DI-BSCCO wires by Controlled over pressure sintering

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Abstract. Sumitomo Electric successfully developed drastically innovative Bi-2223 (DI-BSCCO), namely, commercially produced Bi2223 long length wires using the controlled over pressure sintering (CT-OP) with unique properties quite different from conventional silver sheathed BSCCO wires. CT-OP prevented pores occurring in BSCCO cores, so it reformed conventional Bi2223 wires to DI-BSCCO with excellent properties of higher critical currents, stronger mechanical strength and better durability against temperature rise in cryogen such as pressurized liquid nitrogen. It enhanced the critical current by 50 percent conventional wires sintered in normal atmospheres. Critical tensile stress was also improved by more than 150 percent. Any ballooning defects and degradation of critical current, one of the critical problems for the conventional BSCCO wires, were not found in full length of several km long DI-BSCCO tapes after 24 hours immersion into 1MPa liquid nitrogen.

1. Introduction
Silver sheathed Bi-2223 multi-filament tapes are the most advanced high temperature superconductors, which can satisfy some requirements for applications, namely long length more than one kilometer, high critical current and thermo-mechanical robustness. They are, however, facing some serious problems such as ballooning [1], which collapses the tapes with gas vaporized from liquid nitrogen that infiltrates the core of the tapes. The controlled overpressure sintering (CT-OP)[2] is a novel technique that could solve the problems and improve their performance drastically. The present study describes the typical specifications and characteristics of the drastically innovative Bi-2223 tapes (DI-BSCCO) to which CT-OP is applied, as the most advanced commercially produced high temperature superconductors.

2. Typical specifications
Figure 1 shows the aspect and the cross-sectional view of a kilometer long DI-BSCCO. Table 1 shows typical specifications and characteristics of DI-BSCCO. The present lineup includes two types, “High Ic” and “High Strength”. The difference of both types is the ratio of silver-alloy sheath as reinforcing member. The long length up to 1.5 km is available for both types. The CT-OP increases critical currents more than 1.5 times against those of the conventional tapes sintered at normal pressure. Mechanical properties are also improved drastically by CT-OP. The typical data are presented in the following sections.
Table 1. Typical specifications/characteristics of DI-BSCCO

| Items                        | High $I_c$ Type | High Strength Type |
|------------------------------|----------------|-------------------|
| Width                        | 4.3 ± 0.2 mm    |                   |
| Thickness                    | 0.22 ± 0.02 mm  |                   |
| Length                       | ~1500 m         |                   |
| $I_c$ (77K, Self Field)      | 110 A, 125 A, 150 A | 80 A, 100 A, 110 A |
| $I_c^*$ (77K, Self Field)    | 11 kA/cm$^2$, 12.5 kA/cm$^2$, 15 kA/cm$^2$ | 8 kA/cm$^2$, 10 kA/cm$^2$, 11 kA/cm$^2$ |
| Critical Tensile Strength** (RT) | 100 MPa | 170 MPa |
| Critical Tensile Strength** (77K) | 160 MPa | 230 MPa |
| Critical Bending Diameter** (RT) | 70 mm | 50 mm |
| Sheath                       | High Strength Silver-alloy | |

3. Critical current

Critical current should be inspected completely throughout the length of long wires, because only one defective portion on a long wire could cause a fatal problem such as a burnout to the whole system of applications. We established the sequential critical current measurement system that evaluates the transport properties in liquid nitrogen directly by four-probe technique on the long Bi-2223 tapes [3]. Every DI-BSCCO is qualified with this system before shipping. Figure 2 shows the critical current distribution on a “High $I_c$ Type” 1.1 km long DI-BSCCO wire as a typical measurement using the sequential measurement system. The critical currents are shown in figure 2 within a margin of plus or minus 3.5 percentage points against the average of 153 A for the total length. The n-indexes, derived from the exponent model on the electric potential as the function of transport current are also within a narrow margin of plus or minus 8.6 percentage points against the average of 21.1. The transport current dependence of the electric potential for the total length, which was derived from all of the data measured for each section, is presented in Figure 3. Both of the critical current and n-index, derived from the $E$-$I$ characteristics for the total length, are consistent with the averages of all values measured on each section.

The critical currents at a specific temperature and magnetic field, which is also required for the design of every application, are estimated easily with the measurement at 77 K by the abovementioned
system according to the simple scaling law [4]. More precise transport properties are measured on the short specimens sampled from long tapes with the temperature and magnetic field variable system [3]. Figure 4 shows the typical measurement in 20 K and the perpendicular transverse magnetic field of 3 T.

Figure 2. The measurement of transport properties all over the length on a “High Ic Type” 1.1 km long DI-BSCCO wire. The critical currents are defined with electric potential of $10^{-4}$ V/m. The n-index’s are defined with the electric potential range from $10^{-5}$ V/m to $10^{-4}$ V/m.

Figure 3. The whole length $E$-$I$ characteristics in 77 K liquid nitrogen on the wire described at figure 1.

Figure 4. The length $E$-$I$ characteristics in 20 Kelvin and 3 T perpendicular transverse magnetic field of the short specimen sampled from a long DI-BSCCO.

4. Thermo-mechanical robustness

Mechanical robustness of wires is especially required for applications where they cannot help the wires giving some stress or strain. DI-BSCCO demonstrates the highest mechanical properties without any additional reinforcing members except for the silver-alloy sheath due to the high density of HTS filaments. Figure 5 shows, for instance, the tensile stress dependence of the critical current as room temperature or liquid nitrogen on a “High Strength Type” DI-BSCCO. The stress is defined as the tensile force divided by the product of width and thickness of the tape. The critical tensile stresses, namely the irreversible limiting points at 95% retention for the initial critical current are 180 MPa and
245 MPa in room temperature and 77 K liquid nitrogen, respectively. They are corresponding to the strength more than 1.5 times against the normal sintered Bi-2223 tapes with the similar configuration. The high density of the HTS filaments also improves anti-ballooning properties [5]. Densification of the HTS filaments prevented liquid nitrogen penetration during long term exposure to liquid nitrogen. Any ballooning defects and degradation of critical current were not found in full length of several km long DI-BSCCO tapes after 24 hours immersion into 1MPa liquid nitrogen.

5. AC loss
Figure 6 shows the magnetic AC loss of a “High Strength Type” DI-BSCCO, as the function of the amplitude of the sinusoidal 50 Hz transverse field, which is perpendicular or parallel to the wide plane of the tape. They are considerable energy dissipations corresponding to the full coupled state on the whole filamentary area, because twisting is not adapted to the present DI-BSCCO. Alternative study describes the current status of the development for the low AC loss type wires [6].

References
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Figure 5. The tensile stress dependence of the critical currents on a “High Strength Type” wire in room temperature or liquid nitrogen. The critical currents are normalized by the unloaded initial value.

Figure 6. Magnetic AC loss of a “High Strength Type” wire in liquid nitrogen and 50 Hz parallel or perpendicular transverse magnetic field as a function of the external field amplitude. AC losses are normalized by the length and the critical current in 77 K, self-field of the specimen.