CERN

Collaboration meeting on DS 11T Dipole grounds

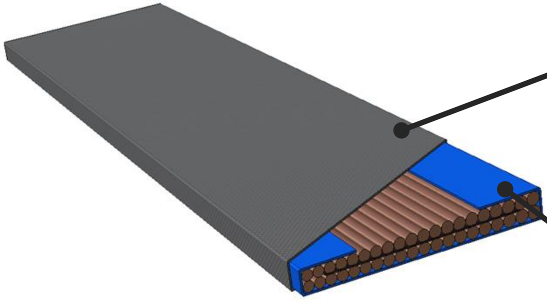
CERN technological choices: Cable insulation and coils

D. Smekens

Outline

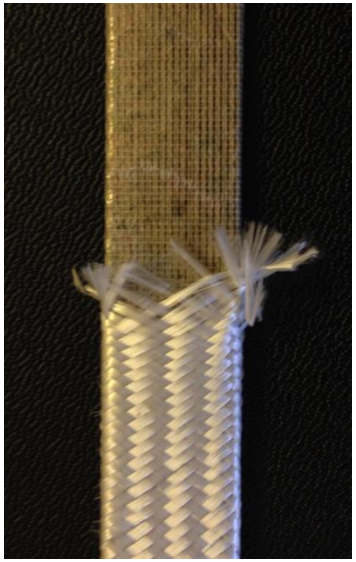
- Cable Insulation
  - Schematic
  - Wall thickness under compression
  - Inter-turn Dielectric Strength
  - 10 Stacks
  - Compressive strength / cracking
  - Stress-Strain Behavior (at RT)
  - Open questions
- Coils
  - Autopsies, findings, defects (core, epoxy adhesion, cracks, voids)
  - What shall we look for ?
  - G11 Splice Block & Splice
- Topics for discussion

Cable Insulation: schematic



S2 Glass Sleeve
32 threads over-braided
bundles of 9 yarns for each thread;
Yarn: AGY S-2® 11TEX 636
Yarn count: 12 threads over 20 mm

Parameters
Yarn: alternatives not evaluated
Bundle: 9 yarns (tested 6 & 5 yarns)
thickness variation @30MPa : ~10 μ
Yarn count: 18→12/20mm
thickness variation @30MPa : ~15 μ

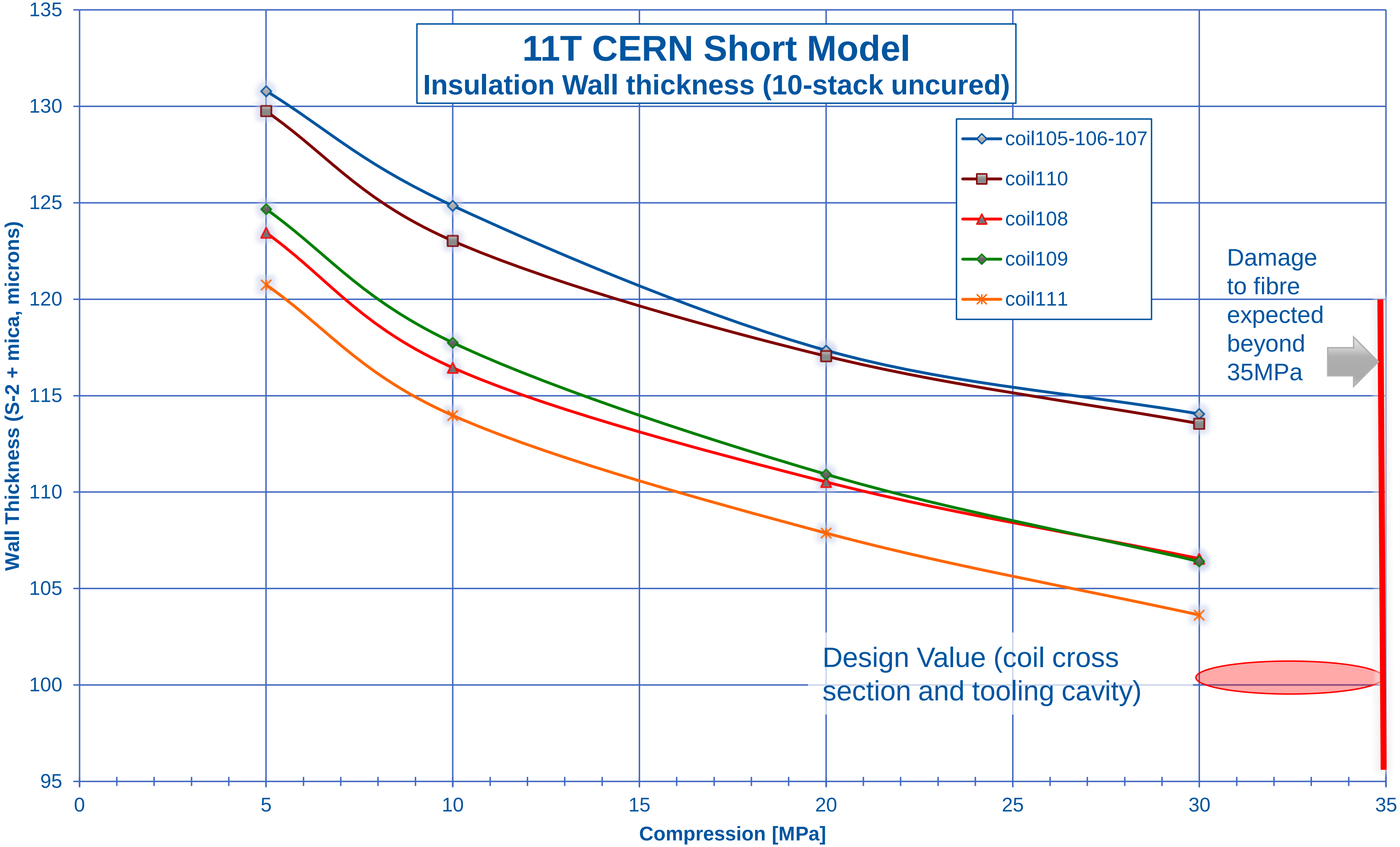


Mica Tape
COGEBI FIROX®
Thickness: 80μ (~90μ)
Phlogopite mica
E-glass backing strip
800V dielectric strength

Parameters
Prototype under development
Thickness: 75μ
Muscovite mica
1.6 kV dielectric strength

The mica layer is the main dielectric barrier

Insulation: Wall thickness under compression



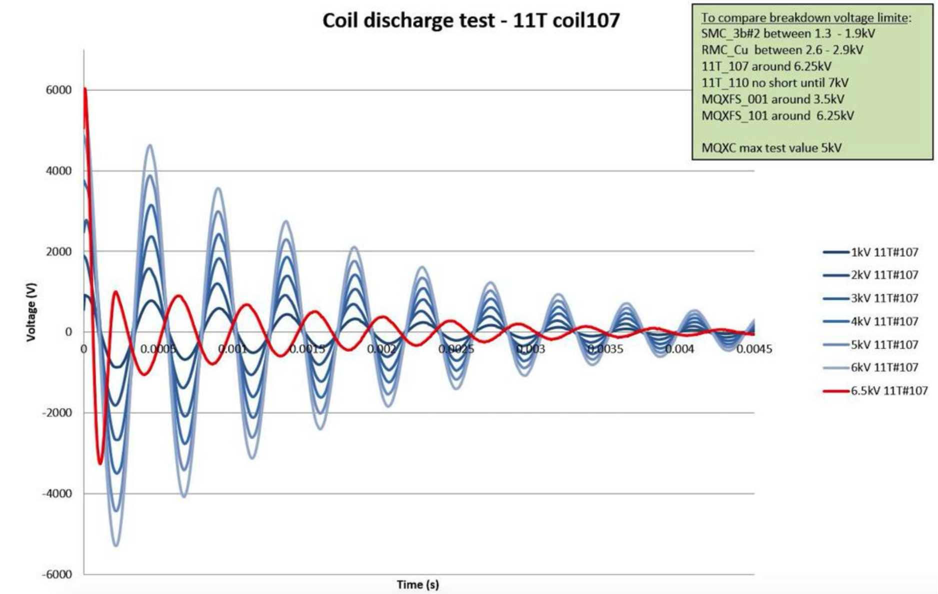
Cable Insulation: Dielectric Strength

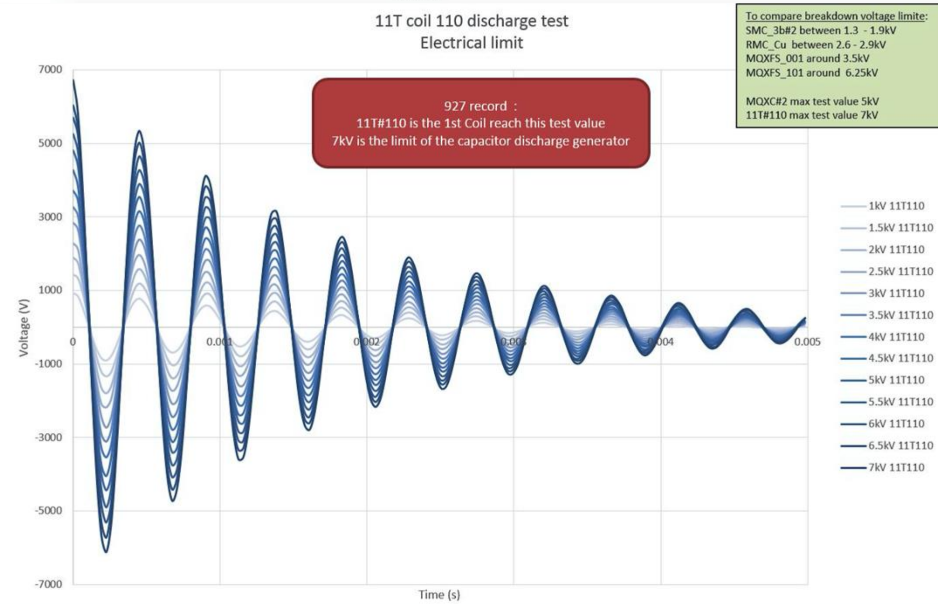
Impregnation of the <u>mica insulated cable</u> is very good

(based on autopsies on coils 104, 107 and SMC 11T02 [1])

Electrical tests are excellent (#110: >7kV discharge ; 107: >6kV discharge, after cold testing and decollaring)

New development ongoing to increase the performance with a thinner and better mica tape based on muscovite



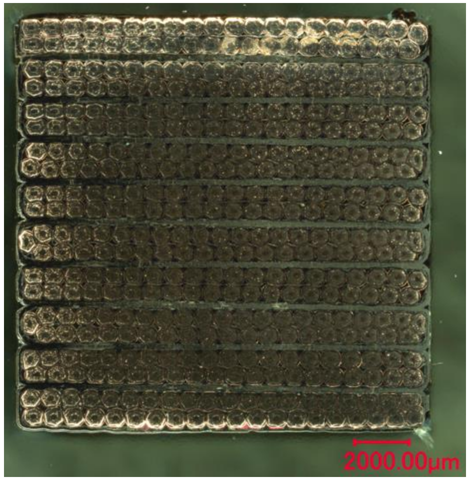


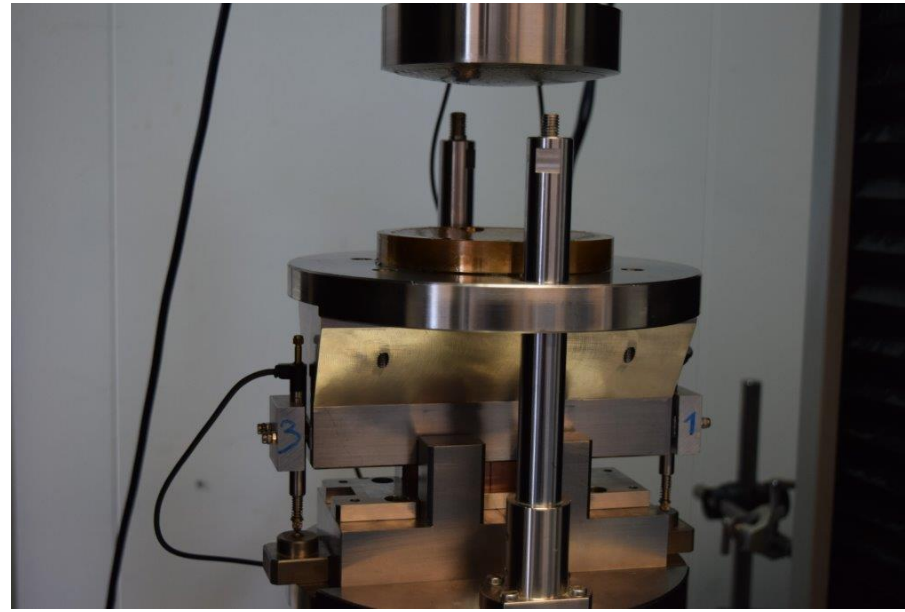
Courtesy of F.-O. PINCOT - TE/MSC

[1] *"Post-mortem examination of the coils SMC 3b #2 and SMC 11T #2 " X.Sarasola, S.Langeslag, EDMS1528722, 2015*

"Inspection of the 2-m long 11T coil #104 – Position of the conductors and quality of the impregnation" X.Sarasola, S.Langeslag, EDMS1473645, 2015

10-stacks



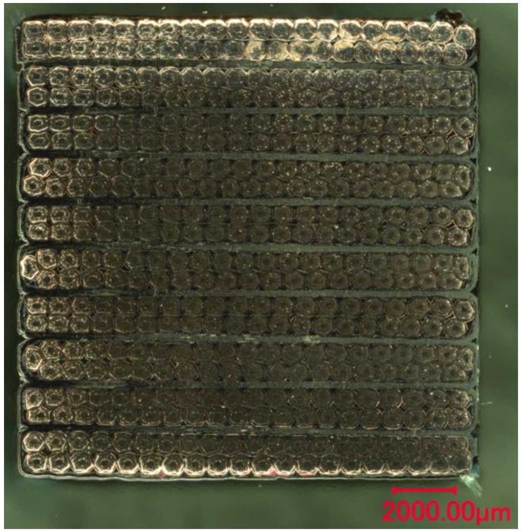


Mech. Tests, courtesy of Oscar Sacristan EN/MME

- 10-stacks are currently under testing:
  - Compression tests at RT and at 77K
  - Metallographic examination
- Mismatch e-modulus from 10-stacks and modulus used for coil design

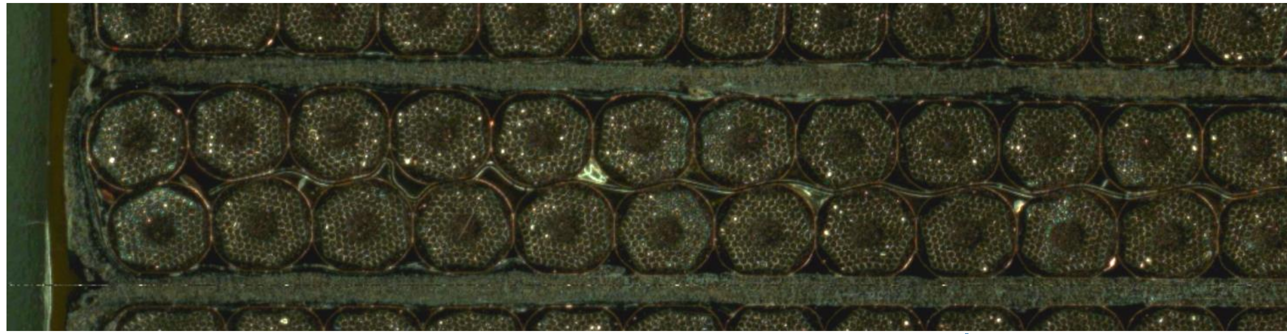
Tests based on 10 samples of 10-stacks. Cable H15OC0127A, OST RRP 108/127, from coil 105 production. Ceramic Binder applied by brushing laterally in quantity representative of the quantity used for coils. Curing, reaction and impregnation (CTD-101K) in tools of 3 different sizes, representing a low compression state (~10MPa); a medium compression state (~20 Mpa) and a high compression state (~30MPa, equivalent to 11T tooling design)

10-stacks: Compressive Strength/Cracking

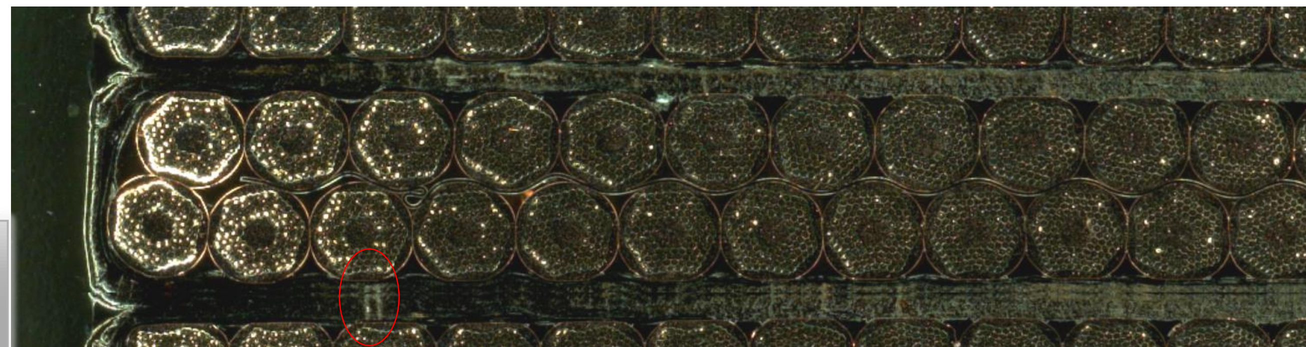


Test based on 3 virgin stacks, single compression cycle

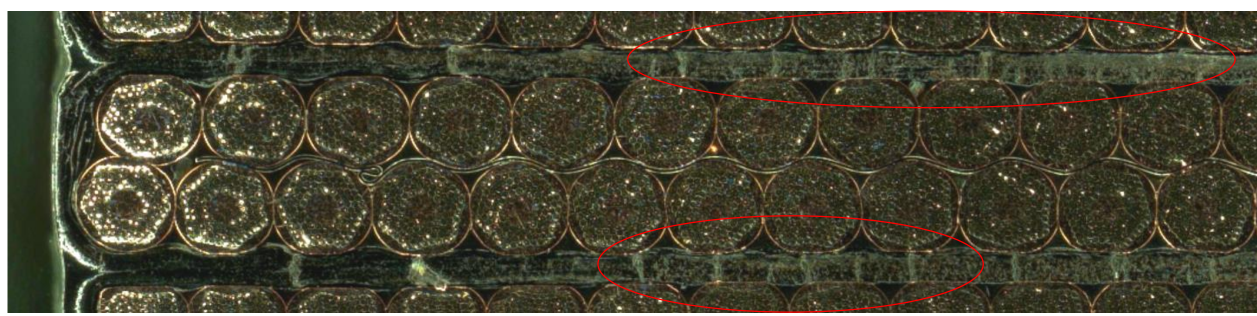
Cracks initiate as from 150MPa, and are generalized at 200 Mpa (in 10-stacks, are 10-stacks representative of the coil ?) 10-stacks with no binder will be prepared for comparison



Sample S2-1: 50 Mpa

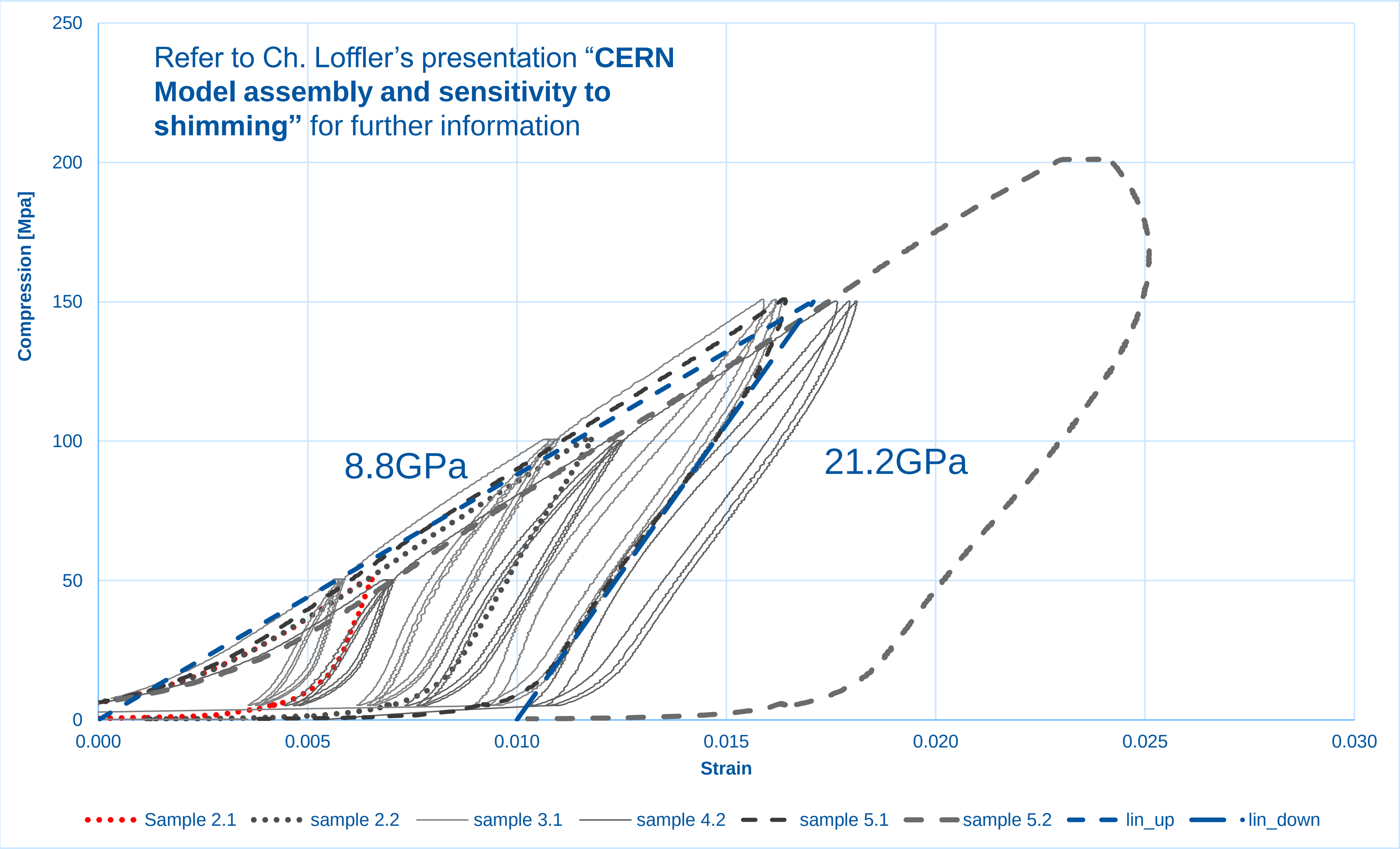


Sample S5-1: 150 Mpa



Sample S5-2: 200 MPa

10-stacks: Stress-Strain behavior (at RT)

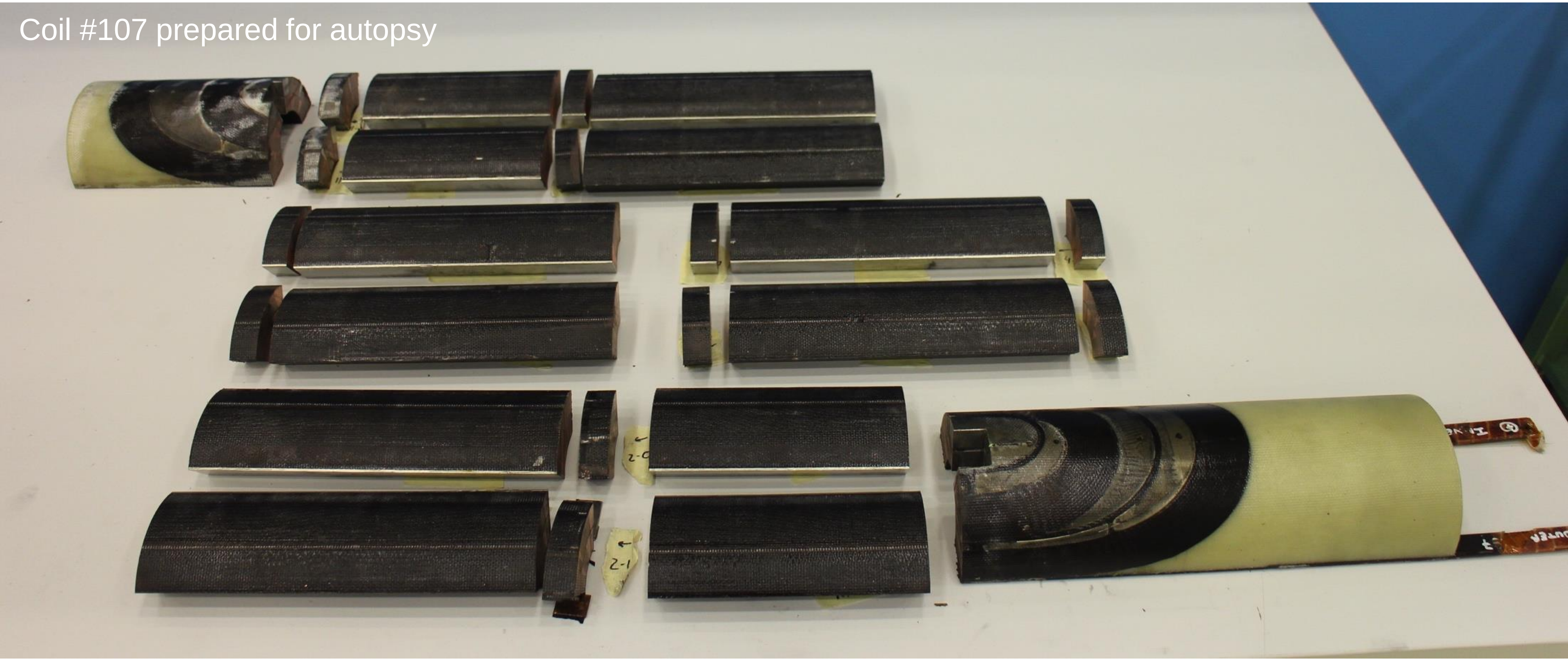


Cable Insulation: Open Questions

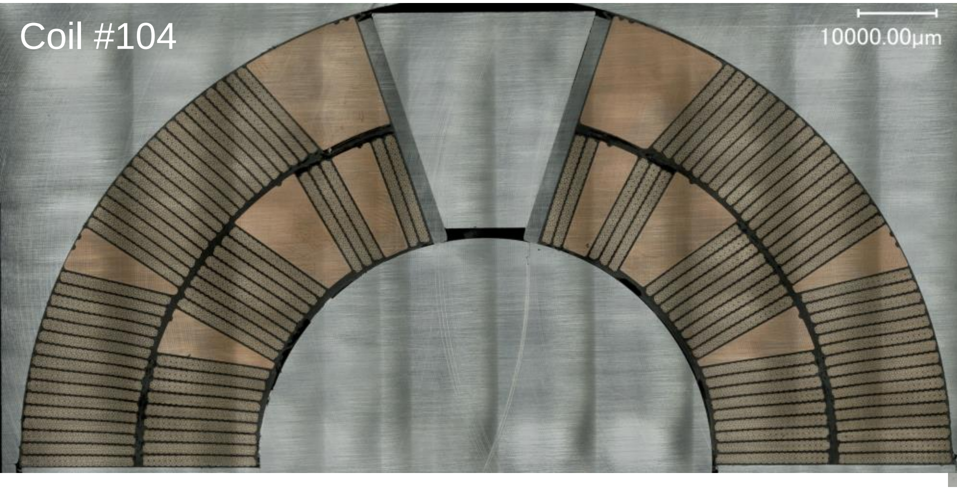
- Mica based insulation, any further questions?
- 10-stacks useful ? (representative of the coil ?)
- What maximum stress acceptable ?
- Sensitivity of the FE model to the coil's elastic modulus
- what stress-strain model to use in FEA?

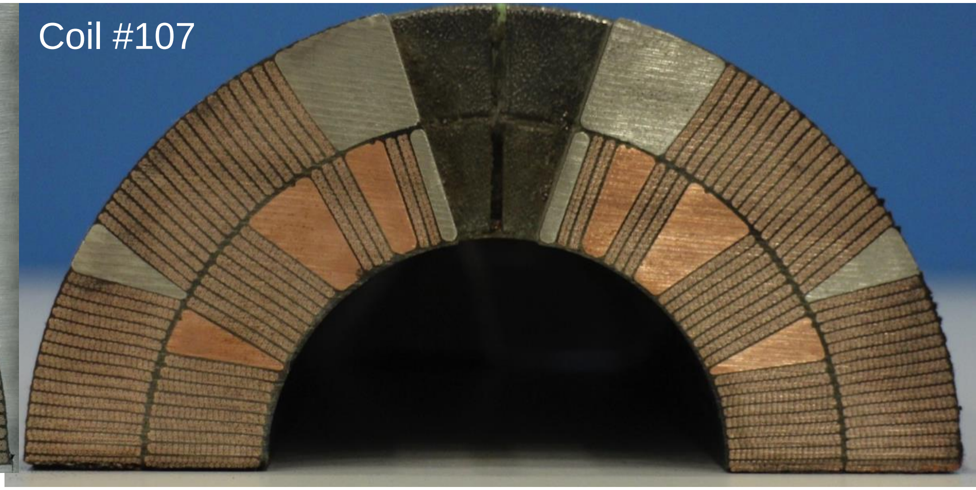
Coils

Coil #104 (RRP54/61), used for collaring tests, never cooled down.
Coil #107 (RRP108/127), tested in aperture SP101 in 2014



Autopsies

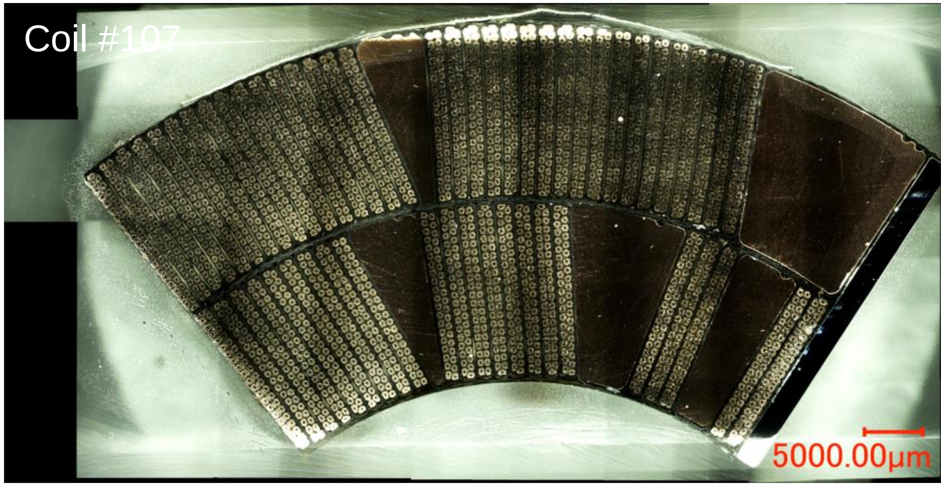




Metallurgical examinations of coils:

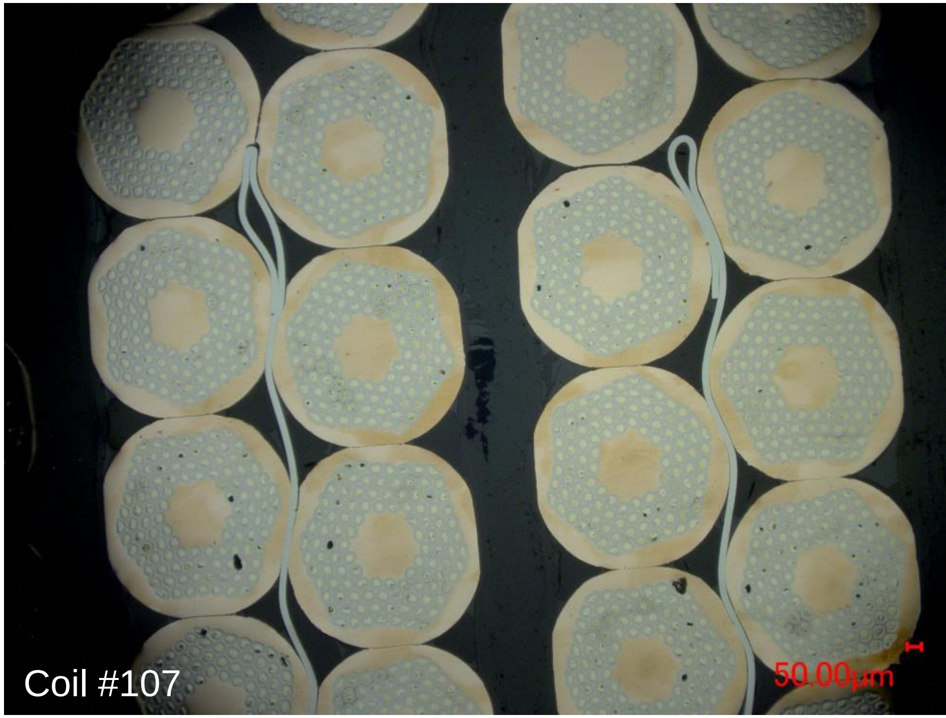
- Sample preparation is difficult and lengthy
- Protocols are not yet fully defined
- Kills the coil

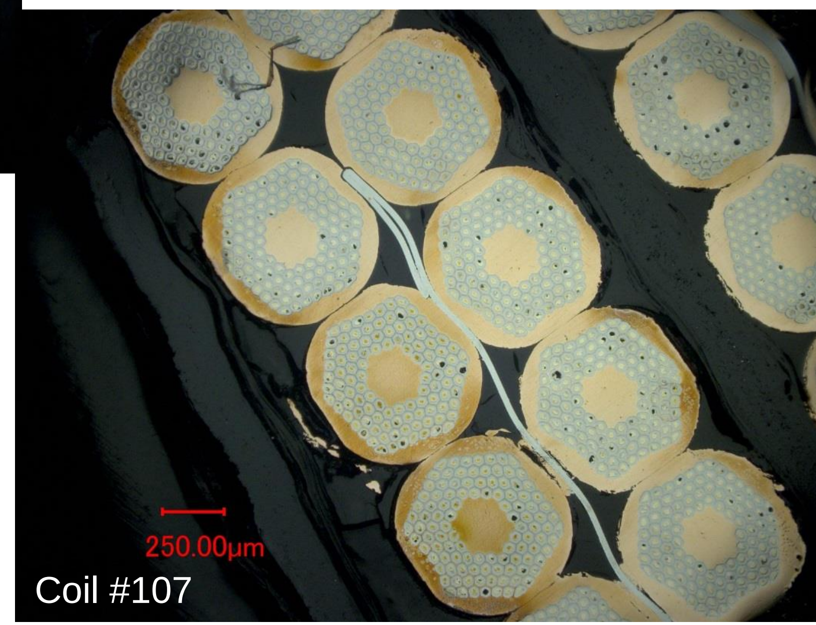
Extremely valuable to find and characterize defects.



Cable Coring

Defects in the placement of the core inside the cable

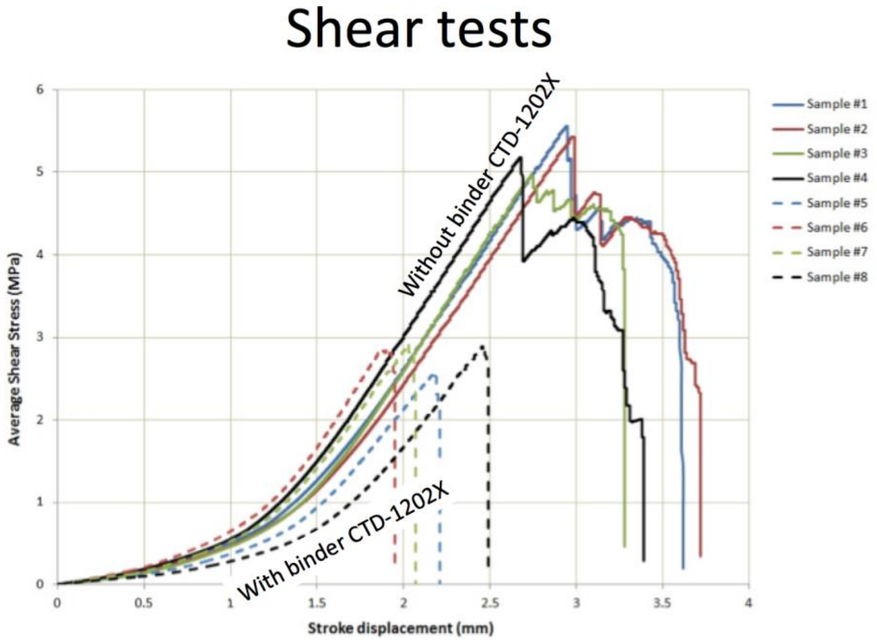




Metallurgic Inspections Coil #107, Courtesy of M. DALY, TE/MSC

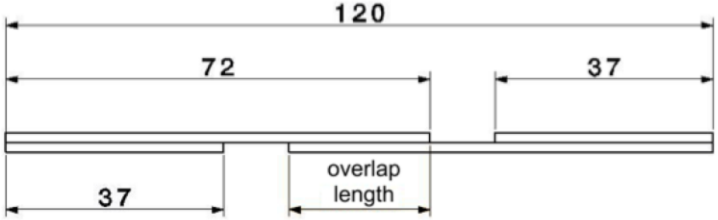
Epoxy Adhesion

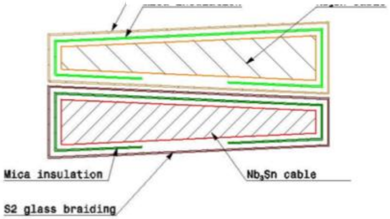
Delamination of the strands during preparation of the samples (cutting)



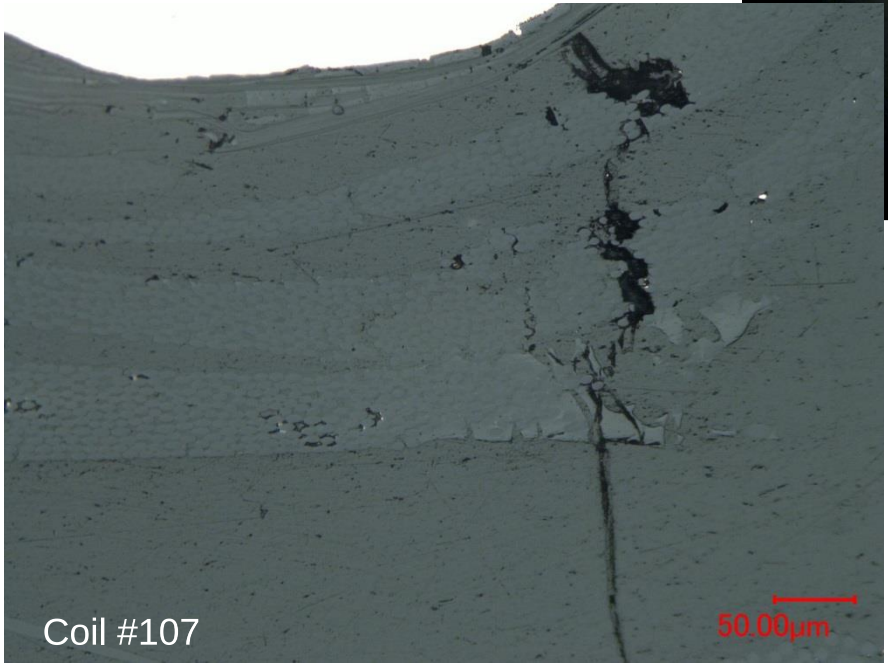
Shear tests

Tests[1] realized on lap joints show that ceramic binder may significantly reduce the bonding strength





[1] "Preliminary shear test results – Influence of the ceramic binder CTD-1202X on Nb_3Sn cable – epoxy bonded joints" X. SARASOLA, EDMS1476587

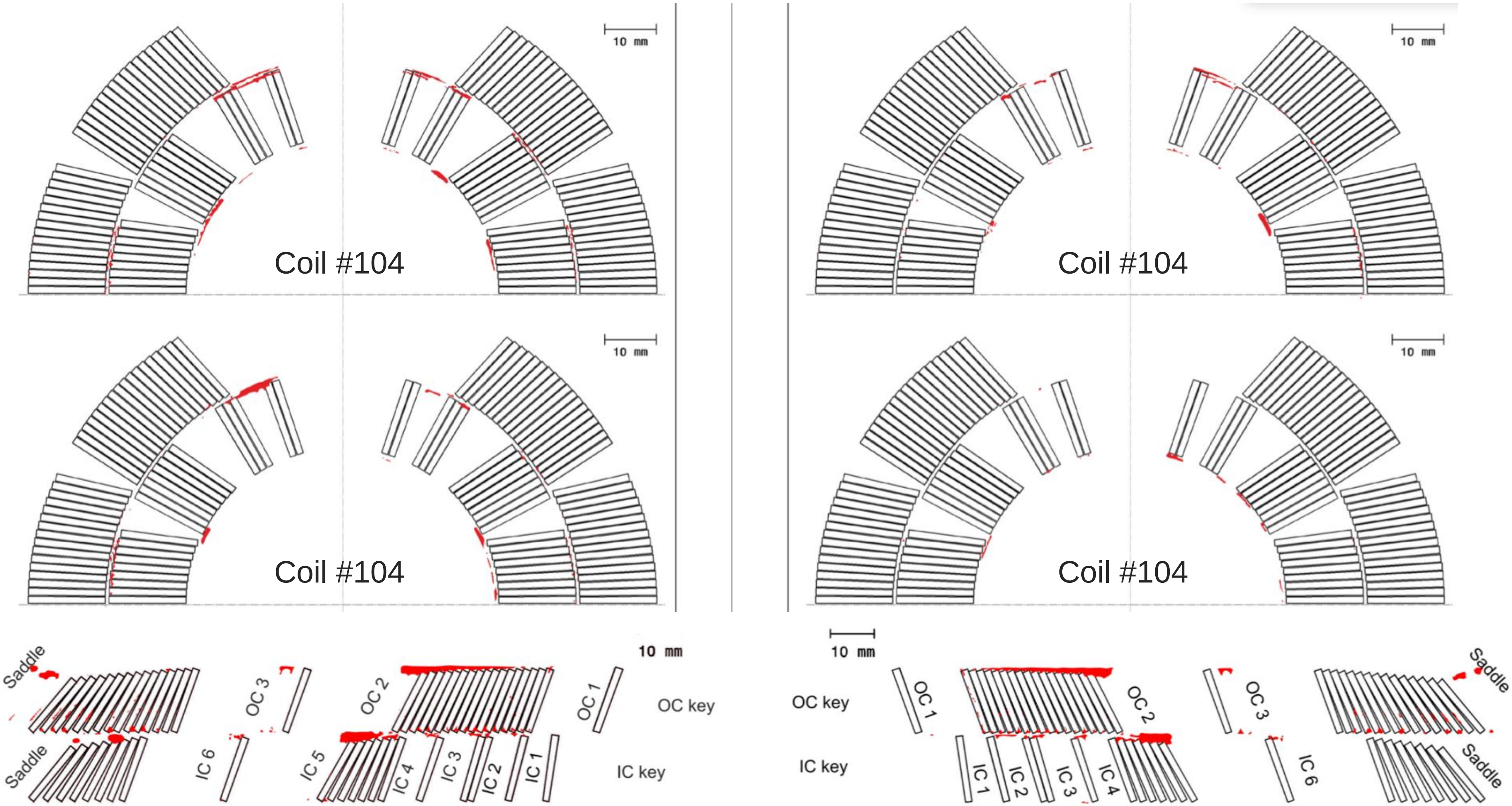


Crack Propagation
A crack spotted in coil 107. from strand to outward. The mica layer is not perforated. Crack propagation to be investigated

Metallurgic Inspections Coil #107, Courtesy of M. DALY, TE/MSC

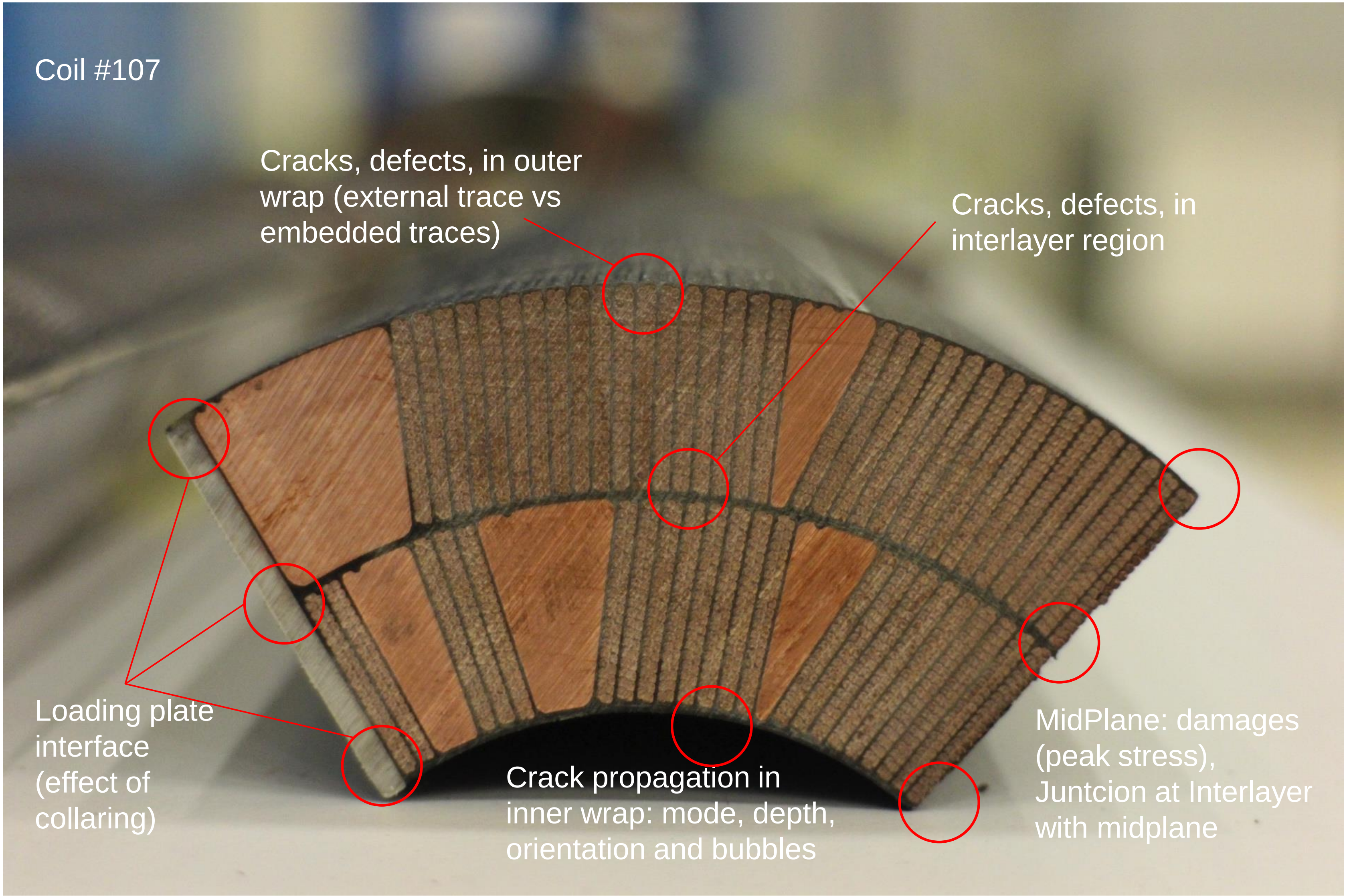
Coil 104: voids location

Similar work will be carried out on coil 107



"Inspection of the 2-m long 11T coil #104 – Position of the conductors and quality of the impregnation" X.Sarasola, S.Langeslag, EDMS1473645, 2015
"11T Coil #104 – Metallurgical Examination" S. Langeslag, EDMS1433007, Oct. 2014

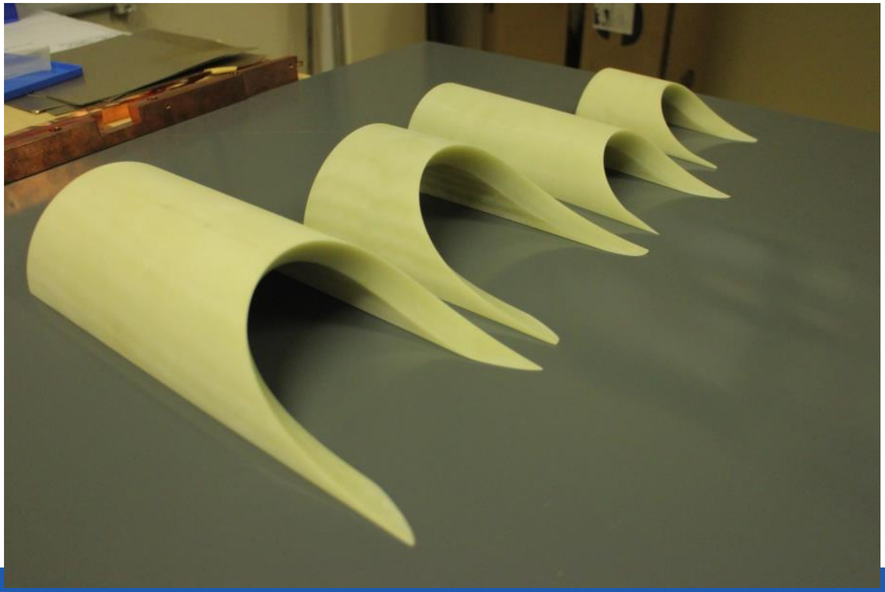
Autopsies: What shall shall we look at ?

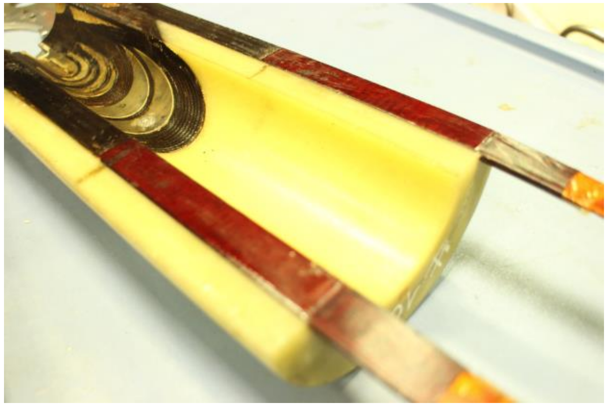


EP-GC22 (G11) Saddles & Splice Blocks

The use of G11 parts for the splice region allows to:

- Lower the rigidity of the coil head and limit the stress on the splice during collaring (the pole loading concept allowing to easily increase the shimming in the straight section of the coil, keeping the stress low in the coil ends and in particular the splice region)
- The G11 insulation material excludes the risk of shorts between splice and saddle-splice block
- The removal of the metallic saddle after reaction allows easy access to clean the splice before and after soldering (flux cleaning)

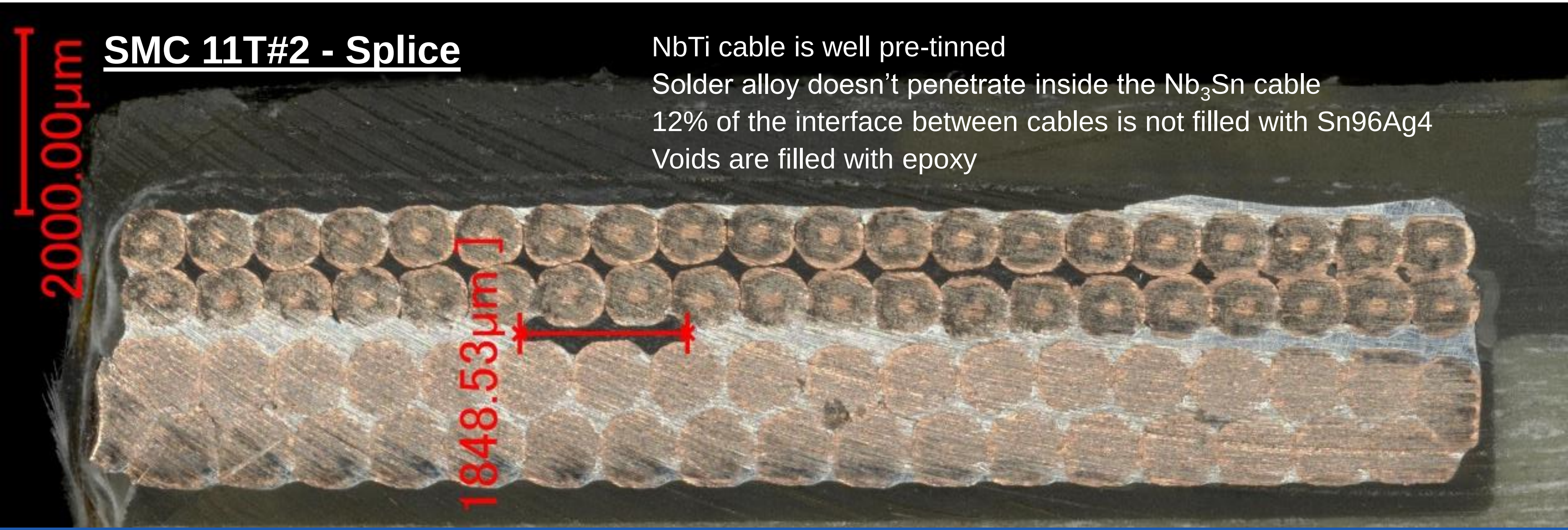




Splice

- The quality of the splice has still to be analyzed by metallurgic examinations for coil 107 [1] The splice resistance measurement during cold tests, has been found not relevant to detect a poor quality soldering. X-Ray Laminography was not fully conclusive [2]
- The proper selection of the alloy and of the flux has not been confirmed yet for the 11T dipole coils, due to the complexity of the splice when the coil is on the baseplate of the reaction tooling

[1] Pb-Sn solder, used on coils 104, 105, 106 , 107, 108; Pb-Ag solder for coils 110 and onward ;
[2] X-ray inspection of the splices of the coil SMC 1 #2 , X. Sarasola, EDMS 1540446



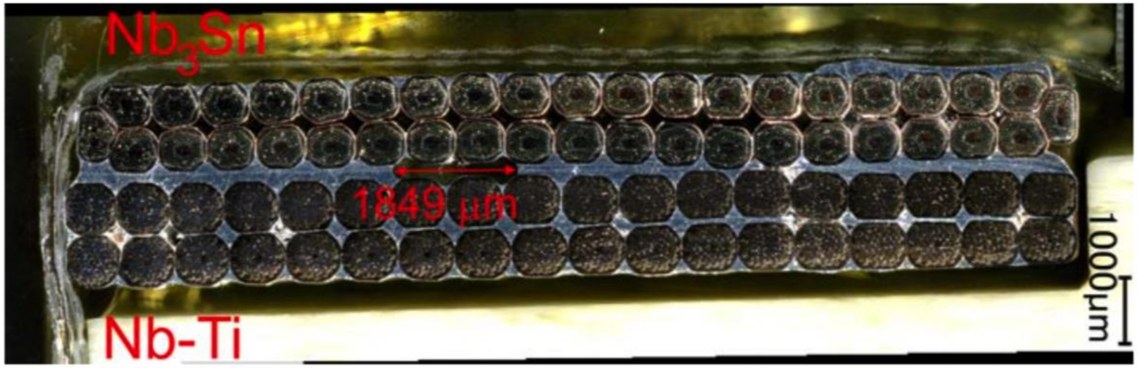
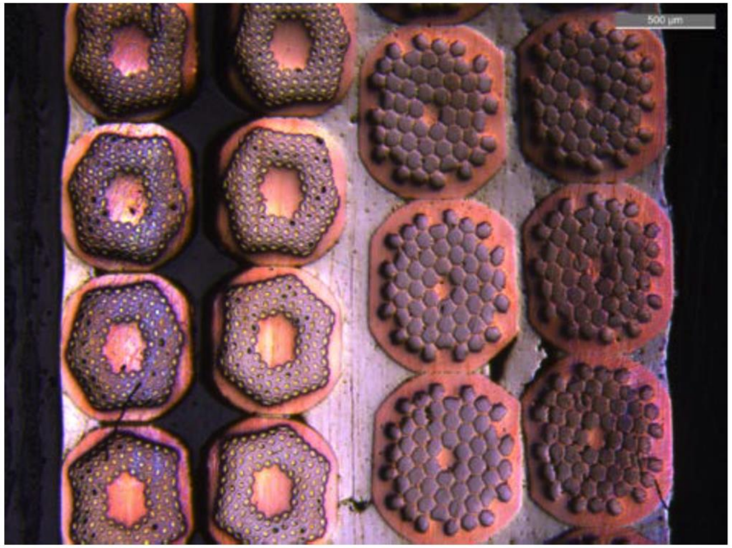


Figure 12. Image of the lower layer splice of the coil SMC 11T #2.

Figure 13. Image of the upper layer splice of the coil SMC 11T #2.



"Post-mortem examination of the coils SMC 3b #2 and SMC 11T #2 " X.Sarasola, S.Langeslag, EDMS1528722, 2015

Topics for discussion

- What shall we measure and analysis to define whether we have reached an “accelerator quality magnet”?
- How should we proceed to analyze all the coils currently available at CERN and at FNAL?
- What are the main remaining open issues concerning these coils:
  - Impact of ceramic binder
  - Selection of epoxy,…
  - Splice Quality
  - Quench Heaters (external trace, embedded trace, inter-layer quench heaters)

Acknowledgments

Special thanks to the people having contributed to the coil autopsies, 10-stack preparation, tests and analysis:

- Michael Daly
- Laura García Fajardo
- Carlos Fernandes
- Remy Gauthier
- Loïc Lambert
- Stefanie Langeslag
- Christian Löffler
- Jacky Mazet
- François-Olivier Pincot
- Oscar Sacristan
- Xabier Sarasola