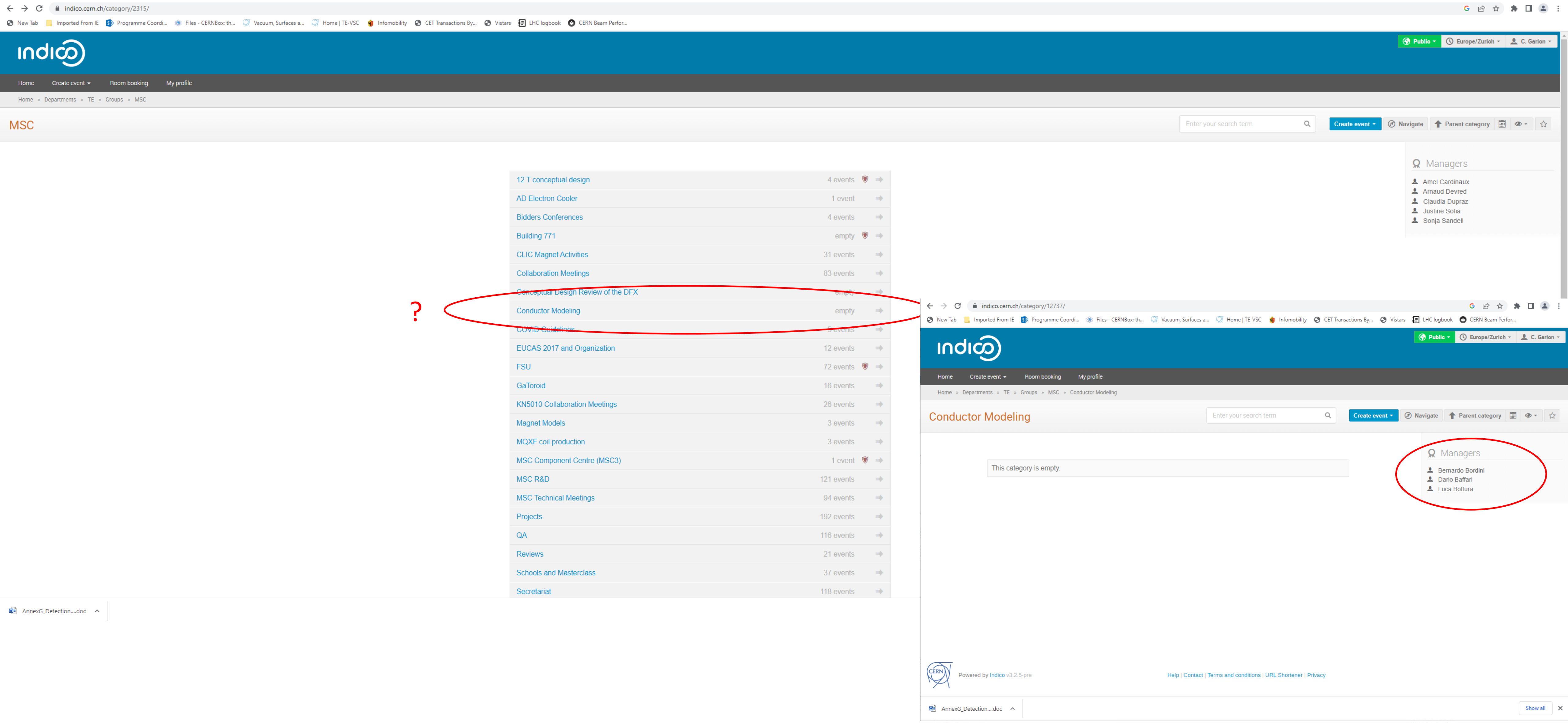
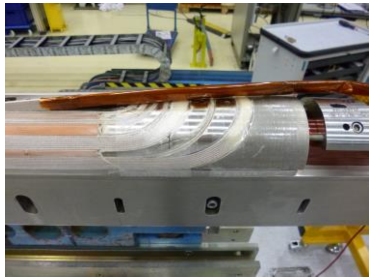
Indico page for Nb3Sn cable modeling



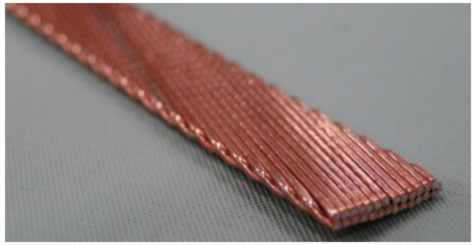
Slot for the meeting:

- **Monday 14h**
- (Tuesday 9h)
- Wednesday 11h or 14h
- Thursday 11h
- Friday 9h or 14h



Thermal mechanical behaviour of the cable during and after RHT for:
→ Stress state/geometry after RHT
→ Dimensioning of the tooling/mould

Cable before RHT defined by:
- Geometry
- prestress



(Orthotropic) cable model:
- Elasticity
- Thermal expansion
- Phase transformation
- Plasticity: Yield surface, flow equation, hardening

Multi-scale FEA approach :
- Identifications of parameters at microscale (nanoindentation)
- Modelling of filaments, wires and cable
- Simulation of RVE of cable

Experimental tests:
- Identifications of parameters at cable scale
- Validation/calibration of the multi-scale approach

Needed to:
- Assess the local stress state after RHT
- Reduce complex exp. Tests
- Extrapolate to other cable geometries

Experimental tests:

"CTE" (axial & lateral) measurements on wires and cables

- without or after an annealing treatment (250C?)

Measurement of Force/displacement (axial & lateral) curves on wire and cable before and after RHT → E, nu, plasticity
Chamber required → budget > 100 kCHF.

Measurements on constrained cables:
reaction forces during a RHT cycle for cables fixed at the extremities with rigid support in:

- stainless steel,
- Titanium.

Nanoindentation for local material parameters (E, Sy), from RT to RHTT

- RT measures already possible
- High temperatures → budget of ~ 300 kCHF

What is the influence of the prestress in the Nb on the Nb3Sn behavior after the reaction?
Is the Nb3Sn phase created in the "same" stress state as the Nb (constant strain), or in a free stress state?

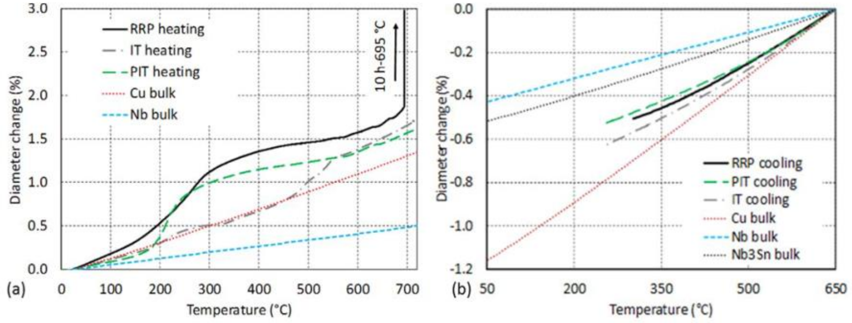


Figure 1. (a) Typical evolution of the RRP, PIT and IT wire diameters as measured by dilation during RHT with a ramp rate of 1.67 °C min^{-1}. (b) Evolution of the reacted RRP, PIT and IT wire diameters during cooling from 650 °C (average of at least two independent measurements). The thermal expansions of Cu, Nb and Nb_3Sn are shown for comparison.

Table 1. Comparison of Nb_3Sn wire diameter and wire and cable length changes before and after RHT. The change to the wire's cross-sectional area was calculated from the diameter change.

	Wire			Cable [11]
	Diameter change (%)	Cross-sectional area change (%)	Length change (%)	Length change (%)
RRP	+2.5	+4.9	−0.07	−0.32
PIT	+1.6	+3.3	−0.15	−0.40
IT	+1.1	+2.3	not measured	not measured

Thermomechanical Behavior of the HL-LHC 11 Tesla Nb_3Sn Magnet Coil Constituents during Reaction Heat Treatment

C. Scheuerlein[1], F. Lackner[1], F. Savary[1], B. Rehmer[2], M. Finn[2], C. Meyer[2]
[1] European Organization for Nuclear Research (CERN), Geneva, Switzerland
[2] Federal Institute for Materials Research and Testing (BAM), Berlin, Germany

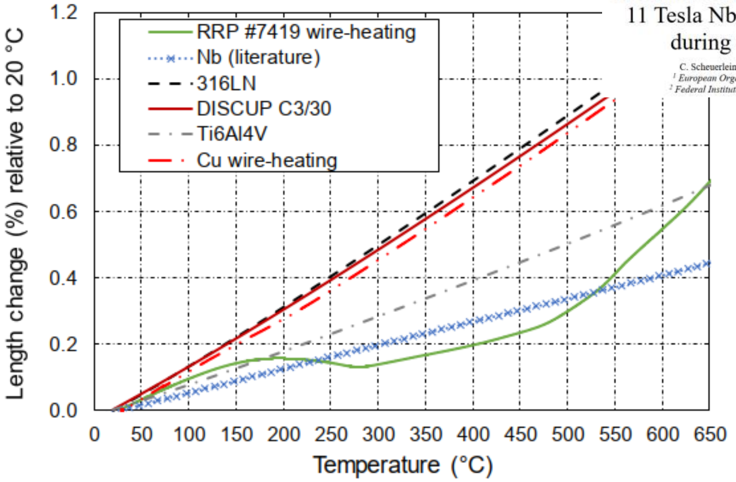


Fig. 10: Comparison of RRP #7419 Nb_3Sn wire axial length change during first heating with that of DISCUP C3/30, Ti6Al4V, and 316LN. The relative length changes of a Cu wire and the Nb thermal expansion from reference [20] are shown for comparison.

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Length Changes of Unconfined Nb_3Sn Rutherford Cables During Reaction Heat Treatment

Matthias Michels, Friedrich Lackner, Christian Scheuerlein, Alejandro Carlon Zurita, Salvador Ferradas Troitino, Nicolas Bourcey, Frederic Savary, and Davide Tommasini

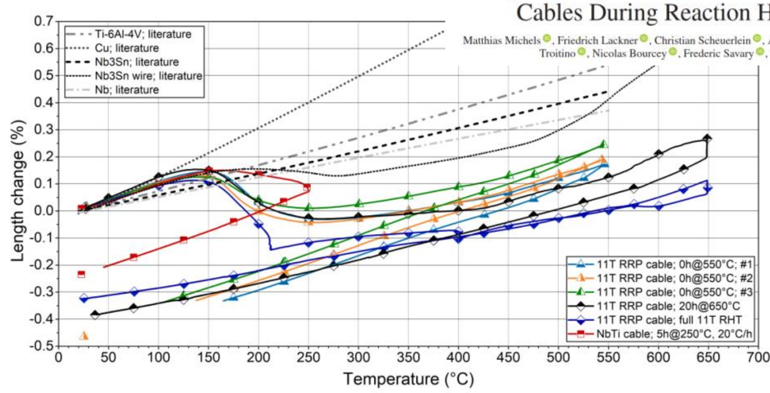


Fig. 5. Comparison of length change behaviour of unreacted Nb_3Sn RRP Rutherford cables (H15OC0220B) with un-annealed Nb-Ti cable and literature values for Ti-6Al-4V [6], Cu [16], Nb [21], bulk Nb_3Sn [16] and Nb_3Sn RRP wires [6].

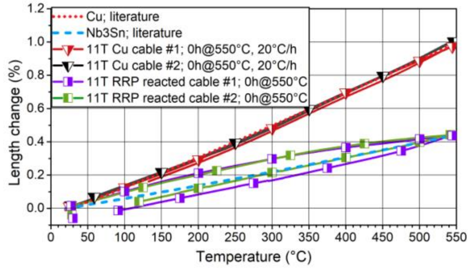
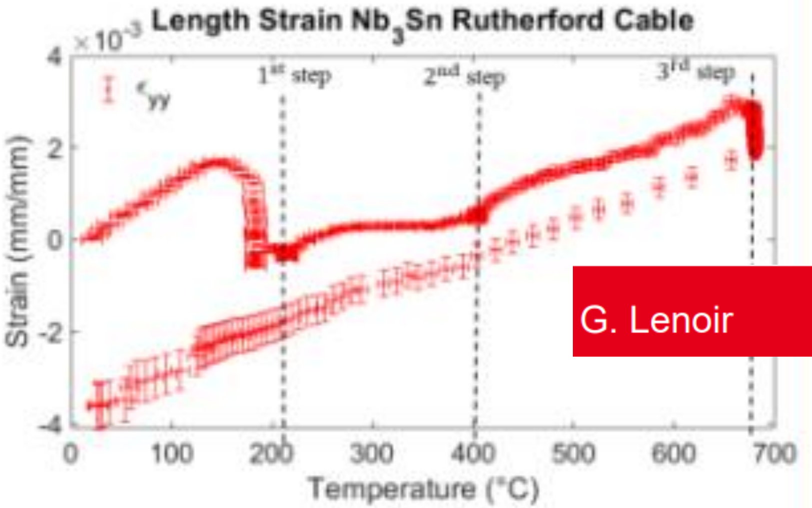


Fig. 6. Relative length changes of un-annealed Cu Rutherford cables and reacted Nb_3Sn RRP Rutherford cables during heat treatment up to 550 °C and comparison with literature values for Cu and Nb_3Sn [16].



Elastic modulus of RRP type Nb_3Sn wire

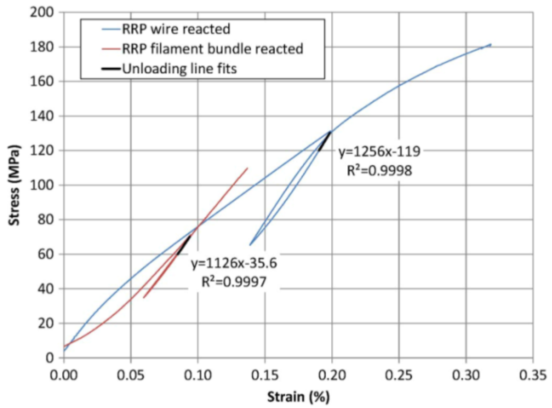


Fig. 3. Stress-strain curves measured at room temperature on a reacted RRP wire and its extracted filaments.

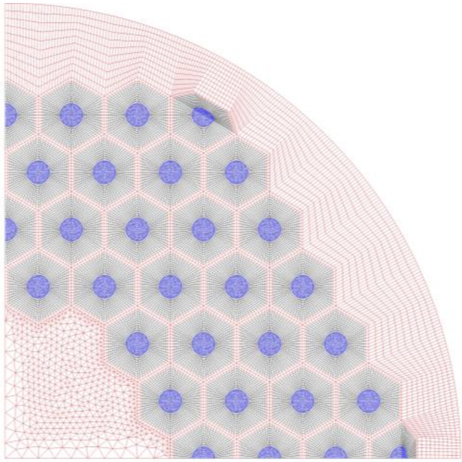
IEEE Trans. Appl. Supercond., 25(6), (2015), 8400605

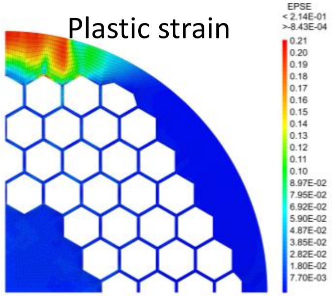
- E is defined as the initial linear slope of the unloading curve.
- Determined elastic modulus of the reacted RRP wire: **126 GPa**

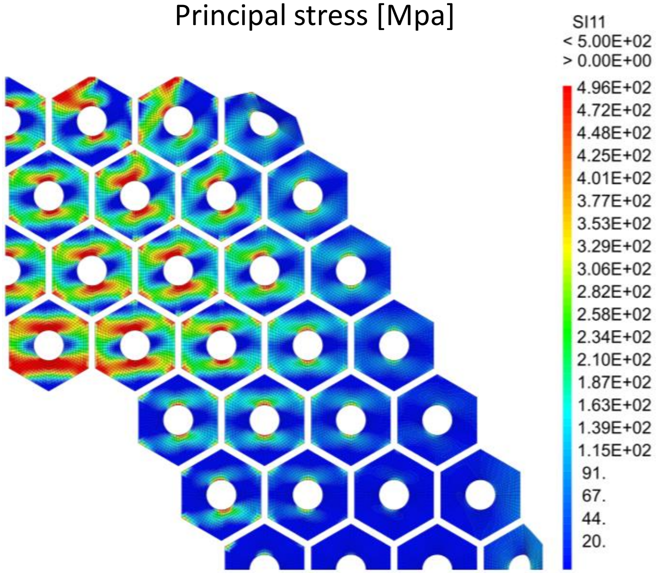
TABLE II
Nb_3Sn ELASTIC MODULI IN AXIAL AND TRANSVERSE DIRECTIONS CALCULATED FOR THE RRP AND PIT WIRES AT RT AND AT 4.2 K

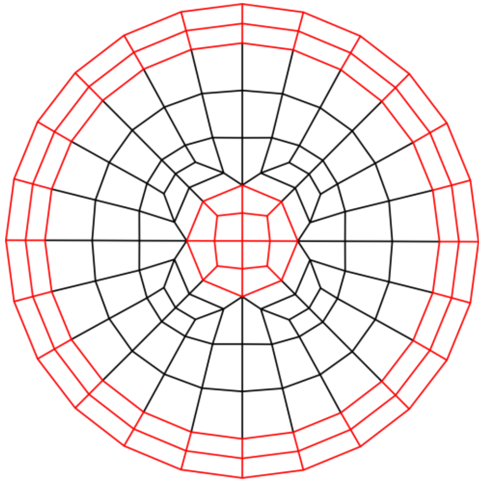
		PIT B215	RRP #7419
RT	E_{axial}	130	140
	E_{trans}	135	129
4.2 K	E_{axial}	106	127
	E_{trans}	116	104

Microscopic and equivalent wire models

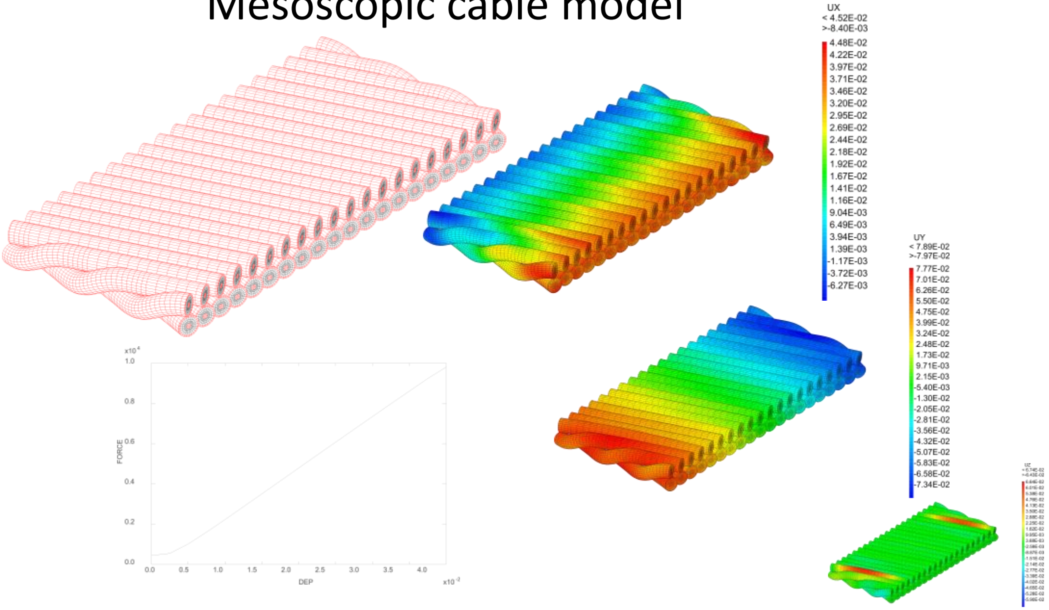




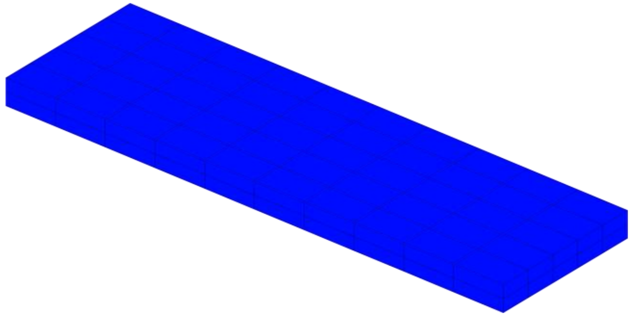


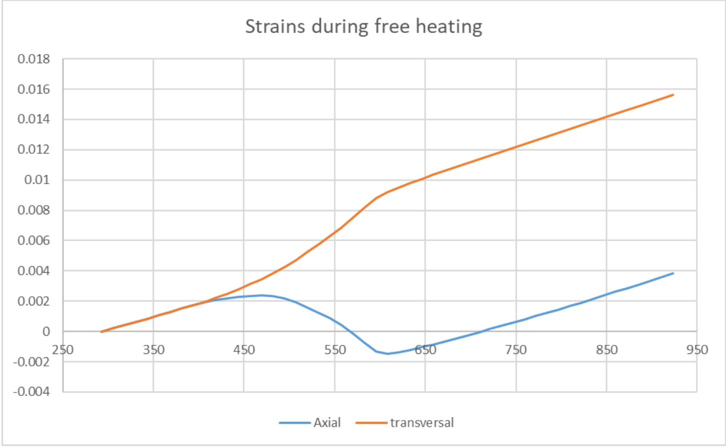


Mesoscopic cable model



Macroscopic cable model





Model with initial back stress

The model shall be coherent with the FEA code expected to be used.