
Project Title:	Electromechanical Studies for Superconductor Development
Organization(s):	National Institute of Standards and Technology
Presenters:	Jack Ekin and Najib Cheggour
FY 2003 Funding:	\$195 K

Project Purpose and FY 2003 Objectives: This project provides the electromechanical data and research needed to develop YBCO and BSCCO superconductors for high-field magnet and electric power applications. Stress and strain management is one of the key feedback parameters needed to move the second generation conductors to the market place. The project utilizes the expertise and unique electromechanical measurement facilities at NIST to provide performance feedback to companies and organizations developing the conductors (AMSC, SuperPower, ORNL, LANL, ANL), as well as to provide engineering design data to the SPI partners.

The primary goals for FY 2003 were to (1) compile conductor mechanical requirements for a wide range of device applications, (2) measure the effect of *axial* strain (ϵ) on J_c in YBCO coated-conductors on pure-Ni and Ni-alloy RABiTS, as well as IBAD YBCO, at 76 K and self field, (3) measure the effect of axial strain on the J_c in YBCO RABiTS at 4 K as a function of high magnetic field, (4) study the microstructure of YBCO RABiTS samples after mechanical testing, using scanning electron microscopy (SEM), to evaluate failure modes and correlate with electromechanical data, (5) measure stress-strain characteristics of candidate substrate materials for RABiTS and IBAD development, (6) measure the effect of axial strain on the J_c in new Bi-2223 conductors produced by AMSC, and (7) compile materials data at cryogenic temperatures and finish editing the manuscript of a textbook on experimental techniques for cryogenic measurements.

FY 2003 Performance and FY 2004 Plans: Significant progress was made in all seven of the FY 2003 objectives: (1) Data on mechanical requirements were compiled from several companies developing HTS devices. (2) Comprehensive $J_c(\epsilon)$ measurements were made in a series of YBCO conductors on pure Ni, Ni-W and Ni-Cr-W RABiTS, as well as IBAD YBCO on Hastalloy substrate. (3) $J_c(B, \epsilon)$ tests at 4 K on Cu-laminated YBCO/Ni-W RABiTS are underway. (4) A microstructure study of YBCO RABiTS was carried out after mechanical testing. (5) Stress-strain measurements were made on various new substrate materials at room temperature, 76 K and 4 K. (6) $J_c(\epsilon)$ tests were made in a series of new Bi-2223 conductors. (7) U.S. and international technical reviews have been completed; 50 years of literature have been compiled into an extensive appendix (51 tables); and the text is scheduled for typesetting at Oxford Univ. Press in 2004.

FY 2004 plans (determined in consultation with the manufacturers and a number of research collaborators within the DoE/ES community). Direct feedback is given to the wire manufacturer within each project and then disseminated to the general wire-development and SPI community:

- Finish the series of studies of the effect of axial strain on J_c of the recently developed CVD and PLD coated conductors fabricated using the IBAD process on Hastalloy substrates.
 - Perform parametric studies of the response of YBCO coated-conductors to axial strain at high magnetic field at both 76 K and 4 K for both magnetic and non-magnetic deformation-textured Ni-alloy substrates.
 - Measure the effect of transverse stress on copper-laminated YBCO coated conductors at 76 K and self field, and at 4 K and 11 T.
 - Perform a parametric study of J_c vs. axial strain and J_c vs. transverse stress as a function of YBCO layer *thickness*, up to 5 μm , at 76 K and self field, in thick-film IBAD under development.
 - Check through *fatigue* testing that slitting procedures do not lead to early onset of degradation.
 - Evaluate the stress-strain characteristics of new substrate materials as they become available.
 - Perform axial strain tests on deformation-textured systems with new geometries as they become available.
 - Measure the effects of axial strain and transverse stress on J_c degradation in laminated Bi-2223
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conductors being produced for the SPI program.

- Study the effect of overpressure treatment on Bi-2223 for both axial and transverse stress degradation at 76 K and self field.

FY 2003 Results: Key results from the FY 2003 program are summarized below.

- a. A comprehensive survey of several US companies developing devices based on HTS wires was conducted. Conductor mechanical requirements for power-cable, motor, generator, and industrial-magnet applications were assembled from multiple sources including AMSC, DuPont, General Electric, Rockwell, Southwire, as well as the SPI program office. These requirements covered benchmark limits of axial tensile/compressive stress and strain, transverse compressive stress, transverse loading, and thermal/mechanical stress cycles for the four groups of applications mentioned above. We made this data compilation available to the entire community by presenting it at the Florida meeting (2003). This was particularly useful for the wire developers, by defining the mechanical requirements their conductors must meet, and for us in order to correlate our electromechanical data on wires to these requirements.
- b. Comprehensive $J_c(\varepsilon)$ measurements were made in a series of YBCO on pure Ni, Ni-W and Ni-Cr-W RABiTS, as well as IBAD YBCO on Hastalloy. The onset of $J_c(\varepsilon)$ degradation in YBCO/Ni-alloy RABiTS occurs at a strain about twice that for YBCO/pure-Ni and, remarkably, significantly beyond the yielding strain of the substrate for all three RABiTS systems. For YBCO/Ni-alloy composites, 5 % $J_c(\varepsilon)$ -degradation corresponds to a strain of 0.56 %, showing the benefit of using strong Ni-alloy materials for the substrate, and indicating that these conductors may satisfy axial-strain performance requirements for the various device applications surveyed in item *a*, including the most demanding of the superconductor applications -- rotating machinery, both motors and generators.

Furthermore, the YBCO/Ni-5at.%W and YBCO/Hastalloy conductors showed an *elastic* strain effect that extends significantly beyond the degradation onset. This new effect may be induced by a reversible strain-field broadening around mismatch dislocations at the grain boundaries. This result is significant, since this may further extend the usable strain range of coated conductors.
- c. The microstructure of YBCO conductors was studied after axial-strain testing. SEM micrographs showed evidence of cracks in the YBCO layer, transverse to the strain direction. Cracks of various lengths from 1 to 15 μm and a width distribution that averages around 50 nm, are distributed throughout the sample area. Crack density appears to be higher for YBCO/pure-Ni as compared to YBCO/Ni-alloy. These results may lead to a better understanding of the crack initiation mechanism in the brittle superconductor/buffer layers.
- d. Measurements of stress-strain characteristics on coated conductor and a number of new substrate materials were obtained at room temperature, 76 K and 4 K. Annealed substrates were supplied by American Superconductor, and SuperPower. They include Ni-10at.%Cr-2at.%W RABiTS, as well as Inconel 625 and Hastalloy C-276. The modulus of elasticity, yield strength, and proportional limit of elasticity were determined for these substrate materials and added to our database on substrate mechanical properties for feedback to the wire manufacturers.
- e. New Bi-2223 conductors with two different metallurgies have been tested to supply design data to the SPI partners. Cu-laminated YBCO/Ni-W RABiTS were received from AMSC. These samples are suitable for testing at 4K. $J_c(\varepsilon)$ measurements at high magnetic field are underway to provide in-field design data for several of the SPI projects.

Research Integration: NIST collaborates closely with researchers and managers at American Superconductor and SuperPower, ORNL, LANL, and ANL to implement a research program that utilizes NIST's specialized electromechanical test facilities and expertise. The resulting data provide feedback to the wire manufacturers, national laboratories, and SPI application developers, where they are integrated into conductor development and system design processes. Several collaborative papers with these

organizations have been published or are being written. A strain benchmark survey was also conducted of many of the SPI organizations, including AMSC, DuPont, General Electric, Rockwell, Southwire, and the results shared with the DoE/ES community.
