Nb_3Sn conductor R&D

Summary of the activities @ UNIGE

Florin BUTA, Christian BARTH, José FERRADAS, Luc GAMPERLE, Carmine SENATORE

Group of Applied Superconductivity
Department of Quantum Matter Physics
University of Geneva, Switzerland

Our conductor related activities in FCC

Florin BUTA

Addendum FCC-GOV-CC-0112 (KE3545/ATS)

Investigations on the enhancement of J_c in $(Nb,X)_3Sn$ superconductors by internally oxidized ZrO_2 particles

@ CERN : Simon HOPKINS, Bernardo BORDINI, Amalia BALLARINO

H2020 EuroCirCol WP5 Task 5: Conductor studies

Electromechanical studies – effects of the transverse stress

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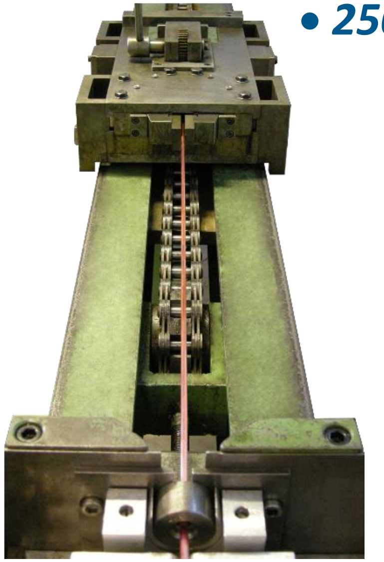
An (almost) unique equipment

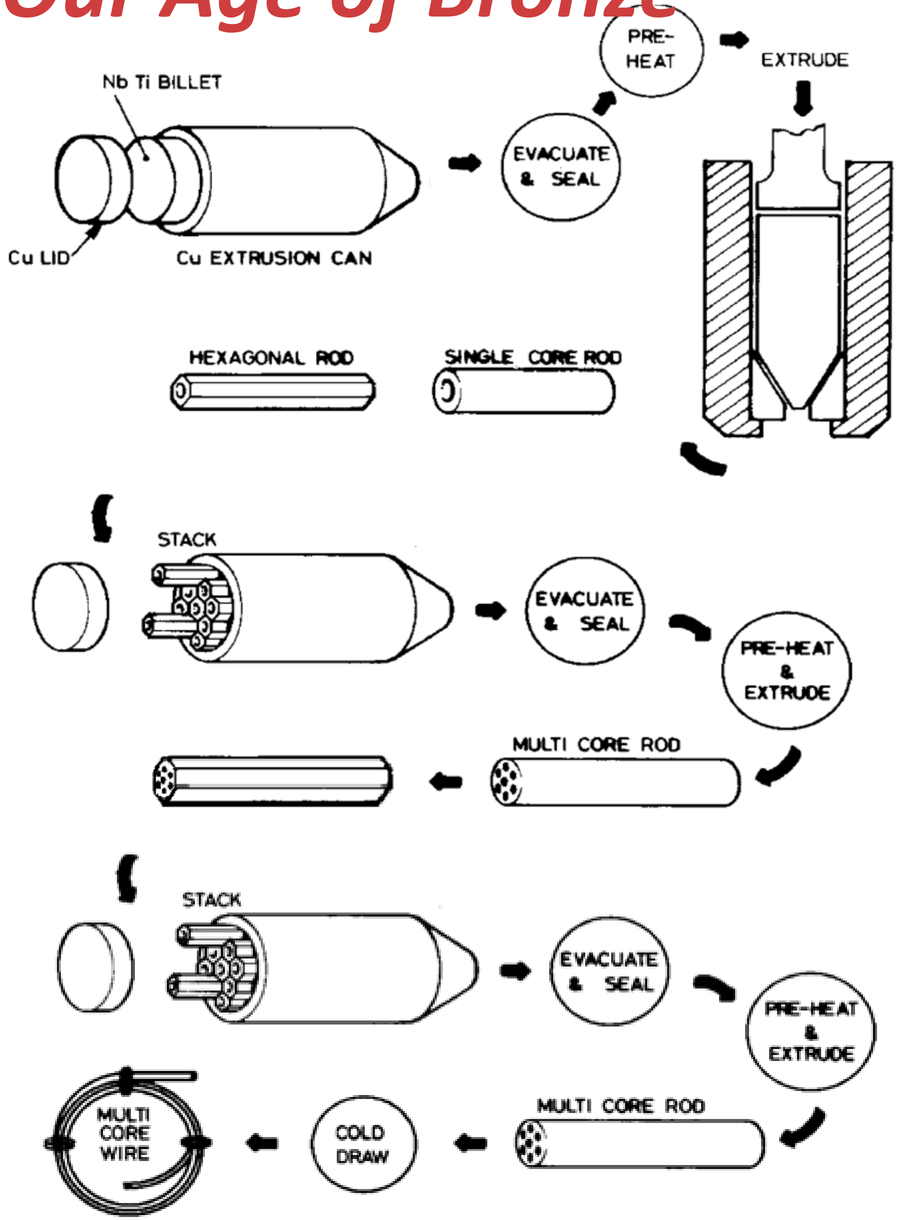
Laboratory for the development of superconducting wires @

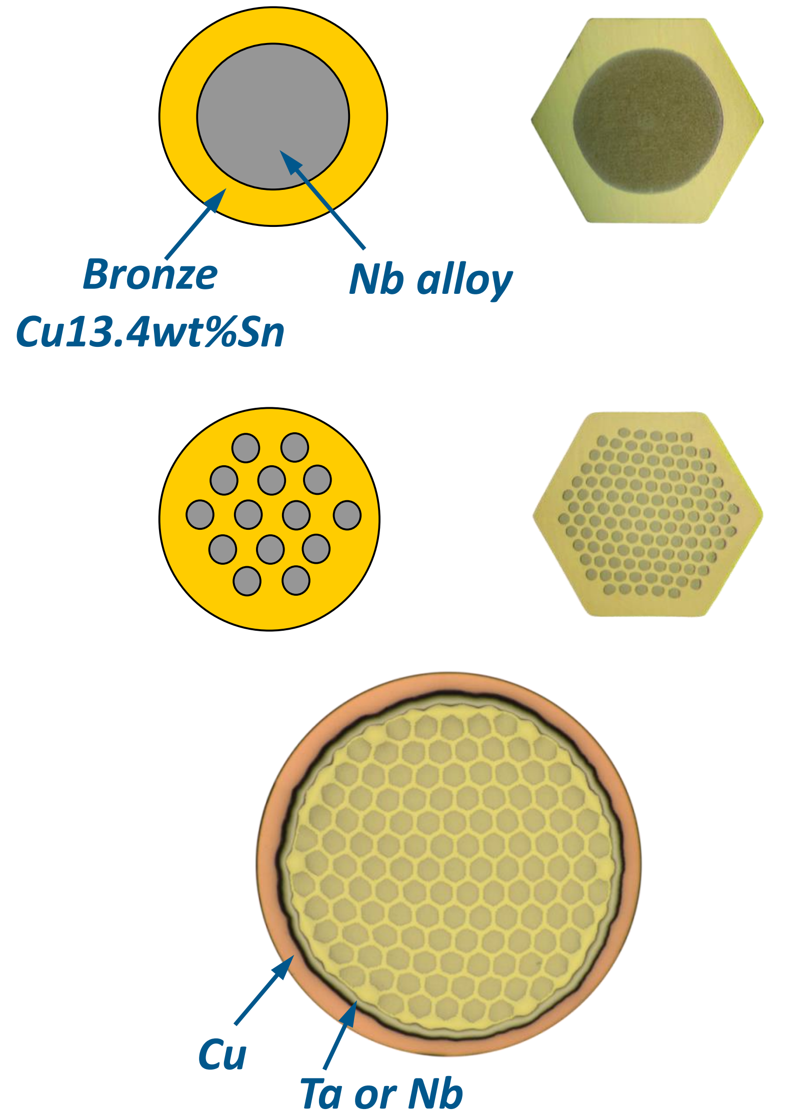
UNIVERSITÉ DE GENÈVE
FACULTÉ DES SCIENCES

- Wire drawing bench 1.5t
- Wire drawing bull-block 0.3t
- Wire drawing dies from ∅15 to ∅0.2 mm
- Hot-rolling mill and hot-rolling groove roller
- Rolling mill with tungsten carbide rollers
- Powered turks head machine
- Two swaging machines
- 250t hydrostatic hot extrusion machine



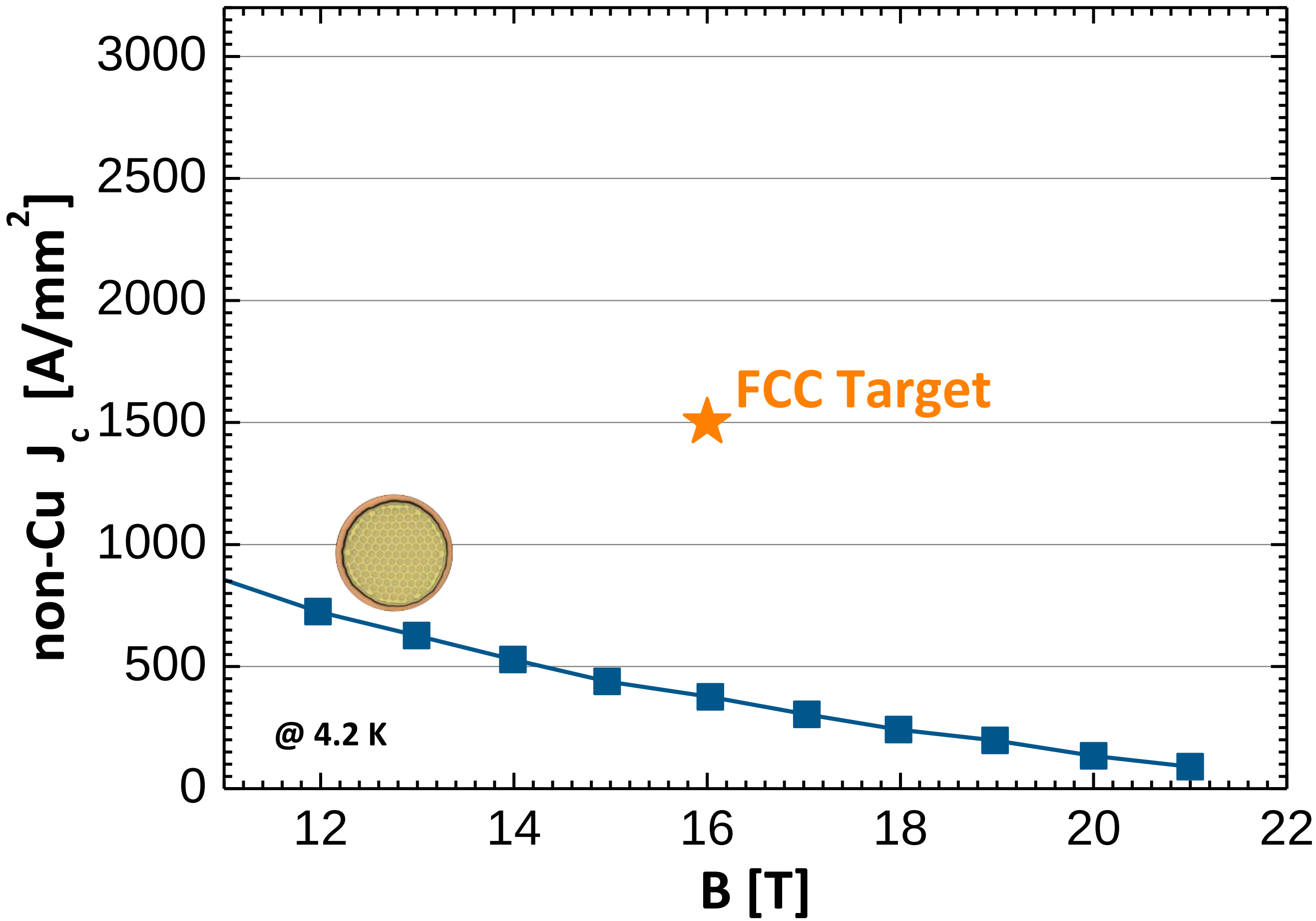
Our Age of Bronze





The final filament size is ~5 μm

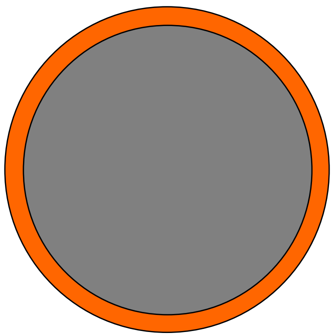
Critical current density vs. magnetic field



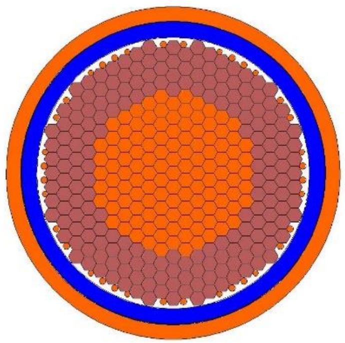
V. Abächerli, PhD Thesis, UNIGE 2005

R&D of internal Sn Nb_3Sn conductors

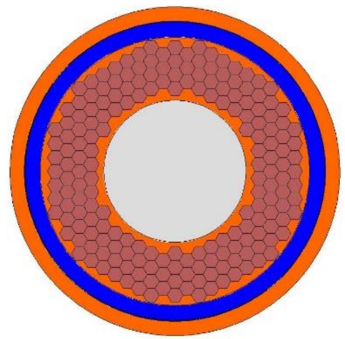
A collaboration between UNIGE and Bruker BioSpin funded by KTI/CTI (2007-2010)



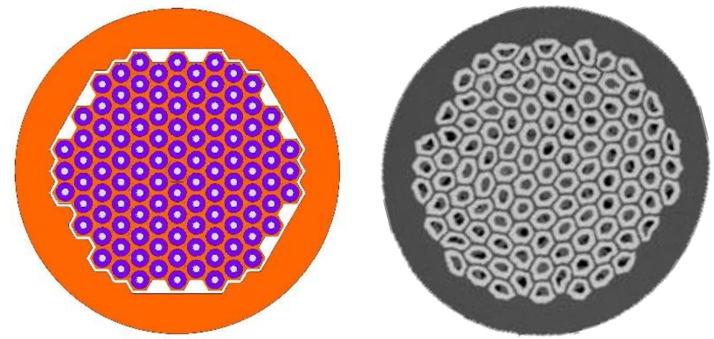
Cu/Nb-Ta rod



Sub-element
bundle

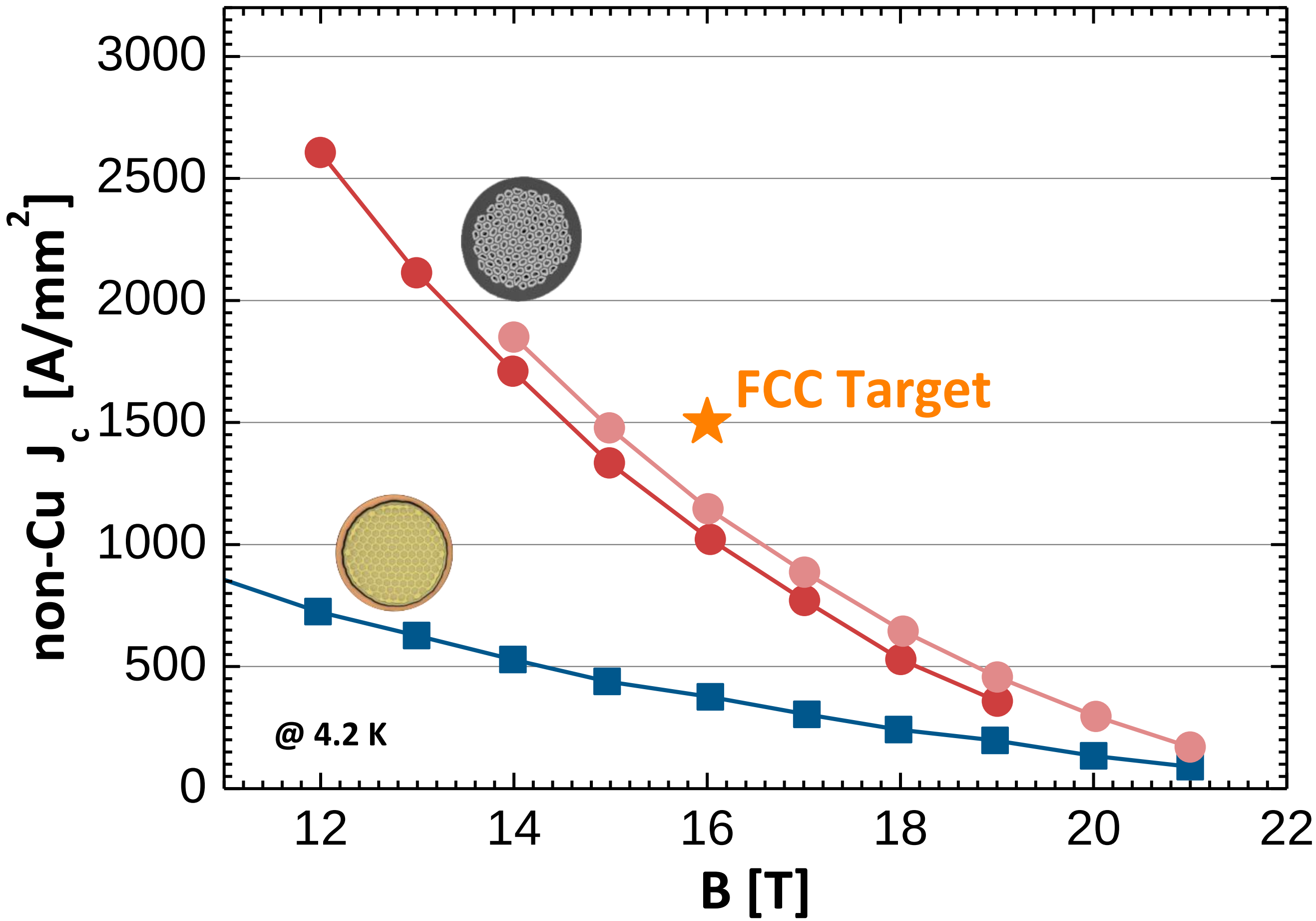


Sub-element
with pure Sn core



Final wire
109 sub-elements

Critical current density vs. magnetic field



F. Buta, R. Flükiger, CTI 9049.1 PFIW-IW final report, 2011

V. Abächerli, PhD Thesis, UNIGE 2005

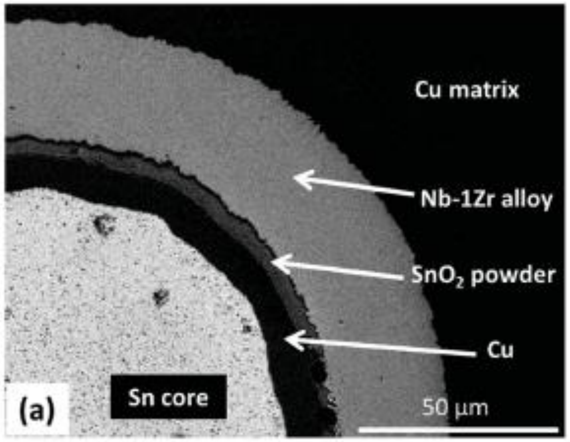
Internal oxidation and grain refinement in Nb_3Sn

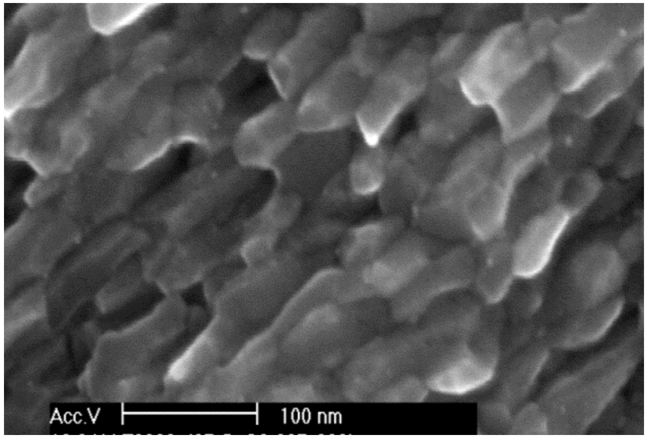
@ Ohio State University

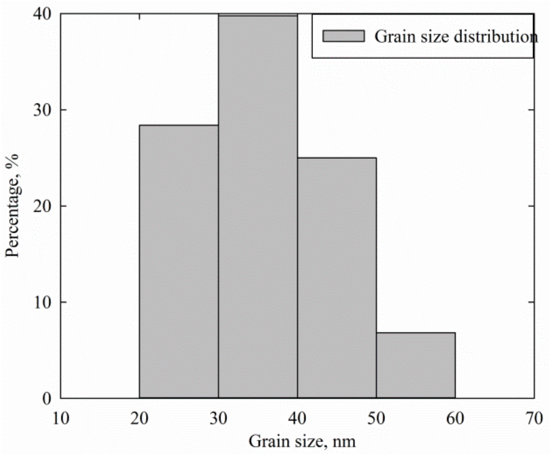
Idea from Benz (1968) to form fine precipitates in Nb to impede the A15 grain growth

Use of a Nb-Zr alloy: Zr has stronger affinity to oxygen than Nb

Oxygen supply added to the composite: oxidation of Zr and formation of nano-ZrO_2







X. Xu et al., APL 104 (2014) 082602

X. Xu et al., Adv. Mat. 27 (2015) 1346

Average grain size is reduced down to < 50 nm

Greatly enhanced pinning in binary Nb_3Sn

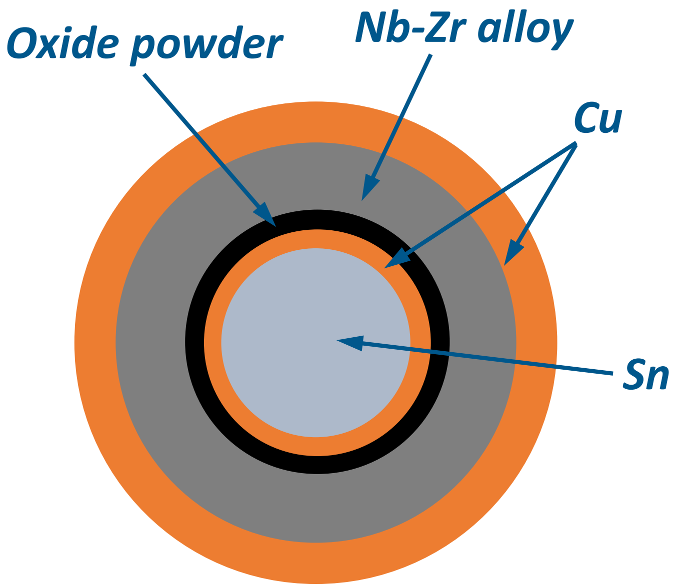
M.G. Benz, Trans. Metall. Soc. AIME, 242 (1968) 1067-1070

R&D on internal oxidation in Nb_3Sn @ UNIVERSITÉ DE GENÈVE FACULTÉ DES SCIENCES

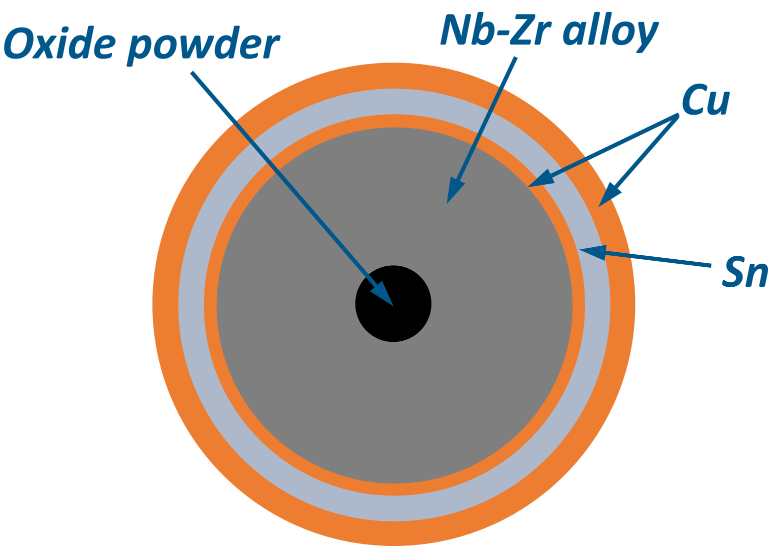
- *Explore routes leading to the increase of the critical current densities in Nb_3Sn by reducing the grain sizes and increasing the upper critical field*
- *Evaluate different oxygen sources for the internal oxidation of Zr atoms present in the Nb filaments*
- *Addition of suitable dopants to enhance the upper critical field*
- *Optimize wire configurations and heat treatments*

R&D on internal oxidation in Nb_3Sn @ UNIVERSITÉ DE GENÈVE FACULTÉ DES SCIENCES

Ohio State Univ. Configuration



UNIGE configuration



Filament material - oxygen source combinations

Nb alloy	Metal oxide	Status
Nb-7.5wt%Ta	none	
Nb-7.5wt%Ta	MoO_3	
Nb-7.5wt%Ta	SnO_2	planned
Nb-1wt%Zr	MoO_3	
Nb-1wt%Zr	SnO_2	
Nb-1wt%Zr	CuO	being drawn
Nb-7.5wt%Ta-1wt%Zr	SnO_2	being drilled
Nb-7.5wt%Ta-2wt%Zr	SnO_2	being drilled

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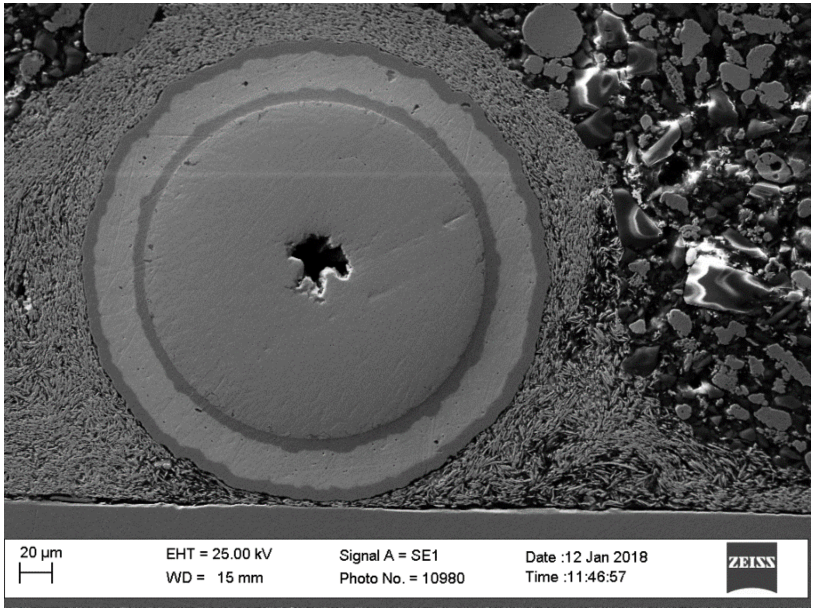
Nb-7.5wt%Ta-1wt%Zr	SnO_2	being drilled
Nb-7.5wt%Ta-2wt%Zr	SnO_2	being drilled

How to select the oxygen source ?

- *high Gibbs free energy of formation*
- *low hardness that would make it compatible with wire fabrication*
- *the metal resulting from the reduction has not to affect superconductivity*

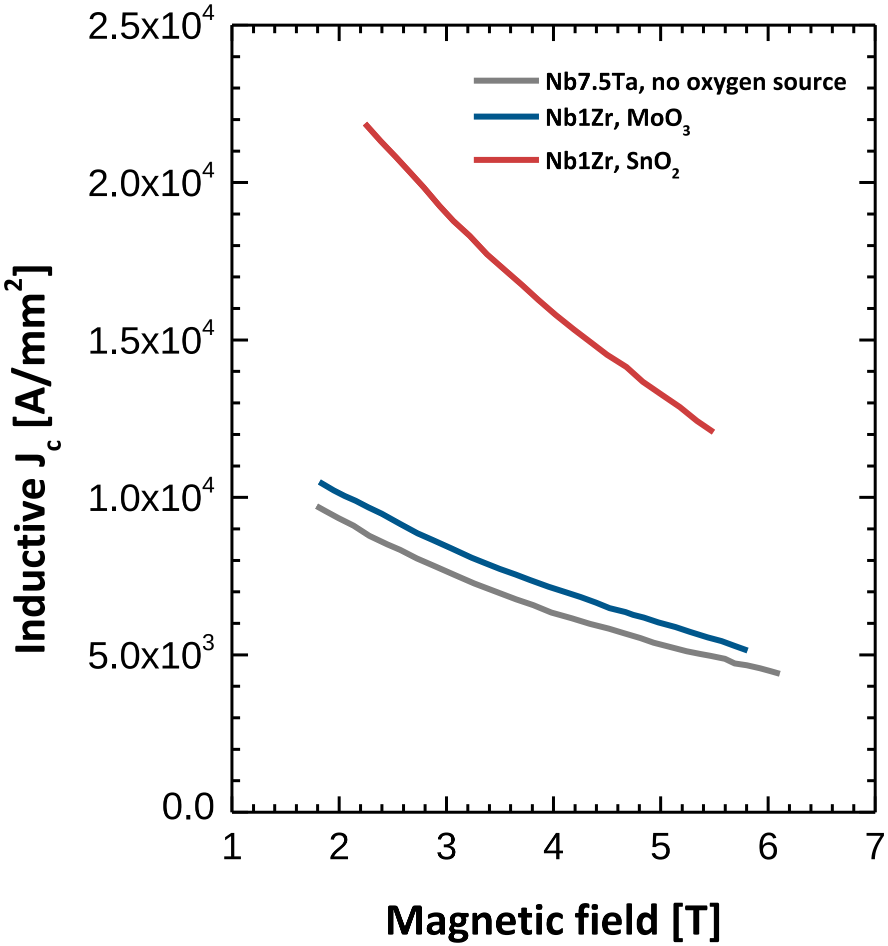
Sample fabrication

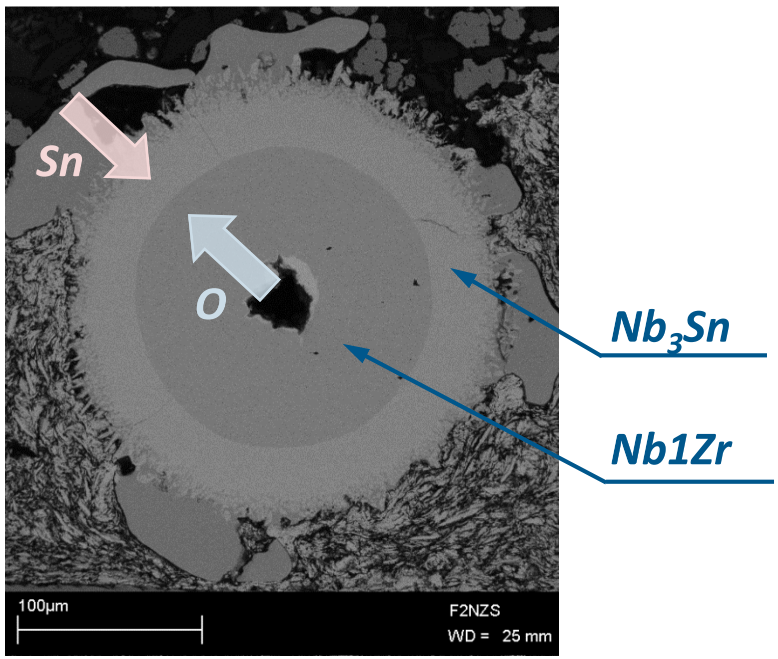


0.22 mm diameter wires of Nb alloy were prepared by cold deformation of a 12 mm diameter rod with nano-sized powders compacted in a central hole

- *The Nb alloy wire was then electroplated successively with: Cu, Sn, Cu*
- *The deposit thicknesses were varied to achieve different Cu/Sn and Nb/Sn ratios*
- *Oxygenation treatment was performed on the Nb alloy wire prior to the electroplating or on the full wire prior to the A15 formation*

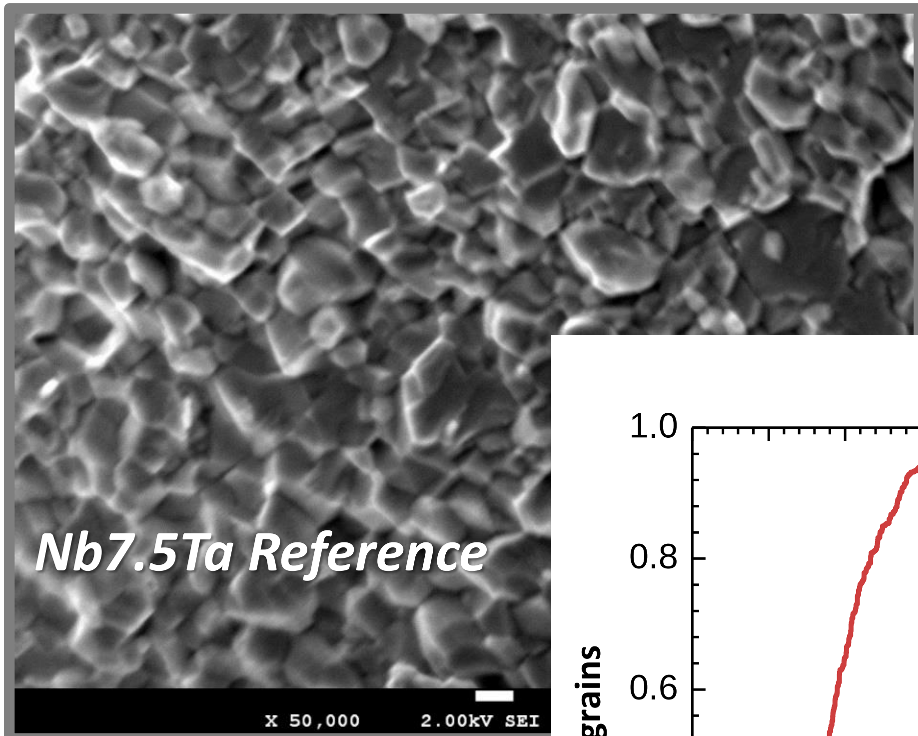
Critical current density



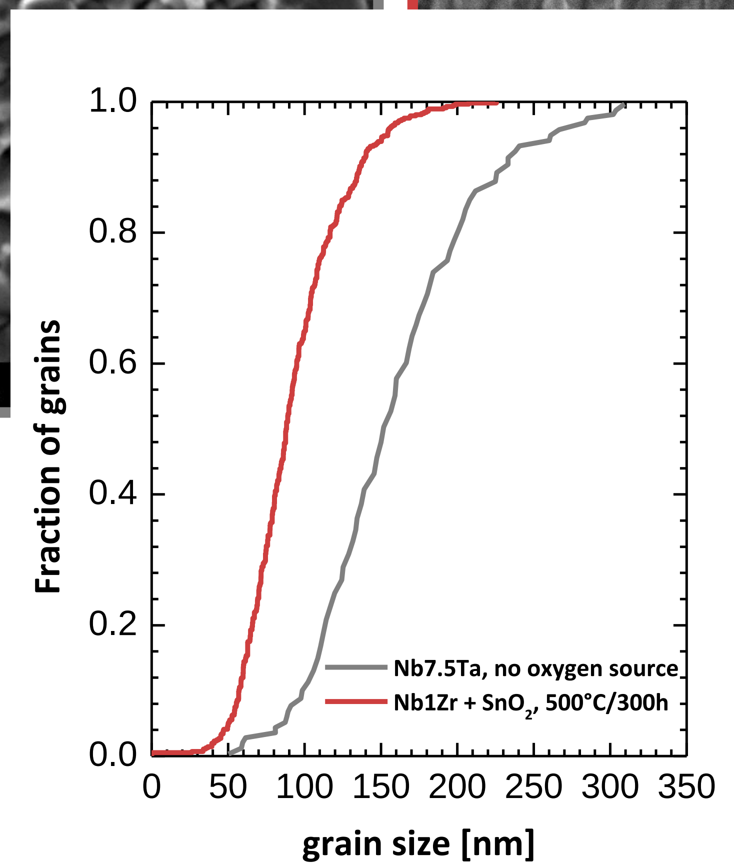


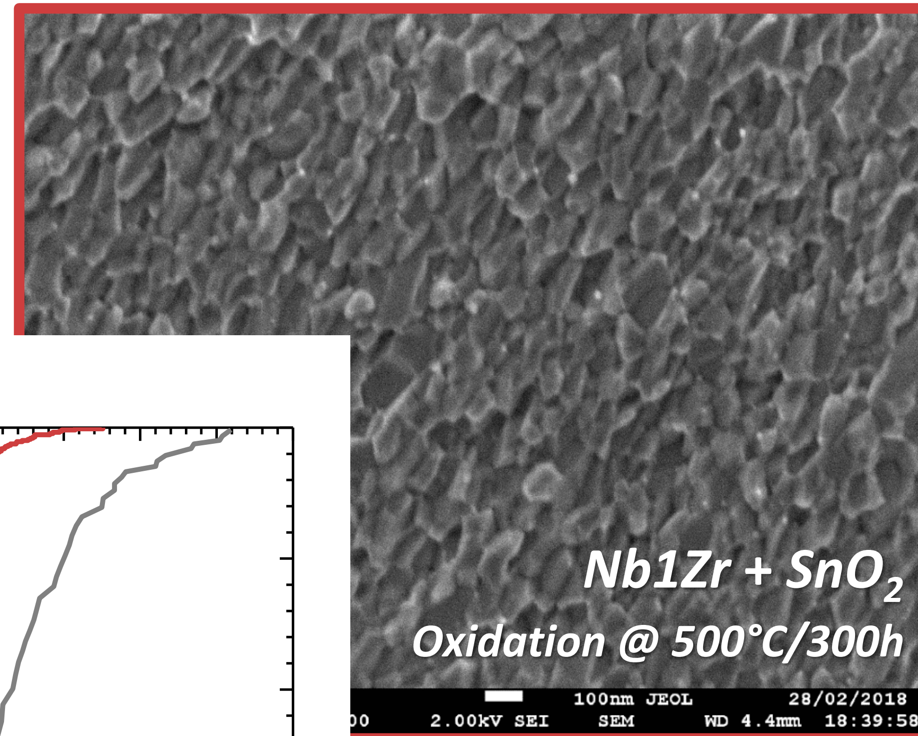
Oxidation treatment @ 500°C/50h

Grain morphology



Median grain size
153 nm





Median grain size
88 nm

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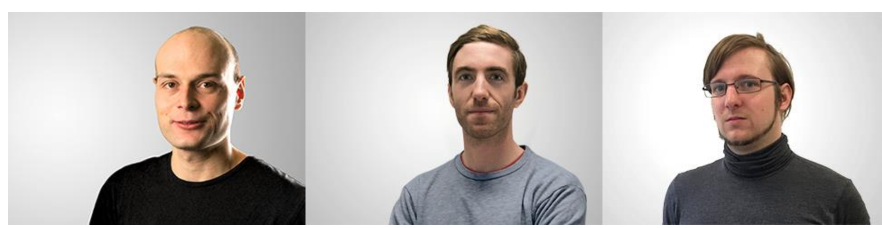


Christian BARTH José FERRADAS Luc GAMPERLE

Degradation upon transverse loads

The 16 T FCC dipoles are being designed with a peak stress of 200 MPa at operation

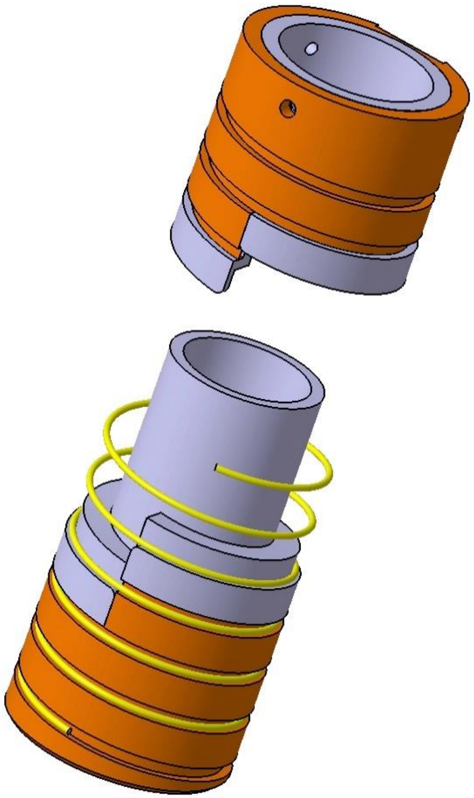
Are the Nb_3Sn wires in the cable able to withstand such a high stress level? Which degradation is tolerable?

Nb_3Sn Rutherford cable for HL-LHC, 40 strands

- Nb_3Sn wires are deformed during cabling
- Cables are braided with glass fiber
- The winding is impregnated with resin

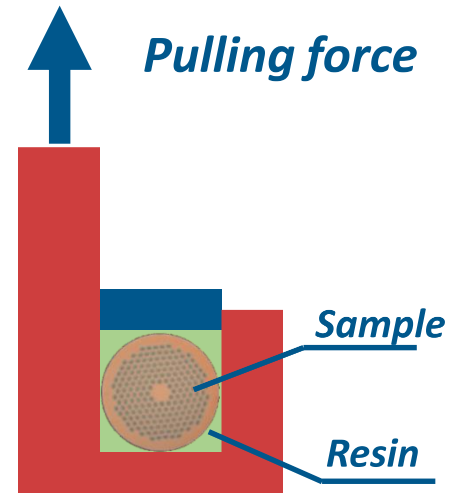
Is it possible to extrapolate the behaviour of the cable from a single wire experiment?

The WASP concept for I_c vs. transverse stress



3 groove widths
- 1.30 mm
- 1.15 mm
- 1.00 mm

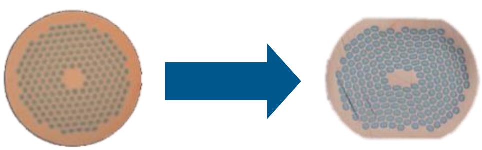
4-WALL + impregnation



CERN-UNIGE collaboration agreement K1629/TE (2009-2012)

The irreversible limit of the wire under transverse stress is influenced by several parameters

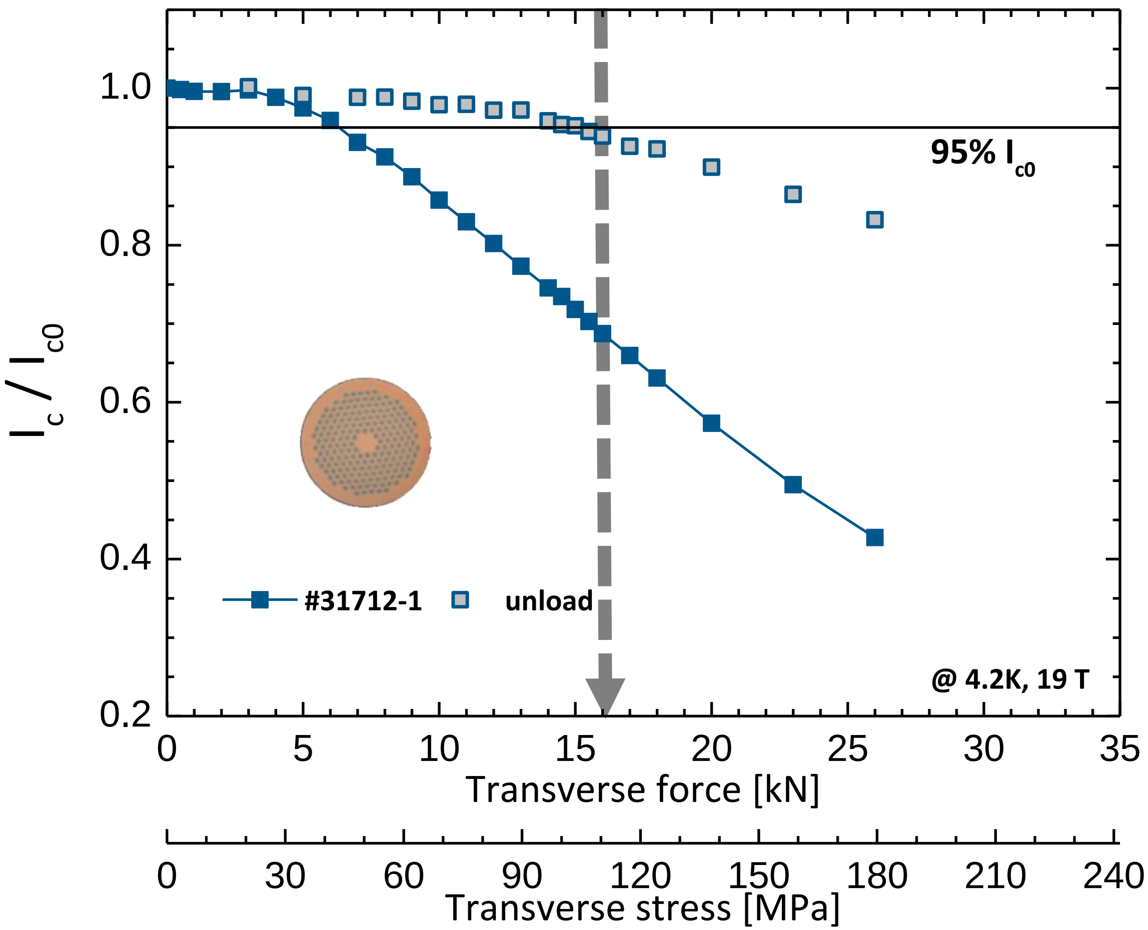
- *the type of impregnation (the elastic modulus of the resin)*
- *the redistribution of the applied stress on the wire*



Rolled wire to simulate the deformation during cabling

- *the wire layout*

I_c vs. transverse stress: PIT 192 + epoxy L



The irreversible limit is defined at the force level leading to a 95% recovery of the initial I_c after unload

Here

$$F_{irr} = 16\ kN$$

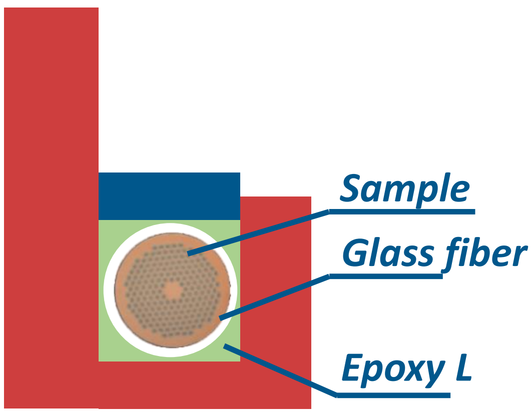
The corresponding irreversible stress limit is

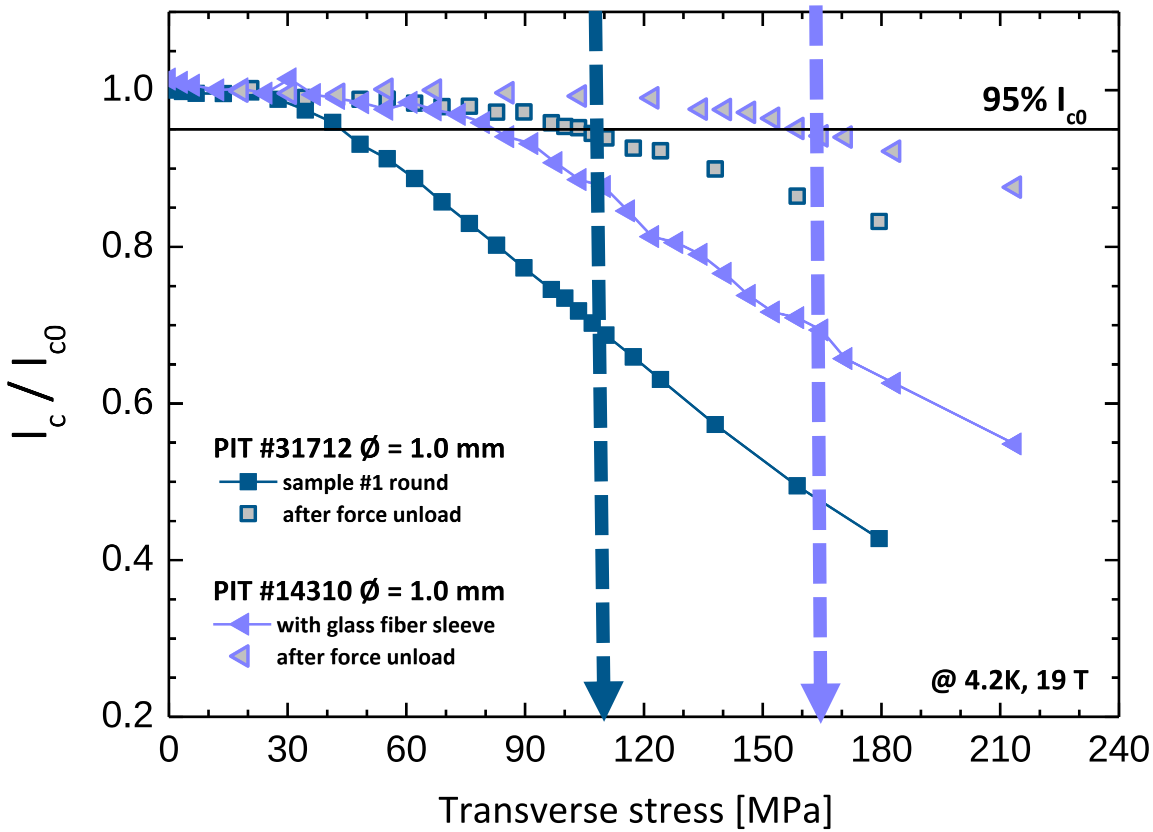
$$\sigma_{irr} = 110\ MPa$$

where

$$Stress = \frac{Force}{groove\ length \times groove\ width}$$

I_c vs. transverse stress: wire in a glass fiber sleeve

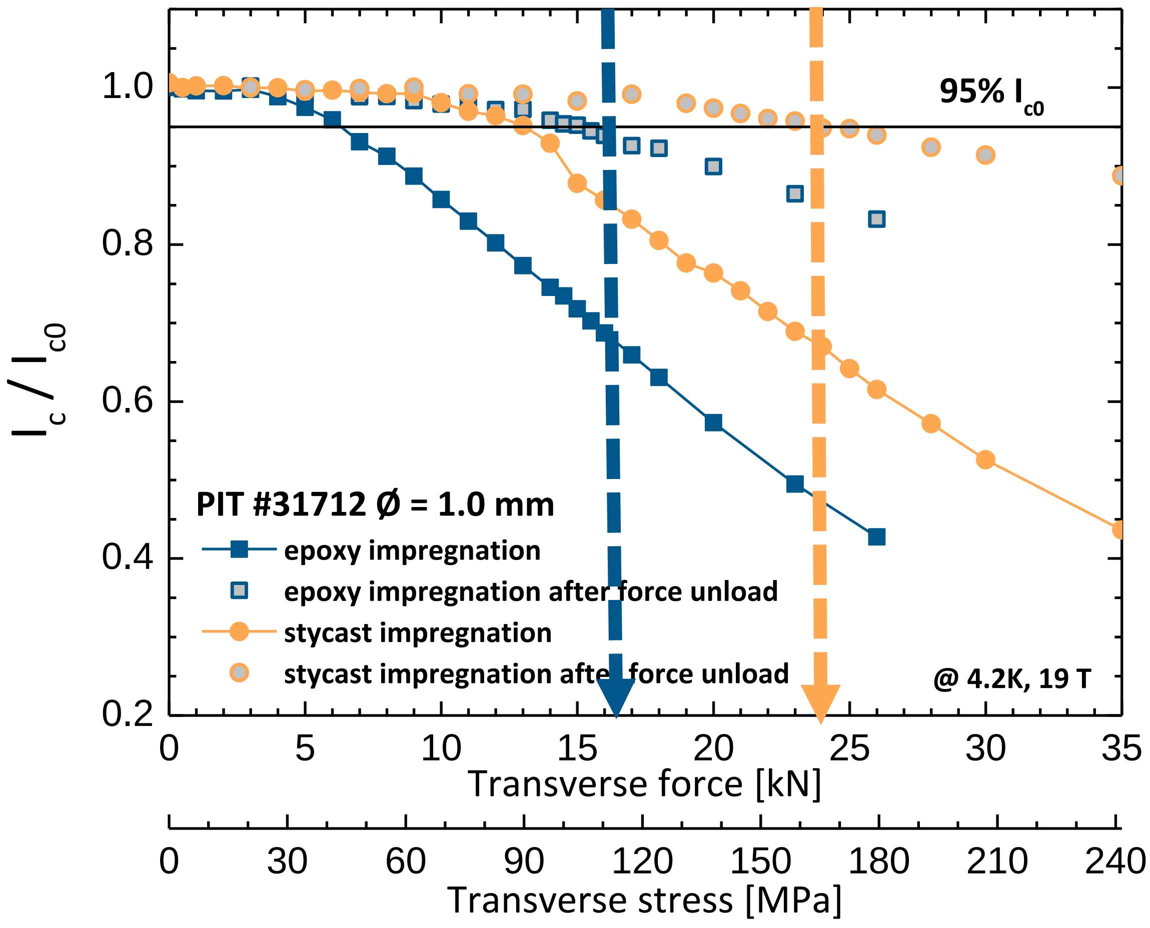




Shift of σ_{irr} by > 50 MPa

The wire with glass fiber sleeve was measured in a larger groove (1.30 mm vs 1.15 mm)

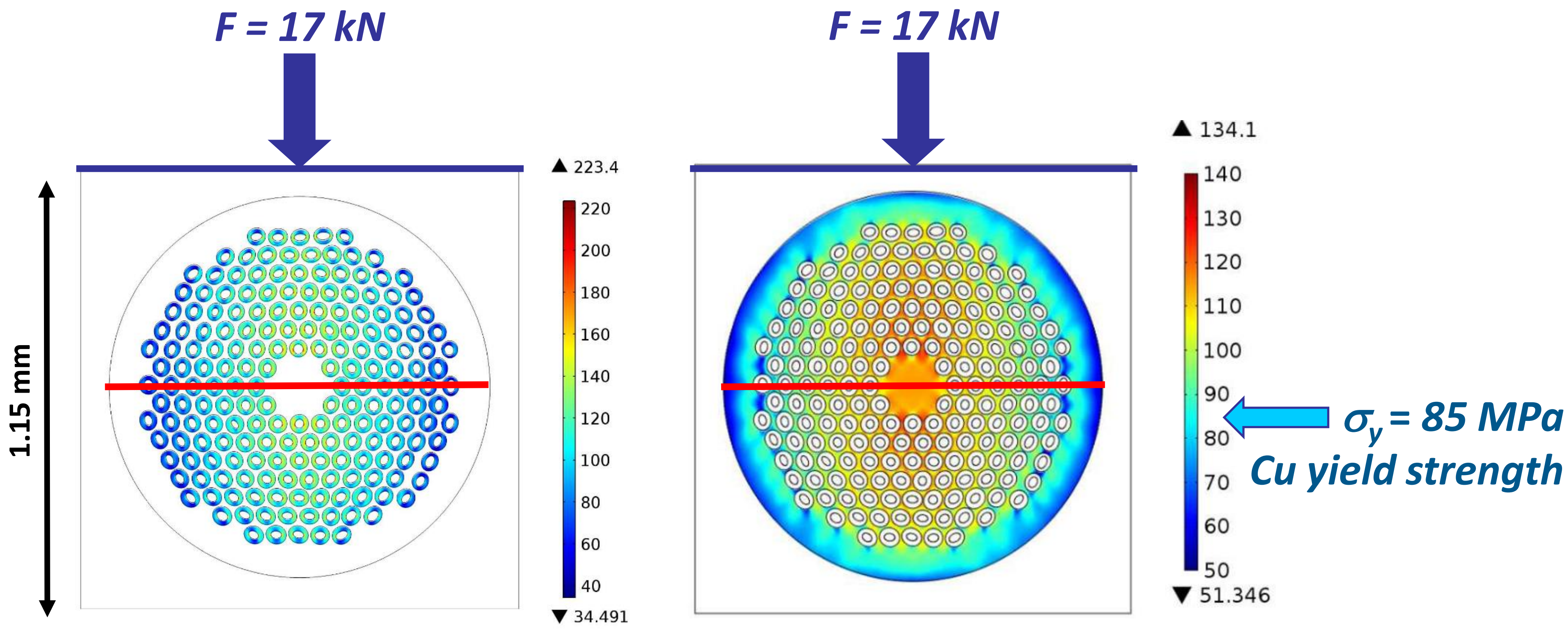
I_c vs. transverse stress: epoxy L vs. stycast



The change of resin, from epoxy to stycast, leads to an increase of σ_{irr} by > 50 MPa

The result is comparable to the value found with epoxy + glass fiber sleeve

FEM: stress redistribution in the wire



Irreversible degradation is determined by filament cracks and residual strain on Nb_3Sn imposed by plastically deformed Cu

FEM suggests that smaller filaments and higher Cu/nonCu ratio lead to higher stress tolerance

C. Calzolaio, CS et al., SuST 28 (2015) 055014

Summary & Outlook

- ***Observed a refinement of the Nb_3Sn grains but the process is still under optimization***
- ***NbTaZr alloys: The goal is to produce material with refined grains (ZrO_2 dispersion) and enhanced B_{c2} (Ta-doping)***
- ***Explored the irreversible stress limit of PIT wires in different load conditions***
- ***Similar studies are being carried out on RRP wires together with FEM analysis***

Thank you for the attention !

Carmine SENATORE

carmine.senatore@unige.ch

http://supra.unige.ch