

Mechanical properties of EuBaCuO superconducting bulk material at liquid nitrogen temperature

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Abstract. In order to understand the mechanical properties of EuBa₂Cu₃O_y “EuBaCuO” superconducting bulk material, 3- and 4-point bending tests were carried out at room and liquid nitrogen temperature (77.3 K) for specimens cut from a EuBaCuO single-grain bulk material. The Young’s modulus evaluated through the 3-point bending test and that through the 4-point bending test were similar to each other. On the other hand, the 3-point bending strength was higher than the 4-point bending strength, which is due to the smaller maximum bending moment area of the specimen in the 3-point bending test. The Young’s modulus at liquid nitrogen temperature was higher than that at room temperature (RT), which is due to the decrease of the interatomic distance by cooling. The bending strength at 77 K was also higher than that at RT. These mechanical property data of the EuBaCuO bulk material were comparable to those of other REBa₂Cu₃O_y “REBaCuO” bulk materials (RE: rare-earth elements).

1. Introduction

It is well-known that REBaCuO (RE: Y or rare-earth elements) single-grain bulk materials have excellent and unique features such as large current transport capacity, automatically stable levitation and extremely high trapped field ability. Various superconducting devices using such excellent and unique features of REBaCuO bulk materials are being developed. Improvement of the superconducting properties and enlargement of the single-grain size of REBaCuO bulk materials are useful for the development of high-performance superconducting devices. REBaCuO bulk materials are subjected to the electromagnetic force and thermal stress in the superconducting devices [1-4]. Since improvement of the superconducting properties and enlargement of the single-grain size cause the increases of the electromagnetic force and thermal stress, improvements of the mechanical properties are also useful for the development of superconducting devices. Also, understanding of the mechanical properties at cryogenic temperature is informative for designing the superconducting devices. NMR application using EuBaCuO bulk material has been suggested [5-7]. However, the mechanical properties of EuBaCuO bulk material have not been understood extensively in comparison with those of other REBaCuO bulk materials such as YBaCuO, GdBaCuO and DyBaCuO. In this study, mechanical properties of a EuBaCuO single-grain bulk material were evaluated through 3- and



4-point bending tests at room and liquid nitrogen temperatures for specimens cut from the bulk material. Effects of loading method and testing temperature on the mechanical property data are discussed.

2. Experimental procedure

One $\text{EuBa}_2\text{Cu}_3\text{O}_y$ single-grain bulk sample fabricated by Nippon Steel & Sumitomo Metal Corporation was used for 3- and 4-point bending tests at room and liquid nitrogen temperatures. The precursor for the bulk sample was heated up to 1443 K, kept at that temperature for 1 h and then cooled down to 1310 K. After that, one $\text{NdBa}_2\text{Cu}_3\text{O}_y$ seed crystal was placed on the top of it in air. After the crystal growth, oxygen annealing was conducted at 673 K for 100 h. The diameter of the bulk sample was 60 mm. 25 mol% $\text{Eu}_2\text{BaCuO}_5$ and 10 wt% Ag were added to the bulk sample. Bending test specimens with the dimensions of $2.8 \times 2.1 \times 24 \text{ mm}^3$ were cut from the bulk sample (Figure 1). Schematic illustrations of the 3- and 4-point bending tests, together with the bending moment diagrams (BMD), are shown in Figure 2 (a) and (b), respectively. Loading was carried out under the crosshead speed of 0.2 mm/min. Strain was measured by using a strain gauge glued to the centre of the tensile side surface of the specimens. In the bending tests at 77 K, specimen was placed on the bending test jig and immersed into the liquid nitrogen bath, together with the bending test jig. After the bending tests, side surfaces of the fractured specimens were polished by using lapping sheets. The polished surfaces were observed by using an optical microscope. Porosities (area fraction of pores) on the optical micrographs were evaluated through image analysis. Stress caused by 3-point bending loading σ_3 and that by 4-point bending loading σ_4 were calculated by the following equations, respectively. Where P is applied load, L is outer supporting span, l is inner loading span, w and t are width and thickness of the specimen, respectively.

$$\sigma_3 = \frac{3PL}{2wt^2} \quad (1)$$

$$\sigma_4 = \frac{3P(L-l)}{2wt^2} \quad (2)$$

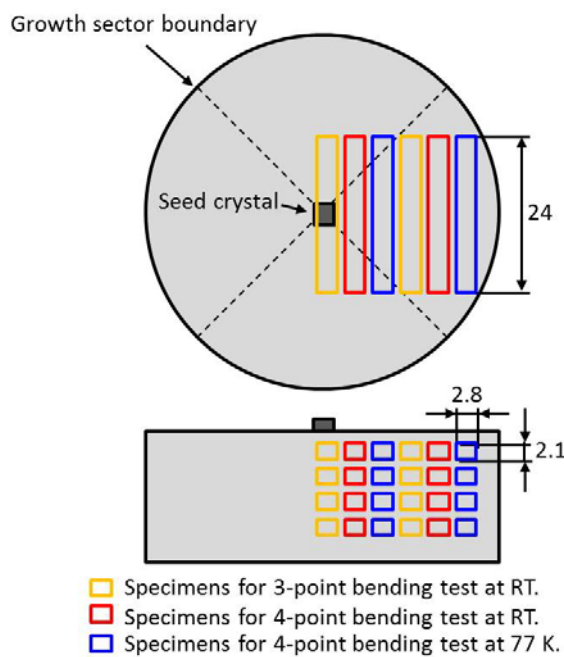


Figure 1. Schematic illustration of cutting out of specimens for 3- and 4-point bending tests at room and liquid nitrogen temperatures.

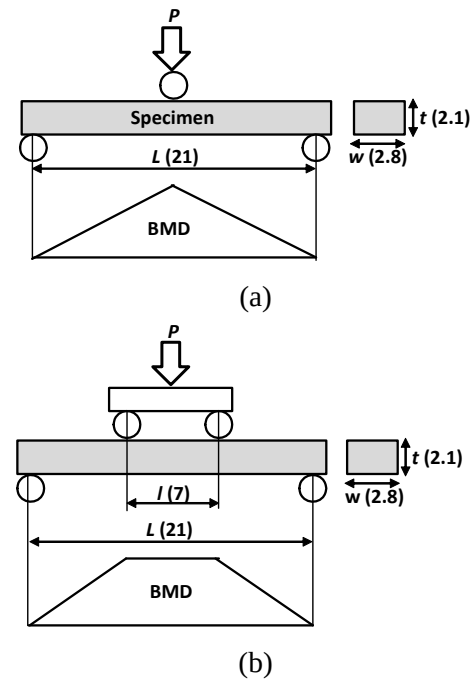


Figure 2. Schematic illustrations of bending tests and bending moment diagrams. (a) 3-point bending test and (b) 4-point bending test.

3. Results and discussion

3.1. Effects of loading method on mechanical property data

Figure 3 shows stress-strain curves obtained through the 3- and 4-point bending tests for specimens at room temperature. Stress-strain behaviours are almost linear until the fracture. Such stress-strain behaviour is typical of brittle materials. There is no significant difference in the slope of the stress-strain curves between the 3- and the 4-point bending tests. Young's modulus data evaluated from the slope of the initial part of the stress-strain curves are shown in Figure 4. Since the Young's modulus is intrinsic to the material, the Young's modulus evaluated through the 3-point bending test and that through the 4-point bending test were similar to each other. On the other hand, the 3-point bending strength was higher than the 4-point bending strength (Figure 5). It is attributable to that the maximum bending moment area of the 3-point bending test specimen is smaller than that of the 4-point bending test specimen (see Figure 2). Both the 3- and 4-point bending tests are commonly carried out to evaluate the mechanical properties of brittle materials. However, the bending strength evaluated through the 3-point bending test is overestimated in comparison with that through the 4-point bending test. Thus, the mechanical properties at 77 K mentioned in the followings were evaluated through the 4-point bending test.

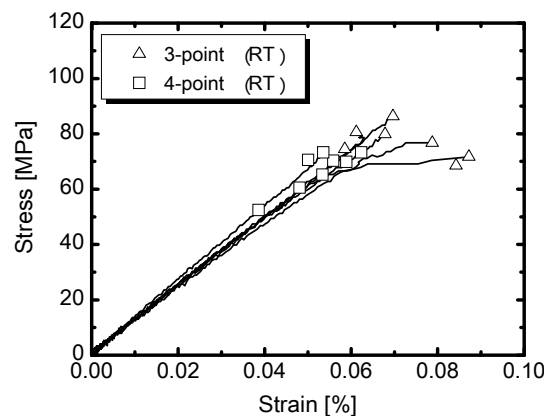


Figure 3. Stress-strain curves obtained through 3- and 4-point bending tests at room temperature (RT). Data points represent fracture point of specimens.

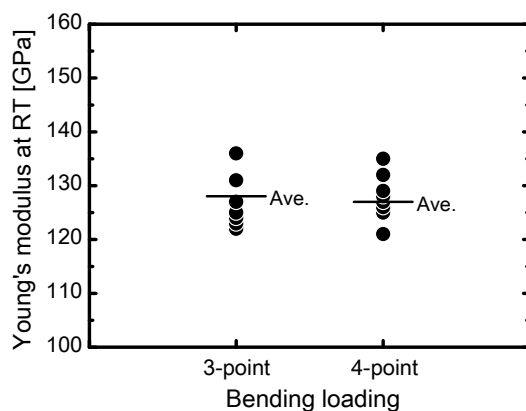


Figure 4. Young's modulus data at room temperature (RT).

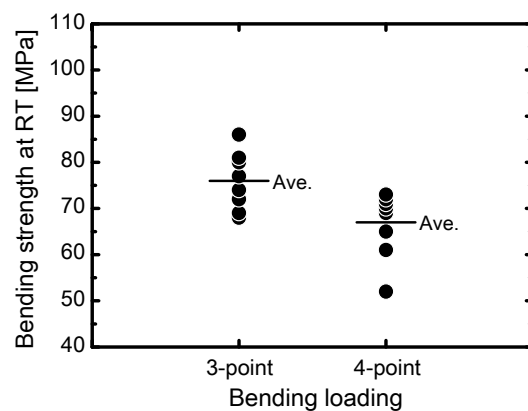


Figure 5. 3- and 4-point bending strength data at room temperature (RT).

3.2. Effects of testing temperature on mechanical property data

Figure 6 shows stress-strain curves obtained through the 4-point bending tests for specimens at liquid nitrogen temperature (77 K). Stress-strain curves at room temperature (RT) are also shown for reference. Slopes of the stress-strain curves at 77 K are steep in comparison with those at RT. Young's modulus data at 77 K and RT are shown in Figure 7. The Young's modulus at 77 K was higher than that at RT. The bending strength at 77 K was also higher than that at RT (Figure 8). These temperature dependences are mainly due to the decrease of the interatomic distance by cooling. Figure 9 shows Weibull plots of the 4-point bending strength data. 3-point bending strength data are also shown for reference. Weibull plot is commonly carried out to evaluate the scatter of the strength data. The slope obtained through the linear fitting of the data represents the Weibull coefficient m ; larger Weibull coefficient value means smaller scatter of the strength data. Since the Weibull coefficient of the 3-point bending strength data at RT and that of the 4-point bending strength data at 77 K are similar to each other, it is deduced that there is no significant difference in the Weibull coefficient between the bending strength data at RT and 77 K although the Weibull coefficient of the 4-point bending strength at RT is smaller than that at 77 K.

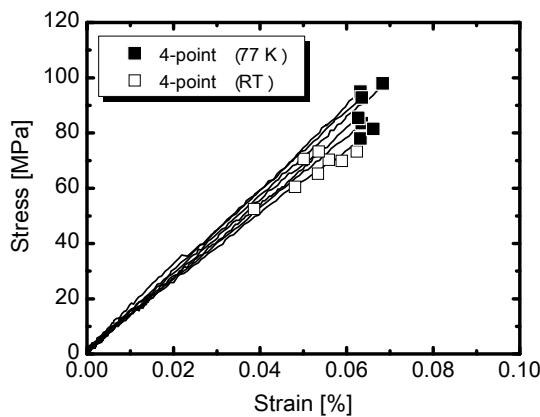


Figure 6. Stress-strain curves obtained through 4-point bending tests at room and liquid nitrogen temperatures (RT and 77 K). Data points represent fracture point of specimens.

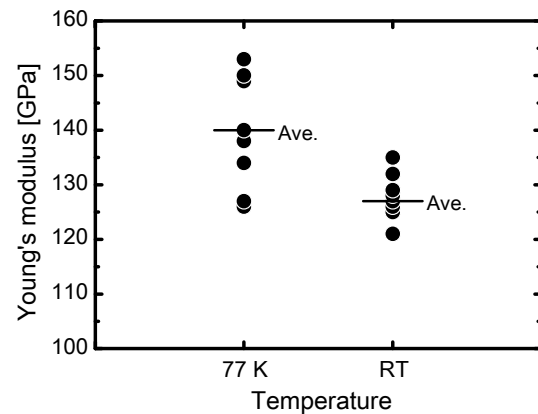


Figure 7. Young's modulus data evaluated through 4-point bending tests at room and liquid nitrogen temperatures (RT and 77 K).

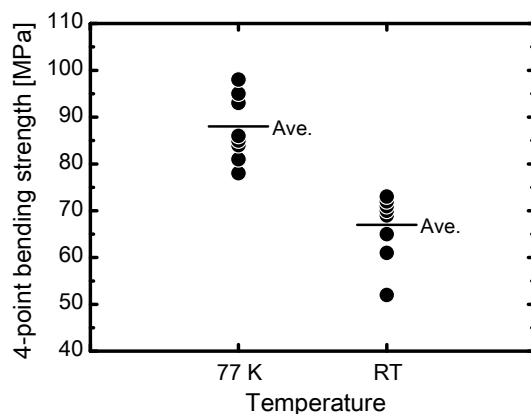


Figure 8. 4-point bending strength data at room and liquid nitrogen temperatures (RT and 77 K).

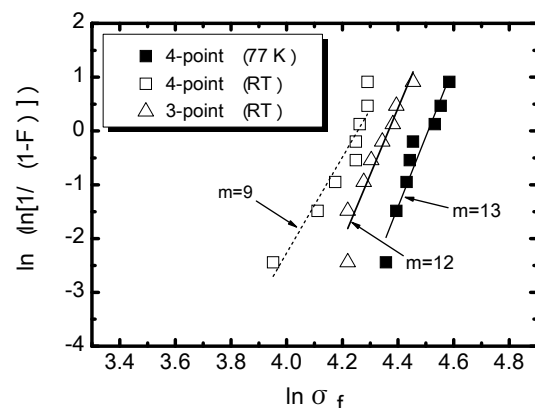


Figure 9. Weibull plots of 3- and 4-point bending strength data at room and liquid nitrogen temperatures (RT and 77 K). F and m represent cumulative fracture probability and Weibull coefficient, respectively.

Figure 10 shows optical micrograph of the polished surface of the fractured bending test specimen. Black and white areas are pores and Ag particles, respectively. In order to evaluate the porosity, pores on the optical micrographs were extracted and the area fractions of pores were measured by using image analysis software. Relationship between the bending strength and the porosity is shown in Figure 11. Approximation curves of the 3-point bending strength data at 77 K of a DyBaCuO bulk material reported in [8] and the 3-point bending strength data at room temperature of a DyBaCuO reported in [9] are also shown for reference. Since low porosity specimens cut from the region just adjacent to the top surface of the DyBaCuO bulk materials were used for the bending tests in the previous studies [8,9], approximation curves (solid and broken lines in Figure 11) were obtained. On the other hand, such approximation curves were not obtained for the EuBaCuO bulk material because the low porosity specimens were not used for the bending tests in this study. It can be seen that the 3-point bending strength data at RT of the EuBaCuO bulk material are comparable to the approximation curve of the 3-point bending strength data at RT of the DyBaCuO bulk material (Figure 11). Also, it can be seen that the 4-point bending strength data at 77 K of some specimens of the EuBaCuO bulk material are comparable to the approximation curve of the 3-point bending strength data at 77 K of the DyBaCuO bulk material. Since 3-point bending strength is commonly higher than the 4-point bending strength, it is deduced that the bending strength at 77 K of the EuBaCuO bulk material is also comparable to that of the DyBaCuO bulk material.

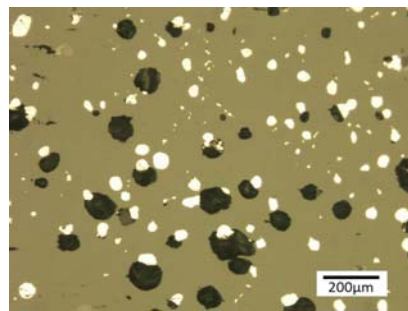


Figure 10. Optical micrograph of polished surface of bending test specimen.

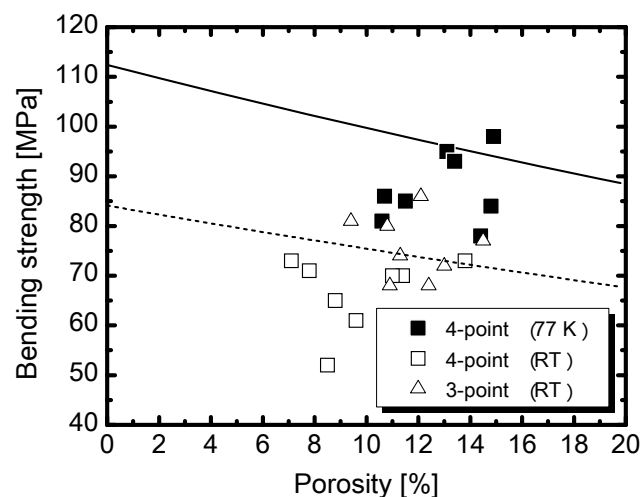


Figure 11. Relationship between bending strength and porosity of the EuBaCuO specimens. Solid and broken lines represent approximation curves of 3-point bending strength for DyBaCuO at 77 K reported in [8] and RT reported in [9], respectively.

4. Summary

Mechanical properties of a EuBaCuO single-grain bulk material were evaluated at room and liquid nitrogen temperatures through 3- and 4-point bending tests for specimens cut from the bulk material. While the Young's modulus evaluated through the 3-point bending test and that through the 4-point bending test were similar to each other, the 3-point bending strength was higher than the 4-point bending strength. It is due to the smaller maximum bending moment area of the specimen in the 3-point bending test. Both the Young's modulus and the bending strength at liquid nitrogen temperature were higher than those at room temperature, which are mainly due to the decrease of the interatomic distance by cooling. Taking into account the porosity, these mechanical property data of the EuBaCuO bulk material were comparable to those of DyBaCuO bulk materials.

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