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Effect of Diffusion Annealing Temperature on Crack-initiating Omnipresent Flaws, Void/crack Propagation and Dislocation Movements Along Ni Surface-layered Bi-2223 Crystal Structure

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ABSTRACT

This study aims to find out the crucial variations in the mechanical performance and characterization of Bi-2223 superconducting compounds with the diffusion annealing temperatures interval 650 °C-850 °C by means of Vickers hardness measurements exerted at the different applied indentation test loads (0.245 N-2.940 N) and derived theoretical findings. All the experimental results and theoretical evidences showed that the mechanical characterization and performances improve with the increment in the diffusion annealing temperature up to 700 °C due to the development in structural properties. Namely, the optimum annealing temperature of 700 °C resulting in the optimum penetration of Ni impurities into both the superconducting grains and over the grain boundaries develops the crystallinity of Bi-2223 crystal structure. In other words, the surface energy related to the crack-initiating omnipresent flaws, void/crack propagation and dislocation movement reduces due to the augmented critical stress value. In this respect, the diffusion annealing temperature of 700 °C develops the mechanical durability, stiffness, ideal fracture and flexural strength. However, after the certain diffusion annealing temperature value of 700 °C, the crystallinity tends to degrade considerably and in fact dwelling in the worst crystal structure for 850 °C annealing temperature. Accordingly, the initial crack growths, sizes of crack-producing flaws, void/crack propagation and dislocation movement in the copper-oxide consecutively stacked layers reach much more rapidly to the critical speeds due to the increased stress amplification so that the Bi-2223 compound with the augmented brittle behavior breaks at even lower test load. Moreover, it is observed that the presence of optimum nickel impurities in the crystal structure strengthens the standard indentation size effect behavior.

Keywords: Bi-2223 crystal structure, Ni impurity diffusion, annealing temperature, cracks/voids, dislocations.

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1. INTRODUCTION

As well-known, the superconductivity phenomenon observed at the certain temperature such below a critical transition temperature is related to two fundamental information (I) Exactly zero electrical resistivity (suddenly disappearance of electrical resistivity) and (II) Expulsion of magnetic flux fields at certain applied magnetic fields. The phenomenon got first discovered for the mercury element on 8th April in 1911 by Dutch physicist Heike Kamerlingh Onnes from the university of Leiden [1]. The materials exhibiting the superconductivity are classified in two participants: (I) Type-I or soft and (II) Type-II copper oxide or hard ceramic materials. The soft compound opens a dawn of superconductivity era whereas the hard materials are composed of perovskite structures with bended Cu–O chains throughout the crystal structure [2]. In this respect, the hard compounds present different phases according to the stacked planes in unit cell. The fundamental quantities such as resistanceless (no dissipation), small energy losses and power consumption, high current and magnetic field carrying capacity enables the superconducting materials to use in the industrial, technological, metallurgical, and especially engineering application fields [3–5]. Especially the Type-II superconductors with higher critical transition temperature and greater applied magnetic field and current carrying capacity take more places in the sensitive process control, refrigeration, electro-optic, heavy-industrial technology, future hydrogen society, spintronics commercial, future, innovative energy infrastructure, network, magnet and energy technology applications [6–11]. Moreover, inexpensive (lower material cost) and innocuous chemical contents, easier availability of starting chemicals, environmental benefits as well as rather easier and faster phase formations during the material preparation process are the other advantages for the type-II ceramic materials [12, 13]. However, these kind of materials suffer from some nasty properties as regards the narrow operating temperature ranges, sensitivity towards to the applied magnetic field and current and especially excessive brittleness nature under the loads applied [14, 15]. Hence, every study performed on the improvement in the nasty properties given above is essential for the novel, innovative and feasible market areas for the application fields of these kinds of materials [16, 17]. In the present study, we endeavor to survey the variations in mechanical characterization and performance of bulk Bi-2223 superconducting compound (being from Type-II copper oxide parents) with the diffusion annealing temperature in a range of 650-850 °C with the aid of the microhardness experimental results based on the Vickers hardness measurement method conducted at different test loads intervals 0.245 N-2.940 and derived theoretical findings for the first time.

2. EXPERIMENTAL DETAILS

This study is a continuation of mechanical characterization and performance of Bi-2223 superconducting compounds subjected to the nickel impurity evaporation onto the specimen surfaces. In the previous studies [18, 19], the influence of diffusion annealing temperature in a range of 650 °C-850 °C on the structural, electrical, flux pinning, superconducting properties and mechanical characterizations founded on the mechanical modellings was examined by using the dc electrical resistivity, transport critical current density, powder X-ray diffraction, and Vickers's hardness experimental measurements and theoretical approaches. At the same time, the material preparation procedure including the standard solid-state reaction route and evaporation environments was clearly provided in the experimental details of Ref. [18, 19]. According to the experimental measurement findings, we declare that all the characteristic properties got found to be improve significantly in the existence of optimum Ni particles embedded into the Bi-2223 crystal lattice. Likewise, the crucial properties given resided in the global top points until the critic annealing temperature of 700 °C above which fundamental physical quantities tend to suppress dramatically and in case of 850 °C the properties damage seriously. Hence, the previous studies cited in [18, 19] display that 700 °C is the optimum annealing temperature value for the Ni diffusion-layered Bi-2223 superconductor to open up the novel, innovative and feasible market areas for the universe economy.

As for the microhardness experimental procedures, microhardness measurements get conducted by means of a model digital microhardness tester of SHIMADZU HVM-2 at the normal state temperature standard in the air atmosphere. Small bars pressed as the rectangular solids in the dimensions of 1.5x0.5x0.2 cm3 under

300 MPa at room conditions are fitted vertically into the tester apparatus. Static compression loads between 0.245N and 2.940N are applied to the solidified bars for 10 seconds. The tracks of scratch on the surface belonging to the bulk compound are observed by the microscope calibrated before. The optimum microhardness parameters get recorded from the Vickers hardness measurements exerted at various locations to avoid the hardening problems accumulated on the surface. The accuracy of notch tracks as diagonal shapes is determined as ±0.1 μm.

In the following parts of paper, the pure Bi-2223 inorganic solid compound will be called as pure sample when the other superconductors subjected to the different diffusion annealing temperatures including 650 °C, 700 °C, 750 °C, 800 °C and 850 °C will be demonstrated to be Ni-650, Ni-700, Ni-750, Ni-800 and Ni-850 material, respectively. All the prepared materials are further characterized by the parts of Microhardness Measurement Results, Fitting Equations between Microhardness Values and Indentation Test Loads, and Determination of Volume Fraction Porosity Based on Young's Modulus of Elasticity.

3. RESULTS AND DISCUSSION

This comprehensive study is continuation of a mechanical characterization of Ni surface-layered Bi-2223 superconducting compounds. In previous studies provided in Ref. [18, 19], we shed lights on the positive effects in the electrical, flux pinning, superconducting, microstructural, mechanical performance and characteristic features of Ni diffusion-layered bulk Bi-2223 copper oxide compounds annealed at the different annealing temperatures between 650 °C and 850 °C via the conventional experimental measurement methods including the transport critical current density, powder X-ray diffraction, dc electrical resistivity, and microhardness investigations and available theoretical modeling approaches. Even, the material preparation process has already been shown in Ref. [18, 19]. According to the results obtained, both the existence of nickel nanoparticles in the bulk Bi-2223 superconducting crystal system and annealing temperature affect remarkably the fundamental characteristic features discussed above. In this respect, the value of 700 °C was noticed to be the best annealing temperature to improve the features of Bi-2223 copper oxide compound for the usages in metallurgical, commercial, electro-optic, engineering, heavy-industrial technology, large scale, refrigeration, sensitive process control, commercial, future, magnet and energy technology application fields.

At the same time, it got observed that at the diffusion annealing temperature above the certain value of 700 °C every crucial property given tends to suppress significantly. In fact, at 850 °C the fundamental aspects of thermodynamics, material science, physical and quantum mechanical quantities as well as all the characteristic properties obtained locate in the minimum points. Accordingly, the previous publications clearly address that the optimum annealing temperature opens up the innovative, feasible and novel market areas for the universe economy of Ni surface-layered Bi-2223 inorganic compound. In our research for this paper, we firstly deal with the effect of annealing temperature on mechanical performance and characterization of bulk polycrystalline Bi-2223 superconducting samples subjected to the Ni-ion diffusion by the microhardness measurements performed at the force values between 0.245 N and 2.940 N. We, of course, advance in-depth understanding of relation between microstructure and mechanical performance to determine the diffusion annealing process roles. Secondly, we calculate the fitting equations between microhardness parameters and static compression test loads for the virgin and Ni surface-layered Bi-2223 superconducting materials to survey the differentiations of impurity scattering, local structural defects and distortions, grain boundary coupling problems, grain misorientations, lattice strains, dislocations, lattice defects and permanent disorders. This confirms that the void/crack propagations and dislocation movements proceed along with either transgranular regions or intergranular regions in the Bi-2223 superconducting crystal structure. At the same time, the fitting parameters gathered for every solid material give an opportunity to determine which material exhibits the best critical stress, stiffness, durability, fracture and flexural strength parameters. Similarly, it is another valuable finding exacted from the fitting parameters that why the omnipresent flaws, dislocation movements and crack-producing crack/void propagations divert or slow down significantly in case of 700 °C diffusion annealing temperature. Finally, the volume fraction porosities founded on the elastic modulus of superconducting compounds produced in the current study favor all the experimental findings. Further, it is at least equally important finding extracted from the residual fraction porosities that the excess annealing temperature enhances the permanent crack-initiating omnipresent flaws and operable slip system numbers in the crystal lattice. Besides, the residual fraction porosities verify that the artificial cracks, voids and dislocations are out of control due to the increased stress raisers and stress amplification.

3.1. Microhardness Measurement Results

As received, the many tiny cracks and dislocations in the copper-oxide ($Cu\text{-}O_2$) consecutively stacked layers as well as the interatomic bonds in the type-II superconducting material cause the exhibition of brittle nature [20]. Even, the former features result in the omnipresent flaws, irregular grain orientation distributions and coupling connection problems between the superconducting grains and [21] so that the crack-initiating omnipresent flaws, voids/cracks and dislocations propagate harshly. As a result, the ceramic compound tend to break immediately because of the absence of inelastic nature and yield point [22]. In other words, the mechanical performances related to the mechanical resistance towards to the permanent shape change or plastic deformation are not enough to use in the magnet and energy technology applications. Here, we endeavor to improve the nasty properties (voids/cracks, dislocations and permanent structural problems) in the bulk Bi-2223 superconducting crystal structures with the aid of the diffusion annealing temperature so that the cuprate materials can take place in the sensitive process control, commercial, future, magnet and energy technology applications. For this aim, the Vickers hardness measurements of the pure and Ni surface-layered Bi-2223 particulate compounds are conducted at the various static impression test loads (0.245N $\leq F \leq$ 2.940N). One can encounter the experimental findings in Fig. 1 showing the variation of microhardness parameters against to the static indentation test loads applied. In advance, the diffusion annealing temperature affects dramatically the mechanical performances of all the materials produced in the present work. The Ni-700 material exhibits the most resistant to the applied test loads whereas the Ni-850 sample is found to present the most sensitive characteristic to the loads applied. This is in relation to the fact that 700 °C is noticed to be the optimum annealing temperature (causing optimum introduction of Ni

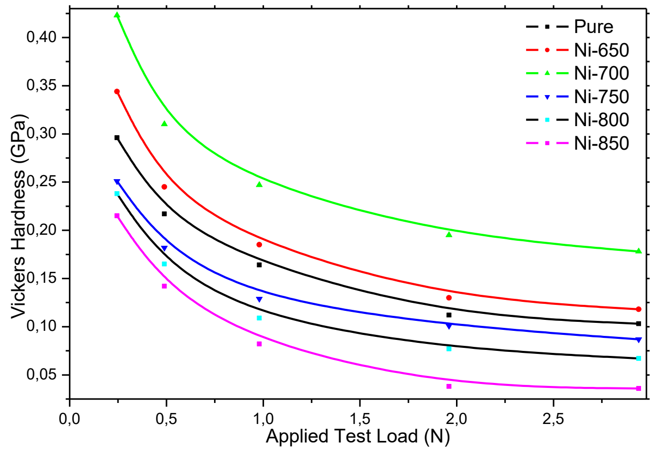

Fig. 1 Differentiation of microhardness parameters with regard to applied indentation test loads.

particles into both the intergranular and over the transgranular regions) for the Ni surface-layered Bi-2223 superconducting materials [23]. Shortly, that the optimum Ni inclusion penetration develops the crystallinity but degrades the impurity scattering, local structural defects and distortions, grain boundary coupling problems, grain misorientations, lattice strains, dislocations, lattice defects and permanent disorders in the adjacent layers. Namely, the surface energy for the crack-producing flaws, dislocation, dislocation movement and crack/void propagation diminish because of the augmented critical stress. Thus, the crack-initiating omnipresent flaws and propagations of voids and cracks divert or slow down through the crystal structure. Conversely, after the certain diffusion annealing temperature value, the critical stress value over the impression test loads undermines seriously. The initial crack growths or sizes of crack-producing flaws begin to increase, or the cracks/voids reach rapidly to the critical speed for propagation and finally the material with the enhanced brittle feature breaks at even lower test load. As for the numerical values, the microhardness parameters are found to change from 0.296 GPa to 0.103 GPa for the pristine compound at the applied test loads interval 0.245 N to 2.940 N. The Ni-700 sample exhibiting the best mechanical performance obtains 0.423 GPa (0.178 GPa) at the static compression test load of 0.245 N (2.940 N) whereas the Ni-850 (worst) sample presents 0.215 GPa and 0.036 GPa Vickers hardness parameters under 0.245 N test load and 2.940 N, respectively (Table 1).

Table 1. True Young's modulus of elasticity parameters based on applied indentation test loads

Materials	*F (N)*	*E (GPa)*
	0.245	21.566
	0.490	15.269
Pure	0.980	10.959
	1.960	7.182
	2.940	6.401
	0.245	25.783
	0.490	17.864
Ni-650	0.980	13.023
	1.960	8.947
	2.940	7.806
	0.245	32.406
	0.490	23.331
Ni-700	0.980	17.908
	1.960	14.006
	2.940	12.345
	0.245	17.233
	0.490	12.002
Ni-750	0.980	8.104
	1.960	5.991
	2.940	4.965
	0.245	16.178
	0.490	10.715
Ni-800	0.980	6.747
	1.960	4.439
	2.940	3.730
	0.245	13.978
	0.490	8.825
Ni-850	0.980	5.030
	1.960	2.052
	2.940	1.844

It is another feasible evidence evaluated from Fig.1, all the superconducting materials studied exhibit the standard indentation size effect behavior (ISE, meaning the non-linear reduction of the true Vickers hardness values against the applied test loads [24]). It is fair to confirm that the ISE behavior tends to strengthen as the diffusion annealing temperature increases until the value of 700 °C beyond which the nature ISE characteristics of the materials diminishes considerably.

This is the last finding deduced from Fig.1 that every graphic exhibits the same characteristic behavior: the harsh reduction in the Vickers hardness values up to the indentation test load value of about 2 N. However, from the constant load value of 2 N onwards, the Hv values obtained dwell in the saturation limit (known as the plateau region) due to the presence of induced impurity scattering, local structural defects and distortions, grain boundary coupling problems, grain misorientations, dislocations, lattice defects and permanent disorders. Moreover, that the Ni-850 material gets found to reach the plateau region at even lower test loads as a consequence of the rapid increment in the crack-producing sites and especially stress raisers, leading to decrease the mechanical durability, stiffness, critical stress, fracture and flexural strength of the compound is another fundamental evidence evaluated.

3.2. Emprical Relations Between Vickers Hardness Values and Imression Test Loads

With the aid of the Vickers hardness parameters obtained under various indentation test loads (0≤F≤2.940 N), we fit the data with regard to the quadratic formulas and all the fitting data achieved are numerically given in Table 2.

Table 2. Fitting equations between microhardness values and indentation test loads.

Materials	Fitting relations for every superconducting compounds
Pure	$\mathbf{y} = 0.0419\,\mathbf{x^2} - 0.1965\,x + 0.3232$
Ni-650	$\mathbf{y} = 0.0494\,\mathbf{x^2} - 0.2297\,x + 0.3724$
Ni-700	$\mathbf{y} = 0.0528\,\mathbf{x^2} - 0.2449\,x + 0.4494$
Ni-750	$\mathbf{y} = 0.0359\,\mathbf{x^2} - 0.1662\,x + 0.2711$
Ni-800	$\mathbf{y} = 0.0326\,\mathbf{x^2} - 0.1404\,x + 0.2610$
Ni-850	$\mathbf{y} = 0.0242\,\mathbf{x^2} - 0.1294\,x + 0.2448$

On fitting the data tabulated, differentiation of x2 is calculated to be in a range of 0.0242-0.0528 where the maximum value is observed for the bulk poly-crystallized Bi-2223 superconducting (Ni-700) material exposed to the diffusion annealing temperature of 700 °C while the minimum value ascribes to the Ni surface layered Bi-2223 material subjected to 850 °C excess annealing temperature. This is attributed to the fact that the optimum annealing temperature leads to diminish not only the operable slip system numbers but also the cracks and dislocations regions along with the Cu-O_2 consecutively stacked layers in the crystal matrix. Based on the fitting parameters computed, it is reasonable to confirm that 700 °C diffusion annealing temperature makes the dislocation movements and especially void/crack propagations more proceed in the superconducting grains (meaning the transgranular regions) of the crystal system. The crack-producing flaws, dislocation movements and especially crack/void propagation, accordingly, slow down significantly due to the enhanced bond strengths in the adjacent layers. To sum up, the mechanical performances of material improve considerably. On the other hand, the intergranular fracture (known as embrittling of grain boundaries) begins to play the dominant role with enhancing the annealing temperature after the critical diffusion annealing temperature value of 700 °C. Even lower impression test load moves easily the augmented artificial cracks, voids and dislocations (being out of control) because of decrement in the critical stress (being associated with initial crack growths or size of crack-producing flaws) for the propagation and critical crack length. In other words, the induced nasty properties (voids/ cracks and dislocations) in the superconducting matrix become nearly entangled with each other (beginning of the permanent plastic deformation) in the presence of static compression load applied. In fact, in case of 850 °C annealing temperature process, the embrittling (weakening) of grain boundaries becomes predominantly, and the induced omnipresent flaws, crack-producing sites and permanent disorders act as stress raisers and stress amplifications in the solid material. Thus, the voids/cracks and dislocations reach more rapidly to their critical speed for the propagation with the application of even lower indentation test load. In conclusion, the excess diffusion annealing temperature (the mechanical crack-front driving force) leads to the rapid enhancement in the omnipresent flaws in the crystal structure, the critical stress parameter for the propagation and critical crack length as they do.

In conclusion, the experimental measurement evidences demonstrate that the penetration of optimum nickel particles into the transgranular regions or inter-granular regions of Bi-2223 superconducting matrix lead to more stabilize the durable tetragonal phase. Likewise, the optimum diffusion temperature such a value of 700 °C makes the dislocation movements and especially void/crack propagation more proceed along with the transgranular regions instead of through the intergranular regions due to the decreased impurity scattering, local structural defects and distortions, grain boundary coupling problems, grain misorientations, dislocations [25]. Finally, the crack-producing omnipresent flaws, propagation of voids/cracks and dislocation movements divert significantly, and thus the mechanical durability, stiffness, critical stress, fracture and flexural strength parameters of Bi-2223 copper oxide material enhance extensively for the usage of metallurgical, commercial, engineering, industrial, large scale, refrigeration, sensitive process control, commercial, future, magnet and energy technology application fields [26–29]. However, is should strongly be noted here that the increment in the annealing temperature the dislocations and voids/cracks prefer to advance throughout the intergranular regions as a consequence of the considerable decrease in the critical stress value.

3.3. Determination of Volume Fraction Porosity Based on Young's Modulus of Elasticity

This study primarily dealing with the fundamental aspects of material science and physical quantities establishes the novel remarkable links between Young's modulus of elasticity and volume fraction porosity of pure and Ni surface layered Bi-2223 cuprate ceramic materials for the first time. As received, the fraction porosity is sensitive to many factors as regards the sample production conditions (dopant type/dopant quantity, composition, operational procedure time, temperature and ambient, calcination/annealing environments and different heat-treatments: pressure, time and temperature), chemical addition/doping/substitution into the crystalline structure, and transition metal diffusion into the transgranular regions or inter-granular regions [30–33]. In fact, the porosity tends to change during the mechanical tests due to the variation of elasticity modulus magnitude. In more details, the Young's modulus value of elasticity retrogrades with increasing the volume fraction porosity. In this respect, we endeavor to define the differentiation of relative fraction porosity with the Young's modulus of elasticity based on the diffusion annealing temperatures and static indentation test loads by the following relation [34], in the relation,

$$E = E_0(1 - 1.9P + 0.9P^2) \quad (1)$$

E_0 (gathered from Ref. [18, 19]) shows the elasticity modulus of every superconducting material under the minimum impression load of

0.2450 N when abbreviation of *P* demonstrates the evaluated relative volume fraction porosity values for every sample. All the computations are numerically displayed in Table 3.

Table 3. Differentiation of relative volume fraction porosities over applied indentation loads.

Samples	***Applied Indentation Test Loads (N)***			
	0.490	***0.980***	***1.960***	***2.940***
	Relative volume fraction porosity (%)			
Pure	11.29	21.15	32.56	35.46
Ni-650	10.96	20.32	31.50	34.97
Ni-700	10.75	18.74	25.67	29.06
Ni-750	11.80	23.34	31.46	36.20
Ni-800	13.35	26.64	37.39	41.36
Ni-850	14.80	30.56	51.41	53.57

It is obvious from the table that the relative porosity values are calculated to be in a range from 10.75 % to 53.57 % with the changes of annealing temperature and static compression load applied. Besides, the *P* parameters observed tend to decrease systemically with the increment in the diffusion annealing temperature until 700 °C above which the parameters are observed to increase significantly and reach to the global maximum values for the Ni-850 sample.

In this regard, the minimum porosity value is observed to be approximately 10.75 % for the Ni-700 sample (exhibiting the best mechanical performance and characteristics) at the impression load of 0.490 N whereas the Ni-850 sample presents nearly 14.80 % volume fraction porosity at the same load process. It is clear that the excess annealing temperature harms the mechanical performance such as the mechanical durability, stiffness, critical stress, fracture and flexural strength parameters of Ni surface-layered Bi-2223 crystal structure due to the augmented initial crack growths, size of crack-producing flaws and stress raisers. Besides, the porosity parameter is noted to ascend considerably with the increase in the impression test loads up to the maximum level of 2.940 N as a result of the enhancement in the crack initiation sites, stress raisers and stress amplification. The highest increment ratio of the volume fraction porosity is also found for the bulk Ni-850 material. Similarly, we examine the differentiation of fraction porosity with respect to the diffusion annealing temperature by receiving 32.406 GPa as E_0 value. The computations are given in Table 4 in detail. It is apparent form the table that the relative volume fraction porosity is determined to change from 7.60 % until 25.72 %. According to the result obtained, it is not wrong to confirm that all the pure and Ni surface-layered solid samples exhibit more porous structures in comparison with that of bulk Ni-700 superconducting material. Numerically, the pure sample obtains the volume fraction porosity of 13.20 % when the maximum residual porosity value of 25.72 % is attributed to the Ni-850 (worst) inorganic compound. Conversely, the Ni-650 material shows 7.60 % porosity value that is relatively closest crystal structure to the Ni-700 (best) material.

Table 4. Volume fraction porosity analysis based on bulk Ni-700 compound.

Superconducting Bulk Samples	***Pure***	***Ni-650***	***Ni-750***	***Ni-800***	***Ni-850***
Relative volume fraction porosity (%)	13.20	7.60	19.85	21.66	25.72

4. CONCLUSION

In this study being interested in the continuation of mechanical characterizations of Ni diffusion-layered bulk Bi-2223 superconducting compounds, the annealing temperature effects on the mechanical characterization and performance of bulk materials are surveyed with the microhardness experimental measurements conducted under the different impression test loads ranging from 0.245 N to 2.940 N and derived theoretical findings. It is noted that the annealing temperature affects seriously the mechanical characterization and performance of Bi-2223 superconducting structures prepared with the nickel impurities. All the results inferred from the microhardness measurements performed under various impression loads intervals 0.245 N to 2.940 N verify the following major findings:

- 700 °C annealing temperature is noted to be optimum temperature that causes the optimum nickel impurities penetration into the transgranular and inter-granular regions for the improvement in the critical stress, stiffness, mechanical durability, fracture and flexural strength parameters. Similarly, the propagations of voids/cracks and dislocation movements more proceed throughout the transgranular regions in the crystal system.
- The volume fraction porosities founded on the Young's modulus of elasticity get found to reduce regularly with ascending the annealing temperature until 700 °C where the parameter falls down to the global minimum point of 10.75 %. From the critical annealing temperature of 700 °C onwards, the fraction porosities suddenly increase, and in fact reach to the global maximum point for 850 °C annealing temperature. In other words, the former (Ni-700) sample exhibits the lowest porous structure whereas the latter (Ni-850) compound with the highest porous structure presents the worst mechanical performances (critical stress, stiffness, mechanical durability, fracture and flexural strength parameters) as a result of the increase of permanent crack-initiating omnipresent flaws and operable slip system numbers in the crystal lattice. Any test load applied on the Ni-850 compound, accordingly, accelerates more easily the critical propagation speed as compared to the bulk Ni-700 sample.
- Likewise, the artificial cracks, voids and dislocations are out of control due to the increased stress raisers and stress amplification with enhancing the applied indentation test load. In fact, the nasty properties (dislocations, cracks/voids) in the crystal structure of Ni-850 sample become nearly entangled rapidly with each other. The properties provided reach more quickly to the critical propagation speed, and the permanent plastic deformation begins considerably due to low flexural strengths. Thus, it is logical to verify that the propagations of cracks/voids and dislocation movements for the Ni-850 sample are very difficult to control.
- The Vickers hardness measurements illustrate that the microhardness values for all the materials are observed to decrease harshly up to the indentation test load value of about 2 N after which the values remain constantly for the compounds. This is related to the beginning of augmented impurity scattering, local structural defects and distortions, grain boundary coupling problems, grain misorientations, dilocations in the crystal systems.

As for the mechanical characterizations of the superconducting samples, every one presents the typical indentation size effect nature but in different strengths. Namely, the increase of annealing temperature strengthens the *ISE* characteristics of materials up to 700 °C above which the *ISE* feature is damaged seriously.

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