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Transverse, axial and torsional strain in ReBCO tapes; experiments and models

C. Zhou[1], K. Ilin[1], K. A. Yagotintsev[1], P. Gao[1], J. Kosse[1], M. Dhalle[1], W. A. J. Wessel[1], H. J. G. Krooshoop[1], T. J. Haugan[2], D. C. van der Laan[3], A. Nijhuis[1]

1. University of Twente, Faculty of Science & Technology, The Netherlands
2. US Air Force Research Laboratory, USA
3. Advanced Conductor Technologies and University of Colorado, USA

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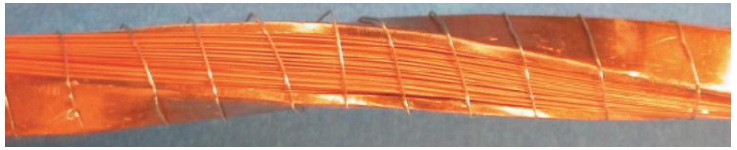
Outline

- Introduction
- Experimental setups
  - ReBCO tape torsion-tensile studies
  - Transverse stress on ReBCO tapes
- Results and analysis
- Summary

Introduction. ReBCO cabling methods

- Conductor on Round Core (CORC)
- Twisted Stack-Tape Cable
- Roebel Cable

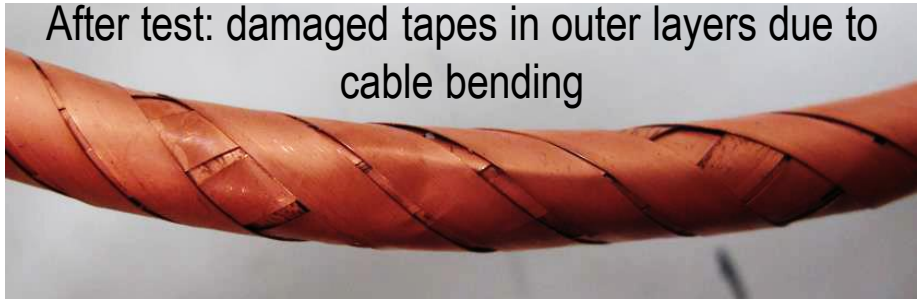
D.C. van der Laan, *SUST* 22, 065013 (2009).



M. Takayasu, *IEEE 23,* 4800104 (2013).

W. Goldacker, Journal of Physics, *43* (2006).

Tape performance when subjected to (combined) torsion, tensile and transverse loading is the key to understand limitations for cable performance.

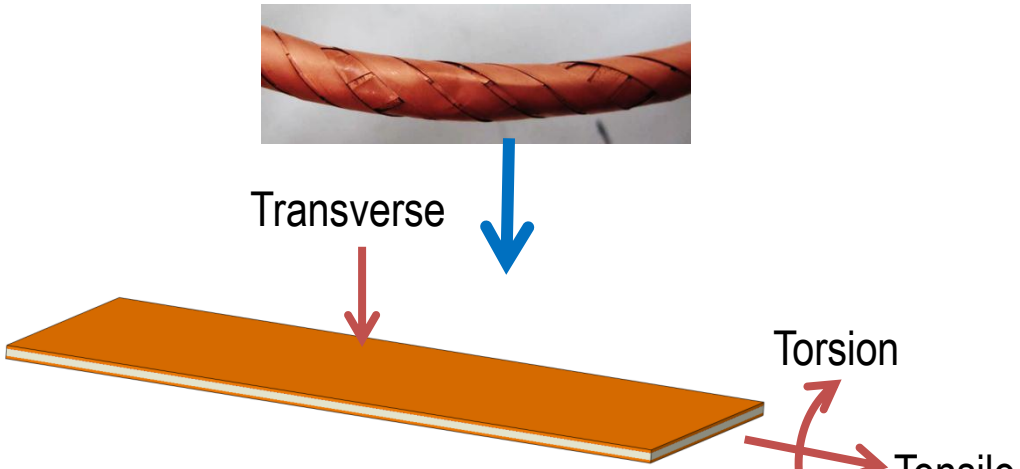


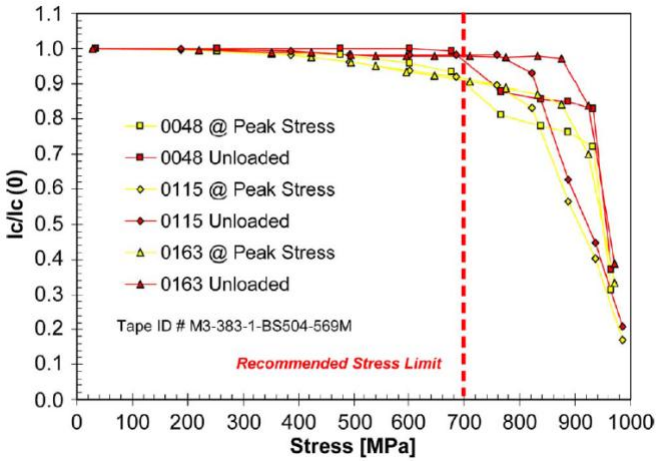
Objective

Modeling of the stress-strain state in a REBCO tape at various loads (temperature, tensile, torsion, transverse load, etc.)

The ultimate goal is to predict the critical strain level of the tape under cabled conditions

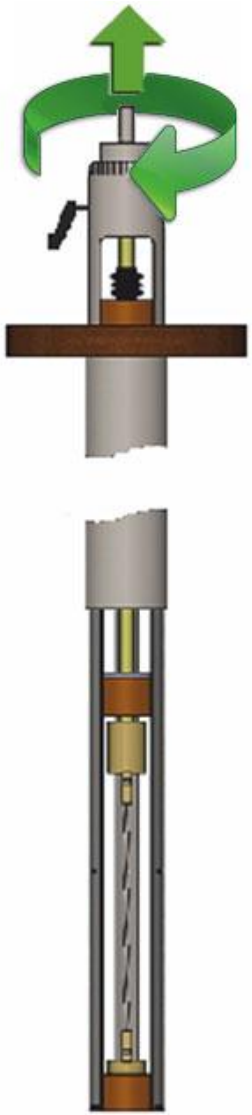
ABAQUS software for modelling with mechanical material properties as inputs (from litt & dedicated experiments)





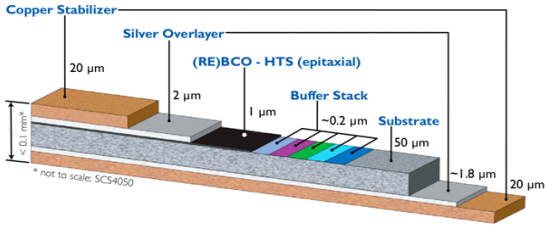
Plot of normalized critical current vs. applied axial stress on a 4 mm wide, SCS4050 SuperPower 2G HTS wire

ReBCO torsion – tensile test



Torsion under controlled axial tensile load by linear stage from TARSIS facility.

Sample - SuperPower SCS 4050 tape

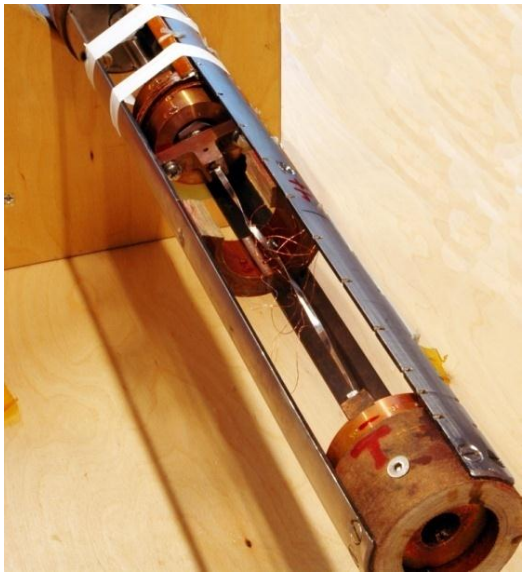


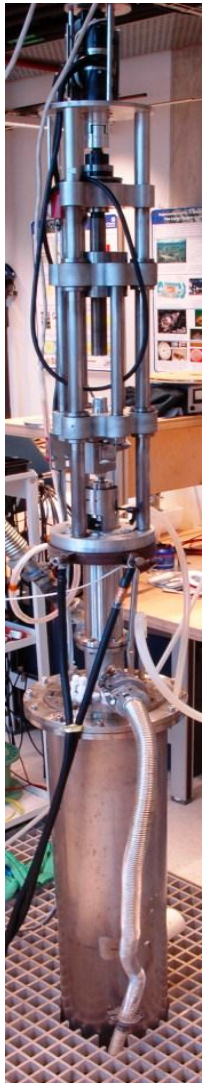
L-tape=175 mm
5 Vtap pairs

Torsional angles used in combiend torsion-tensile tests:

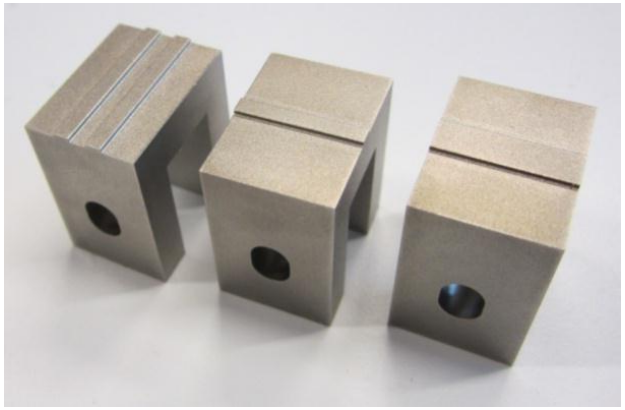
$$\varepsilon_{tor} \equiv \mathrm{t}\frac{\theta}{L}$$

0^0 - $\varepsilon_{tor} \sim 0\%$
300^0 - $\varepsilon_{tor} \sim 0.31\ \%$
480^0 - $\varepsilon_{tor} \sim 0.5\ \%$

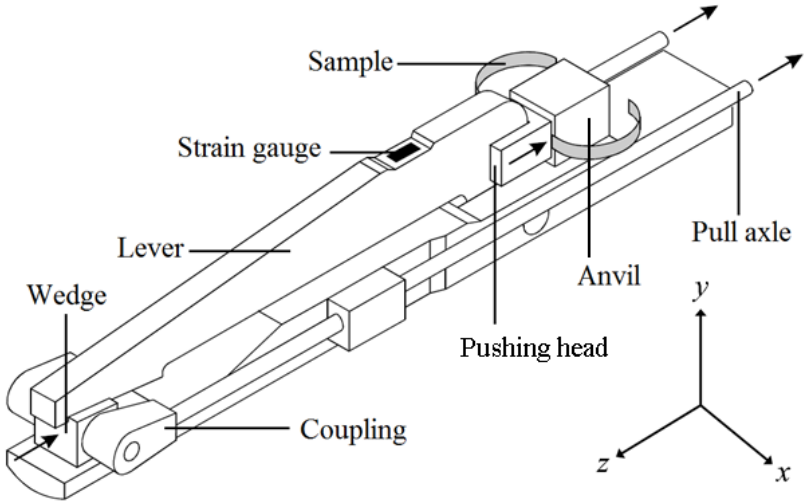


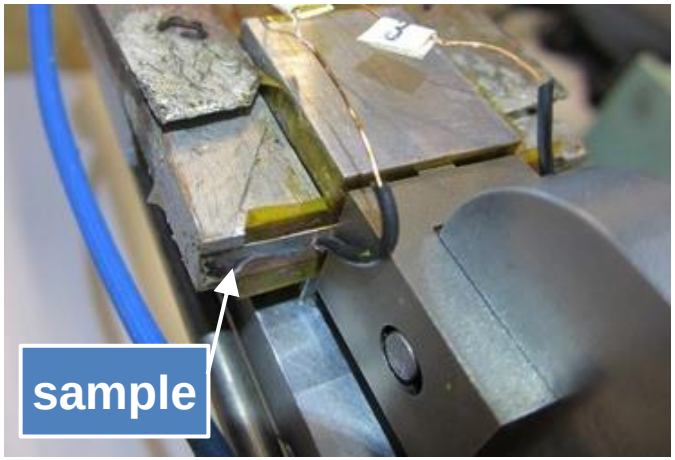


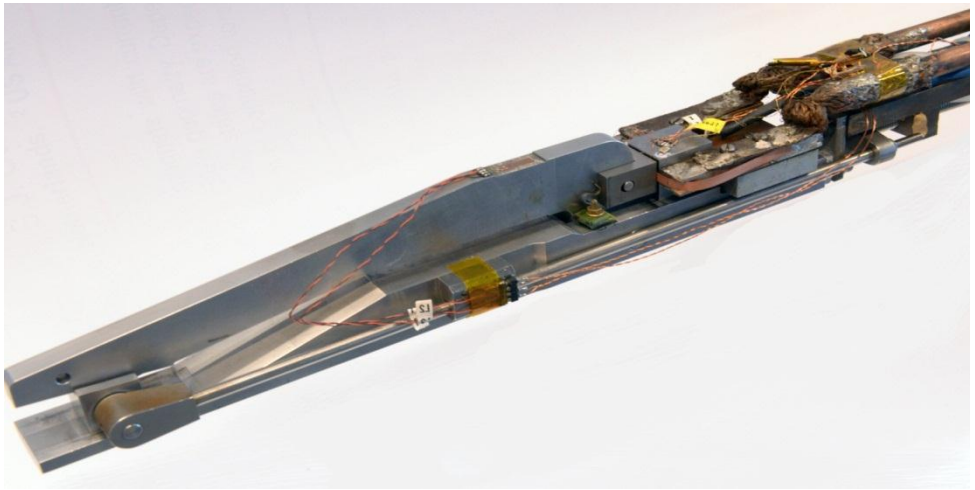
Tape transverse stress setup



Different types of pushing heads allow to control pushing area and stress.

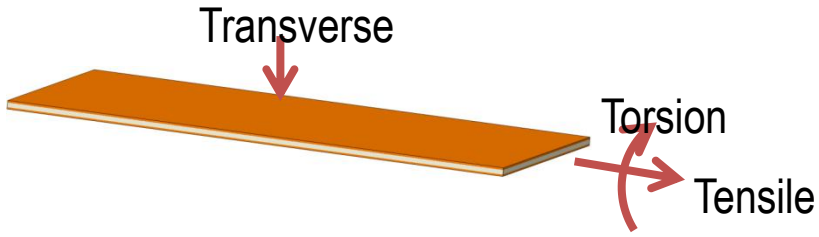






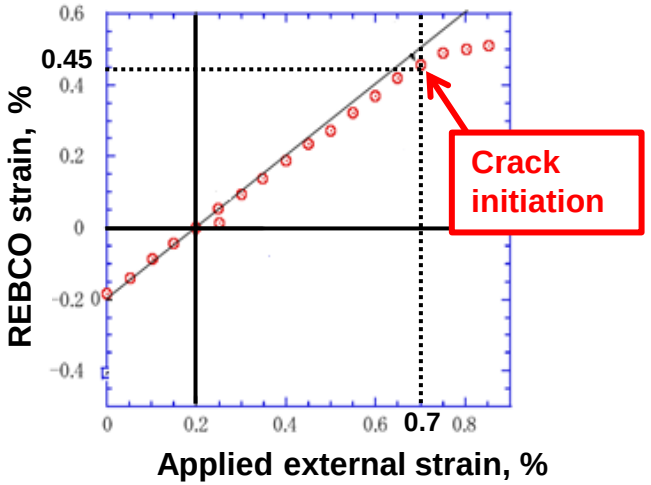
Transverse stress at 77 K, calibrated strain gauge for applied force measurement.

Modeling Assumptions (ABAQUS)

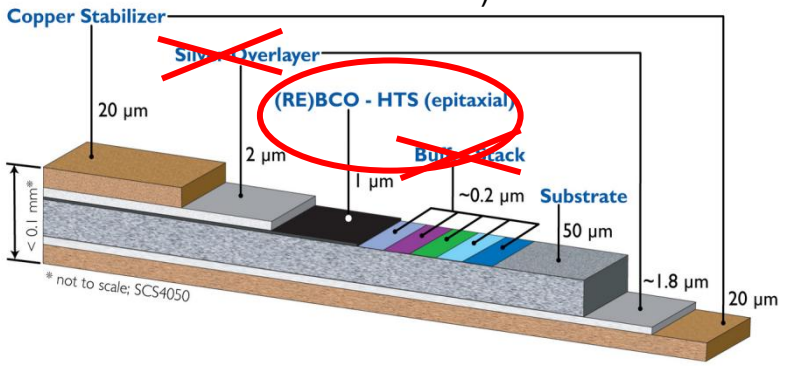


- Degradation of the critical current depending on the strain state of the REBCO layer at the instant of crack initiation (K. Osamura et al.)
- Buffer layers and silver layers do not significantly influence the mechanical behavior of the tape
- SCS4050 SuperPower tape for most experiments and modeling

FE mesh of the tape



State of residual strain on the REBCO layer as a function of applied external tensile strain at RT. (Kozo Osamura et al.)



Configuration of SuperPower 2G HTS Tape SCS4050

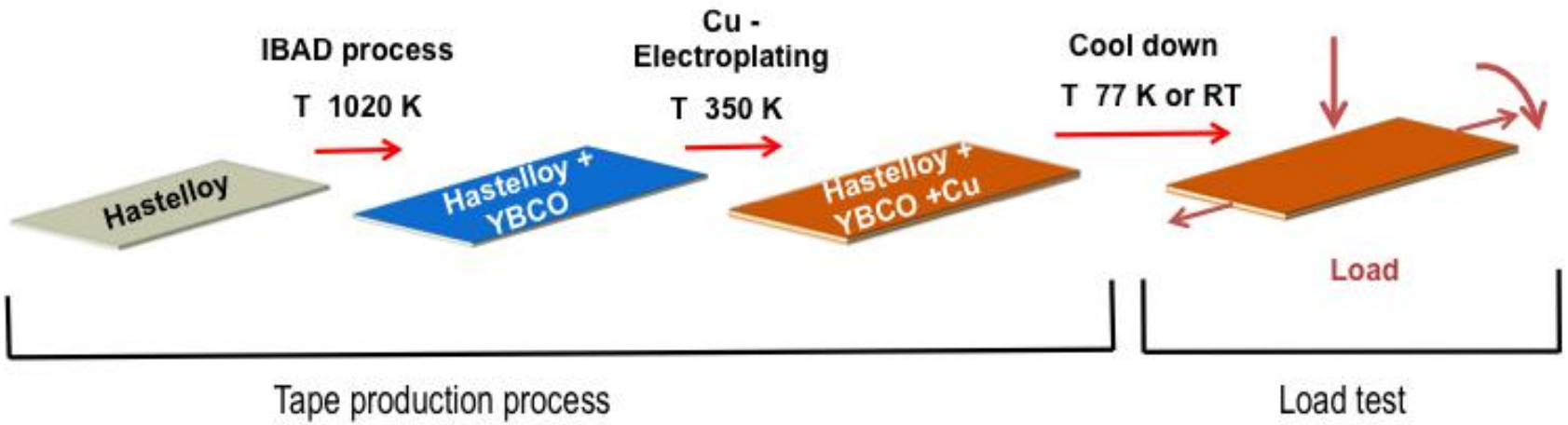
Modeling: properties of materials

Tape SCS4050:

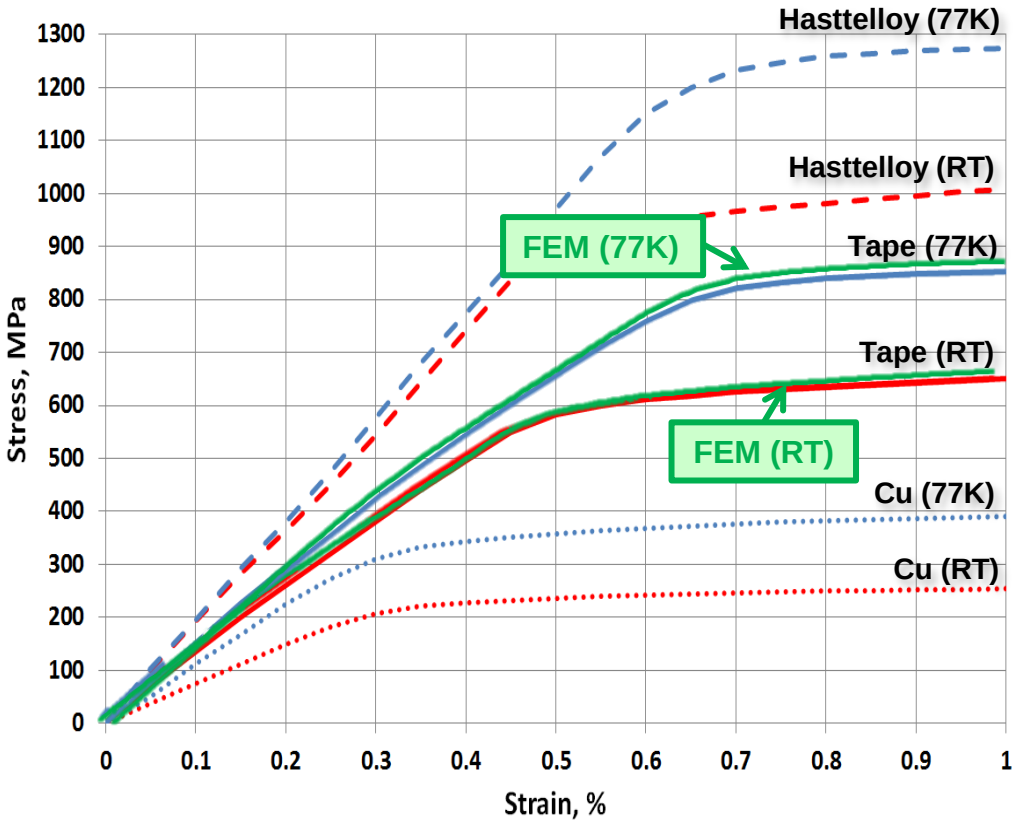
- Substrate (Hastelloy C-276)
- Copper (Electroplating)
- REBCO

It is necessary to model the production process because of the thermal residual strain (~ -0.2 %) at RT in the REBCO layer.

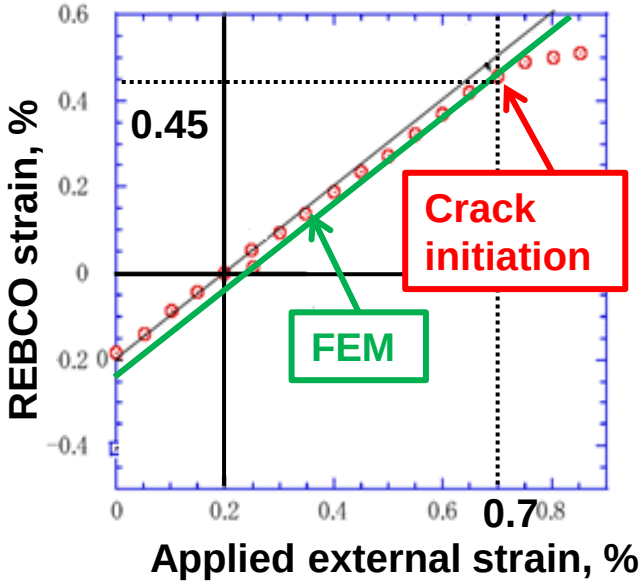
Needed: thermal expansion coefficients and elasto-plastic material properties depending on temperature.



Simulation results: tensile

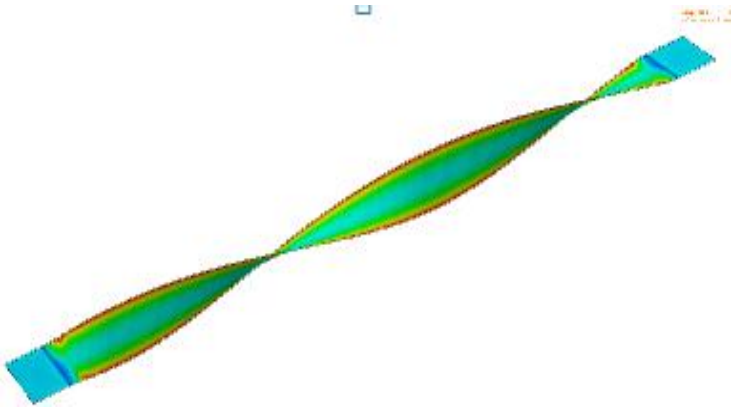


Tensile test and FEM stress vs. strain data for the tape SCS4050 at RT and 77K.

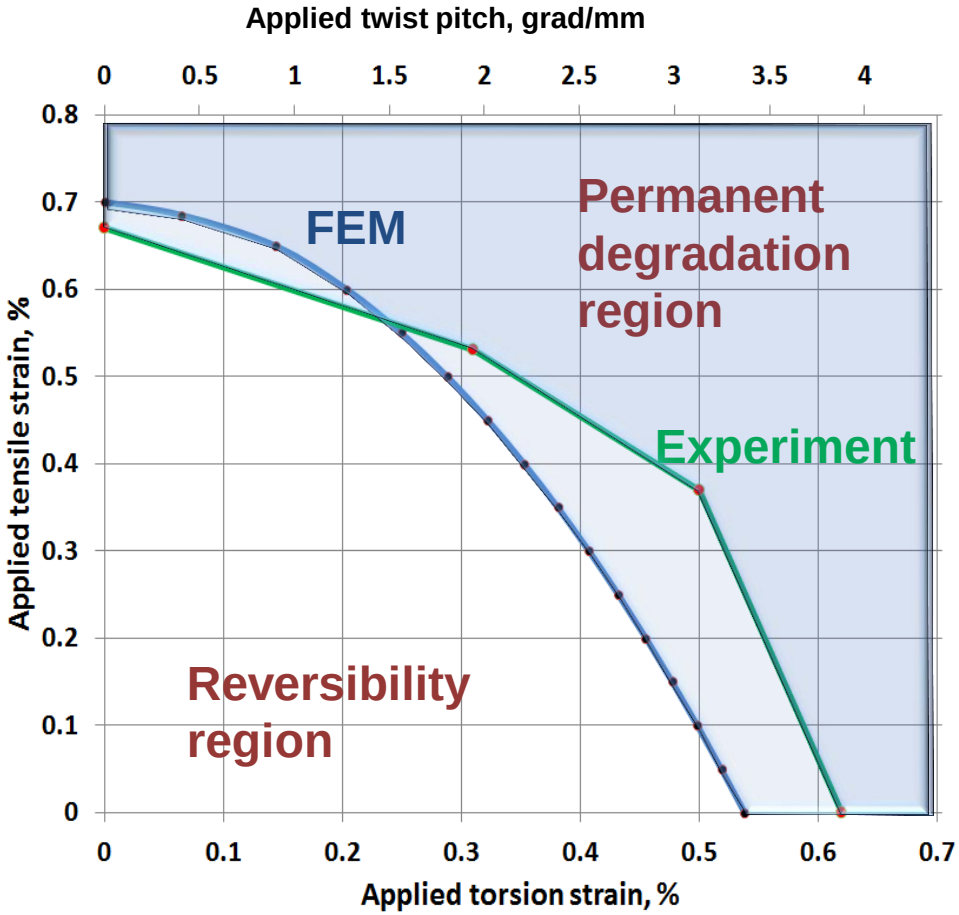


State of residual strain on the REBCO layer as a function of applied external tensile strain at RT from neutron diffraction experiment (Kozo Osamura et al.) and FEM results at RT.

Results: torsion - tensile



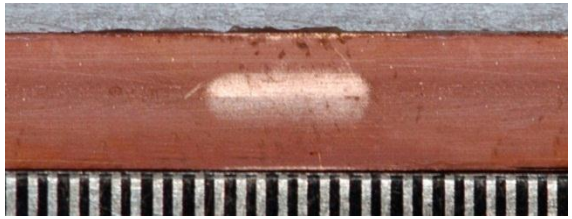
FEM simulation:
Tensile – Torsion at 77 K.
Longitudinal strain in REBCO layer



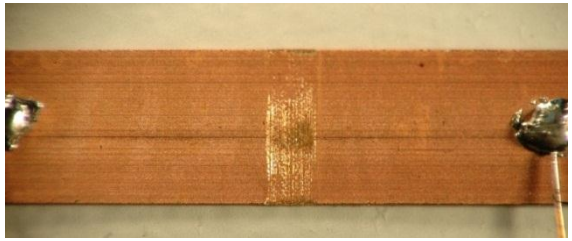
Critical strain in REBCO layer as a function of applied external tensile strain and applied torsion strain at 77K

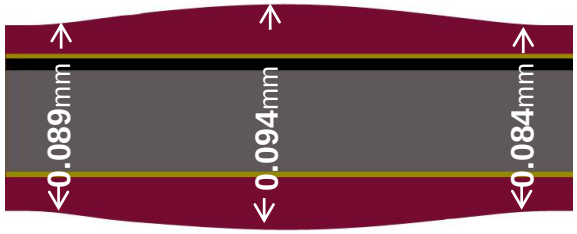
Transverse stress on SuperPower SCS4050

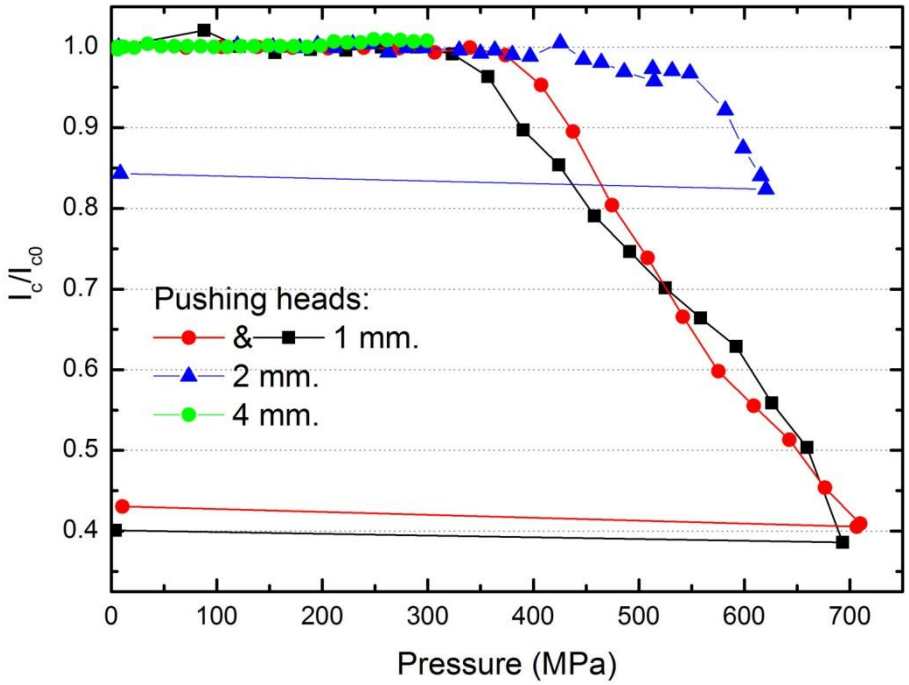
4mm pushing head



1mm pushing head

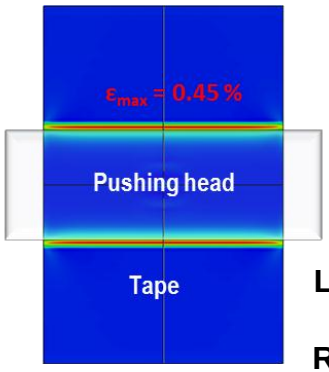




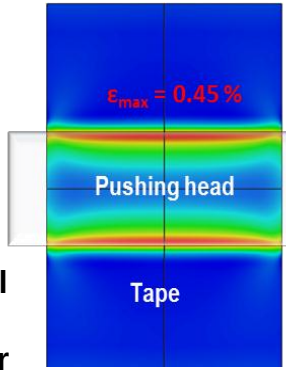


- Tape thickness not uniform over tape width.
- Non homogenous pressure distribution causes early degradation

FEM results: transverse load, thickness of the copper

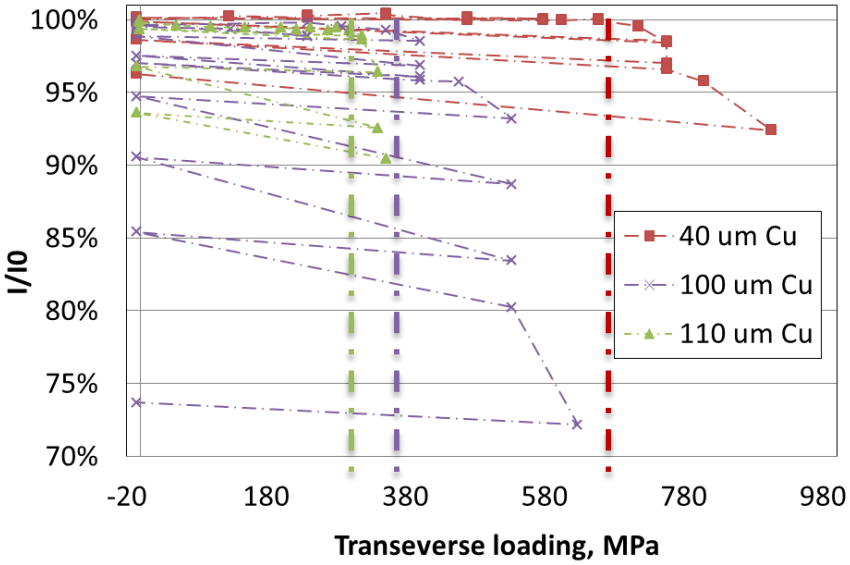


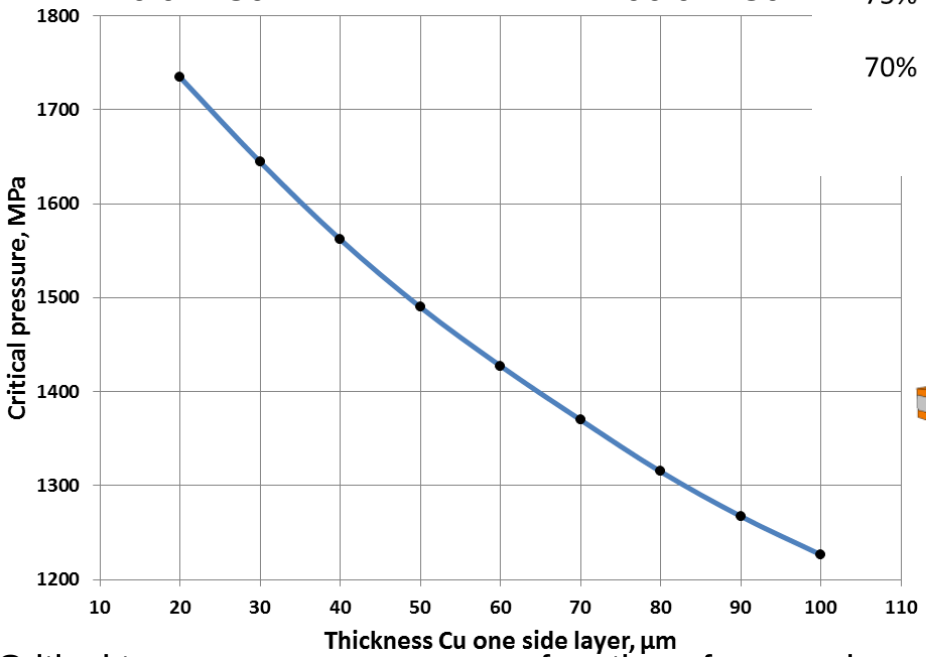
Longitudinal strain in ReBCO layer

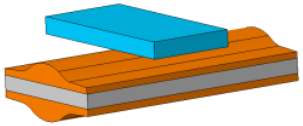


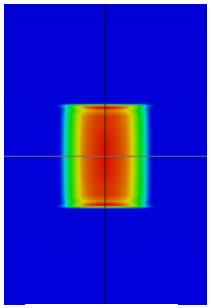
40 um Cu

100 um Cu

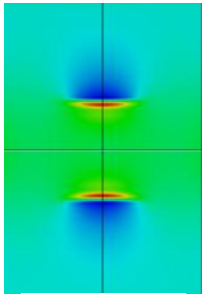








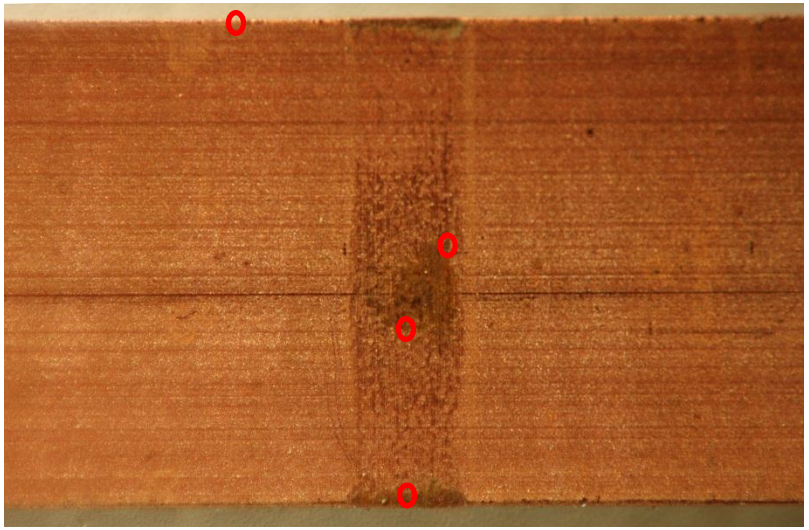
Contact Pressure

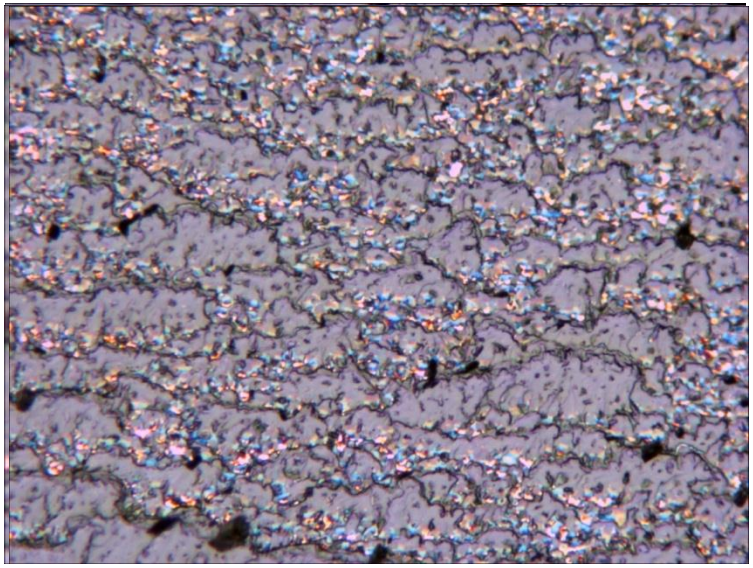


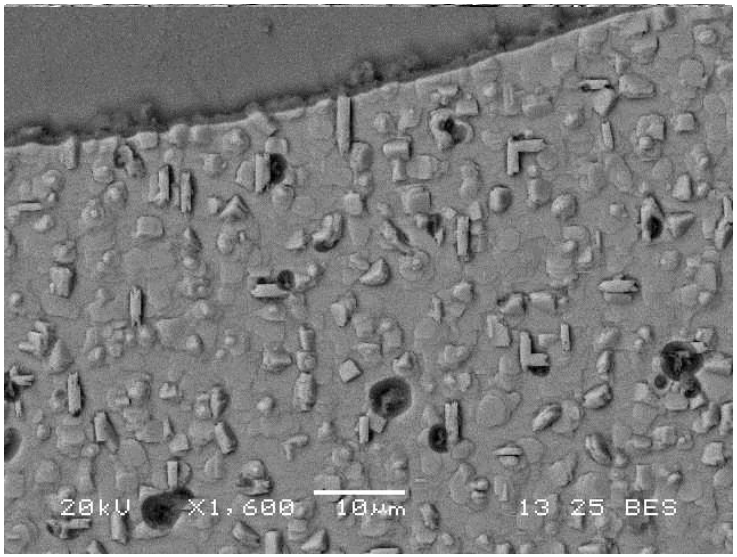
REBCO strain

Critical transverse pressure as a function of copper layer thickness at 77K

Transverse stress micrographs and SEM







Summary

- Systematic studies of ReBCO tapes under twist, tensile and transverse load were performed.
- SCS4050 tape shows good Ic reversibility for tensile axial strain up to ε =0.55%. For combined torsion–tensile loading, increase in torsion strain leads to earlier and more gradual Ic degradation upon a controlled applied tensile axial strain.
- Locally transverse applied stress leads to crack formation mostly at the edges of the pushing area. SEM analysis and modeling are in good agreement for peak in plane strain concentrations.
- The homogeneity of applied stress plays a significant role just as the thickness of the tape layers (copper) causing stress concentration spots.