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Research paper

Effect of single and multi-wall carbon nanotubes on the mechanical properties of Gd-123 superconducting phase

M. Anas [a,*], Shaker Ebrahim [b], I.G. Eldeen [c], R. Awad [d], A.I. Abou-Aly [a]

[a] Physics Department, Faculty of Science, Alexandria University, Alexandria, Egypt
[b] Materials Science Department, Institute of Graduate Studies and Research, Alexandria University, Alexandria, Egypt
[c] Physics & Chemistry Department, Faculty of Education, Alexandria University, Alexandria, Egypt
[d] Physics Department, Faculty of Science, Beirut Arab University (BAU), Beirut, Lebanon

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ABSTRACT

The influence of single wall carbon nanotubes SWCNTs and multi wall carbon nanotubes MWCNTs on Vickers microhardness of Gd-123 superconducting phase is studied. Samples of type $(SWCNTs)_x$ and $(MWCNTs)_xGdBa_2Cu_3O_{7-\delta}$, composite where, $0.0 \leq x \leq 0.1$ wt.%, are prepared by solid-state reaction technique. The samples are characterized by X-ray powder diffraction (XRD), scanning electron microscope (SEM), transmission electron microscope (TEM). Moreover the samples are examined by measuring electrical resistivity and Vickers microhardness. The obtained results showed an enhancement in the phase formation and grains connectivity up to 0.06 and 0.08 wt.% for SWCNTs and MWCNTs added samples, respectively. Likewise the superconducting transition temperature T_c was improved at a low content of CNTs but it suppressed for higher concentrations. In addition, the analysis of Vickers microhardness measurements suggests that the most suitable model that describes the behavior of our sample is proportional specimen resistance PSR model.

1. Introduction

Generally, $GdBa_2Cu_3O_{7-\delta}$ (Gd-123) is regarded as a promising material in the field of high temperature superconductors HTSCs. It possesses high superconducting transition temperature T_c (around 90 K), large critical current density J_c in high magnetic field [1–3], relative law crystalline anisotropy, high ability to trap the magnetic field up to 2.0 T at 77 K [4], and well developed pinning properties in high magnetic field [5]. But unfortunately, the poverty of mechanical properties of these materials still standing barrier to be used widely in practical applications. Hence, the improvement of mechanical properties of HTSCs plays an important role in technological applications. They restrict the maximum trapped field since a considerable electromagnetic force acts on the bulks when they trap large fields [6]. Mechanical properties of RE-Ba-Cu-O are quite sensitive to the defect density, such as cracks and pores, produced during the oxygen-annealing process due to volume change associated with the tetragonal to orthorhombic phase transition [7]. Some trails are performed to improve the mechanical properties of bulk superconductors. One of them is the addition of nanoparticles as they can reduce the pores between the grains in the structure and increase the mechanical strength. Mohammed et al. [8–10] have studied the effect of nanosizedSnO_2, In_2O_3 and Fe_2O_3 additions on the mechanical properties of $(Cu_{0.5}Tl_{0.5})$-1223 superconducting phase. Their results showed that low addition concentrations (up to 0.6 wt.% for SnO_3, 1 wt.% for In_2O_3 and 2 wt.% for Fe_2O_3) enhances the Vickers microhardness, while the high concentrations reduces it. Hamid et al. [11] have studied the effect of nanosized MgO on Bi-2212 superconducting phase. They have concluded that the addition of 3–5 wt.% MgO decreases the porosity and improves the texture of microstructure and mechanical strength of the phase. Awad et al. [12–14] have examined the influence of SnO_2 nano particles on the Vickers microhardness of (Bi, Pb)-2223 superconducting phase, nanosized $CoFe_2O_4$ and $ZnFe_2O_4$ on the mechanical properties of Gd-123 superconducting phase. They have reported that the Vickers microhardness increases with the rise of SnO_2 up to 0.4 wt.% then it decreases with further increase in x. Nanosized $CoFe_2O_4$ addition up to 0.01 wt.% enhances the mechanical properties of Gd-123 phase then it decreases with further increase in x. Likewise, the addition of $ZnFe_2O_4$ increases Vickers microhardness of the same phase up to $x = 0.1$ wt.%. Another way used to improve the mechanical strength for RE-Ba-Cu-O is the dispersion of second phase RE-211, in the original phase [15]. Tomita et al. [16] have found that the inseminating of epoxy resin into the RE-123 sample

* Corresponding author.
E-mail address: m_anas_gaafar@yahoo.com (M. Anas).

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can prevent the cracks from expanding or initiating operation. Subsequently, this leads to an improvement in mechanical properties of RE-123 phase. Sakai et al. [17] concluded that, Ag addition is an effective method in improving the mechanical properties through the densification and/or the reduction in defects density. Additionally, CNTs play an important role in improving the mechanical properties of materials because of their high hardness due to the SP^2 bonds among the individual carbon atoms. The addition of CNTs improves the mechanical properties of hydroxyapatite until the optimum point x = 1 wt.% [18]. Further, CNTs added to AL_2O_3 with 5–8 wt.% leads to 8.4% increase in hardness and 21.1% increase in toughness [19]. On the other hand, the mechanical properties of micro-electromechanical bridge resonators (PMEMS) based on polymer carbon nanotubes composite are presented. Hence, it is found that the CNT multilayers increase the rigidity and subsequently the resonance frequency [20].

On the other hand, the high content of CNTs addition retards the strength and toughness of some composite materials due to the agglomeration of CNTs. This result was reported by Yamamoto et al. in the study of fractional properties of carbon nanotubes/aluminum composite [21].

This research aims to explore the effect of SWCNTs and MWCNTs addition on the mechanical properties of Gd-123 superconducting phase. For this purpose superconducting samples of type $(CNT)_xGdBa_2Cu_3O_{7-\delta}$, for x = 0.00, 0.02, 0.06, 0.08, and 0.1 wt.% were prepared and investigated using X-ray powder diffraction (XRD), Scanning electron microscope (SEM), Transmission electron microscope (TEM), electrical resistivity and Vickers microhardness measurement.

2. Experimental technique

2.1. Samples preparation

Stoichiometric ratios of high purity Gd_2O_3, $BaCO_3$ and CuO with purity 99.99% (Aldrich) are mixed together and crushed in agate mortar. The resulted powder was sifted by a 125 μm sieve. This process is repeated twice to obtain fine and homogenous powder. Next, the calcinations processes are carried out at two temperatures 840 °C and 880 °C for 24 h each. Between these two processes the powder was ground and sifted then x wt.% of SWCNTs (inner diameter 1.1 nm, outer diameter 2 nm) or MWCNTs (inner diameter 7.5 nm, outer diameter 10–30 nm) with purity 99.00% (SES Research) are added to the resulting powder. Subsequently, the powder was pressed in a disc form (1.5 cm in diameter and about 0.3 cm in thickness). The sintering process is conducted at normal room temperature up to 930 °C by heating the samples with a rate of 4 °C/min, and the samples are held at this temperature for 24 h. Then, they are cooled by a rate of 1 °C/min down to 450 °C, and kept at this temperature for 10 h under oxygen flow to control the oxygen-content of the final compounds. Finally, they are cooled by a rate of 1 °C/min to room temperature.

2.2. Samples investigation

The superconducting samples were characterized by X-ray powder diffraction (XRD) using Bruker D8 advance powder diffractometer with Cu K_α radiation (λ = 1.54056 Å) in the range $10^\circ \leq 2\theta \leq 80^\circ$. Next the grain morphology was identified using a Jeol scanning electron microscope (SEM) JSM-5300, operated at 25–30 kV, with a resolution power of 4 nm and Jeol transmission electron microscope (TEM) JEM-100CX, operated at 80 kV. The superconducting transition temperature of selected samples was measured by a conventional four-probe technique at room temperature down to zero-resistivity temperature T_0 with a closed cycle helium cryogenic refrigeration (Displex) system [22].

2.3. Vickers microhardness measurements

The Vickers microhardness of the prepared samples was measured in air using a manual Vickers microhardness tester IN-412A at room temperature. The applied load varies from (0.5–10 N) for loading time 40 s, the reasonable average value of Vickers microhardness for each load was calculated by taking five readings at different locations on the sample surface. The Vickers microhardness H_V, elastic modulus E, the yield strength Y, the fracture toughness K_f and the brittle index B_i related to the bulk microhardness applying the following equations, as reported by [23].

$$H_V = 1854.4\frac{F}{d^2}\ \text{GPa} \tag{1}$$

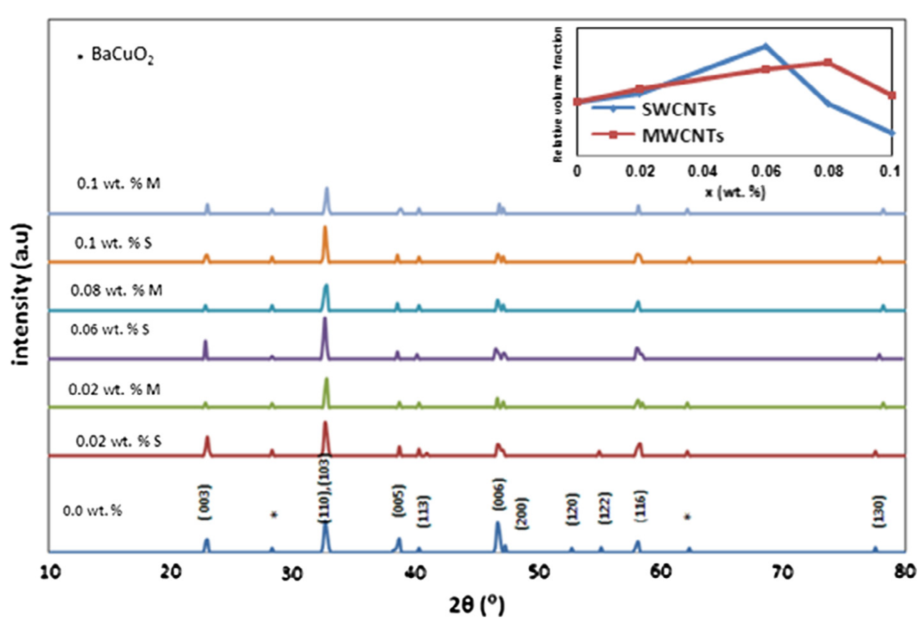

Fig. 1. XRD for $(SWCNTs)_xGdBa_2Cu_3O_{7-\delta}$, (x = 0.0, 0.02, 0.06 and 0.1 wt.%) and $(MWCNTs)_xGdBa_2Cu_3O_{7-\delta}$, (x = 0.02, 0.08 and 0.1 wt.%).