



Mechanical properties of BSCCO compounds doped with nanotin oxide

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Nanomaterials have remarkable mechanical properties attributable to the surface, volume, and quantum effects of nanoparticles. As nanoparticles are introduced in a common material, these particles will enhance the grain to a certain range, forming an intragranular structure, which refines the grain boundary and improves the mechanical properties of materials. The aim of this research is to clarify the effect of nano Sn partial substitution on the structure and mechanical properties of BiSrCaCuO system. Solid state reaction methods are used to synthesize and substitute series samples of Bi-2223 with different weight percentages of Tin nanoparticles. The prepared samples are characterized structurally by X-ray diffraction (XRD). The investigations verified the formation of the low and high phases without altering their orthorhombic structure. Static Vickers hardness test is done at room temperature to investigate their mechanical properties performance with various applied loads. The values of the Vickers microhardness Hv, Young modulus E and yield strength Y have shown improvement with increasing Sn content in the compounds.

Keywords: Superconductor; Mechanical; (BiPb)-2223; Sn nanoparticles.

1. INTRODUCTION

BiSrCaCuO (BSCCO) high temperature superconductors (HTSCs), one of the most important special ceramic compounds, which is utilized in various applications, each application requires specific specifications and specific geometric shapes. Those requirements depend upon the combination of the compound's properties, which is a reflection of the internal composition and its quality. The obstacles facing superconductivity applications are represented in several forms.

Superconductor coil properties are affected by the increase of applied magnetic field. Where local critical current degrades under high Lorentz force, this causes a change of the current density and distribution of magnetic field, which leads to the variation of central field. In addition, magnetization of the superconductor materials produces large mechanical stresses that can result in mechanical failure, which typically fails for magnetic field [1-2].

Although Bi-2223 system is the most attractive for potential applications due to its highest superconducting transition temperature, T_c , in its series, there are limitations that must be overcome, specifically: weak links intergrain, and weak flux pinning capability in bulk samples. Therefore, researchers sought to improve the qualities and properties of super materials through various methods of preparation, impregnation, or adding oxides during the preparation of samples [3-6]. On other hand. The presence of lead in bismuth compounds enhances stability of the composite structure, also it reduces the partial melting temperature and produces more liquid phase during sintering, which sequentially improves the formation rate of Bi-2223 phase [7].

Moreover, it's found that nanoparticles can be simply combined and diffused widely among the grains in the BSCCO system because of their small size. Consequently, the structural and electrical properties, in addition to the mechanical properties, are improved [8-10]. To know more about the effect of nanoparticle doping on the formation and stability of the 2223 phase and mechanical properties such as Young's modulus, yield strength, and Fracture toughness, we considered in this research the partial replacement of bismuth in the BiPb-2223 composite with different proportions of nano-tin oxide.

2. EXPERIMENTAL

A series of $\text{Bi}_{2-x}\text{Sn}_x\text{Pb}_{0.3}\text{Sr}_2\text{Ca}_2\text{Cu}_3\text{O}_y$ samples are prepared by the solid-state reaction method. The process of replacing Bi with Sn nanoparticles (40 nm) in different weight ratios ($x = 0.1, 0.2, 0.3, 0.4$ and 0.5) is done in the first stage of preparation. Molar ratios of the high purity powders of Bi_2O_3 , SnO_2 , Pb_2O_3 , Sr_2CO_3 , Ca_2O and Cu_3O are well mixed. The mixture is calcined in air at 790°C for 30 h. The powder is pressed into pellets under pressure 0.7 GPa by using a manually hydraulic press type (SPECAC). All samples are sintered in air for 140 h at 830°C . X-ray diffractometer type Philips with the $\text{Cu-K}\alpha$ radiation is used to characterize the samples' phase formations and crystal structures.

The mechanical properties are studied using a microhardness tester (HVS-1000), where the applied load for each sample is changed from 0.245 to 2.940 N at room temperature. The test time for each load is 10 seconds. All samples are polished before mechanical investigation. An average Value of the Vickers microhardness for each load is calculated by taking three readings location on the SPECIMEAT Surface. The Vickers microhardness (HV), Young modulus (E) and yield Strength (Y) are obtained by using equations as represented in reference [11].

3. RESULTS AND DISCUSSION

XRD spectra of the $\text{Bi}_{2-x}\text{Sn}_x\text{Pb}_{0.3}\text{Sr}_2\text{Ca}_2\text{Cu}_3\text{O}_y$ compounds with different Sn concentrations are illustrated in figure 1. Miller indices of the samples had been taken in comparable with the references [3,9].

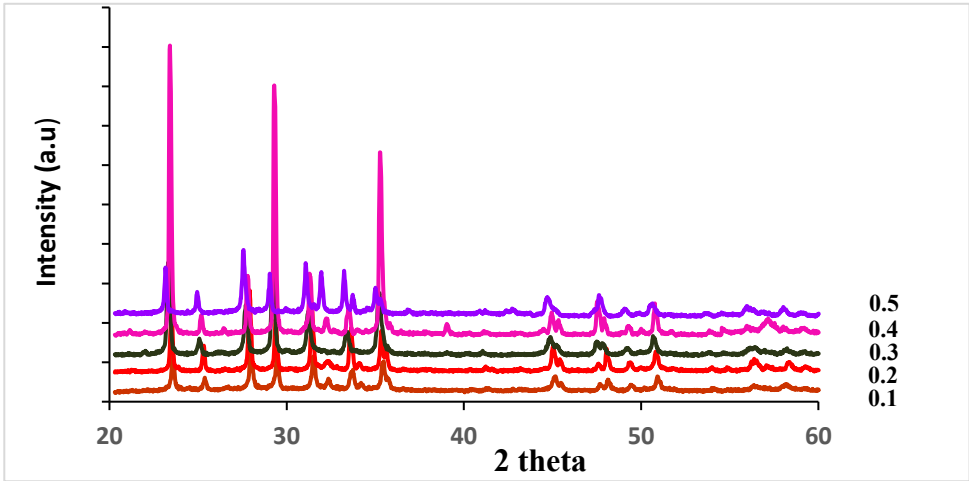


Figure 1 XRD pattern of $\text{Bi}_{2-x}\text{Sn}_x\text{Pb}_{0.3}\text{Sr}_2\text{Ca}_2\text{Cu}_3\text{O}_y$ compounds with different Sn concentrations.

It shows an orthorhombic structure of all the samples with two main phases: low- T_C phase (2212) and high- T_C phase (2223). The appearance of more than two phases could be related to the stacking faults along the c-axis. It should be noted that the relative intensity of the diffraction peaks and their positions vary with different increases in the Sn concentration, likewise resulting, a change in the lattice constant of the sample. Interestingly, samples with $x = 0.4$ showed intense peak pattern due to the enhanced grain growth and better orientation of grains with Sn diffusion.

Cohen’s least square method used to calculate the lattice constants of the samples. The parameters a, b, c, V and c/a are listed in Table 1. As the Table shows c parameter decreases monotonously with increasing Sn nanoparticle concentration. Furthermore, upon increasing tin content in the samples, the c/a ratio increases, forming a parabolic curve whose peak is at the concentration 0.4, as observed in figure 2. This could be attributed to the charge ordering phenomenon (probably induced as a pair breaker) might be accompanied by change in oxygen content or oxygen ordering effects.

Table 1 Values of lattice parameters a, b, c, V, c/a ratio and volume fraction for different composition of $\text{Bi}_{2-x}\text{Sn}_x\text{Pb}_{0.3}\text{Sr}_2\text{Ca}_2\text{Cu}_3\text{O}_y$ samples.

x	a (Å)	b (Å)	c (Å)	c/a	V (Å) ³	Volume fraction of phases 100%	
						Bi-2223 phase	Bi-2212 phase
0.1	5.545	5.543	37.342	6.734355	1147.741	66.2	33.8
0.2	5.445	5.432	37.432	6.874564	1107.135	69.6	30.4
0.3	5.543	5.453	37.543	7.026577	1093.83	73.4	26.6
0.4	5.322	5.321	37.642	7.072905	1065.96	79.1	20.9
0.5	5.321	5.324	37.435	7.035332	1060.496	68.5	31.5

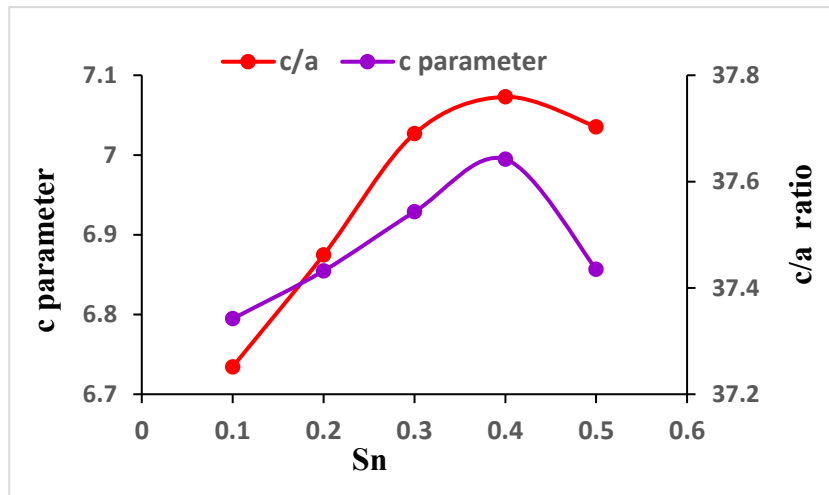


Figure 2 Values of c parameters c/a ratio of $\text{Bi}_{2-x}\text{Sn}_x\text{Pb}_{0.3}\text{Sr}_2\text{Ca}_2\text{Cu}_3\text{O}_y$ compounds with different Sn concentrations.

Moreover, the interaction between additional bands crosses the Fermi level, extracting the holes from CuO band [12], which is decreasing the distance between CuO₂ planes. Changes in the lattice parameters decreased the volume of the unit cell, which shows a lowest value at Sn concentration 0.5. However, the presence of lead in the samples adjusts the oxygen content, charge balance, and structural composition of the relevant layers [13].

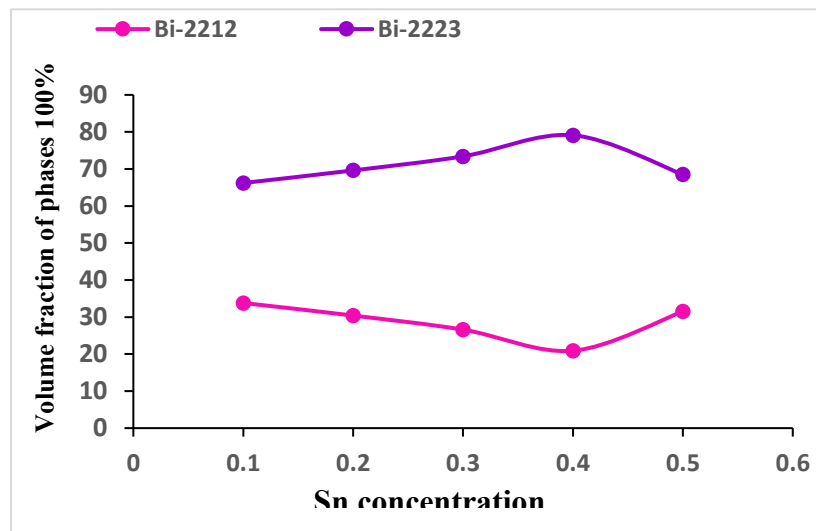


Figure 3 Volume fraction of Bi-2223 and Bi-2212 phases of $\text{Bi}_{2-x}\text{Sn}_x\text{Pb}_{0.3}\text{Sr}_2\text{Ca}_2\text{Cu}_3\text{O}_y$ compounds with different Sn concentrations.

A series of hardness measurements as a function of applied load for the sample with different concentrations of Sn are done on the samples, and the results are illustrated in Figures 4,5 and 6.

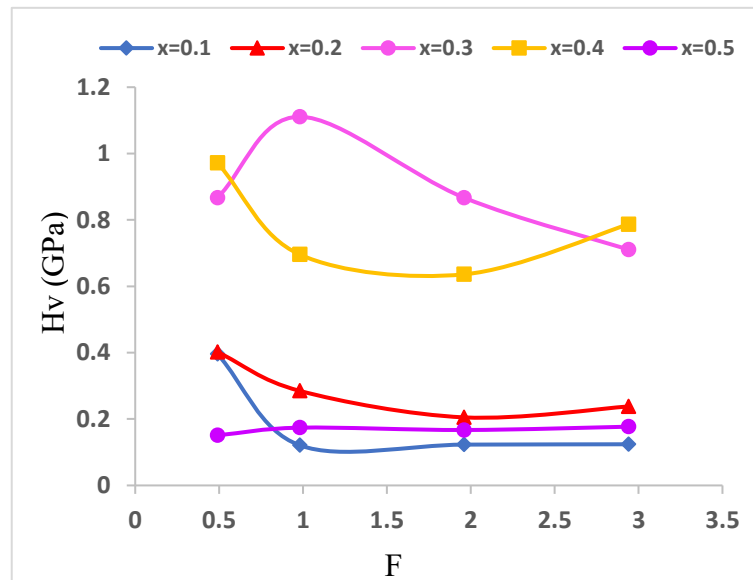


Figure 4 Variation of Hv as a function of applied load of $\text{Bi}_{2-x}\text{Sn}_x\text{Pb}_{0.3}\text{Sr}_2\text{Ca}_2\text{Cu}_3\text{O}_y$ compounds with different Sn concentrations.

It is noted that the values are affected by the change in the applied force and the change in the Sn content in the investigated samples, where the highest value is at force 1.96 N for the concentration 0.3, and after that it began to decrease. Some values changed slightly, showed nonlinearly behavior and reached the saturation stage as the applied load increases, demonstrating the indentation size effect [14].

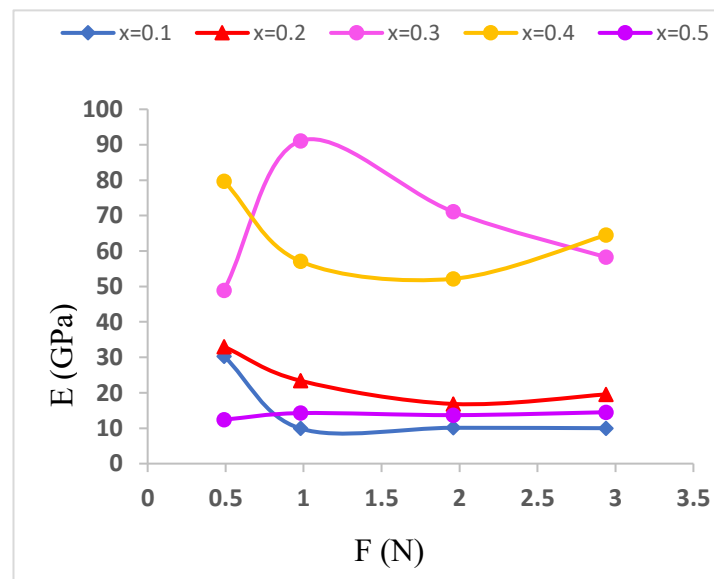


Figure 5 Variation of E as a function of applied load of $\text{Bi}_{2-x}\text{Sn}_x\text{Pb}_{0.3}\text{Sr}_2\text{Ca}_2\text{Cu}_3\text{O}_y$ compounds with different Sn concentrations.

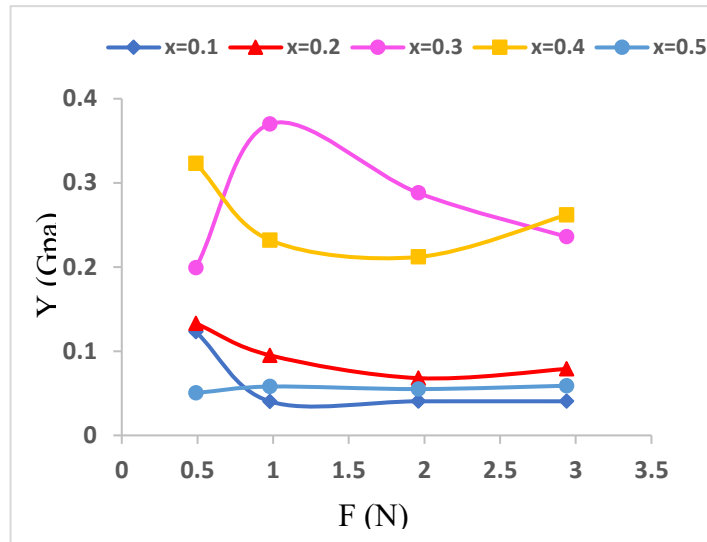


Figure 6 Variation of Y as a function of applied load of $\text{Bi}_{2-x}\text{Sn}_x\text{Pb}_{0.3}\text{Sr}_2\text{Ca}_2\text{Cu}_3\text{O}_y$ compounds with different Sn concentrations.

Sample with 0.4 concentration shows different behavior as the load increases; this observation is associated with the weak grain boundaries of the sample. For higher applied loads microhardness values of the increases exhibit Reverse Indentation Size Effect [15,16] and converge to a plateau region. Which are considered to be the load independent real hardness values. This could be due to specimen cracking. Excessive cracking in the sample decreases the elasticity and thus H_v value of the sample; thereafter, no elastic recovery, but only plastic deformation is observed [17, 18] same behavior agrees with the search results [11]. The variation of H_v , Y , and E with increasing Sn-content at certain applied loads of the superconducting samples is shown in Figures (7,8 and 9) respectively.

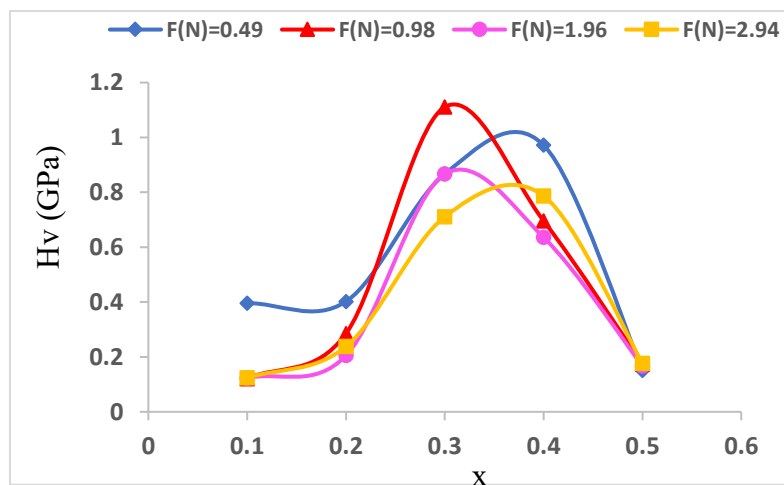


Figure 7 Variation of H_v with different Sn concentrations of $\text{Bi}_{2-x}\text{Sn}_x\text{Pb}_{0.3}\text{Sr}_2\text{Ca}_2\text{Cu}_3\text{O}_y$ compounds for different applied load.

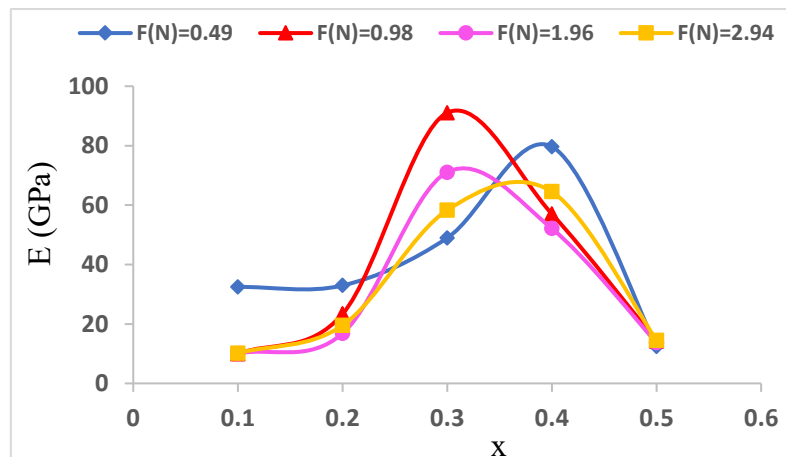


Figure 8 Variation of E with different Sn concentrations of $\text{Bi}_{2-x}\text{Sn}_x\text{Pb}_{0.3}\text{Sr}_2\text{Ca}_2\text{Cu}_3\text{O}_y$ compounds for different applied load.

These figures demonstrate that H_v , E and Y increased gradually up at a certain value then decrease with increasing Sn nanoparticle content. This may be due to the increasing in nanoparticles content in the samples causes different effects: substitution of Sn lattice atoms and becoming part of the structure, as well as enrichment and uniform distribution. On other hand, Sn nanoparticles fill spaces between the intergrains, which leads to improving their growth and size, and then enhances the connection between the particles. On other hand decrease in the H_v , E and Y of the samples with increasing Sn substitution may be due to the pinning of dislocations at the impurity sites and other defects caused by the presence of impurity atoms in the crystal, and the variation in the magnitude of the bond forces in the crystal containing impurities [4].

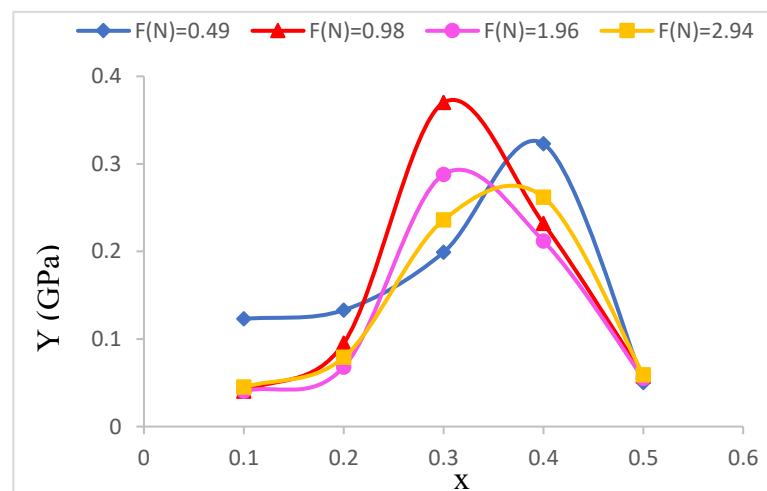


Figure 9 Variation of Y with different Sn concentrations of $\text{Bi}_{2-x}\text{Sn}_x\text{Pb}_{0.3}\text{Sr}_2\text{Ca}_2\text{Cu}_3\text{O}_y$ compounds for different applied load.

4. CONCLUSIONS

The substitution by Sn nanoparticles promotes the volume fraction of the 2223 phase and crystalline arrangement degree. Mechanical properties of the samples were found to be load dependent. Moreover, increasing doping concentrations strengthen interlayer bonding as confirmed by the increase in the Hv, E and Y values of $\text{Bi}_{2-x}\text{Sn}_x\text{Pb}_{0.3}\text{Sr}_2\text{Ca}_2\text{Cu}_3\text{O}_y$ compounds. Substitution with Sn nanoparticles enhanced the grain to a certain range, forming an intragranular structure, which refines the grain boundary and improves the mechanical properties of materials.

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