver foil

Figure 1 shows the coating process of the silver foil to fabricate single-core and double-core tapes. Figure 2 shows the regimental heat treatment during the partial melt process. Partial melt temperature of 865ºC with 6 minutes duration was applied in this segment and it was employed to overcome the problem of weak-link within the Bi-2212 superconducting grains.

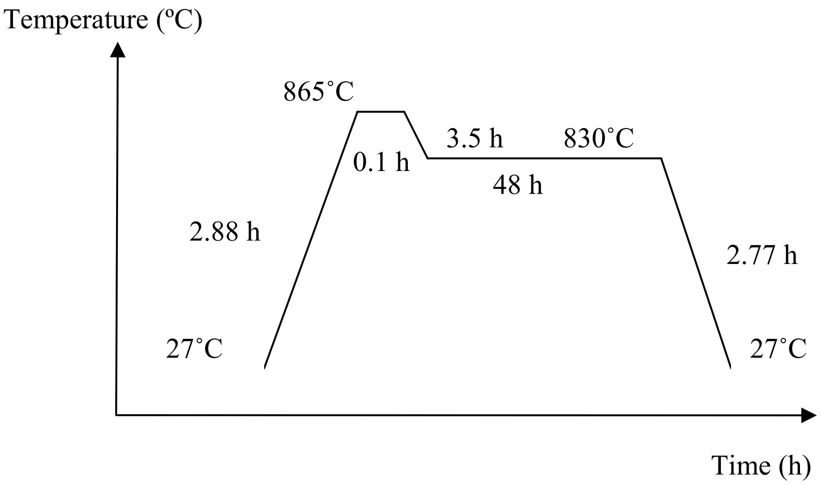

Figure 2: Heat treatment after rolling of the tape

The fully processed tapes were characterized through dc electrical resistance measurements, XRD patterns, SEM micrographs, and transport critical current density, J_c. In the dc electrical resistance measurements, $T_{c,\ \mathrm{onset}}$ corresponds to the transition onset temperature which is the point on the R(T) curve where the resistance starts decreasing dramatically, and $T_{c,\ \mathrm{zero}}$ corresponds to transition zero temperature where the resistance is zero. The XRD patterns were recorded on a Siemen D5000 diffractometer using Cu K_α radiation. The SEM analysis of the longitudinal and broad-face cross sectional of the tapes were conducted using the Philips XL30 environmental scanning electron microscope with EDX analysis. The transport critical current (I_c) of short samples was measured in a cryostat at 77 K and zero electric field using the four-probe method with a 1 μV/cm criterion. The transport critical current density (J_c) was calculated by dividing I_c with the cross-sectional area of the superconducting core. The mechanical properties of the tapes were studied using tensile tests that were conducted at room and cryogenic (77 K) temperatures. The tests were conducted using the Instron Material Testing System model 5567. The slope of the stress-strain curve in the elastic region represents the stiffness of the material. In a tensile test, a sample is extended at a constant rate and the maximum load is measured. The Young's modulus was estimated from the linear part of the stress-strain curve.

RESULTS AND DISCUSSION

Figure 3 shows a typical resistivity curve of the tape samples. The curve shows a metallic behavior due to the silver tape until the onset temperature where the resistance propitiously dropped to zero. The sharp drop of the curve indicates high purity of Bi-2212 phase in the superconducting core of the tape.

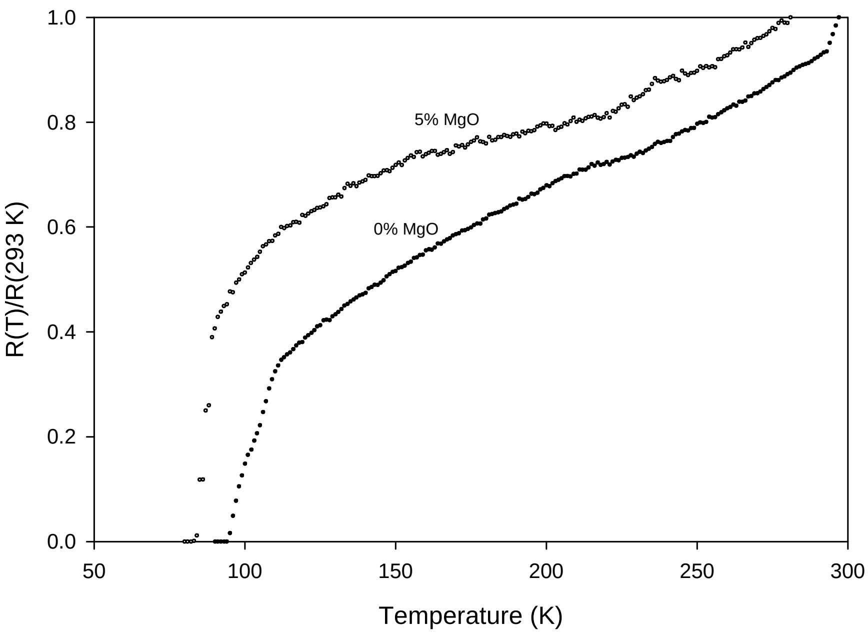

Figure 3: Temperature dependence of resistance of dip-coated Bi-2212 superconducting tape

Figure 4 shows the XRD patterns for the single-core dip-coated tapes. Similar patterns were observed in the double-core tapes. The XRD patterns for both the non-added and nanosize MgO added Bi-2212 tapes show a well defined peaks all of which could be indexed on the basis of a Bi-2212 structure. The (115) peak, which is the characteristic of the Bi-2212 phase, can be observed clearly in all the samples. Patterns of the nanosize MgO added tape samples show a more distinct and sharp Bi-2212 phase peaks, indicating a highly crystalline and well textured microstructure. A few peaks which correspond to secondary phases such as Bi-2201 phase and other impurities could also be observed. Those unidentified peaks are probably due to inappropriate heat treatment during the sintering process which resulted in unidentified secondary phases.

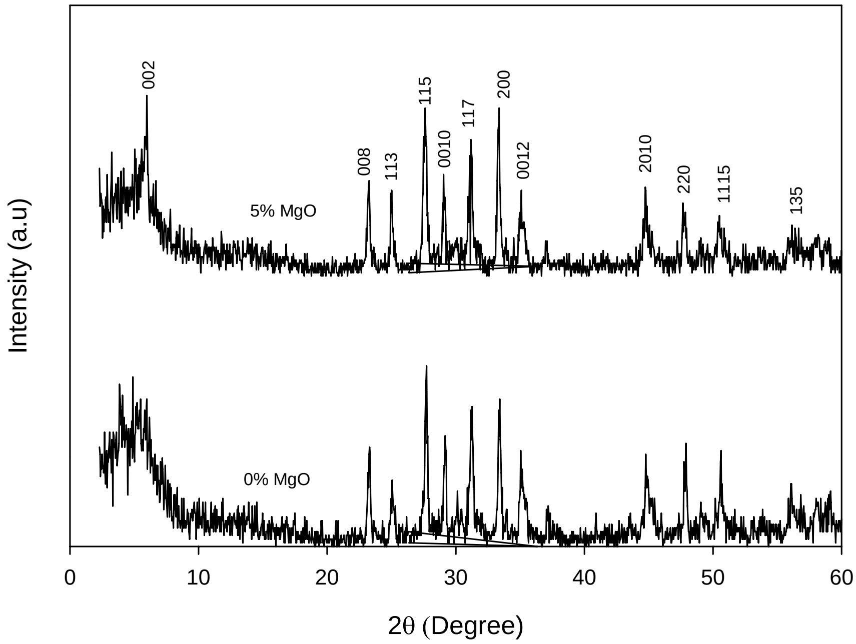

Figure 4: XRD patterns of single-core dip-coated Bi-2212 superconducting tapes with 0% and 5% nanosize MgO addition, respectively

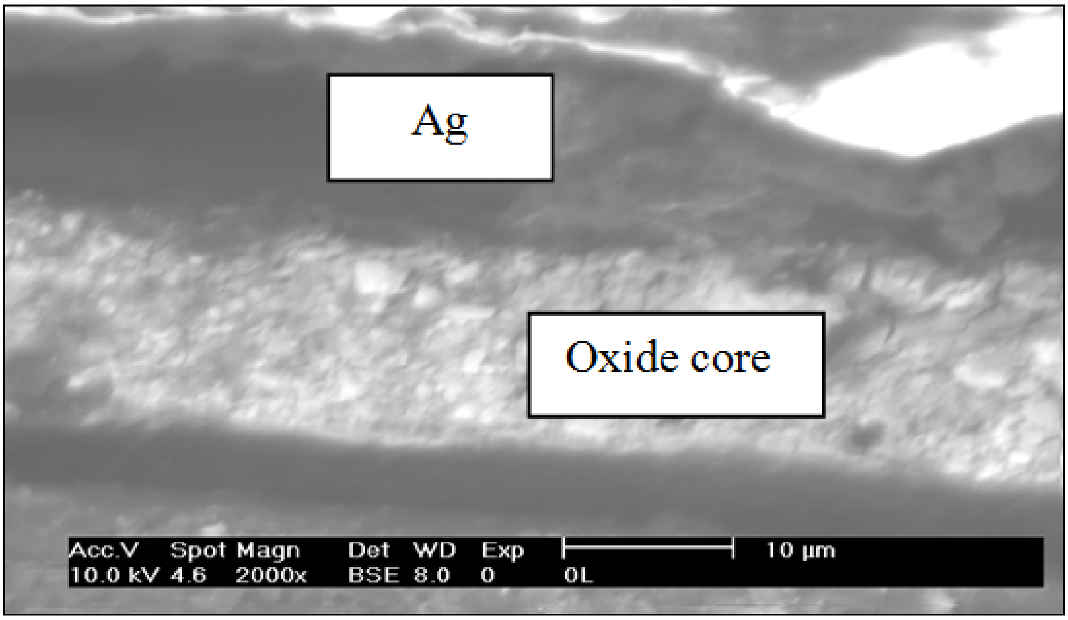

Figure 5: Typical SEM micrograph of the longitudinal cross-sectional of the dip-coated Bi-2212 superconducting tape

Figure 5 shows a typical SEM micrograph of the longitudinal cross-sectional of the dip-coated Bi-2212 superconducting tape with nanosize MgO addition. The micrograph exhibits a well aligned microstructure of the Bi-2212 superconducting core with closely connected grain boundaries.

Table 2 shows the critical current density, J_c, zero transition temperature, $T_{c,\ zero}$ and onset transition temperature, $T_{c\ onset}$ of the tapes. For both the single-core and double-core tapes, there is enhancement in the J_c after addition of nanosize MgO. From the observation of XRD patterns and SEM micrograph, the enhancement is most likely due to better texturing and well connected grain boundaries of the superconducting core. The J_c of the tapes is very much dependent on microstructural features such as phase purity, grain alignment and grain boundaries.

Table 2: The critical current density, J_c and transition temperature, T_c of the dip-coated Bi-2212 superconducting tape

Nanosize MgO Addition	J_c (A/cm^2) ± 10	$T_{c\ zero}$ (K)	$T_{c\ onset}$ (K)
0% (single-core)	1800	94	101
5% (single-core)	2400	82	95
0% (double-core)	1900	82	88
5% (double-core)	2300	89	98

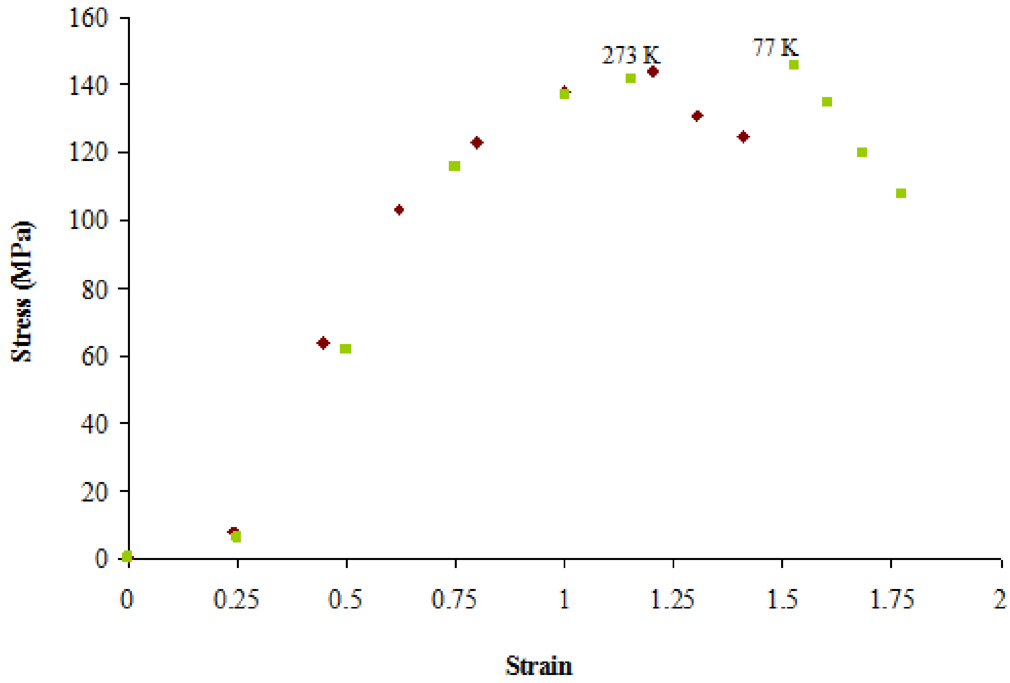

Figure 6: The stress-strain curve for a double-core dip-coated Bi-2212 superconducting tape with nanosize MgO addition at room temperature (♦) and 77 K (■)

Mechanical properties such as stiffness, strength and toughness are important parameters to indicate the versatility of superconducting tapes [12,13]. Those properties at room temperature are able to predict such behaviors at cryogenic temperature. Figure 6 shows a typical stress-strain curve for a double-core dip-coated Bi-2212 superconducting tape with nanosize MgO added both at room and cryogenic temperatures. The non-linear curve at the initial load is due to low rigidity in which the tape sample was not completely attached to the tester. As the load increases, a more linear relationship is observed until deformation and eventually to the failure point. From our results, a more distinct linear curve was observed in the MgO added samples before deformation both at room and cryogenic temperatures. The presence of MgO particles resulted in different mechanical behavior between the MgO added and non-added tapes.

Table 3: The tensile test results for double-core and single-core tapes both at room and cryogenic temperatures

Nanosize MgO Addition	Max. Strength at 77 K (MPa) ±0.01	Max. Strength at Room Temperature (MPa) ±0.01
0% (single-core)	144.91	117.59
5% (single-core)	146.22	144.83
0% (double-core)	151.01	116.65
5% (double-core)	159.81	146.68

Table 3 shows the tensile test measurements for the single-core and double-core tapes both at cryogenic and room temperature. At cryogenic temperature, all the tapes exhibit higher strength when compared to room temperature. The double-core tape added with nanosize MgO recorded the highest strength at about 160 MPa. In addition, the Young's modulus for each tape can be estimated based on the linear part of each curve. In contrast to the tapes' strength, the Young's modulus of the MgO added tape slightly decreased at cryogenic temperature. This is mostly due to lower stiffness of the tape initiated by microcracks that developed between the MgO particles and the Bi-2212 superconductor matrix during cooling to cryogenic temperature [14]. Nevertheless, the Young's modulus is still higher when compared to the non-added tape sample. As such, the Bi-2212 superconducting tapes with nanosize MgO addition show better resilience at cryogenic temperature.

CONCLUSION

In this work, we have successfully fabricated nanosize MgO added Ag-sheathed Bi-2212 superconducting tapes using the dip-coating-then-stacking (DIS) method. The samples were subjected to a combination of partial melt and slow cooling during heat treatment and annealing processes. The addition of nanosize MgO in both single-core and double-core tape samples enhanced the J_c and this was attributed to the presence of MgO that acted as pinning centers. The double-core tape with 5% nanosize MgO addition recorded the highest strength. As such, the addition of nanosize MgO contributed to the improvement of the mechanical properties of the tapes without compromising their superconducting properties.

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