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International round Robin test for mechanical properties of BSCCO-2223 superconductive tapes at room temperature

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ABSTRACT

International RRT was carried out in order to establish the test method for mechanical properties of commercial BSCCO superconductive tapes under cooperation of seven research laboratories. From the stress versus strain curve, the following quantities were evaluated; modulus of elasticity, 0.2% proof strength, fracture strength and stresses at fixed strains. The scatter of measured values was analyzed by evaluating the relative standard uncertainty (*RSU*), which is the standard uncertainty divided by the average. The expected value of *RSU* for $N = 3$ was derived for each mechanical quantities. In order to make clear the major contribution to the scatterings, the *F* test was applied. The major source of *RSU*'s was attributed mostly to the influence of inter-laboratory scattering.

1. Introduction

Several types of composite superconductors have been now commercialized. Especially, the HT-SC BSCCO-2223 tape-shaped wires are now manufactured in the industrial scale, of which the major superconducting component comprises $(Bi, Pb)_2Sr_2Ca_2Cu_3O_{10}$ phase. Commercial composite superconductors have a high current density and a small cross-sectional area. The major application of composite superconductors is to build electrical power devices by using superconducting magnets. While the magnet is being manufactured, complicated stresses/strains are applied to its windings and, while it is being energized, a large electromagnetic force is applied to the superconducting wires because of its high current density. It is therefore indispensable to have full knowledge of the mechanical properties of the relevant superconductive tapes.

The BSCCO-Bi2223 superconductive composite tapes fabricated by the powder-in-tube method are composed of a number of oxide filaments with silver and silver alloy as a stabilizer and supporter, respectively. The tapes realize the high engineering critical current, but their tensile strength is rather low because the silver components are used under the fully annealed state. Therefore in order to resist the larger electromagnetic force, the external reinforcement of BSCCO tapes has been attempted by laminating thin stainless steel or brass foils. In the present paper, those two types of tapes are called the bare tape and the 3ply one, respectively.

The assessment of mechanical properties of some commercialized superconductive tapes has been carried out under the framework of international round Robin tests (RRT) [1,2], which mean the cooperative research among multiple laboratories by using the common samples. Based on their results, the international standard on the mechanical test was established for the Nb–Ti wires [3] and another has been proposed for the Nb_3Sn wires.

The preliminary study on the tensile property of BSCCO-2223 tapes was conducted in 2002 [4]. There the coefficient of variance (*COV*) was used as a measure of scattering of experimental data. Recently the technical committee TC90 of IEC decided to evaluate the scattering by using the uncertainty recommended in the guide (GUM:1955) [5] published by ISO/IEC. Recently International RRT was again conducted for BSCCO-2223 tapes, which was fulfilled under the activity of VAMAS/TWA16. The present study has been

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Table 1
BSCCO-2223 tapes used for the present RRT.

Sample	Materials for lamination	Typical values of width (mm) × thickness (mm)
E bare	Non-lamin.	4.0 × 0.21
S bare	Non-lamin.	4.3 × 0.23
S SS 3ply	Stainless steel	4.5 × 0.28
S brass 3ply	Brass	4.5 × 0.46

carried out under two purposes. One is to test the original bare tapes as well as the laminated ones developed recently. The second purpose is to change the evaluation technique based on the uncertainty analysis recommended by GUM:1955.

Here the results of RRT carried out by seven laboratories on four kinds of BSCCO-2223 tapes are reported. The standard uncertainty with observed values is discussed for necessary mechanical properties and the origin of scattering sources on the measurands is evaluated.

2. Experimental procedure

Four kinds of commercial BSCCO-2223 superconductive tapes were used as test samples in the present RRT, of which specification is listed in Table 1. Here SS and brass 3ply indicate the tape laminated by stainless steel and brass, respectively. Their cross sectional view is shown in Fig. 1. The S bare tape consists of BSCCO filaments (black part in the center) embedded in pure silver and the surrounded silver alloy (outer white part). The S SS 3ply is the composite of the S bare tape soldered with the stainless foils at both surfaces. The samples designated by the initial "E" and "S" have been supplied from European High Temperature Superconductors GmbH and Co., and Sumitomo Electric Industries Inc., respectively. The cross-sectional area of each sample was practically measured at each laboratory.

The number of participated laboratories was 7. Hereafter the symbol "$P_j(j = 1–7)$" is used for identifying the laboratory. Four pieces of each sample were delivered to each laboratory. The data obtained by three repeated tests for each sample was requested to be reported.

The test method for the BSCCO tapes had been discussed by the international member of WG5, IEC/TC90 since 2006. The Korean member of WG5 submitted a draft of the test method in February, 2007, which is called the text BSCCO07 after that. It is possible to request this text at the secretary office of IEC/TC90 [6]. According to the directions of the text BSCCO07, the international RRT started in April, 2007. Each laboratory provided his own setup for the tensile test, of which the conditions conform to the text BSCOO07. The total length of the test sample is the sum of inward distance between grips and both grip lengths. The inward distance between grips is 60 mm or more, as requested for the installation of the extensometers. The test machine and the extensometers shall conform to ISO 7500-1 and ISO 9513, respectively. The calibration shall obey ISO 376. The mass of the extensometer is 30 g or depending on wire diameter even less, so as not to affect the mechanical properties of the brittle reacted superconductive wire. The mass of the extensometers has to be balanced symmetrically around the wire to avoid any non-alignment force. The extensometer is attached at the center of sample between two grips. The reported values of extensometer gage length were in the range of 15 and 30 mm. The test consists of straining a test piece by tensile force beyond the elastic deformation regime, in principle for the purpose of determining the modulus of elasticity (E), the 0.2% proof strength ($R_{p0.2}$), and/or the fracture stress (R_f). Further the stresses at fixed strains were determined in the low strain region.

3. Experimental results

3.1. Stress–strain curve

Fig. 2 shows the typical stress versus strain curves for the present tapes. Two bare tapes revealed so low fracture strain that it was not possible to evaluate the 0.2% proof strength. Two laminated tapes, on the other hand, had sufficiently large elongation to determine the 0.2% proof strength.

The tensile test has been carried out as follows. The tensile machine was operated after the initial testing speed was set to the specified level. Various initial strain rates between 1.67×10^{-5} and 3.2×10^{-4} (1/s) were reported from seven laboratories. The strain and stress calculated from the output signals of extensometer and load cell, respectively were plotted on the abscissa and ordinate of the diagram as shown in Fig. 3. When the total strain reached a value of approx. 0.1%, the tensile force was reduced by approximately 30–40% without changing the strain rate. Then, the load was increased again to the previous level and the test was continued up to the point where the specimen is fractured. The fracture was reported to occur often at the position close to the grips.

3.2. Moduli of elasticity (E_o and E_u)

Modulus of elasticity was calculated using the following formula and the straight portion of the initial loading curve and of the unloading one,

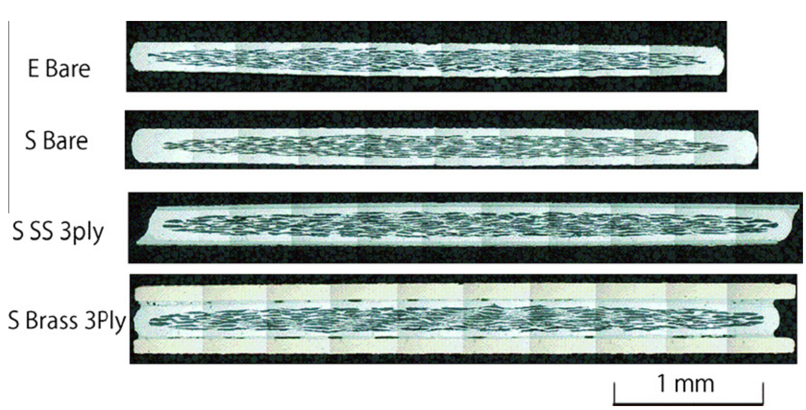

Fig. 1. Cross sectional view of the BSCCO-2223 tapes.