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Stress-Strain relationship, critical stress, and irreversible stress of REBCO coated conductor wires under uniaxial tension

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Introduction

The mechanical behaviors of a REBCO coated conductor wire under uniaxial tension are largely determined by the two thickest component layers in the architecture, namely the substrate and the stabilizer. A rather complicated stress-strain relationship is often observed when the composite conductor is under uniaxial tension, which is the result of the differences in elastic modulus and yield stress between the Hastelloy substrate and the electroplated Cu stabilizer. In this study, the stress-strain relationships of a free standing Cu stabilizer and a partially processed wire, i.e., a tape without any stabilizer were measured. The results are utilized for the calculation of fully processed SCS (Surround Copper Stabilizer) type wires using a two-component composite model, given the thicknesses of the substrate and stabilizer. The calculated results agree well with the measured stress-strain curves which otherwise can be well fitted with the Ramberg-Osgood equation. The tensile stress (strain) dependence of the critical current (I_c) was experimentally studied at 77K in liquid nitrogen. The critical current were measured either with a wire under the load or after the load was completely released in such a way a critical stress ($\sigma_{c,0.95}$) and an irreversible stress ($\sigma_{irr,0.99}$) are determined, respectively.

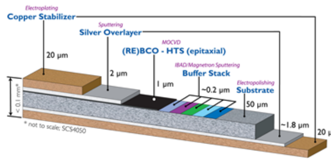

Figure 1. SCS type REBCO wire architecture

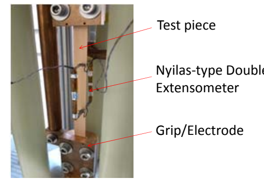

Figure 2. Tensile testing setup

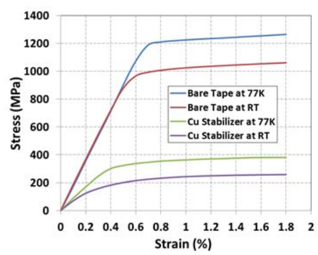

Figure 3. Measured SS relationship of bare REBCO tape and electroplated Cu stabilizer

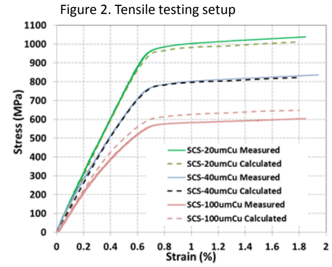

Figure 4. Calculated and measured SS relationships of SCS wires on 50µm thick Hastelloy with various Cu stabilizer thickness (77K)

Stress-strain relationship measured at RT or at 77K in LN2 for

- Electroplated Cu stabilizer, free standing samples prepared by peeling off Cu layers from SCS type wires
- Partially processed wires, e.g., tape after MOCVD, which is bare REBCO tape without any stabilizers
- Fully processed wires, SF type or SCS type, i.e., without or with Cu stabilizer

Stress-strain relationship can be calculated for an SCS wire given any thickness of "bare tape" and "Cu stabilizer"

- Two-component assumption, i.e., "bare tape" in parallel with "Cu stabilizer", or component "1" and "2"
- Equal strain assumption, i.e., same strain in "bare tape" and "Cu stabilizer"
- $\sigma=F/A=(F_1+F_2)/A=(\sigma_1A_1+\sigma_2A_2)/A$, where σ_1 and σ_2 are determined from measured SS relationships given a strain

Curve fitting of measured stress-strain relationships using Ramberg-Osgood equation

$$\epsilon = \frac{\sigma}{E} + 0.002\left(\frac{\sigma}{\sigma_{0.2}}\right)^n$$

where E is elastic modulus, $\sigma_{0.2}$ is yield stress, and n is Ramberg-Osgood parameter

Table I: 77K curve fitting parameters

Tape Type	E (GPa)	$\sigma_{0.2}$ (MPa)	n
Bare Tape	180	1225	56
SCSXX50-20Cu	150	998	38
SCSXX50-40Cu	125	795	38
SCSXX50-100Cu	98	580	38
Cu Stabilizer	85	339	15

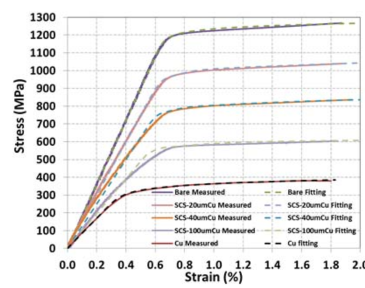

Figure 5. Measured stress-strain relationships and curve fitting with Ramberg-Osgood equation (77K)

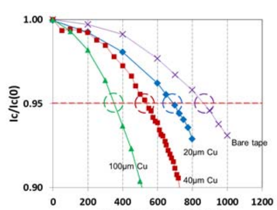

Figure 6(a). Ic/Ic(0) vs. stress measured with stress on (77K)

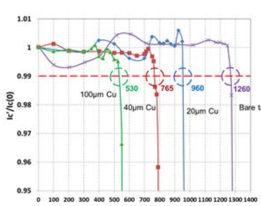

Figure 7(a). Ic'/Ic(0) vs. stress measured after stress released (77K)

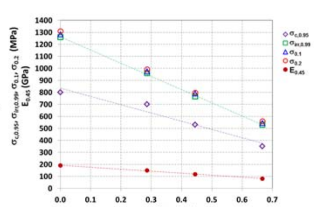

Figure 8. Cu thickness dependence of the properties (77K)

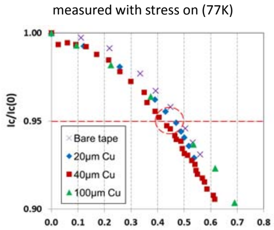

Figure 6(b). Ic/Ic(0) vs. strain measured with stress on (77K)

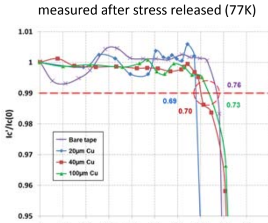

Figure 7(b). Ic'/Ic(0) vs. strain measured after stress released (77K)

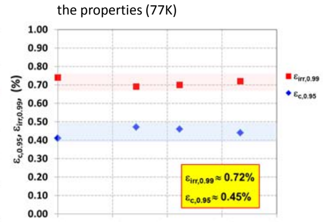

Figure 9. Cu thickness dependence of the properties (77K)

Conclusions

- Tensile tests were performed on free standing electroplated Cu stabilizer, resulting in elastic modulus (E) of about 70GPa and 85GPa, and yield stress ($\sigma_{0.2}$) of about 200MPa and 340MPa, at RT and 77K respectively.
- The elastic modulus (E), yield stress ($\sigma_{0.2}$), critical stress ($\sigma_{c,0.95}$), and irreversible stress ($\sigma_{irr,0.99}$) of the REBCO wires decrease with increasing Cu thickness or Cu/(Cu+Sub) thickness ratio.
- Critical strain ($\varepsilon_{c,0.95}$) and irreversible strain ($\varepsilon_{irr,0.99}$) are independent of Cu thickness, being intrinsic values at 0.45% and 0.72%, respectively.