UNIVERSITY OF TWENTE.

EMS

Transverse, axial and torsional strain in REBCO tapes; experiments and model

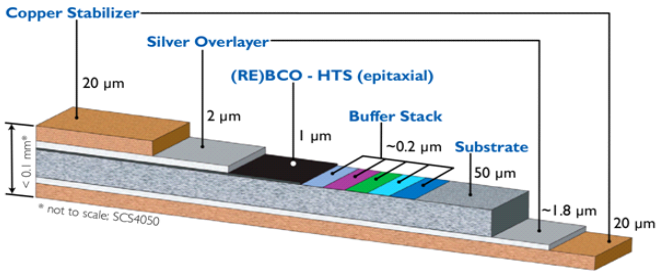
A. Nijhuis[1], K. Ilin[1], K. A. Yagotintsev[1] P. Gao[1], J. Kosse[1], W. A. J. Wessel[1], S. Otten[1], V.A. Anvar[2], C. Zhou[3], T.J. Haugan[4], D.C. van der Laan[5]

[1] University of Twente, Faculty of Science & Technology, The Netherlands
[2] T K M College of Engineering, Kollam, Kerala, India
[2] ITER International Organisation, Cadarache, France
[3] US Air Force Research Laboratory, USA
[4] Advanced Conductor Technologies and University of Colorado, USA

CHATS'15, Bologna, Sep 2015

Outline

- Introduction
- Tape model and experiments
- CORC cable model, work in progress
- Summary



All samples - SuperPower SCS 4050 tape

CORC cable FE modeling steps

Step 1
- Tape material thermal-mech. properties

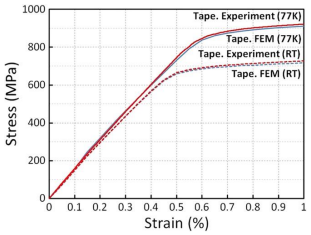
Step 2
- Tape production (different *T* process)

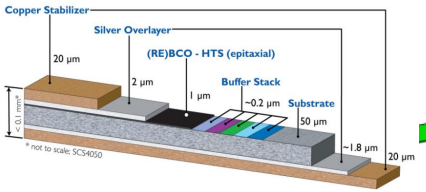
Step 3
- Tape winding to CORC @ RT

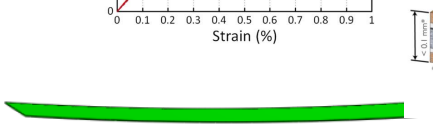
Step 4
- CORC bending to coil @ RT

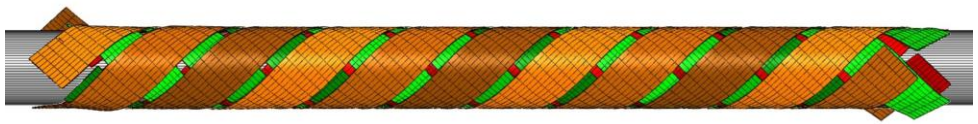
Step 5
- Cooling to operating T_{op} (77 K)

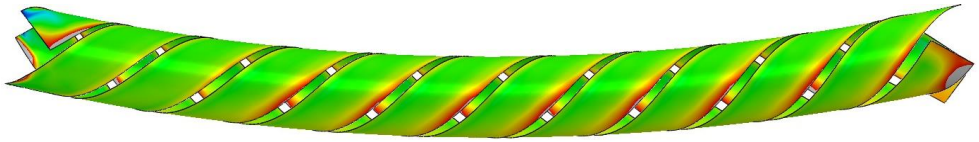
Step 6
- Electromagnetic load @ T_{op}

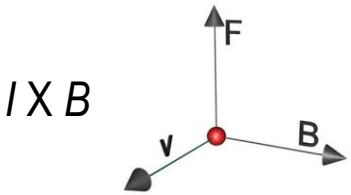




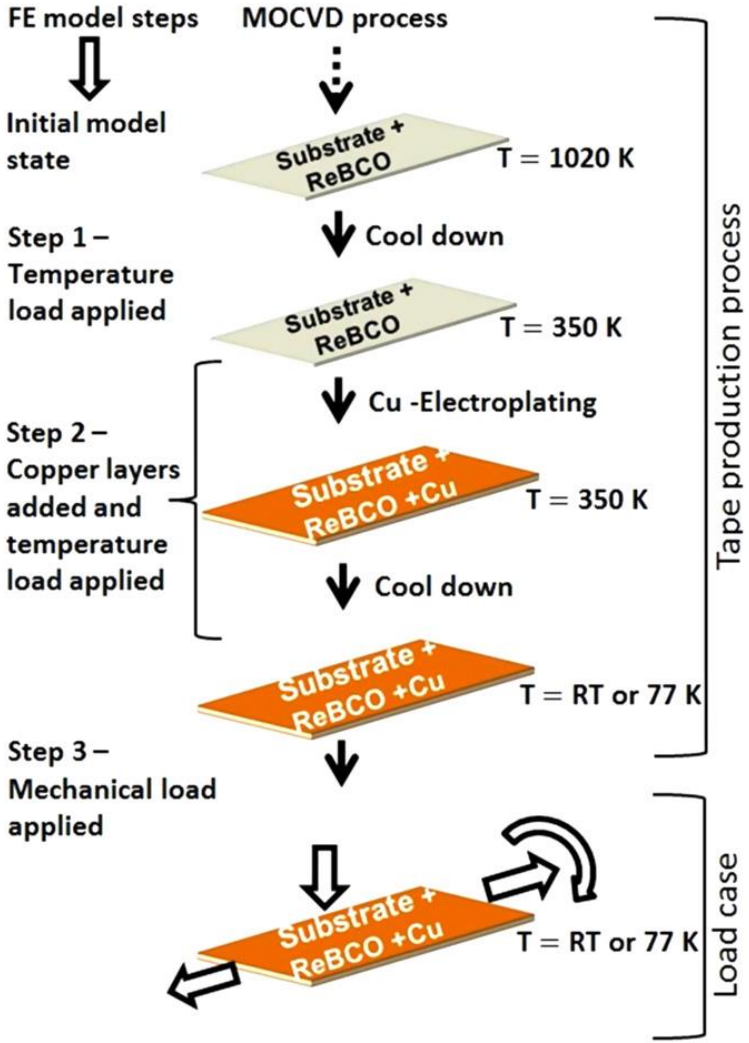






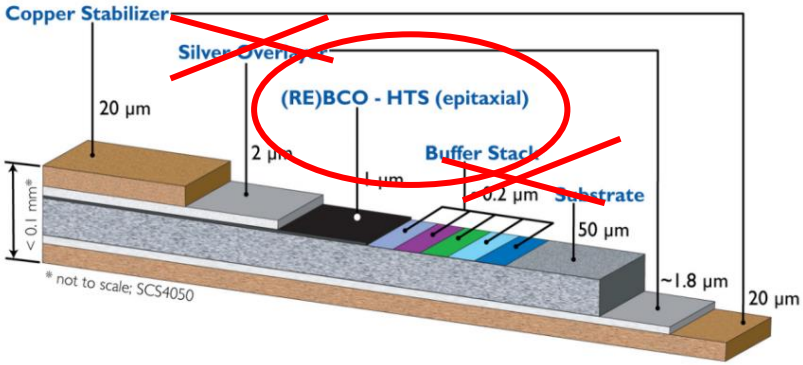


Modeling tape from initial state



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

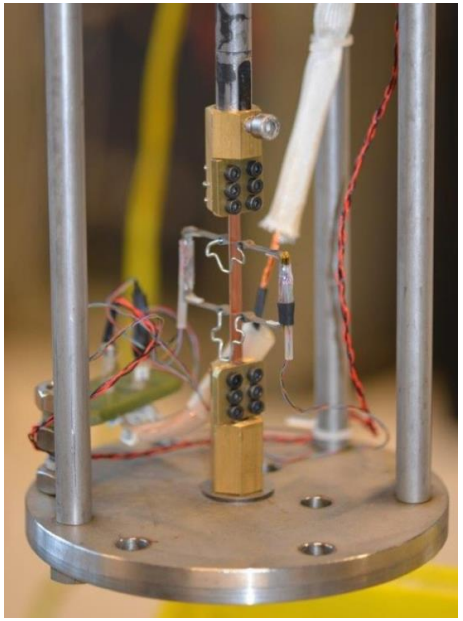
Buffer and silver layers excluded from model (minor influence on tape mechanical behavior)



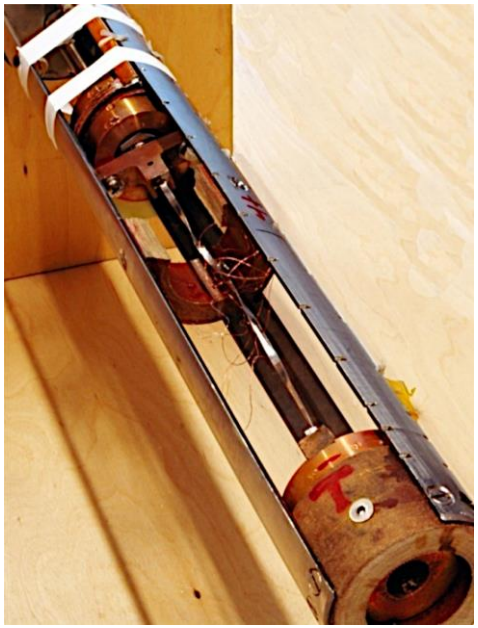
Model: residual strain in REBCO layer at RT – 0.17 %.

Cooling down to 77 K increases compressive strain further to ~ –0.24 %.

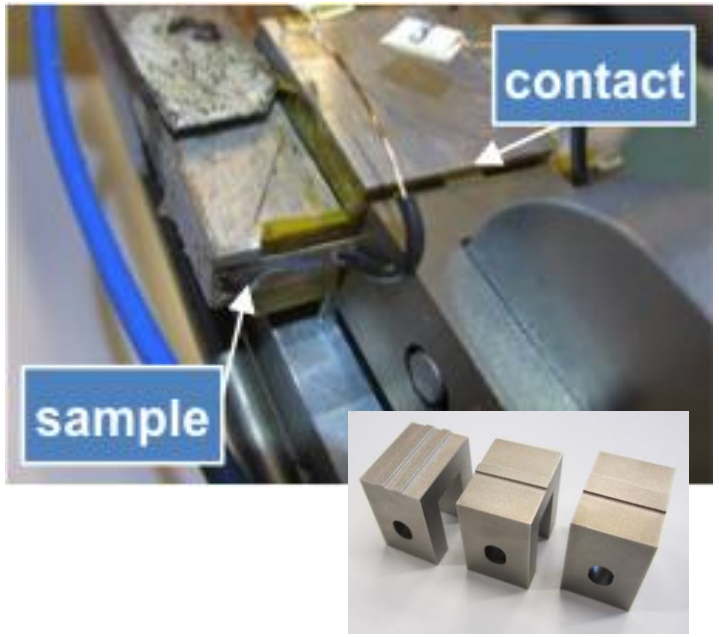
Tape strain test setups



Tensile axial stress-strain for thermo-mechanical material properties of tape components (copper, hasteloy)



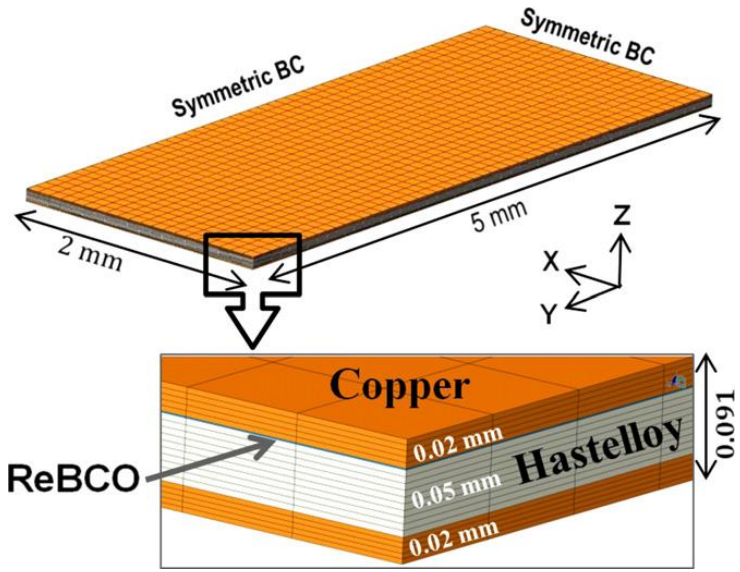
Combined controlled torsion + tensile axial stress

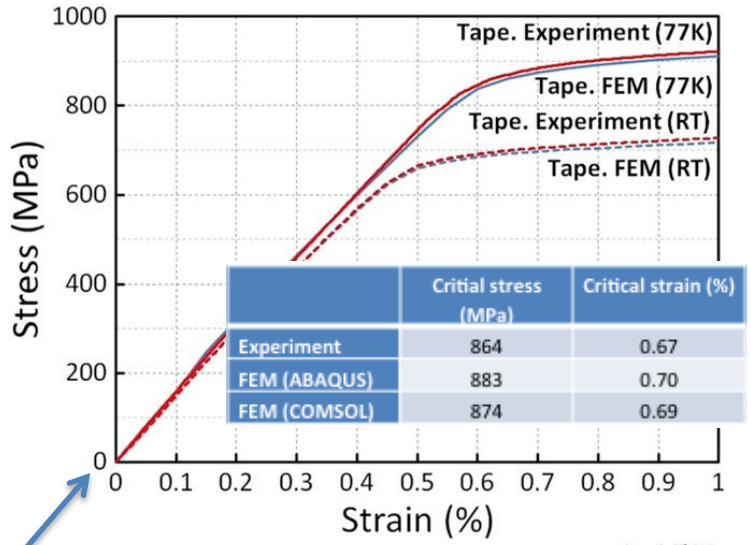


Transverse stress with different loading profiles

Simulation and experiment: tensile

Geometry: FE mesh and boundary conditions

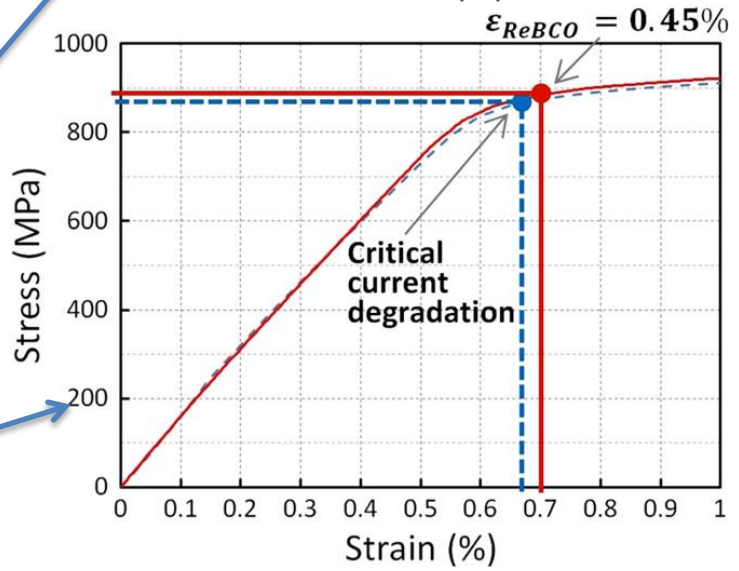




	Critial stress (MPa)	Critical strain (%)
Experiment	864	0.67
FEM (ABAQUS)	883	0.70
FEM (COMSOL)	874	0.69

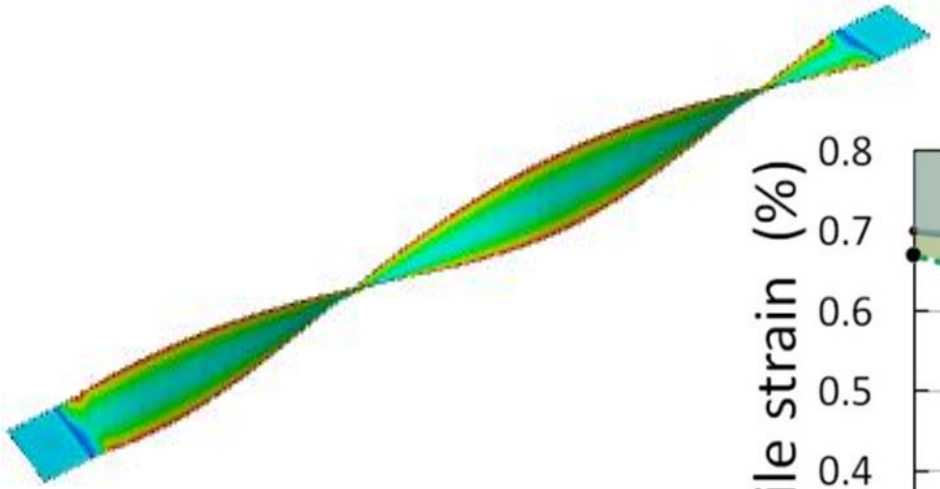
After exp. determining copper & Hastelloy properties, good agreement tensile load experiments and modeling results at RT and 77 K.

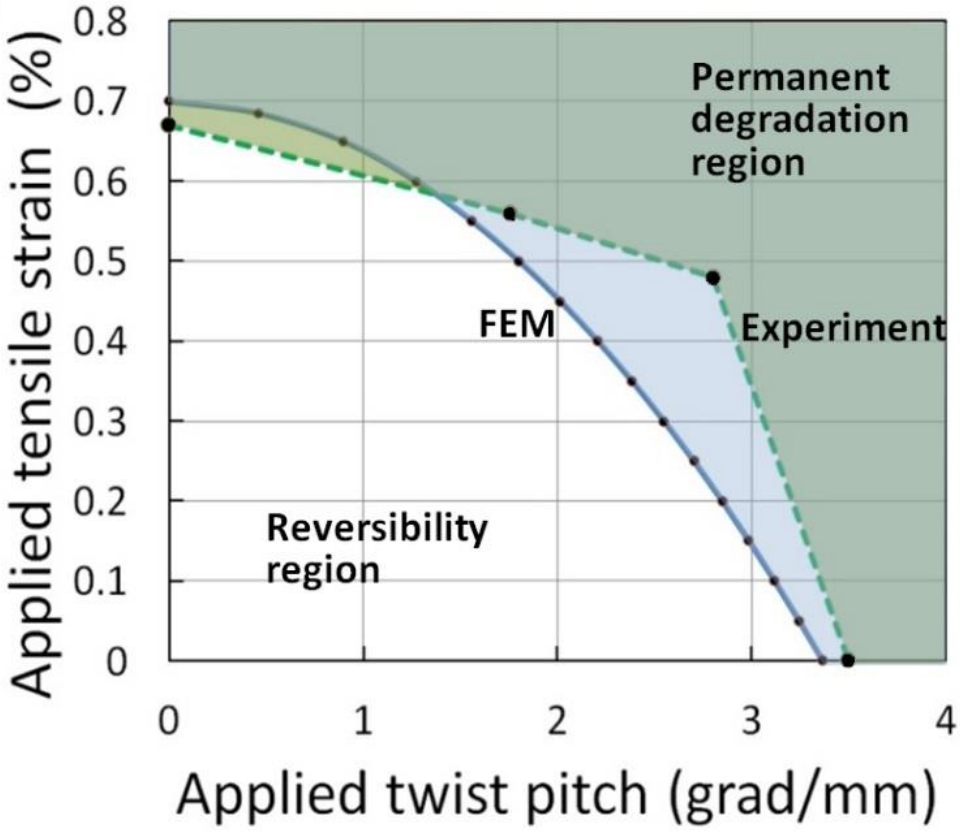
Critical intrinsic tensile strain = 0.45%. (neutron diffraction experiment K. Osamura et al.).
Results FEM and experiment at 77 K.



Simulation and experiment: tensile + torsion

FEM simulation: Tensile + Torsion at 77 K, with longitudinal strain in REBCO layer

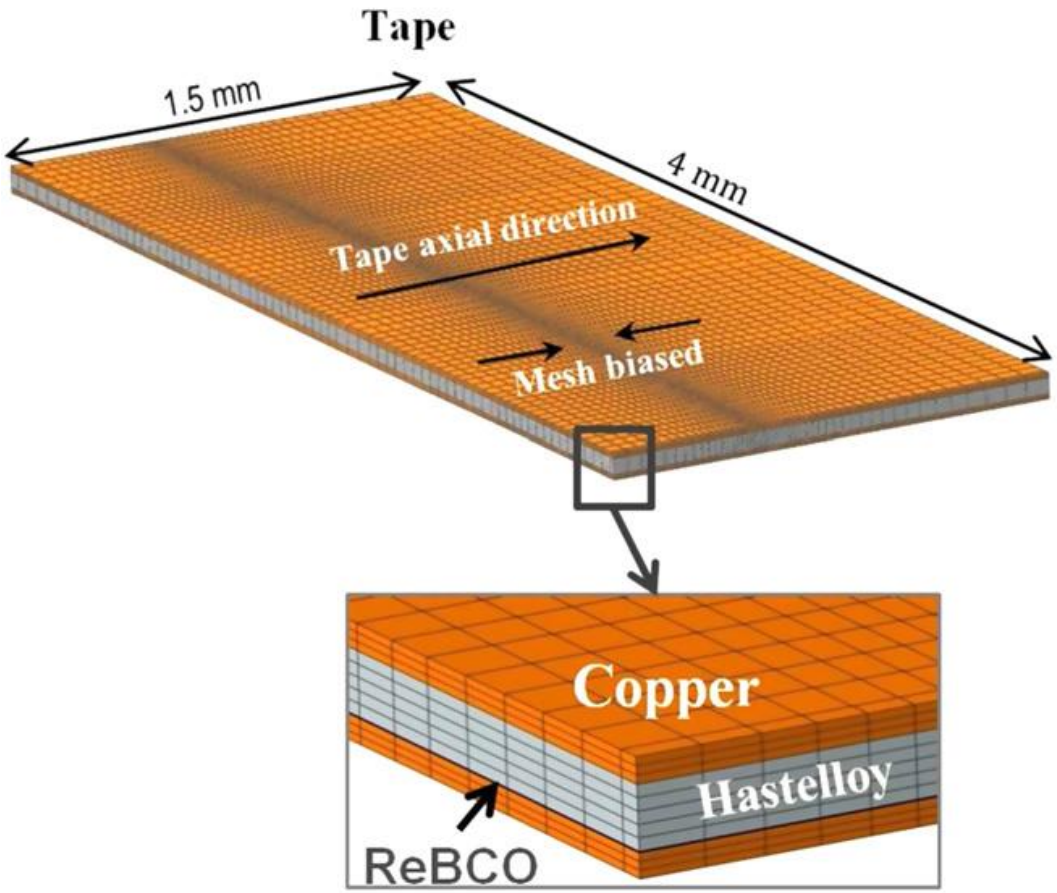


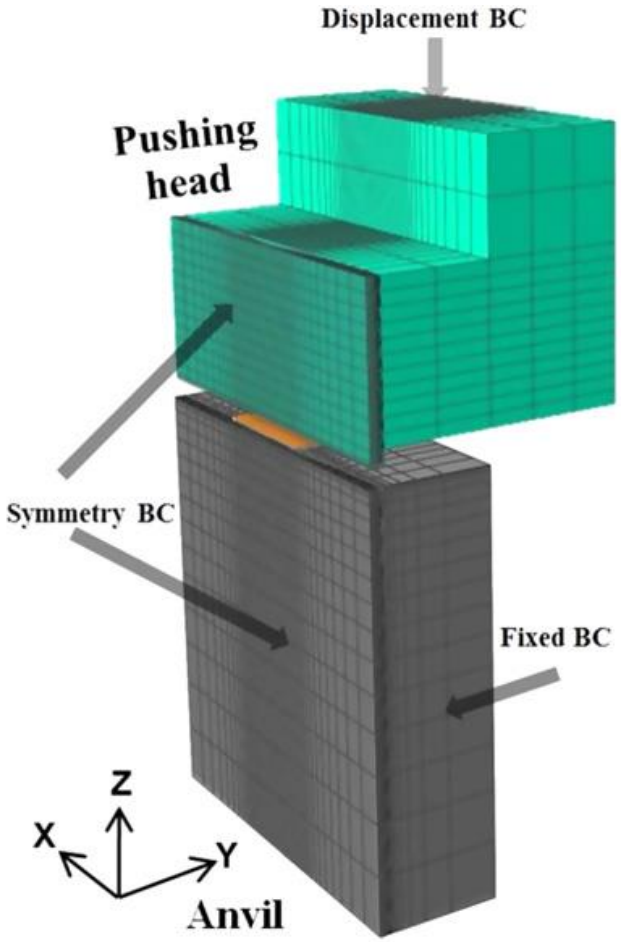


FEM computation: critical strain in REBCO layer as a function of applied external tensile strain and applied torsion strain at 77 K

Experimental: I_c measurement with 10 μV/m criterion (less sensitive with increasing torsion)

FEM transverse load

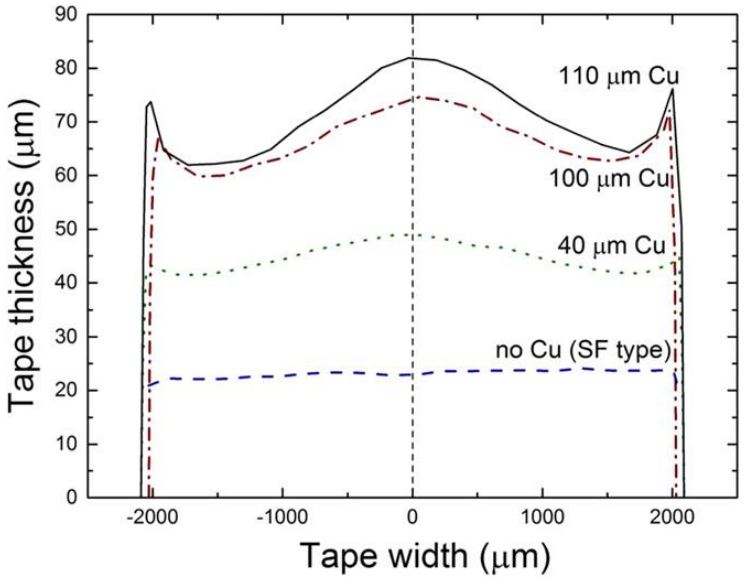




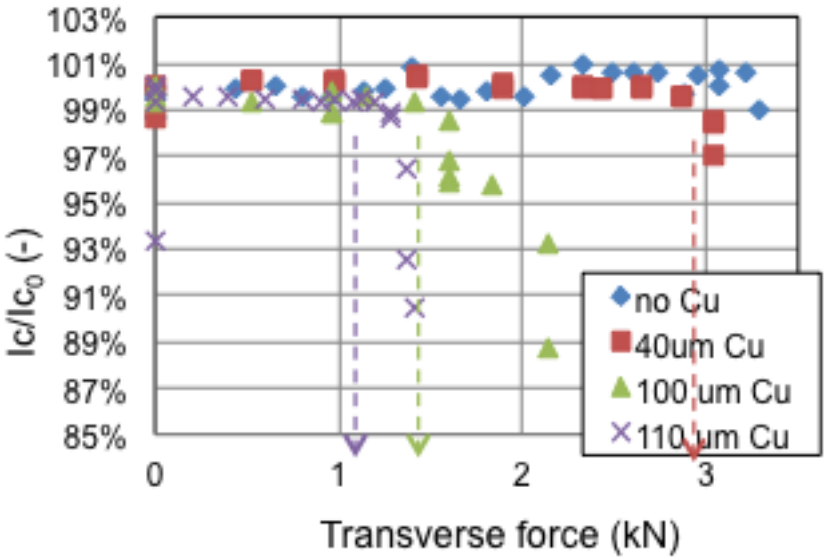
Extensive FE mesh of tape, anvil and pushing head, since deformation of all parts is important

Tape thickness variation, transverse stress

SEM analysis of tape thickness



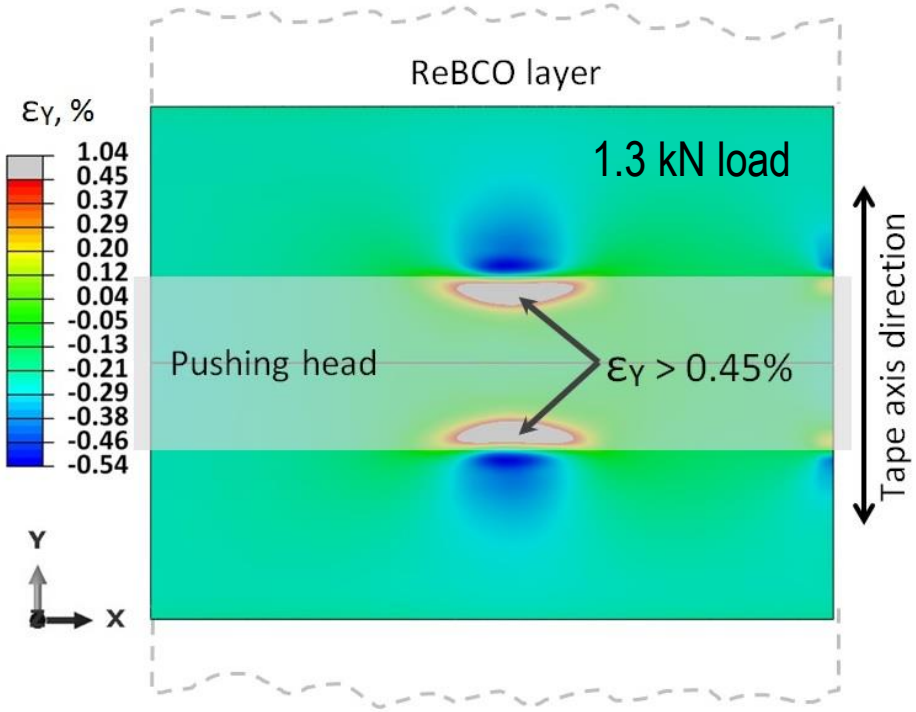
I_c degradation vs tape thickness

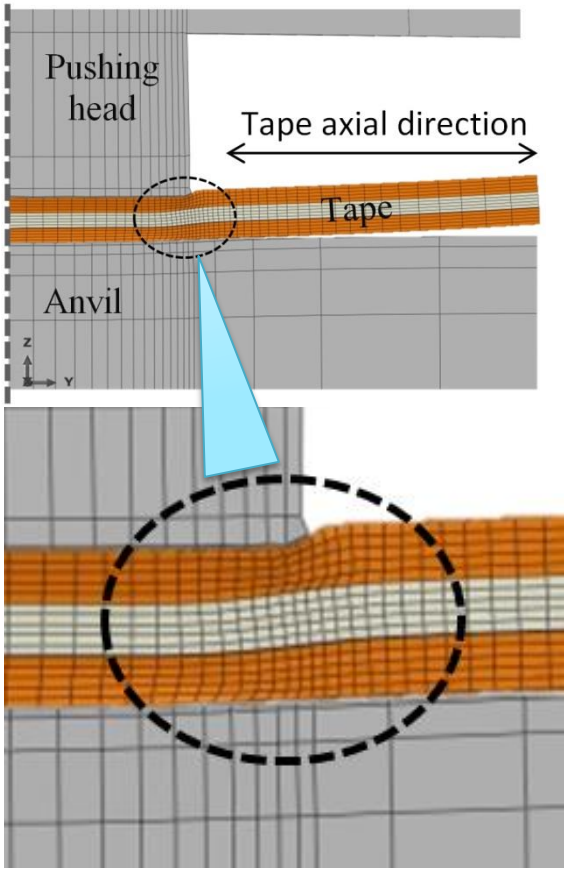


4 mm pushing head (40 µm Cu)

- Copper thickness not uniform over tape width.
- How much is influence of copper thickness, how much of inhomogeneity?

FEM transverse load, thickness copper

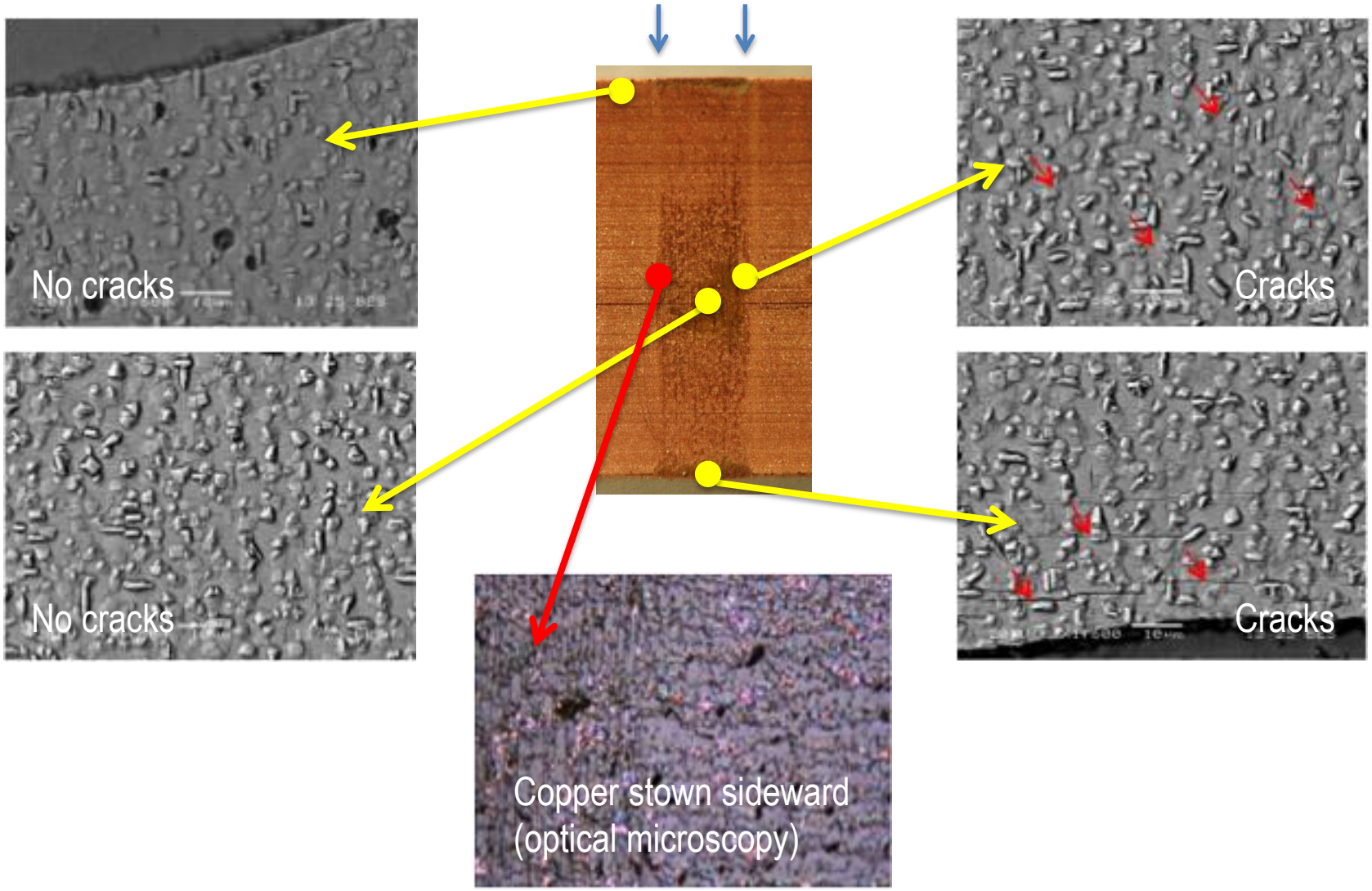




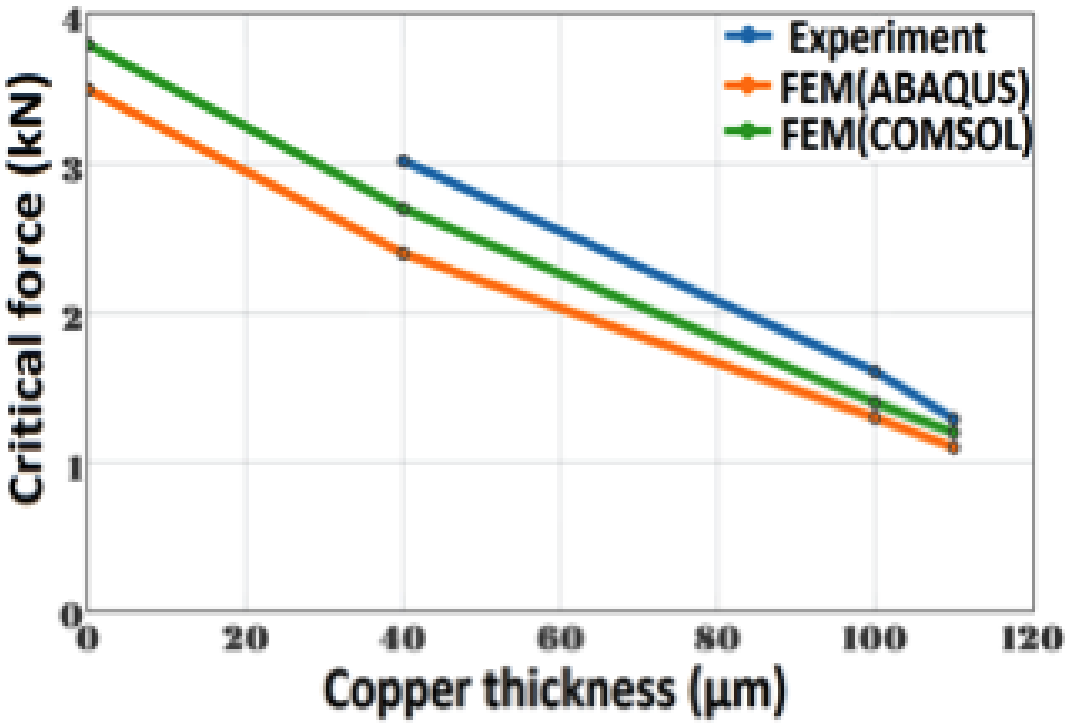
In plane strain in REBCO layer calculated using 100 µm copper thickness.

- The strain concentration areas are localized at boundaries of the pushing head
- Copper starts flowing in outward direction, increasing strain in REBCO plane

Transverse stress SEM micrographs



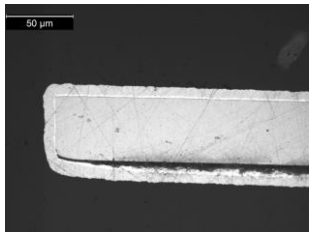
Transverse load, FEM versus experiment



Critical force as a function of copper layer thickness at 77K. FEM model and experimental results.

Measured Cu thickness profiles are used for FEM computation

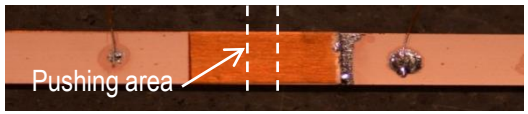
Transverse load: Cu thickness & profiles



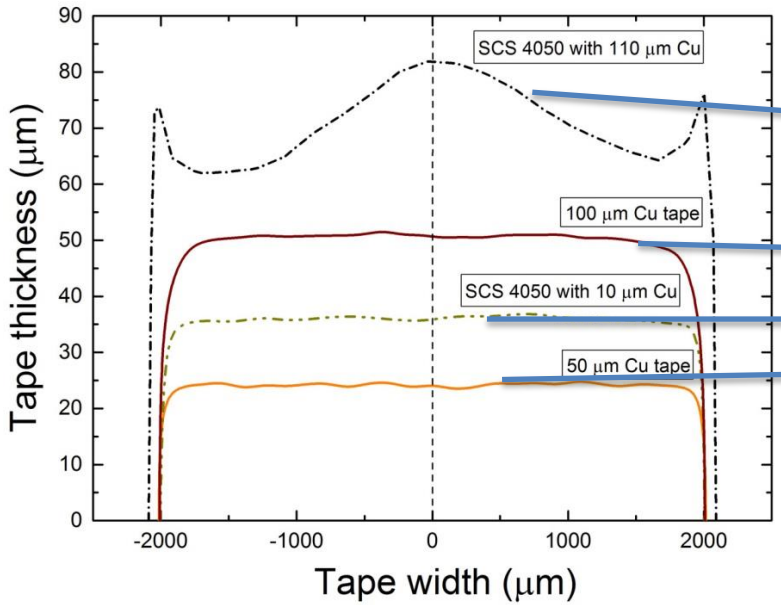
50 µm Cu tape

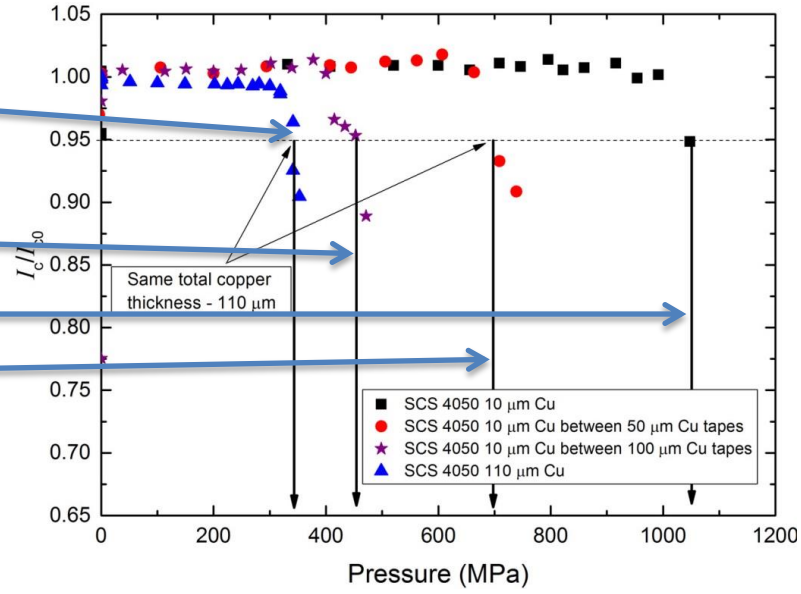
100 µm Cu tape

Super power® 2G SCS4050 with 10 µm Cu layer



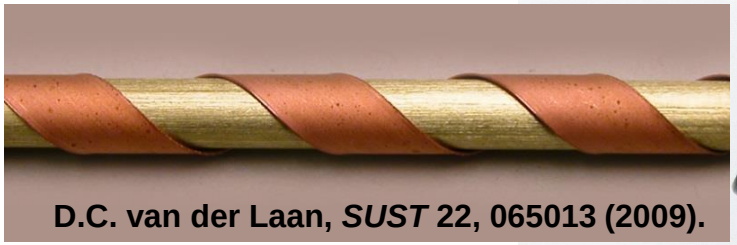
No “dog boning” effect, uniform tape thickness is over width.



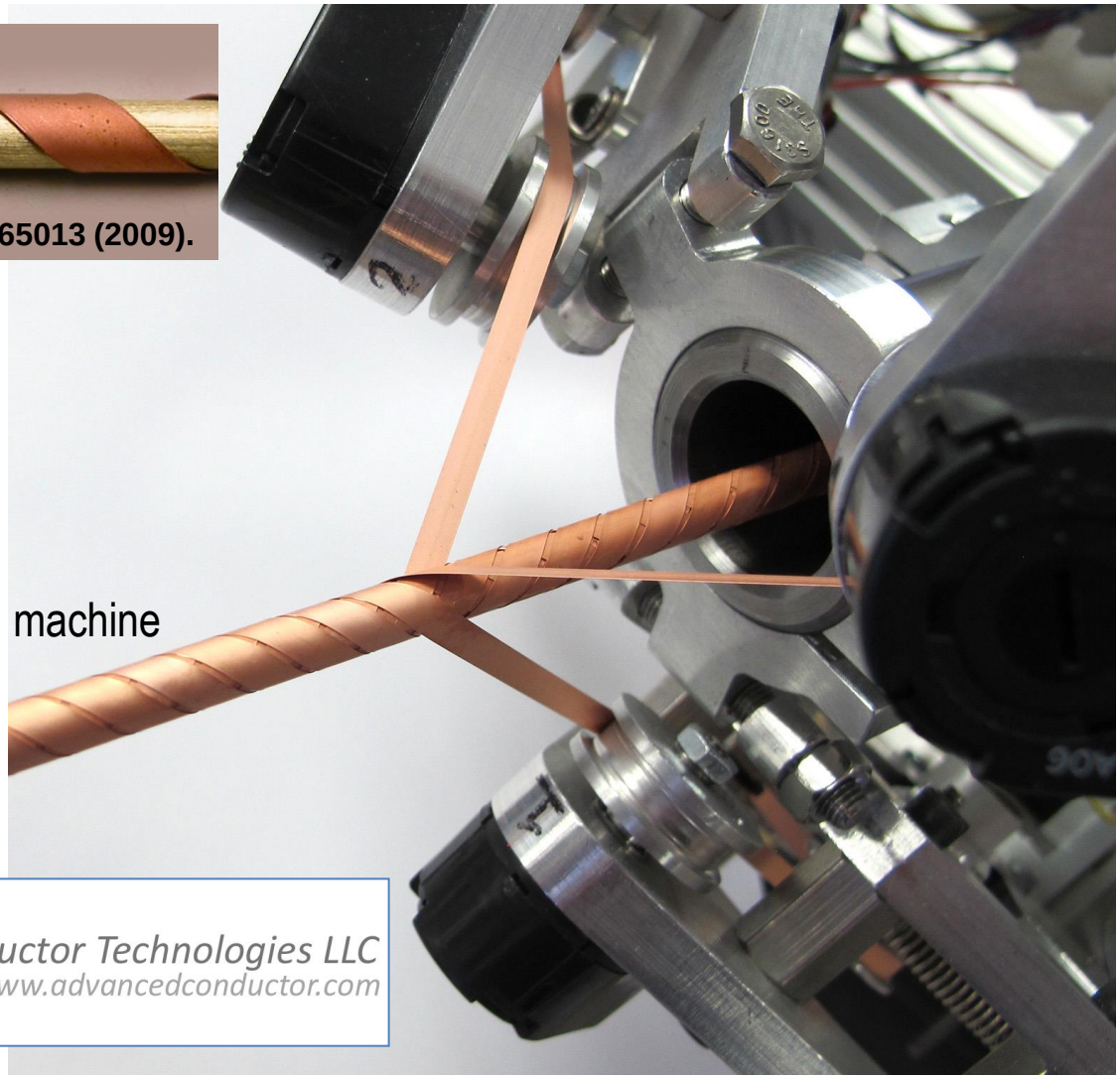


Both, copper layer thickness and surface homogeneity play a role, thickness-Cu most.

CORC cable



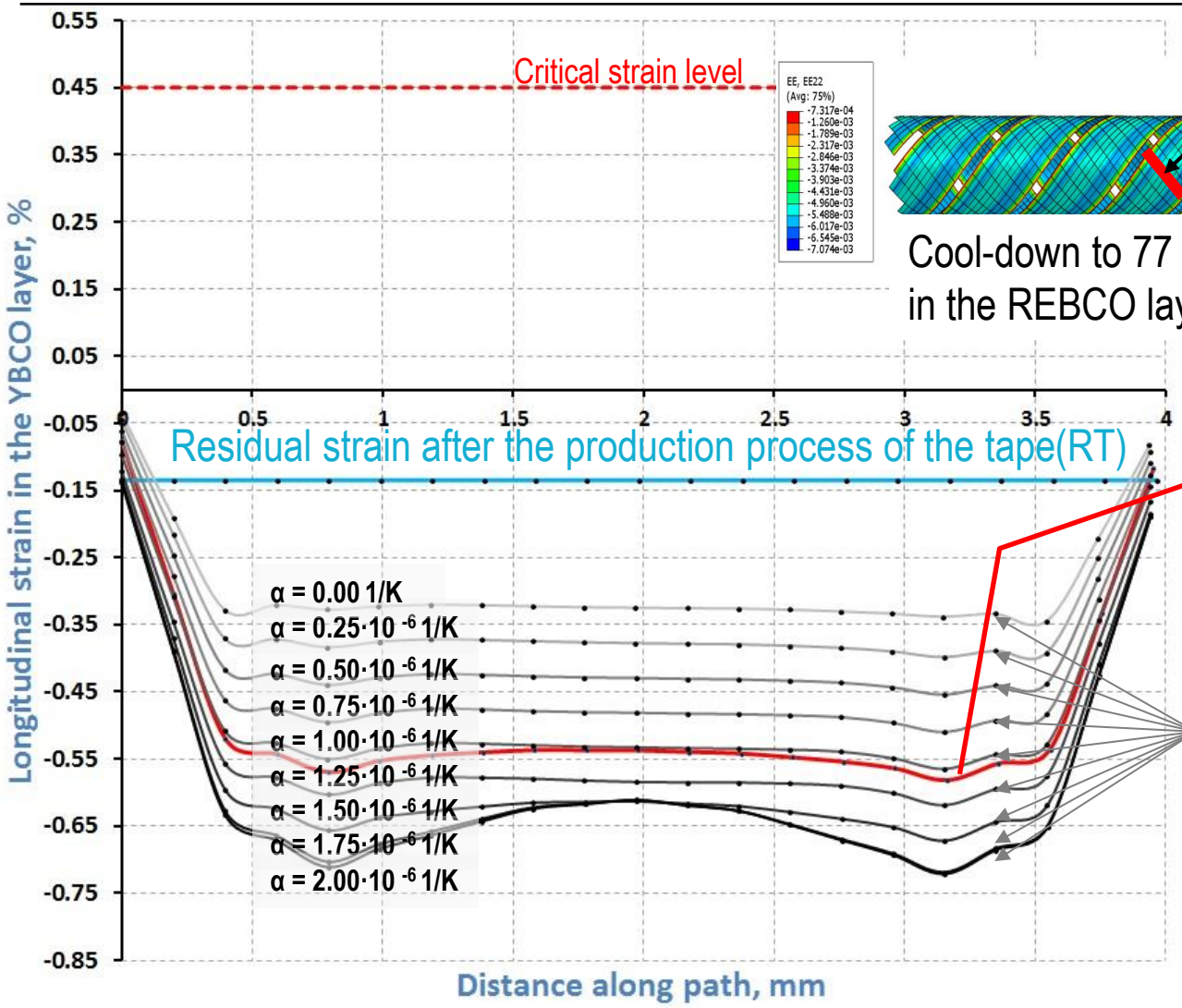
D.C. van der Laan, *SUST* 22, 065013 (2009).

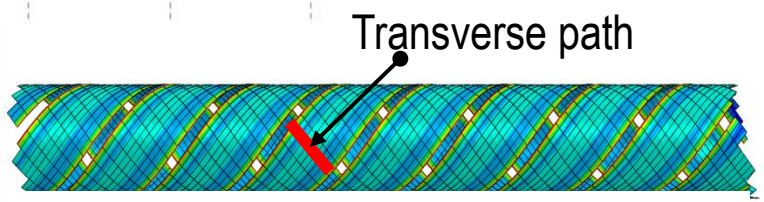


Cable winding machine

Advanced Conductor Technologies LLC
www.advancedconductor.com

CORC cable FE modeling: cool down





Cool-down to 77 K. Longitudinal strain in the REBCO layers (6 mm core).

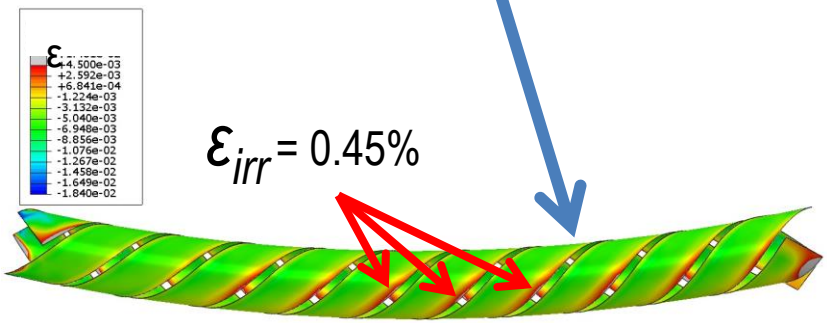
Strain after winding (RT)

Longitudinal strain in REBCO layer width at 77 K with varied thermal expansion coefficient of core tube (α)

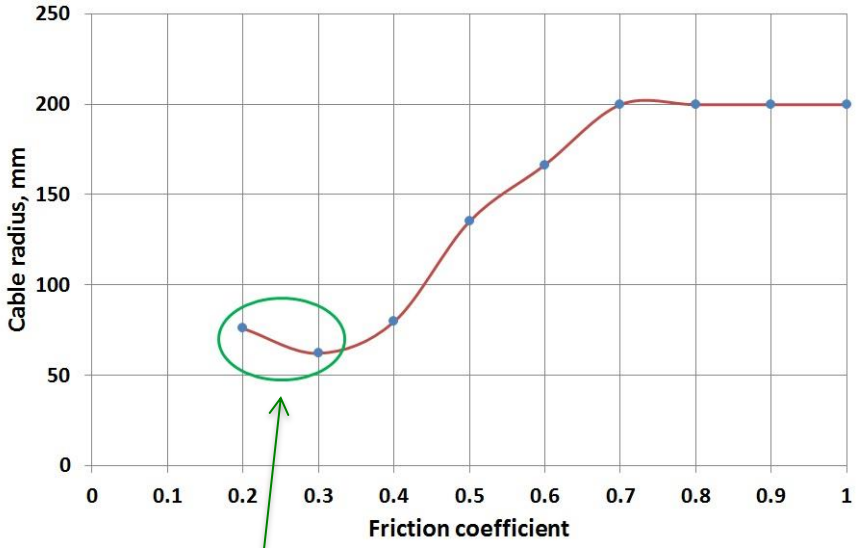
Bending one layer CORC cable (3 tapes)

Variable parameter:
μ – friction coefficient tape-core interface

Cable bending radius
R = 200 mm



Strain along tape direction in REBCO at cable radius R = 200 mm and μ = 1 (cable core 6 mm)



Bending R for ε=0.45% versus friction coefficient

For μ = 0.2 and 0.3 no convergion reached in computation

Work in progress …. but use of lubricant to reduce μ seems a good idea …

Summary

- Systematic studies performed on SCS4050 REBCO tape under tensile, torsion and transverse load.
- Tape FE model validated against experiments.
- Homogeneity of tape surface but mostly thickness of copper layer plays significant role in allowable transverse peak load.
- CORC modeling in progress for tape/cable/core optimization.

K Ilin, K A Yagotintsev, C Zhou, P Gao, J Kosse, S J Otten, W A J Wessel, T J Haugan, D C van der Laan, and A Nijhuis, “Experiments and FE modeling of stress–strain state in ReBCO tape under tensile, torsional and transverse load”, Supercond. Sci. Technol. 28 (2015) 055006 (17pp) doi:10.1088/0953-2048/28/5/055006