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A comparative study for magnetic levitation force in Type-II superconductors

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ABSTRACT

Meissner Effect is, of course, an essential characteristic of a superconductor besides the zero resistivity since the discovery by Meissner and Ochsenfeld in 1933. They showed by experiment that the magnetic field inside a superconductor is always zero. This implies that we can think of a superconductor as being a perfectly diamagnetic material. It is highly attractive for the technological applications of the type-II (High temperature) superconductors as YBa2Cu3O7, Bi2Sr2Ca2Cu3O10 and HgBa2Ca2Cu3O8. One important property is the levitation force and its MagLev application. MagLev systems have become very important in the transportation and other applications. These applications are ranging from in an energy efficient prototype of a cryogen transfer line to in space energy storage systems. In this study, we compared that the effect of magnetic levitation force BSCCO and YBCO superconductors. The results were showed that the BSCCO superconductor's family is very poor in case of the levitation force compared with the YBCO superconductors. It may be attributed that the YBCO family superconductors have the high critical current density which occurs in the case of the flux pinning and the high magnetization behavior.

Keywords: Ceramic; Superconductor; BSCCO; YBCO; Levitation Force; Maglev

II Tip süperiletkenlerde manyetik kaldırma kuvveti için karşılaştırmalı inceleme

ÖZ

Meissner etkisi, 1933'te Meissner ve Ochsenfeld tarafından keşfedildiğinden beri sıfır direncin yanı sıra elbette bir süperiletkenin önemli bir özelliğidir. Deneylerle, bir süper iletken içindeki manyetik alanın daima sıfır olduğunu gösterdiler. Bu, süper iletkeni mükemmel diamanyetik bir malzeme olarak düşünebileceğimizi ima eder. $YBa_2Cu_3O_7$, $Bi_2Sr_2Ca_2Cu_3O_{10}$ ve $HgBa_2Ca_2Cu_3O_8$ gibi tip-II (Yüksek sıcaklık) süperiletkenleri teknolojik uygulamaları için oldukça caziptir. Önemli bir özellik levitation kuvveti ve MagLev uygulamasıdır. Nakliye ve diğer uygulamalarda MagLev sistemleri çok önemli hale gelmiştir. Bu uygulamalar, kriyojen transfer hattının enerji açısından verimli bir prototipinden uzay enerji depolama sistemlerine kadar değişmektedir. Bu çalışmada, BSCCO ve YBCO süperiletkenlerinin manyetik kaldırma kuvveti etkisini karşılaştırdık. Sonuçlar, BSCCO süper iletken ailesinin YBCO süper iletkenlerine kıyasla levitasyon kuvvetinde çok zayıf olduğunu gösterdi. YBCO ailesindeki süperiletkenlerin, akı sabitlemesi ve yüksek mıknatıslanma davranışı durumunda ortaya çıkan yüksek kritik akım yoğunluğuna sahip olduğu düşünülür.

Anahtar Kelimeler: Seramik, süperiletken, BSCCO, YBCO, Kadırma kuvveti, MagLev

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1. INTRODUCTION

Superconductors differ from each other in terms of their critical temperature (Tc) and magnetic field (Hc), therefore, classified as Type-I and Type-II, also they named as low and high-temperature superconductors. The high purity lead, mercury, and tin are examples of Type-I. YBCO and BSCCO are examples of Type-II [1]-[3].

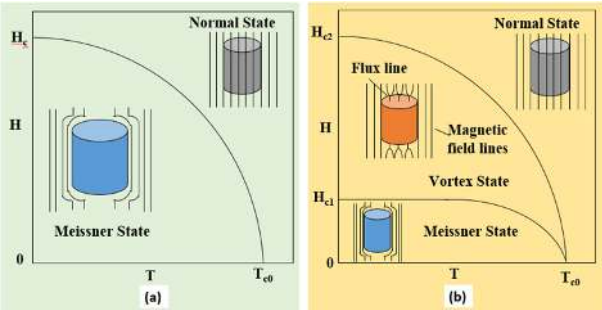

Fig. 1: Superconductor type's relation between the magnetic field and temperature (a) Type-I and (b) Type-II [4].

The superconducting properties originate from the electrical resistance below the transition temperature and the Meissner effect with an applied magnetic field [5]. As well-known as, the high-temperature superconductors with a vortex state which originate the magnetic properties differ from low-temperature superconductors. In this state, magnetic field penetrates a flux tube into the superconductor below the critical temperature. The vortex state of a type II superconductor in an applied field Ha > Hc1, with normal cores threading the bulk of the material. The lattice of cores and associated vortices. The surface current flowing around the periphery maintains the bulk diamagnetism are shown flux line in Fig 2.

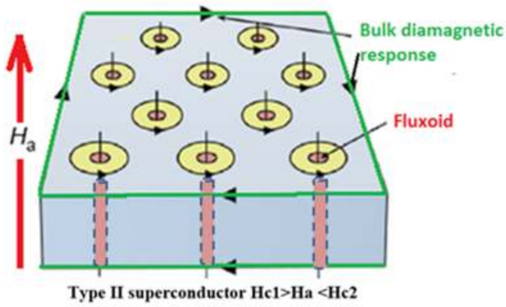

Fig.2: The mixed state of a type II superconductor in an applied field Hc1>Ha <Hc2. This modified from Rose-Innes and Rhoderick (1978, p. 186).

The magnetic field associated with each normal core is spread over a region and each normal core is surrounded by a vortex of circulating supercurrents. As like Top seed and Melt quench methods as solidification processes for producing high-temperature superconductors are effective for obtaining a high critical current (Jc). A considerable magnetic field can be trapped by a superconductor when it exhibits large flux pinning forces [6]. The force-distance (permanent magnets and superconductor) hysteresis loops during the descending and ascending process expanded with critical current density increases in BSCCO and YBCO. The hysteresis curves strongly depend on the size of grains and their connectivity in these materials.

In this century, because the higher magnetic field can be created with the high-temperature superconductors, they have been an attractive material for technological applications. To achieve this purpose, many researchers investigate the superconducting different materials physical properties. One of them is the research of Wang and et al. They investigated that the critical current density and critical magnetic flux on the melt-textured YBaCuO bulk superconductors. They compare the levitation force over the NdFeB guideway with that over a single cylindrical NdFeB permanent magnet [7]. Based on the energy cost of vortices a model that the flux penetration makes possible the stable levitation of a magnet over a flat superconducting disk was suggested by Hellman [8]. Moon et al. [9] have suggested a useful experimental setup which the measurement of the forces on a permanent magnet levitated above bulk superconductors properties. One of them is magnetic levitation properties which are important for different applications as Maglev. Maglev systems have become very important in the future life is generally based on the superconductor technology ranging from in a superconducting wind turbine generator [10], [11] and a superconducting magnetic energy storage (SMES) [12] to an Infra-Red (IR) sensor leads to Earth Orbit Systems (EOS) [13]

In this study, it is represented that the differences of the levitation force for two (BiPb) SrCaCuO and YBaCuO superconductors using with the handmade system at 77K. The levitation hysteresis has two different behaviors, one is the repulsive and other is the attractive force. The aim of this work is to obtain higher attractive force to determine their certain application.

2. EXPERIMENTAL PROCEDURE

2.1 Prepare (BiPb)SrCaCuO Ceramics

The studied samples were prepared by weighing appropriate amounts of high purity starting powders of Bi2O3, PbO, SrCO3, CaO, and CuO and then using these powders were produced with Bi1.7Pb0.3Sr2Ca2Cu3O10 nominal composition by solid state reaction with 5 h grinds to obtain a chemically homogeneous mixture [14]. The samples were calcined at temperatures 700, °C to purify the unexpected oxides and others with KSL-1100X- Compact Muffle Furnace. After the calculations, the resulting powders are mixed and then pressed into a pellet under a pressure of 250 MPa atmospheric pressure. This pellet is placed into a furnace at room temperature and sintered at 845°C in air for 130 h. Then it is directly taken to room temperature. We named the samples as BSCCO samples. The sintering process is depıcted in Fig. 1(a). After this sintering process pellet regrinding and the powders at 250 MPa pressure were pressed into cylindrical superconductor a disk with a diameter of 14 mm and height of 3.72 mm. The BSCCO sample was placed into a preheated furnace from 800 °C at a rate of 0.05 °C/min to 845 °C for 100 h annealed then directly cooled to room temperature [15]. The heating process is depıcted in Fig.3.

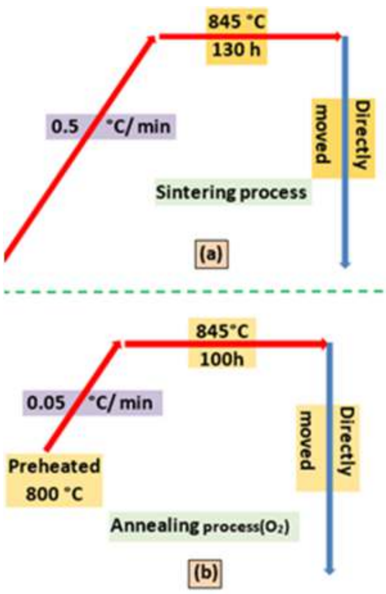

Fig 3: A schematic representation of the heat treatment of the BSCCO growth process.

2.2. Prepare YBaCuO Ceramics

The appropriate amounts of Y2O3, BaCO3, and CuO were mixed in the stoichiometric ratios of 1:2:3 grounding for 2 h. The mixture was calcined at 950°C for 10 h in the air in a KSL-1100X-Compact Muffle Furnace with Programmable Controller. After calcination, the powders were grounded for 2.5 h. Then, the fine powders were pressed into pellet form of 14 mm in diameter and 4 mm in thickness. The YBCO pellet was placed in a preheated furnace at 1030 °C for 50 min, then cooled to 980 °C at a rate of 2 °C/min and then cooled to 930 °C at a rate of 0.02 °C/min. The samples were then allowed to cool to room temperature for 3 °C/min. Finally, the samples were oxygen-annealed at 600 °C for 2 h [16]. A schematic representation of the heat treatment is shown in Fig.4.

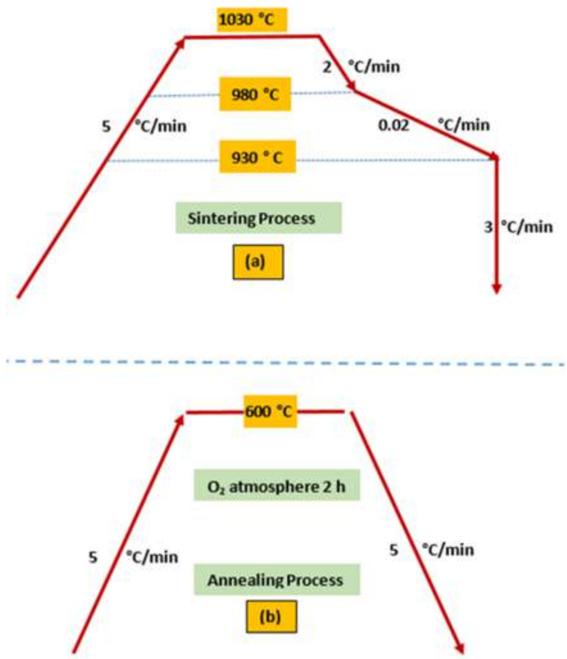

Fig 4: A schematic representation of the heat treatment of the YBCO growth process.

3. RESULTS AND DISCUSSION

If a magnet is lowered towards a superconductor, the movement generates currents and therefore a magnetic field. Type-II superconductors have fundamentally hysteretic behavior which depicted to their having a vortex state. Because in the vortex state (or Shubnikov phase) [17] an applied external field penetration into the body of the superconductor generates the flux line, the superconductor behaves as a quasi-permanent magnet. In other words, for magnetic fields in the vortex state (Hc1 >Ha< Hc2), the superconductor is not perfectly diamagnetic. Definitely, a partial penetration of magnetic lines occurs and the field penetrates into the bulk in association with supercurrents vortices that surround a normal core. They carry a quantum of flux (φ0 = h/2e =2.07x10-15 Wb) [18]. On the contrary of the Type-I superconductors that the repulsive force reaches its maximum possible value, the repulsive force reduces because of this penetration. If the flux doesn't move, a desirable mechanical stability is realized. Thus, the magnetic flux lines are pinned in the structure of the superconducting material. The large force attributes commonly on the quality of the sample and capability of the sample which is the expulsion of the applied field. According to magnetic force, this is indicated that the greater the repulsion, the higher the critical current (Jc) and good connectivity through the grains without weak-links. [19], [20]. So grain size and crystallographic orientation are well done on the structure of bulk superconductor [21].

Magnetic properties were measured by using the magnetic levitation force-distance (between HTS and PM) system at 77 K with Nd-Fe-B magnet in Fig.5. For the zero-field-cooled (ZFC) process in the applied magnetic field, the repulsive and attractive force data is calculated at zero separation distance. They were measured using a homemade levitation measuring device, given in details our previous work [22]. The repelling force effects on the magnet (PM) producing a change in its weight. The change in the magnet weight is directly proportional to the magnetic force which originated from superconductor behavior in this handmade system. [23], [24]. The force can be written as F = m (dH/dx), where m is the magnetic moment related with magnetization M and the volume of the superconductor and dH/dx is a field gradient produced by the magnet [24]. Due to the magnetic stress between a trapped field in the sample and the permanent magnet, an attractive force occurs when the sample is moved away from the magnet and a repulsive force occurs when the sample is moved down to the magnet. The calculated data differences between repulsive and attractive force have described the irreversible behavior. This indicates that the occurrence of the basic hysteresis loop. The result can be attributed to the amount of pinning centers increase of the trapped magnetic field inside the samples. In addition, levitation force is a function of the grain size and crystallographic orientation [25], [26].

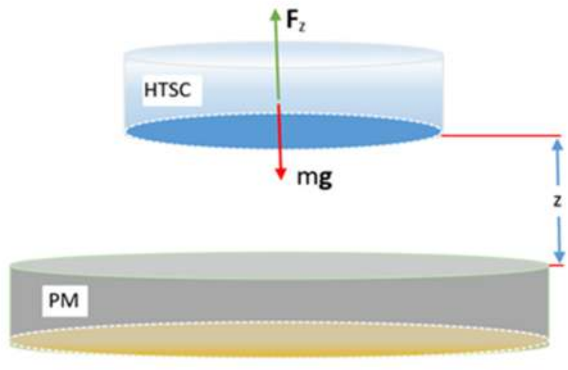

Fig. 5. The magnetic levitation force-distance between HTS and PM, hysteresis loop measurement system schematic view.

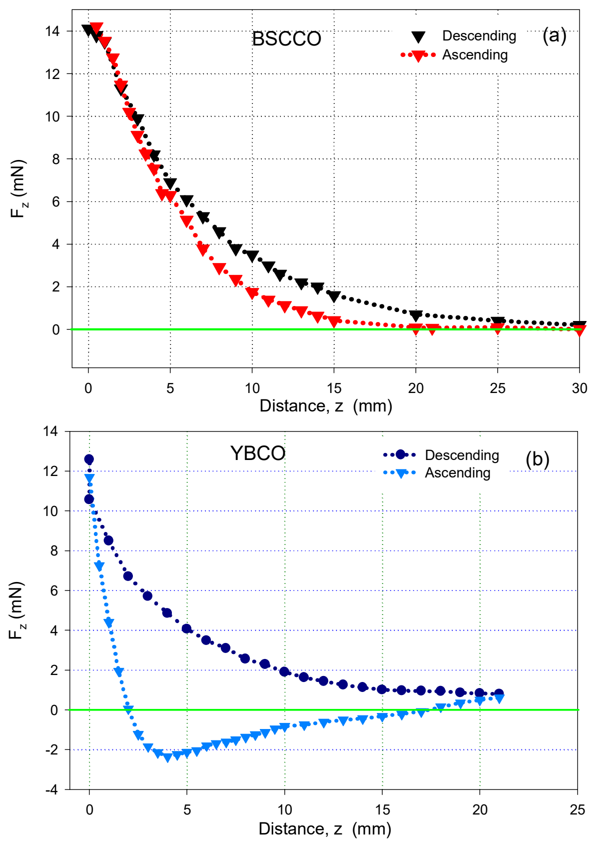

Fig.6. (a) BiSrCaCuO (b) YBaCuO descending and ascending process superconductors at 77 K in ZFC regime.

Fig.6 shows the (a) BiSrCaCuO (b) YBaCuO superconductor's typical hysteresis loops at 77 K in ZFC regime for the axial levitation force between the permanent magnet and superconductors. From the Fig.6.a, BSCCO and YBCO are the two different materials which have completely unlike superconducting properties as critical transition temperature are 110 K (crystal structure is Tetragonal) and 92 K (crystal structure is Orthorhombic) [27], respectively. This difference was shown from the changing of levitation force versus vertical distance data.

During the descending process, calculated force data are a completely positive sign and indicate that a repulsive force occurred between the PM and superconductors. The low repulsive force of superconductor materials can be attributed to intrinsic problems of a superconductor as like the grain boundary weak-link problem and the weak flux pinning problem [25].

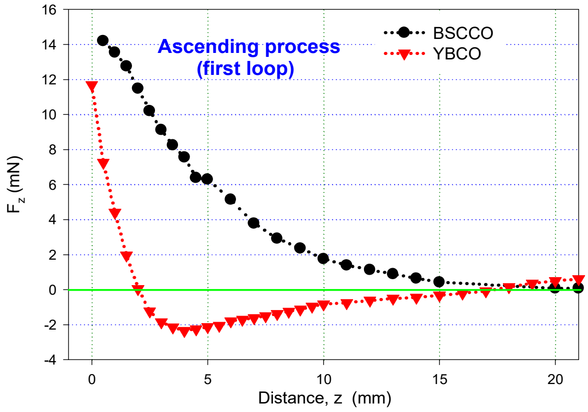

Fig. 7 BiSrCaCuO and YBaCuO superconductor's ascending process at77 K.

The BiSrCaCuO and YBaCuO superconductor's ascending process at77 K was seen in Fig.7. This indicates that the during the ascending process attractive force which is originated from the flux behavior of the superconductors in the vortex state [28]. The differing of the attractive forces from the BSCCO to YBCO samples is large enough to say to BSCCO sample has less force, magnetization, critical current and grain size than YBCO sample in ZFC regime during the first loop [29]. BSCCO sample has a positive sign of the weakly attractive force [30]. This indicates that the positive magnetization according to the Beans critical state model [31]. But YBCO sample has either positive or negative sign of the force which is attributed that the positive and negative magnetization produced by ascending process in this state. This is clearly related to the change of the orientation and size of the grains in the YBCO sample. This yields to higher critical current and grain connectivity. Thus the higher flux pinning is occurring as expected from YBCO sample [21], [32].

4. CONCLUSION

As a result, the levitation force improvement can be achieved by using or producing Y-based superconductor which has short annealing time with oxygen atmosphere instead of the Bi-based superconductor which has long annealing time. Because of the large attractive and hysteresis, YBCO sample yields to higher critical current and grain connectivity than BSCCO sample. The results are needed to be a detailed investigation in view of the attractive force enhancement and use of the technological application as Maglev vehicles.

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