**Strain effects on the critical current of Bi-2223/Ag tape**

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Mechanical properties of Bi-2223/Ag tapes have been studies. The conductor's critical current ($I_c$) keeps nearly constant when the tensile strain is low than a critical value. As tensile strain increase, $I_c$ decreases slowly at the beginning, and then degrades sharply near 0.3% of strain. Degradations of $I_c$ caused by the bending strain are in good agreement with the tensile testing results. Synchrotron radiation shows that the degradation of $I_c$ is related directly with propagation of micro-crack in the oxide layer under tensile tests.

## INTRODUCTION

High temperature superconducting (HTS) tapes can be regarded as a typical two component composites consisting of a brittle oxide core, which is composed of ceramic material, covered by a ductile layer. The $I_c$ reduction in strained HTS tapes is irreversible. The explanation for this is that the stress or strain will lead to the appearance and propagation of the micro-cracks, and degrade the $I_c$ of HTS tapes [1-2]. The influence on the $I_c$ during the tensile and bending strain, which decrease the tape cross-section and increase the pinning center concentration, is investigated in some paper [3-5]. In this paper, tensile and bending tests on Bi-2223/Ag tapes were taken to study the effect of the strain on the $I_c$ of HTS tapes. We discuss that the propagation of the cracks plays an important role in the impeding of the superconducting current by using the high-energy ions irradiations photos test.

## EXPERIMENTAL RESULTS AND DISCUSSION

The mean thickness and width of Bi-2223/Ag tapes are 0.2 and 4.0 mm, respectively. The tensile and bending tests were taken at liquid nitrogen temperature (77 K). The signals from transducers were measured using a KEITHLEY 2000 multimeter equipped with a scanning card. The entire experiment is software/computer controlled. High-energy ions irradiated by the synchrotron radiation source at Beijing Synchrotron Radiation Laboratory have been used in taking pictures of damaging process of Bi-2223/Ag tapes under tensile test at room temperature.

Typical V-I curves under tensile stress for Bi-2223/Ag tape are shown in figure 1. When the tensile stress below 118 MPa, the critical current has little degradation. However, when the tensile stress is higher than 123 MPa, apparent decrease on critical current was observed, which is thought to be caused by the cracking of the oxide and called multiple cracking [6]. The results for normalized critical current $I_c/ I_c(0)$ as a function of applied axial stress under self-field are shown in figure 2. As seen in figure 2, for all the five specimens, the Bi 2223/Ag tapes keep the initial critical current density until the tensile stress up to a critical value, which causes significant damage to the superconductor ceramic core so that the measured critical current decreases greatly. $I_c$ degradation started from 100 MPa tensile stress to 150 MPa, which shows in spite of the overall similarity in structure of the five specimens, there are subtle differences among tapes.

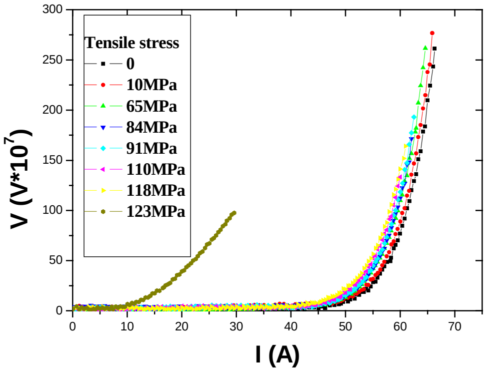


Figure 1 V-I curves of Bi-2223/Ag tape under different tensile stress.

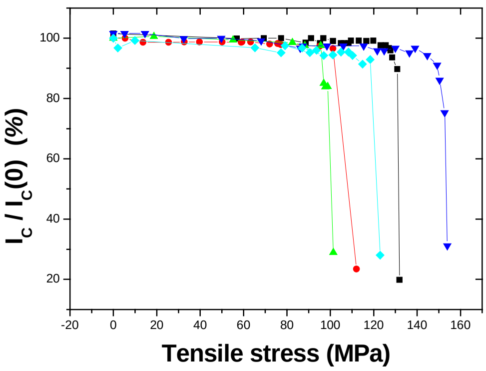


Figure 2 Normalized $I_c$ at 77K under self-field for as a function of axial tensile stress for Bi-2223/Ag tapes.

Figure 3 shows typical results of the strain dependence of the normalized $I_c$ for tensile tests. The $I_c$ of the Bi2223/Ag tape decreases drastically at tensile strain of $\varepsilon_{irr}$=0.3. Therefore, the point of irreversibility in the $I_c$ is about $\varepsilon_{irr}$=0.3%. When the tensile strain is lower than the critical value, the ceramic core and sheath only have elastic deformation, and no fracture happened. When the tensile strain is larger than the critical value, because ceramic materials can undertake lower strain than the sheath, cracks will appear in the core and propagate quickly. During this process, the existing cracks will become larger and new cracks will appear. The existence of these cracks will decrease the capability of the pass of the current and lead to the fracture of the whole superconducting core.

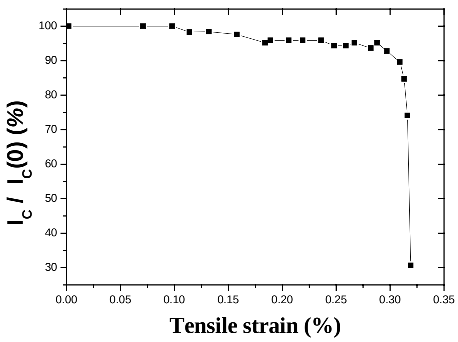


Figure 3 Normalized $I_c$ densities at 77k under self-field as a function of tensile strain (ε) at 77 K.

The bending properties of the Bi2223/Ag tape are given in figure 4. The results of rapid degradation of $I_c$ at bending measurements for the specimens indicate the likely formation of cracks. During the process of bending, the inner side of tape would undergo compressive stress, and the out side would undergo tensile stress, which cause the strain in the oxide core and leads to the decrease $I_c$.

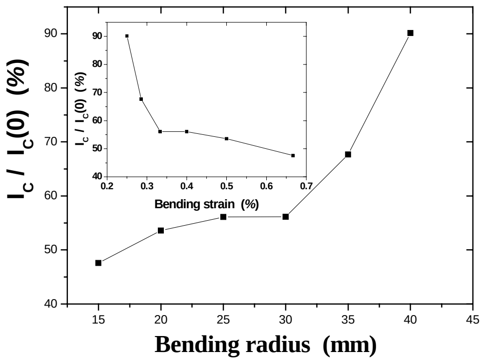


Figure 4 Normalized $I_c$ with bending at 77K under self-field as a function of bending radius for the sample Bi-2223/Ag tape. The insert shows the relationship of the bending strain and normalized $I_c$.

The bending strain (ε) was determined from the relationship of $\varepsilon = t/2R$, where t is the total thickness of the tape and R is the radius of curvature. In order to study the influence of the bending strain on $I_c$, the tapes were bent around six different rollers, the diameters change form 30 to 80 mm, corresponding to tensile strains (ε) in the oxide layer from 0.67% to 0.25%. The beginning crack formation and current degradation is observed for a bending radius =35 mm corresponding to 0.29% strain on the convex side of the tape, which is good agreement with the tensile testing results.

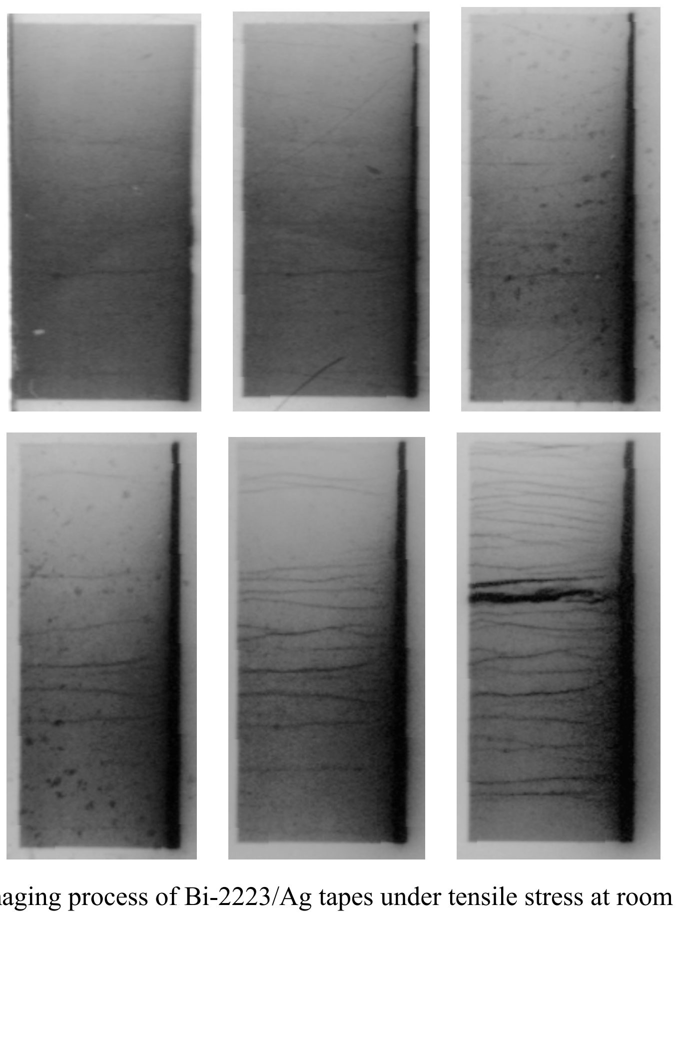

Figure 5 Damaging process of Bi-2223/Ag tapes under tensile stress at room temperature.

The tensile and bending strain results can be explained by the expansion of the micro-cracks existed in the tape. Figure 5 gives the inner-structure damaging photo of Bi-2223/Ag tapes under tensile stress at room temperature by synchrotron radiation. The recorded photos show that with increasing of tensile stress, thin and short cracks appear at beginning, propagates along cross-section of oxide core and many new cracks appear with the increase of the stress. The cracks are not totally parallel, which means it might appear and propagate along the poorest connection among ceramic grains. When a certain strain is exerted on samples, there appear micro-cracks in oxide core at beginning, and then the extension of the cracks is the main reason for the decrease of the $I_c$ density.

## CONCLUSION

In order to study the influence of the strain on properties of HTS tapes, especially the critical current, tensile, bending tests are taken. It shows when the strain is higher than a critical value (about 0.3% for our specimens), the critical current begin to decrease, slowly at first, then quickly. According to the results got by synchrotron radiation, the existence and propagation of cracks in superconducting core might be the main reason to cause the decrease of the critical current. Therefore, the critical strain is the critical parameter to instruct the rolling and application of HTS tapes.

## ACKNOWLEDGEMENTS

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