§17. Mechanical Properties and Reinforcement of Bi-2212 Bulk Superconductor

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The performance of high-Tc superconductors have improved rapidly. They have been expected as a current feeder between a low-Tc superconductor and a current transport material at higher temperature. Yamada et al. have developed Bi-2212 bulk material by using diffusion process and current transport tests for the bulk at 4K have been conducted at NIFS under a research collaboration program. The maximum transport current density of 35 kA/cm^2 was successfully achieved at the diffusion layer so far. However, in these current transport tests, some specimens got a structural damage, which were caused by the thermal stress in the bulk specimen when a part of a surface of the specimen transferred to normal conductivity. It is needed to reinforce the bulk superconductor or to fix the bulk to an appropriate support structure as a size becomes large, especially for a practical use. Rigidity reinforcement and absorption of thermal contraction have to be considered simultaneously for a design of a current lead using HTS. We measured mechanical properties of the Bi-2212 tubular bulk to investigate an optimal design of HTS current lead using this material.

The size of the Bi-2212 superconductor used for mechanical tests was 27 mm/19 mm in outer/inner diameters and 30 mm of length, respectively. Since the Bi-2212 is a 0.15 mm thick layer on both outer and inner surfaces and a residual region is a bismuth-free substrate, the substrate specimen was also prepared.

The thermal contraction between room temperature and 77 K were measured for both the Bi-2212 and the substrate. Strain gauges were attached on the surface of the specimen. Thin copper and 304 stainless steel plates were used for reference. The thermal contraction from 300 K to 77 K of the Bi-2212 bulk was $0.20 \pm 0.01\%$ that was as well as that of bismuth free substrate. There was no significant difference between them concerning overall thermal contraction.

Compressive tests were carried out with an electromechanical tension/compression test system. The tests were carried out at room temperature except for bismuth-free substrate. The substrate was cooled in liquid nitrogen and tested at atmosphere keeping its temperature by supplying the coolant around the specimen. The compression was loaded until the specimen broke. All specimens were broken without plastic deformation. It seemed that the compressive strength at 77 K did not change so much compared to the result at room temperature. We estimated the Young's moduli of the materials from linear behavior region in a stress-strain curves; omitting an initial load condition which showed low rigidity since the specimen did not touch completely to the tester. The estimated Young's modulus of Bi-2212 bulk tube and bismuth-free substrate were 37.4 GPa and 44.5 GPa, respectively. The diffusion layer of the Bi-2212 HTS consists of thin-plate like grains grown to the radial direction. This could be the reason why the thermal contraction shows no difference between HTS and its substrate. There is also a silver layer on the diffusion layer, but the silver layer must have reached yield stress caused by the difference of the thermal contraction against the substrate. Consequently, the thermal contraction of the HTS yields to that of the substrate. The compressive strength among the HTS, the substrate (both at 300 K and 77K) were not so different. The substrate of the HTS must be a main member against load. Once an initial crack is generated in the substrate, the crack grows rapidly then reaches to fracture. It is needed to prevent a generation of a crack and to increase a resistance against crack growth or crack opening. The Bi-2212 diffusion layer may act as initial crack from its structure.

We made a prototype of fiber reinforcement Bi-2212 HTS by binding unidirectional glass/epoxy tapes as shown in fig. 1 to confirm a possibility of this reinforcement. The nominal thickness of the tape is 0.33 mm and volume fraction of epoxy is 24 to 30 %. The 19 mm in width tape was wrapped on the outer surface of the tubular HTS in two layers. We measured the thermal contraction between room temperature and 9 K of the reinforced Bi-2212 by attaching strain gauges on it. The estimation of the thermal contraction is shown in Table I. Only the oblique direction which almost coincides with the direction of glass fiber was smaller than that of others. The reinforcement did not affect the electrical specification of the HTS and there was no generation of defect after several normal transitions in the current transport test.

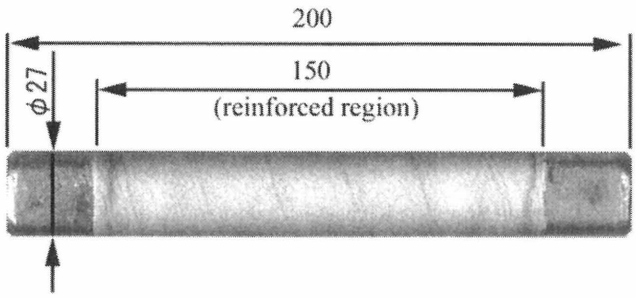

Fig. 1. Bi-2212 bulk with glass-epoxy reinforcement.

Table I
Thermal contraction of Bi-2212 and reinforced sample.

	Thermal contractin (%)	
	300K to 77K	300K to 9K
Bismuth-free substrate	0.20	-
Bi-2212 bulk	0.20	-
Bi-2212 with glass-epoxy tape		
longitudinal	0.20	0.24
oblique	0.15	0.17
circumferencial	0.20	0.23