

Mechanical Properties and Strain Effects in $\text{Bi}_2\text{Sr}_2\text{CaCu}_2\text{O}_x/\text{AgMg}$ Composite Conductors

Justin Schwartz^{1,2,3}, Bruce C. Amm^{1,2}, Hamid Garmestani^{1,2}, David K. Hilton^{1,3}, and Yusuf Hascicek¹

¹National High Magnetic Field Laboratory, Florida State University, Tallahassee, FL USA

²Department of Mechanical Engineering, FAMU-FSU, College of Engineering, Tallahassee, FL, USA

³Department of Physics, Florida State University, Tallahassee, FL, USA

Abstract — The development of powder-in-tube $\text{Bi}_2\text{Sr}_2\text{CaCu}_2\text{O}_x$ technology has progressed such that high critical current density (J_c) conductors are produced by many researchers. Prototype systems are being tested to demonstrate engineering feasibility. An important issue that remains, however, is the effect of mechanical strain. While it is evident that large strains induce irreversible damage, applications may be limited by fatigue at low strain values due to crack propagation. Here we report on the development of two devices designed specifically to study strain effects in high temperature superconducting tapes. Preliminary results of the effects of cyclic fatigue on J_c of AgMg-clad $\text{Bi}_2\text{Sr}_2\text{CaCu}_2\text{O}_x$ as measured by electrical transport is shown. Measurements of the constituent and composite mechanical properties are also reported.

I. INTRODUCTION

As the $\text{Bi}_2\text{Sr}_2\text{CaCu}_2\text{O}_x/\text{Ag}$ (BSCCO/Ag) and Ag-alloy composite superconductors approach commercial viability, it is important to investigate the more practical engineering properties of stress, strain, and fatigue behavior of these materials. As an example, the NHMFL has the goal of a 1 GHz NMR magnet. Such systems must have long lifetime while the nature of mechanical forces they may face is unknown. In the case of composite ceramic superconductors, there is the added complexity of the effect of these forces on superconducting properties. The local peak strain within the superconductor filaments may limit the coil properties [1,2]. Recent work suggests that BSCCO tape properties degrade with cycling at low strain. Such fatigue behavior may limit other applications and relate to the fundamental J_c limit as well.

Here we report on techniques to analyze strain effects in HTS conductors. To achieve this goal, the constituent materials of the HTS tapes are first examined. Then, the mechanical properties of the HTS materials itself is studied. Understanding the relationship between mechanical properties and J_c is the ultimate goal. Preliminary results for J_c as a function of applied cyclic strain is reported.

II. EXPERIMENTAL PROCEDURE

Due to the small size of the typical BSCCO/AgX superconducting tape, standard testing machines (hydraulic and pneumatic MTS types) are unusable. The loads required to fail such tapes does not usually exceed 200 N (45 lbf). Also, the tape geometry (width to height ratios on the order of 20 or more) necessitate special gripping techniques. Smaller and more sensitive instrumentation is required to perform mechanical testing. Two devices have been specifically developed for such small scale testing. One device, for room temperature tests, employs a stepper motor and conventional transducers for force and extension measure. The other device, for cryogenic temperature testing, uses a more novel approach employing Lorentz force and capacitance to make the required measurements.

A. Room Temperature Device

The room-temperature mechanical tester, shown in Fig. 1, is a table-top device employing a linear stepper motor capable of delivering 330 N (75 lbf). Small 50 and 150 lbf load cells and Linear Variable Displacement Transducers (LVDT) are employed for highly accurate measurement of applied load and displacement. The load cell has a resolution of 6.0 mN and the LVDT has a resolution of 0.6 μm . The sample is placed between the grips and pulled as in traditional tensile testing. Typical sample gauge lengths are on the order of 35 mm and the device can accommodate a length as small as 30 mm and as large as 50 mm. Computer control through an IEEE 488 (GPIB) bus allows complete test control. The samples can be run through a tensile test until failure, or they can be fatigued using either a strain limit or a test limit.

B. Liquid Helium Temperature Device

The LHe temperature tester is a new apparatus that utilizes the circumferential stress induced by the current carried in a conductor of circular geometry in a uniform externally applied magnetic field (Lorentz force). The conducting sample to be tested is wound around a disk in a nearly complete circle, and placed in the bore of solenoid magnet. When current is run through the sample while the magnet provides a

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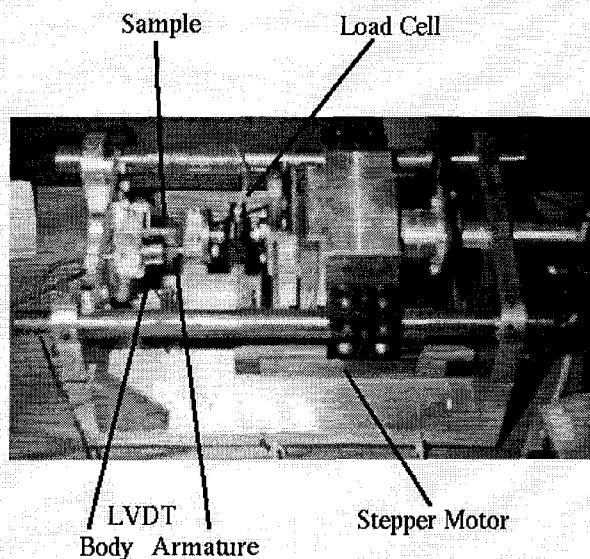


Fig. 1. The table-top testing device

uniform field, the circumferential stress is easily calculated from the sample current density J (A/m^2), sample radius r (m), and the applied magnetic flux density B (T) as $\sigma = J B r$ (Pa). The range of applied stress is thus limited by the bore size and magnetic field of the magnet and the maximum current density in the sample. For resistive materials, J is limited by heating and it is important to monitor the sample temperature via continuous, simultaneous, I-V measurements on the sample. For High Temperature Superconductor (HTS)

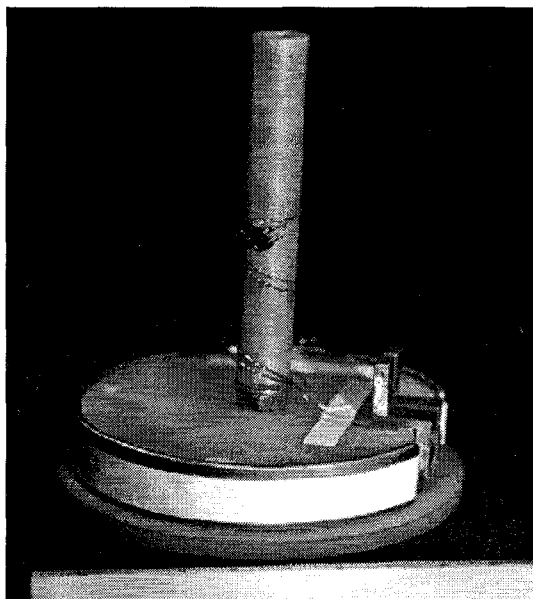


Fig. 2. The LHe temperature device. The white is the Kapton dielectric on top of the Cu "plate". The sample is then attached concentrically and serves as the other plate of the capacitor.

samples, heating only becomes an issue if $J > J_c(H, T)$. In this case, changes in J_c with cycling are monitored in real-time.

The strain in the sample is determined by a capacitive technique. Using the sample as one plate and a copper strip on the circular test rig as a second, a capacitor can be formed. A piece of Kapton tape is used as a dielectric between the two strips (to prevent shorting). As the sample deforms, the capacitance of the circuit changes. By connecting the circuit to an external inductor, a LC oscillator is formed. Thus, by measuring the frequency of this LC oscillator, which can easily be converted to a change in the capacitor gap, the strain of the sample is calculated directly. By careful control of the applied current, a sample can be run through a typical stress-strain test or it can be fatigued by cycling the applied current.

C. Sample Preparation

Several different materials were tested in the devices. The first material tested was well characterized Cu for benchmarking purposes. Once the results of the testers were confirmed accurate, the relevant materials were tested. The sheath materials of annealed Ag tape and oxidized Ag1.2at%Mg tape were tested. Powder-in-tube (PIT) AgMg/BSCCO tape was tested. The tapes were heat treated in straight samples for the room temperature tester, and heat treated curved for *in-situ* tests.

IV. RESULTS

A. Room Temperature Tensile Testing

The first tests conducted were simple stress-strain test to failure on all samples. This was used as a confirmation of the expected values for the metals, and to give a feel for the behavior of the BSCCO/AgMg. Typical results from such tests are shown in Fig. 3.

B. Liquid Helium Temperature Testing

The first tests conducted were once again simple stress-

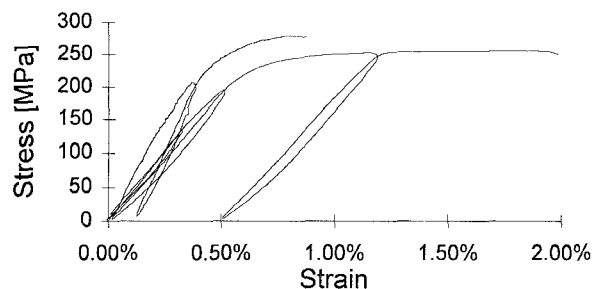


Fig. 3. Stress-strain curves for AgMg (upper) and AgMg/BSCCO (lower) at room temperature.

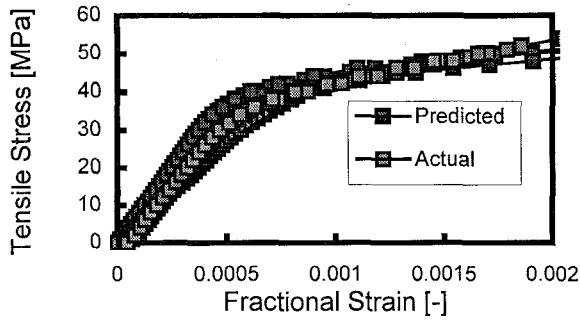


Fig. 4. AgMg stress-strain results at 4.2K. Shown are the predicted and actual values.

strain tests of all samples. The results from this test are shown in Fig. 4. In this figure, “Actual” refers to measured stress-strain values, while “Predicted” was determined using literature values and adjusting for thermal expansion due to resistive heating. The sample temperature was monitored via I-V measurements and previously measured resistivity data. The point at which heating plays a factor in the measured strain is apparent from the figure and should not be confused with mechanical yielding.

C. Young’s Modulus Values

The results of Young’s Moduli measurements are summarized in Table I. For the 4.2 K data, only the lowest stress-strain range of data was used so that heating was not an issue.

D. Effects on J_c

Mechanical cycling was applied to the BSCCO/AgMg conductor. The room temperature device was used to apply 10 and 100 cycles at 0.15% strain. One sample was also strained to yield in the first cycle for comparison. The 4.2 K

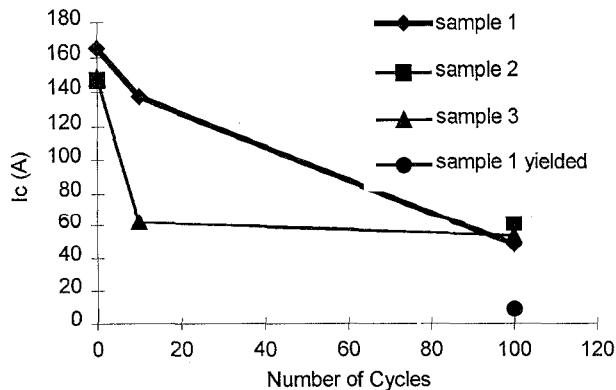


Fig. 5. J_c vs number of cycles (N) of AgMg/BSCCO for room temperature mechanical cycling

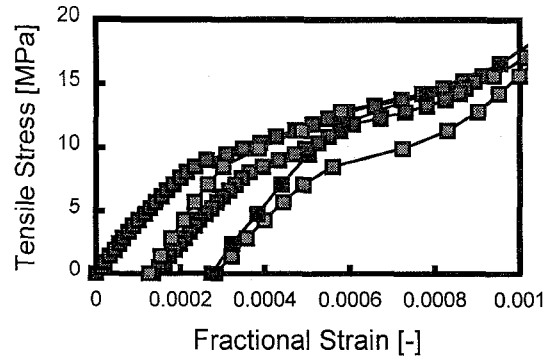


Fig. 6. Three up-down cycles of AgMg/BSCCO at 4.2 K.

device was used to apply a few large-strain cycles.

Fig. 5 shows J_c versus the number of cycles (N) at 0.15% strain. As expected in a moncore tape, significant damage resulted. In the yielded sample, less than 7% of the initial critical current remained.

Fig. 6 shows three up/down cycles at relatively high strain. As $J > J_c$ was required to introduce the large strain, heating occurred and precise stress/strain values are not easily obtained (thermal expansion of the AgMg/BSCCO is not accurately known). Fig. 7 shows the corresponding electric

TABLE I
YOUNG’S MODULI RESULTS

E (GPa)	Linear (RT) [3]	Literature (RT)	Hoop (4.2K)	Literature (4.2K) [3]
Ag	80 [9%]	75 [5%]	76 [7%]	87
AgMg	82 [6%]		68 [10%]	
AgMg/BSCCO	52 [10%]		43 [10%]	

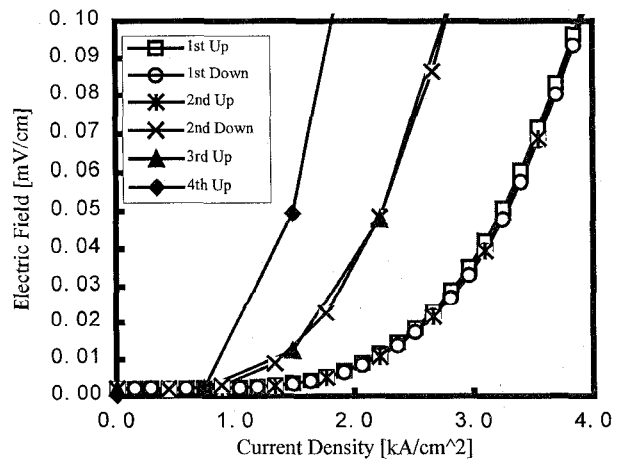


Fig. 7. E-J data for up-down cycling of AgMg/BSCCO at 4.2 K, showing large degradations of J_c .

field versus current density for these cycles. Significant degradation of the conductor is clearly demonstrated. More detailed study at lower strain values is necessary.

V. CONCLUSION

Two effective devices for mechanical testing have been developed. The room temperature device allows fatigue studies over the entire σ - ϵ range. The LHe temperature *in situ* device is ideally suited for HTS studies, but at present, is limited to low ϵ due to heating above J_c . This device will still allow for low strain fatigue cycling to be done. With the 200 mm, 20 T resistive magnet coming online at the NHMFL in

the spring of 1997, a larger similar device will allow for greater stress-strain levels to be investigated with simultaneous monitoring of the superconducting behavior.

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