Development on the Ceramic Insulation for accelerator magnets

F.Rondeaux

CEA saclay - Irfu - SACM - LEAS

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Outline

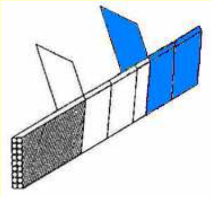
- Context
- Principle
- Technical specifications
- Process
- Characterization
  - Electrical tests (RRR, I_c)
  - Demonstrator
  - Preliminary compression results
- Summary of the results
- The next step…

Context

- At the present time, Nb_3Sn best superconductor candidate for high field magnets (> 10 - 11 T).

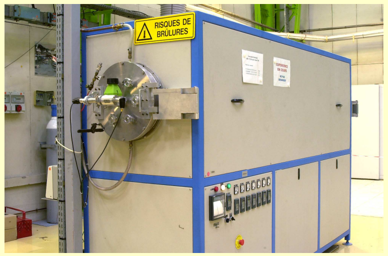
- But delicate implementation:
  - Need long heat treatment at 650 - 660℃ in argon flow ➔ no organic material before treatment.
  - Great brittleness and strain sensitivity of the material after heat treatment ➔ “Wind and React” technique

Wind & React principle with classical insulation



Wrapping

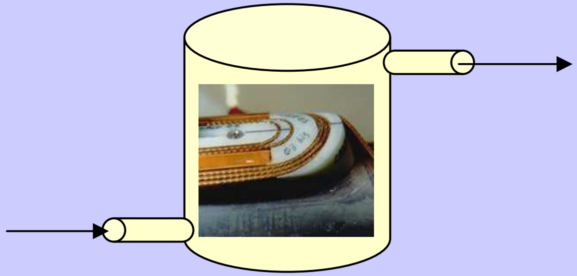
Winding



Heat treatment

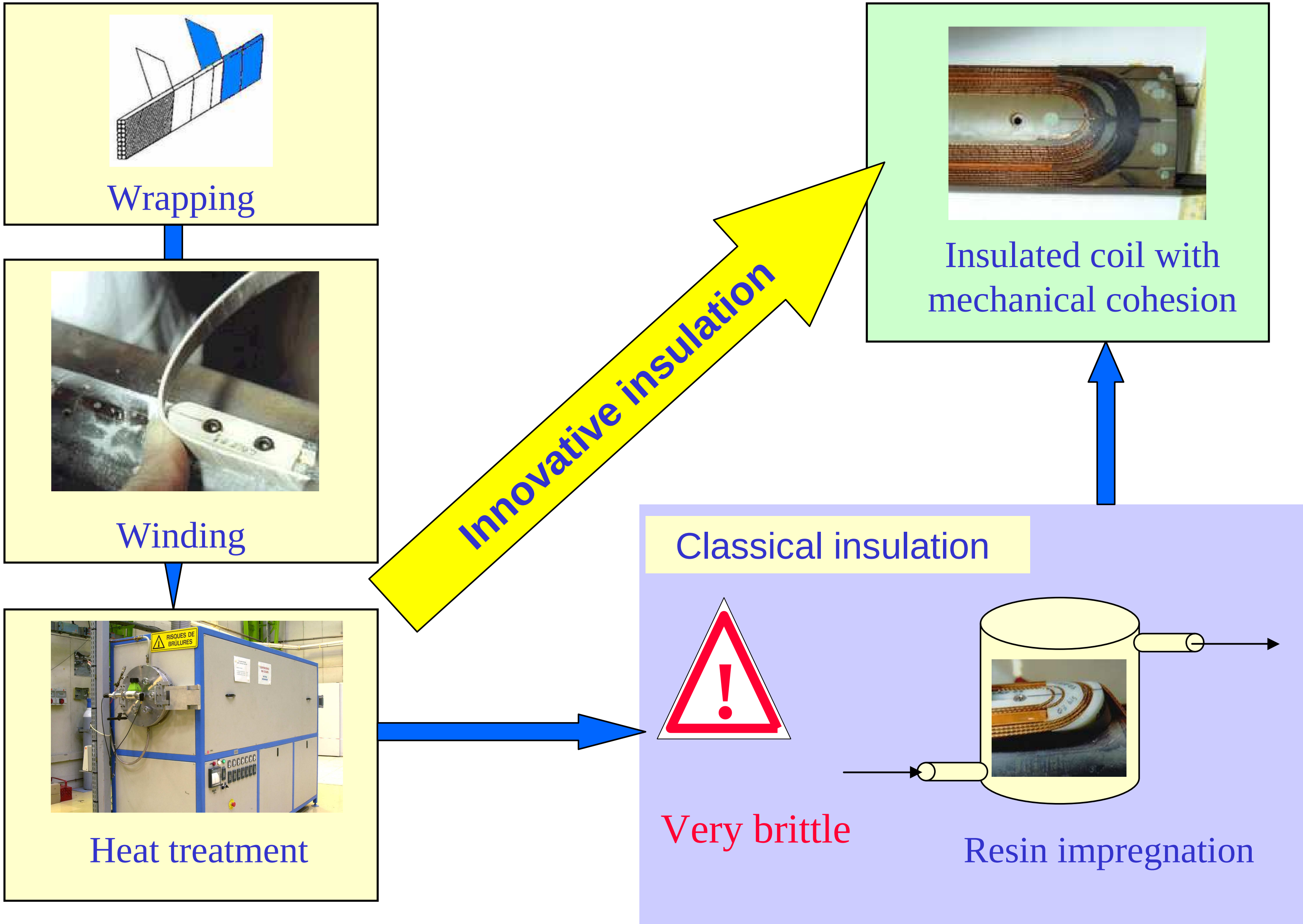
- Cable wrapped with a mineral tape
  - Remove organic sizing with heat treatment
- Coil winding
- Heat treatment at 660℃
- Transfer of the coil into the impregnation mold
- Vacuum impregnation with epoxy resin

Very brittle



Resin impregnation

Insulation R&D



Technical specifications (1/2)

- **Follow the heat treatment imposed by the formation of Nb_3Sn** : ramp at 6℃/h, 240 h at 660℃ in argon flow.
- Appropriate electrical insulation.
  - Dielectric strength at 4.2 K > 75 V between turns
- Mechanical cohesion of the coil during handling and running phases.
- Transverse compression strength .
  - (100 MPa at room Temp. and 70 MPa at 4.2K) / 200 MPa at 300K and 4K
- Dimensional control of the coil.
- Support thermal cycles and running cycles without degradation.
- Radiation hardness > 10^7 Gy.
- Porosity.

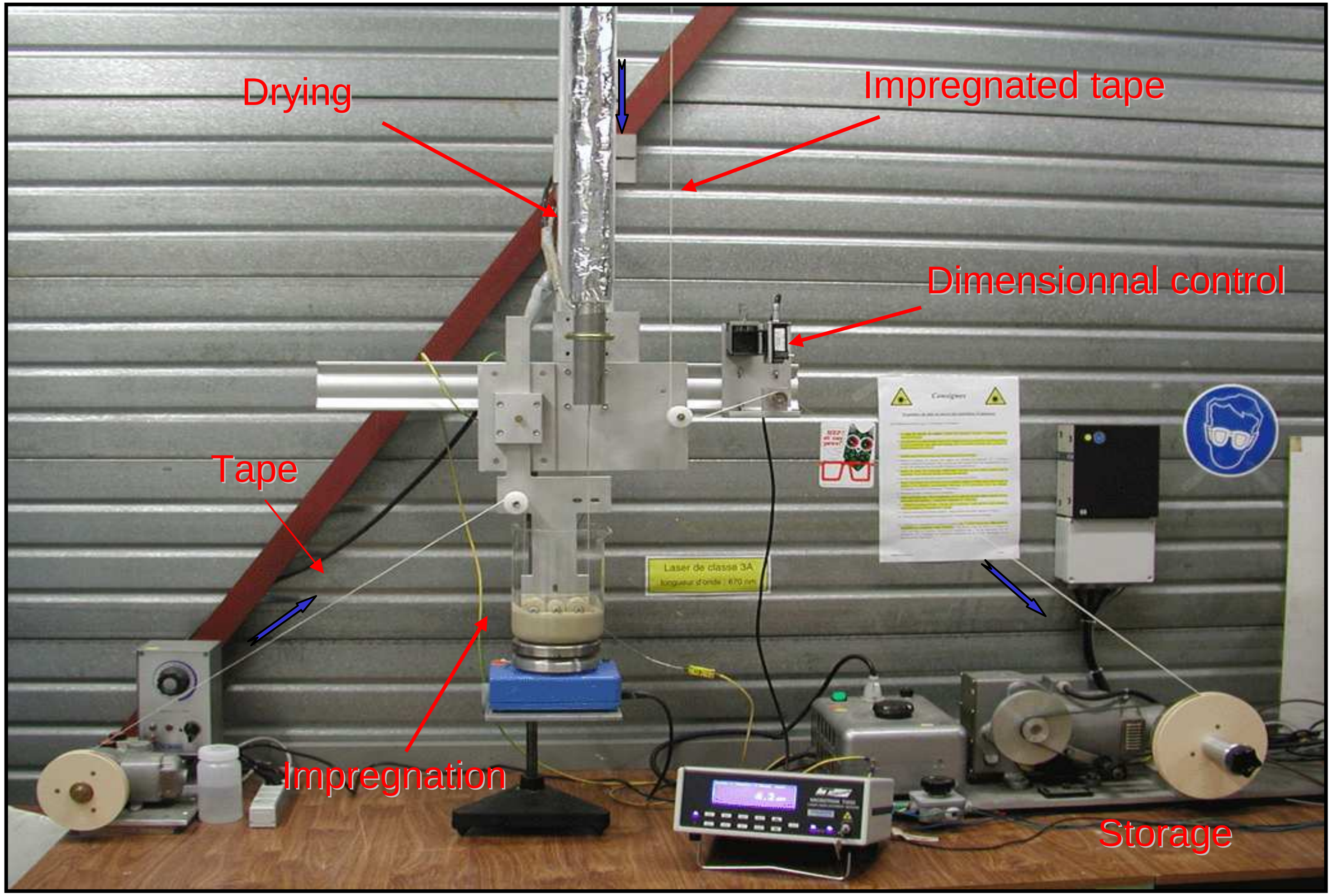
Technical specifications (2/2)

+ conditions for industrial transfer:

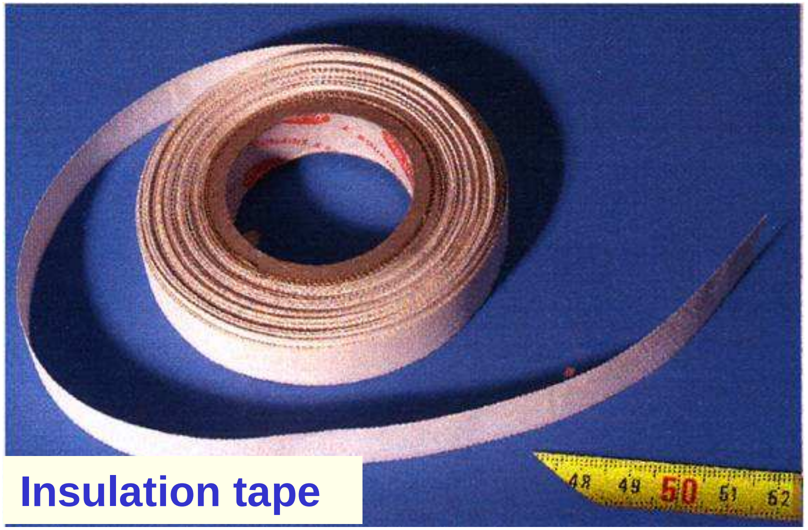
- No change in the superconductor synthesis and shaping.
- Minimize the changes in the process.
- Various stages from manufacture to winding clearly separated to facilitate the implementation.
  - Preparation of solutions
  - Tape impregnation
  - Cable wrapping
  - Winding
  - Heat treatment
- Basis materials easily available and no toxic.

Process (1/3)

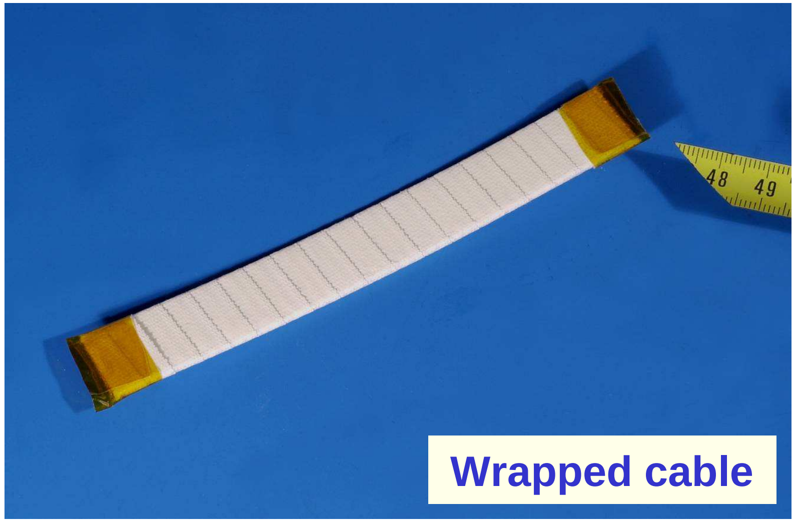
- Solution (rheological behavior, stability, quality of impregnation, plasticity)
- Tape impregnation



Process (2/3)



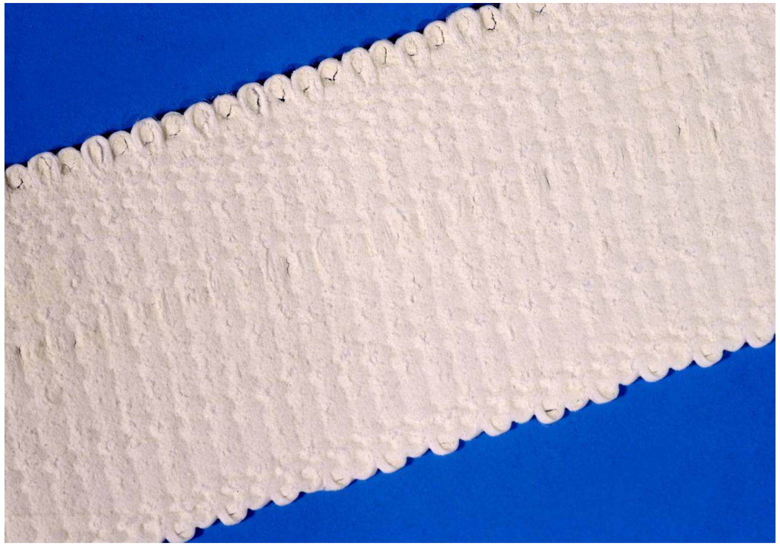
Insulation tape



Wrapped cable

- Glass tape is impregnated with a thick layer of ceramic precursor

Ceramic penetrates entirely the fibers



- Glass tape is wrapped around the conductor

Process (3/3)

Winding

- Plasticity of impregnated ribbon allows the manufacture of coil according to traditional techniques.

Stack of cables

- Heat treatment occurs to form the SC material and synthesize the ceramic material.
- The stack has mechanical cohesion after heat treatment.

Electrical tests

- On ceramic sample:
  - Dielectric strength : > 7.3 kV/mm at 4.2 K

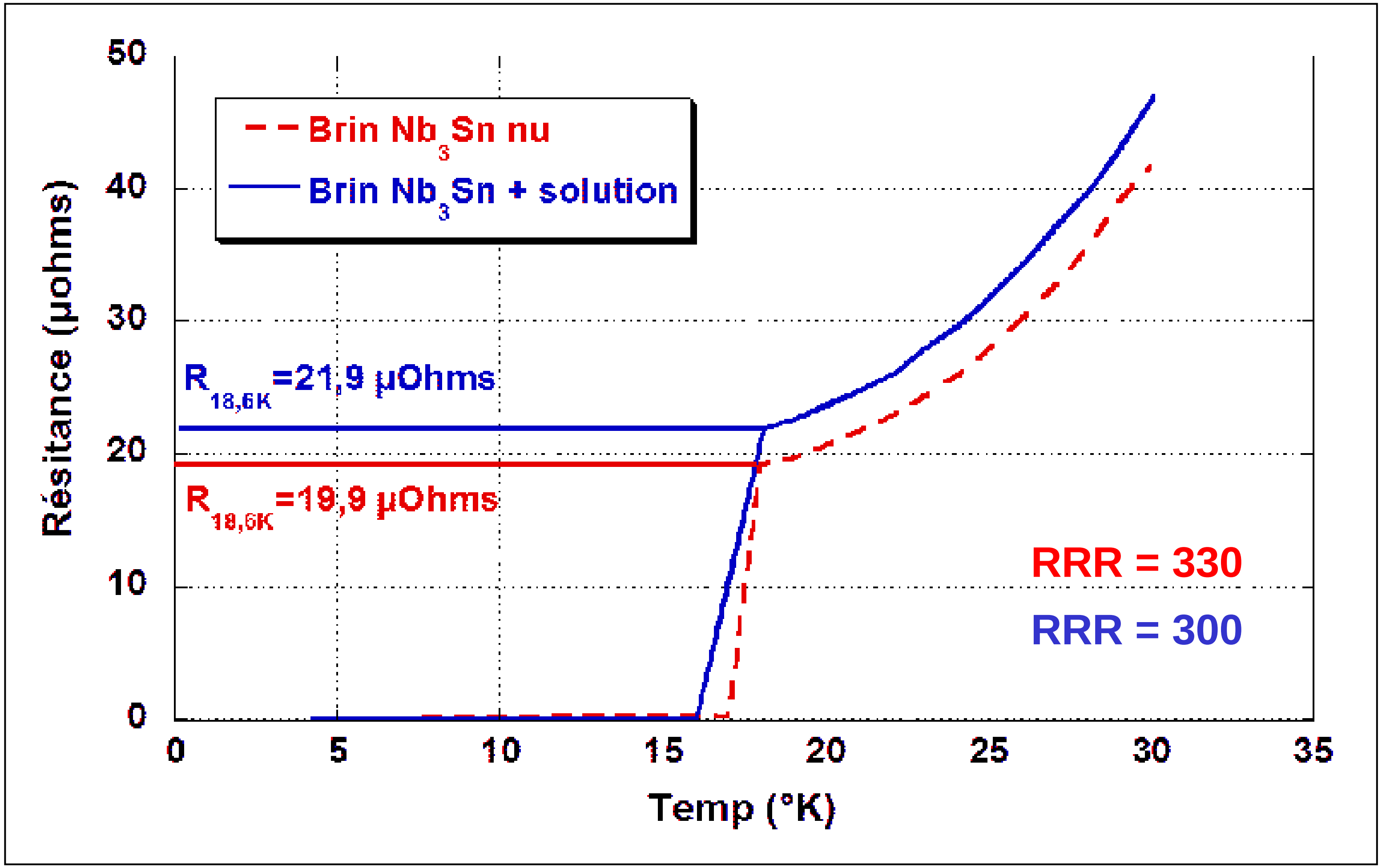
- On wires covered/not covered with the ceramic solution and reacted:

verify there is no modification in electrical properties due to insulation.

  - RRR measurements

The strand is covered with impregnation solution before heat treatment.

RRR measurements



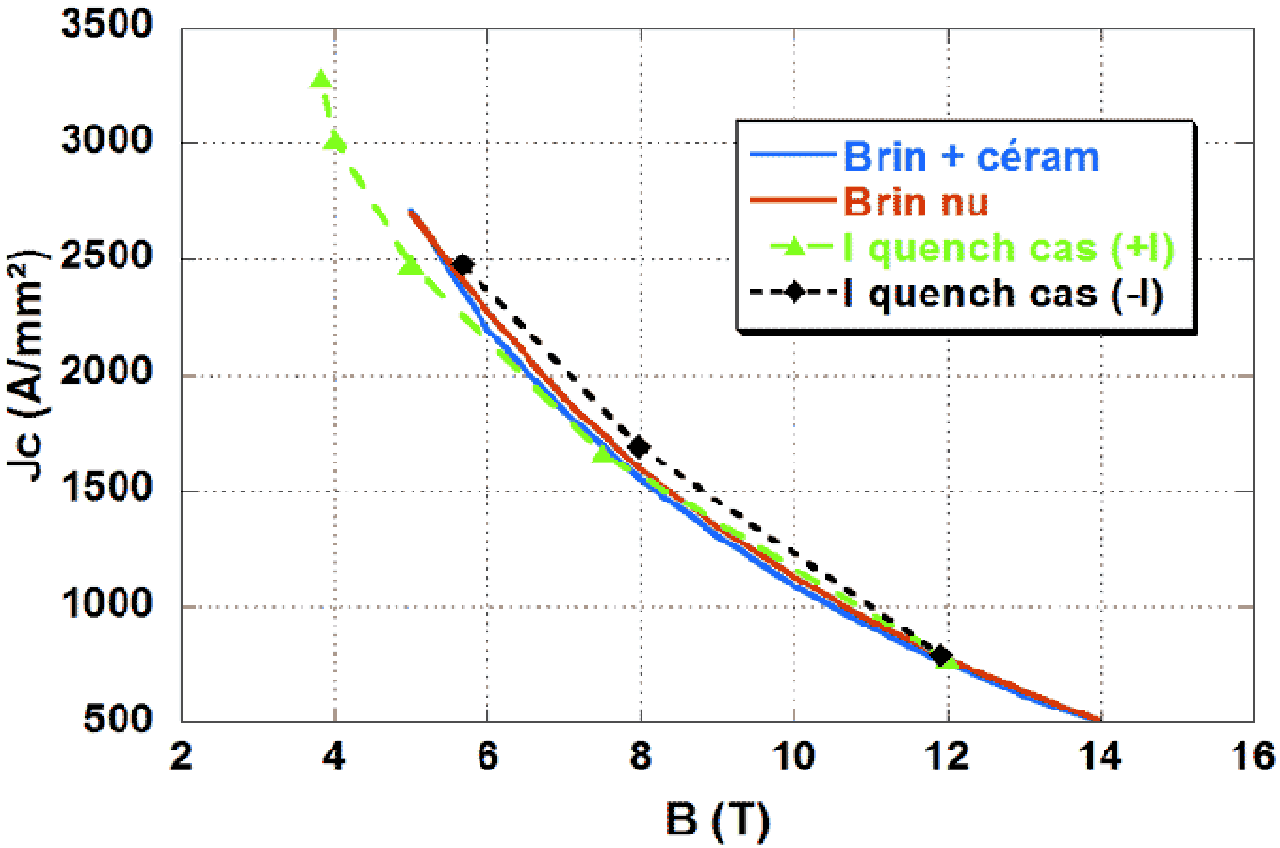
Critical current measurements : experimental setup

Station Cétacés

Sample holder

"Cryostat d'Essai Température Ajustable Champ Élevé Saclay"

Critical current measurements: VAMAS + demonstrators



Sample preparation : as for RRR measurements

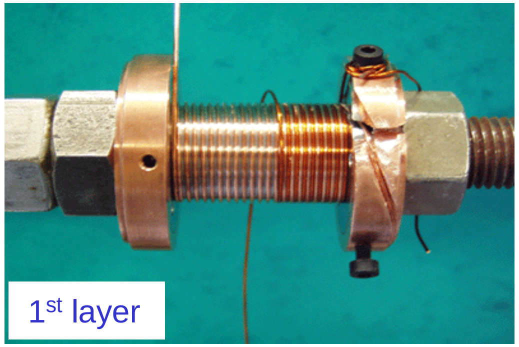
Coil on the CétacéS sample holder

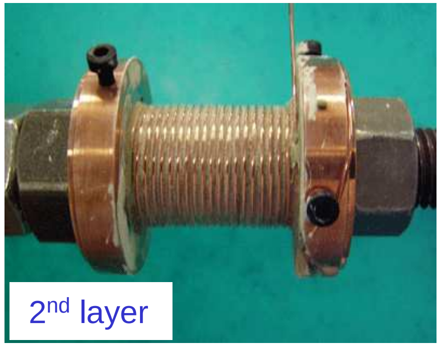
- No difference between VAMAS with and without solution

- Good correlation between Ic measurements and quench in the coil

Demonstrators

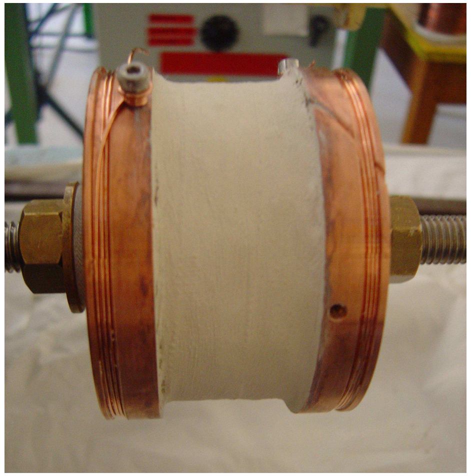
- Solenoid 180 turns ➔ **3.8 T at 740 A**





- Solenoid 400 turns
  - **➔ 5,63 T at 590 A**
    - **35 MPa in compression**
    - **65 MPa in tension**

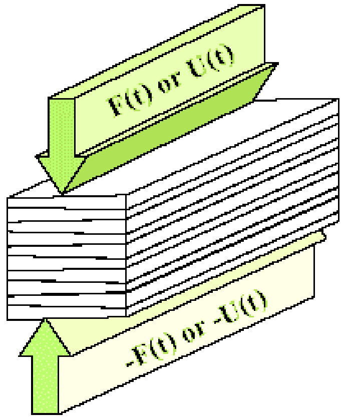
(Stress levels evaluated with simulations in Roxie)



Compression tests

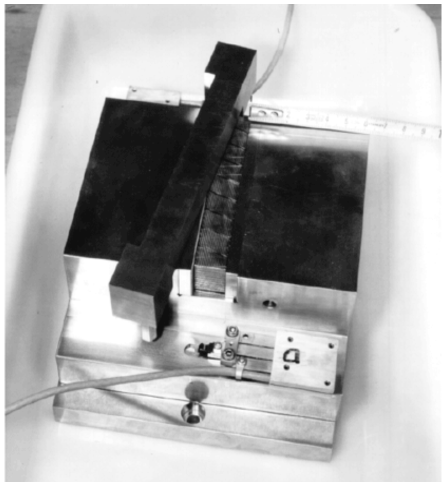
- 3 cycles of uniaxial compression from 0 to 150kN max.
  - Measure of displacement as a function of stress

- Tests at T_{room} and 4.2K



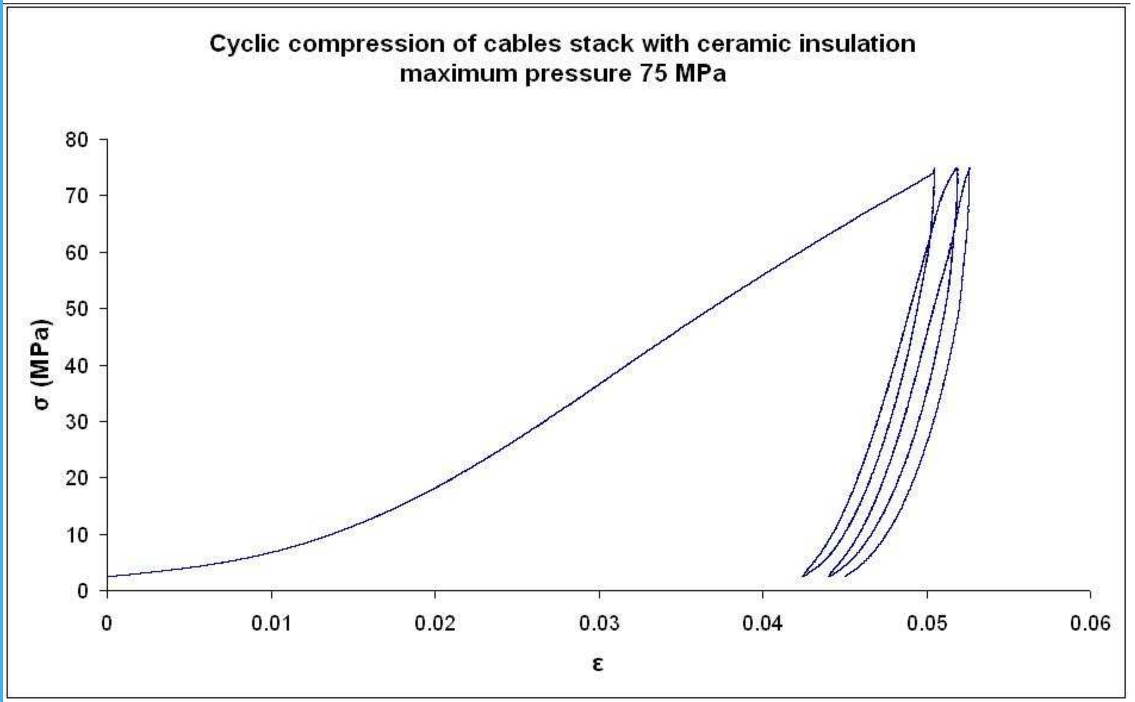
L = 50 mm

Pre-compression during heat treatment

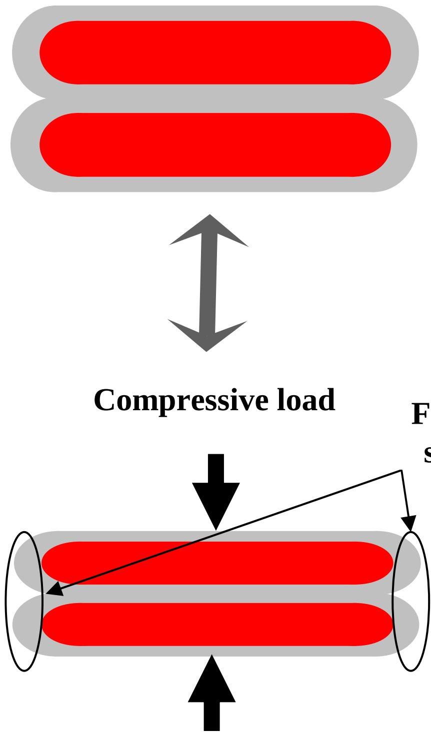


Measurement cell

Compression tests : preliminary results



Flexion stress during compressive test



Summary of the results

- Precursors solution adapted to the insulation process.
  - Typical rheological behavior

- Impregnation setup.
  - Deposit homogeneous on important lengths of tape
  - Variation of thickness controlled

- No degradation in the properties of the strand by using this insulation.

- Ceramic insulation tested with 2 solenoid demonstrators of 180 and 400 turns :
  - No degradation of the solenoids during the test
  - They have produced a field of 3.8 T / 5.63 T

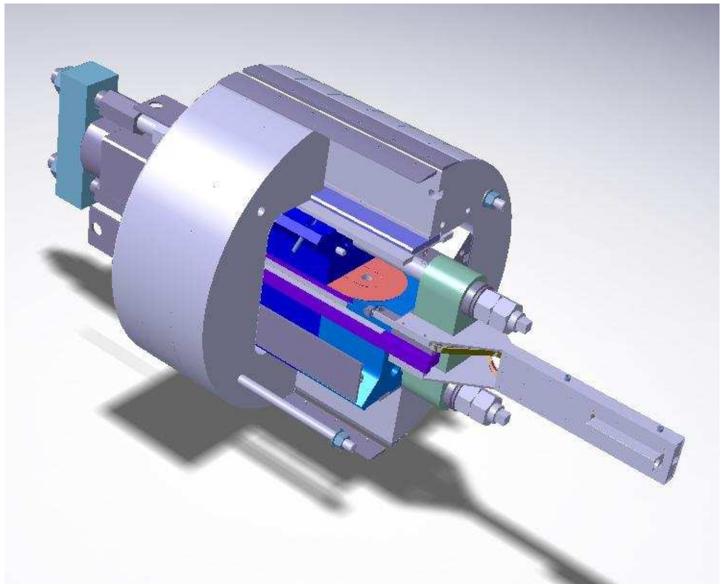
- Heat Transfer measurements on stack of five insulated conductors under mechanical constraint (10 MPa) ➔ cf.H.Allain presentation

The next step…

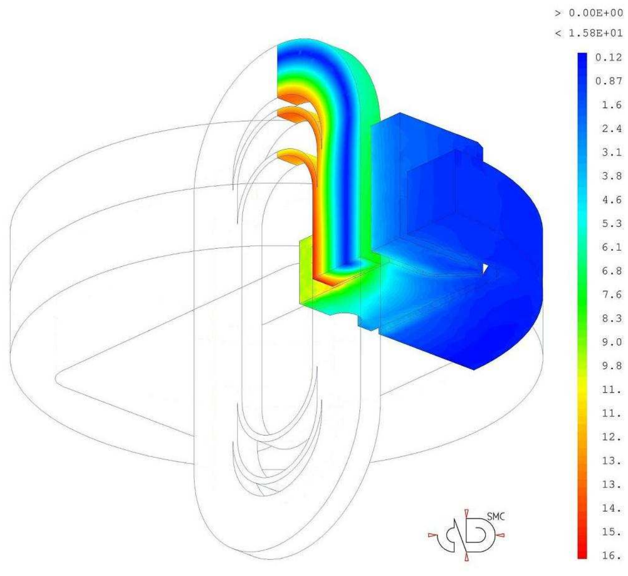
- Complete mechanical characterizations
  - Compression tests

- Prototype SMC : **S**hort **M**odel **C**oil Program

  Built 2 coils with ceramic insulation on the SMC model (same external dimensions).



Courtesy of R.Hafalia



CAST3M model of a SMC coil

Courtesy of P.Manil

Irfu

saclay

After NED : Short Model Coil Program

- **Conceiving a short model coil package in the aim of:**

- testing short model coils in charge in NED dipole configuration
  - safe stress limit?
  - peak field in the straight section
- being able to apply very high or low pre-σ ➔ bladders and keys, rods
  - what happens without pre-σ? ➔ variable pre-σ
- being easy to assemble and disassemble ➔ subscale racetrack coils
- being able to test different coils ➔ coherent conception

- **Conceiving the associated tooling**