# 외부 보강된 Bi-2223테이프의 가압 $LN_2$하에서 임계전류 열화거동의 굽힘변형률 의존성

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# Bending strain dependence of the critical current degradation behavior in externally-reinforced Bi-2223 tapes with different hermeticity under pressurized liquid nitrogen

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**Abstract:** The $I_c$ degradation behaviors of externally-reinforced Bi-2223 superconducting tapes under pressurized liquid nitrogen were investigated. Tapes with different thickness of reinforcement layers were compared and the results showed that when the bending strain was calculated at the outer surface, the tape with the thicker reinforcement showed a better bending strain tolerance of $I_c$, but when the bending strain was calculated at the outermost filament, the $I_c$ degradation behavior became identical for all tapes. $I_{c0}$ decreased with the increase of applied pressure. After depressurization to atmospheric pressure from 1 MPa, the $I_c$ was completely recovered to its initial values. Ballooning occurred after a thermal cycle.

**Key Words :** Bi-2223 tapes, Bending strain, Critical current, Pressurized $LN_2$, External Reinforcement

## 1. Introduction

For practical applications such as power cables adopting Bi-2223 tapes, the tapes are subjected to various stresses and strains during fabrication and operation [1]. The influence of pressurization on the transport property of Bi-2223 tapes should also be considered [2]. Here, the influences of pressurization of $LN_2$ on the transport property of externally-reinforced Bi-2223 tapes at bent state were investigated.

## 2. Experimental Procedure

Three kinds of commercially-available and externally-reinforced Bi-2223 tapes fabricated using the powder-in-tube process were supplied. Table 1 lists the properties of the samples used and the cross-sections are shown in Fig. 1.

For bending tests under pressurized $LN_2$, a ρ-shaped sample holder and a cryostat for pressurization were used as shown in Fig. 2. The test procedures and set-up for the pressurized bending tests were described in Ref. [2].

The nominal bending strain of the tape, $\varepsilon_b$, in a bent position on the mandrel is given in Eq. (1) and was defined at the outer surface of the sample.

$$\epsilon_b = \frac{t}{2R+t} \times 100\% \qquad (1)$$

where t is the sample thickness, R is the bending radius at each voltage separation corresponding to a specific bending strain [1,2].

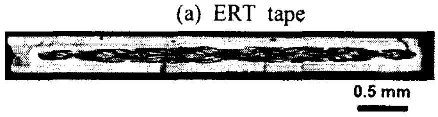
## 3. Results and Discussion

At atmospheric pressure, the $I_c$ degradation behavior of the samples with bending strain are

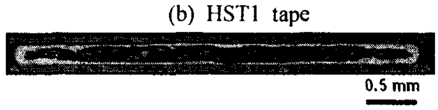
Table 1 Specifications of Bi-2223 tapes

| | ERT | HST1 | HST2 |
|---|---|---|---|
| Dimension (mm) | 4.2 x 0.3 | 4.2 x 0.38 | 4.2 x 0.38 |
| $I_c$ at 77K (A) | 138 | 133 | 155 |
| Reinforcement material | Stainless steel | Brass | Brass |
| Reinforcement thickness (μm) | 40 | 80 | 80 |
| Multi-filament bundle layer thickness (mm) | 0.19 | 0.19 | 0.19 |
| Hermetic Sealing | None | One side | Both sides |


(a) ERT tape

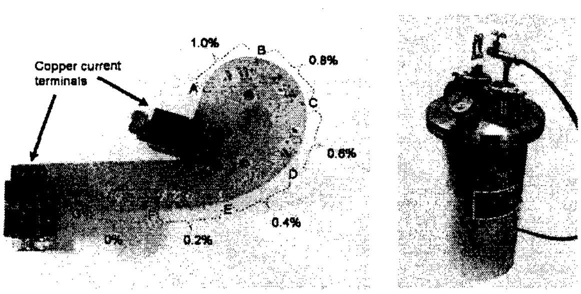



(b) HST1 tape




(c) HST2 tape

Fig. 1 Cross-sectional views of Bi-2223 tapes




(a) (b)

Fig. 2 Devices used to measure $I_c$-$\varepsilon_b$ relationship under pressurized $LN_2$. (a) A sample holder which gives a series of bending strains to HTS tapes, (b) View of the cryostat assembly.

shown in Fig 3. The HST tapes showed a better bending strain tolerance as compared with the ERT tape. The critical bending strains, $\varepsilon_{irr}$, which was defined as the strain for 95% $I_c$ retention are 0.71%, 0.88%, and 0.89% for the ERT, HST1, and HST2 tapes, respectively. This is due to the thicker foils laminated on the HST tapes.

The bending strain at the outermost filament in all samples was also calculated by using Eq. 1 and Table 1. It can be seen that the $\varepsilon_{irr}$ at the outermost filament responsible for $I_c$ degradation became identical for all tapes, i.e., $\varepsilon_{irr}$=0.44%.

Figs. 4 shows the $I_c$ degradation behavior with bending strain at $LN_2$ pressurized to 1 MPa for the HST2 tape. Ic degradation curves for the ERT and HST1 tape is not shown for brevity. All tapes showed a pressure-dependent $I_c$ degradation behavior. It was observed that the $I_c$ at the unstrained state, $I_{c0}$, at 1 MPa for all samples were decreased by over 40% when compared with the case at atmospheric conditions.

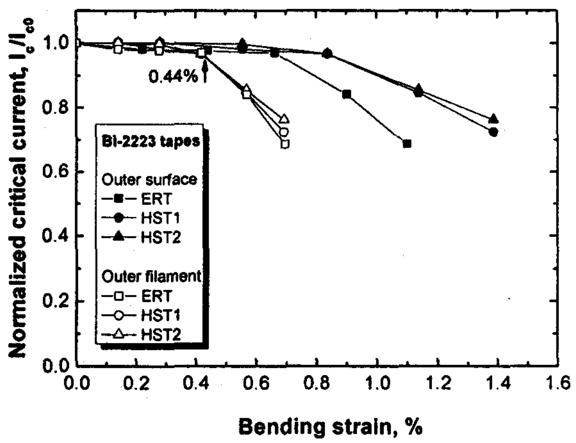



Fig. 3 $I_c$-$\varepsilon_b$ dependence for all tapes.

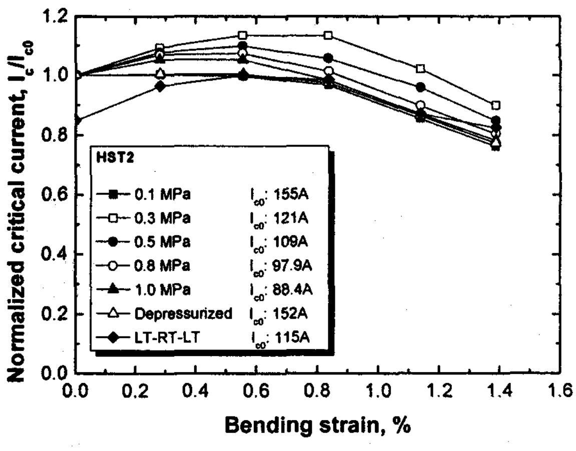



Fig 4. $I_c$ degradation behaviors in HST2 Bi-2223 tape obtained from pressurization tests.

After pressurizing the tape up to 1 MPa, the pressure was released to atmospheric pressure and then the $I_c$ was measured. The $I_c$ was completely recovered to $I_{c0}$ for all samples. It can be seen that pressurization of $LN_2$ up to 1 MPa did not cause any permanent damage to the filaments, although it is believed that it accelerated the diffusion of $LN_2$ into the multifilamentary bundle layer which eventually caused ballooning after a thermal cycle.

A thermal cycle was given to the samples after depressurization in order to investigate the influence of pressurization on the $I_c$ degradation behavior. The result was added in Fig. 4 and represented by a diamond. It can be seen that $I_c$ degraded at low applied bending strain regions which corresponds to the occurrence of ballooning in the sample. Ballooning was caused by the vaporization of $LN_2$, which diffused into the filaments, when the tape was warmed up to RT. This ballooning damage resulted in the significant degradation of $I_c$ [2].

## 4. Conclusion

The $I_c$-$\varepsilon_b$ characteristics of externally-reinforced Bi-2223 tapes under pressurized $LN_2$ were investigated. The tape with the thicker reinforcement showed a better bending strain tolerance of $I_c$ when the bending strain was calculated at the outer surface, but when the bending strain was calculated at the outermost filament, the $I_c$ degradation behavior became identical for all tapes. For all samples, $I_{c0}$ decreased with the increase of applied pressure. And when depressurized to atmospheric pressure from 1 MPa, the $I_c$ completely recovered to its initial values at atmospheric pressure. Ballooning occurred when the samples were warmed up to RT.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