SMC with ceramic insulation

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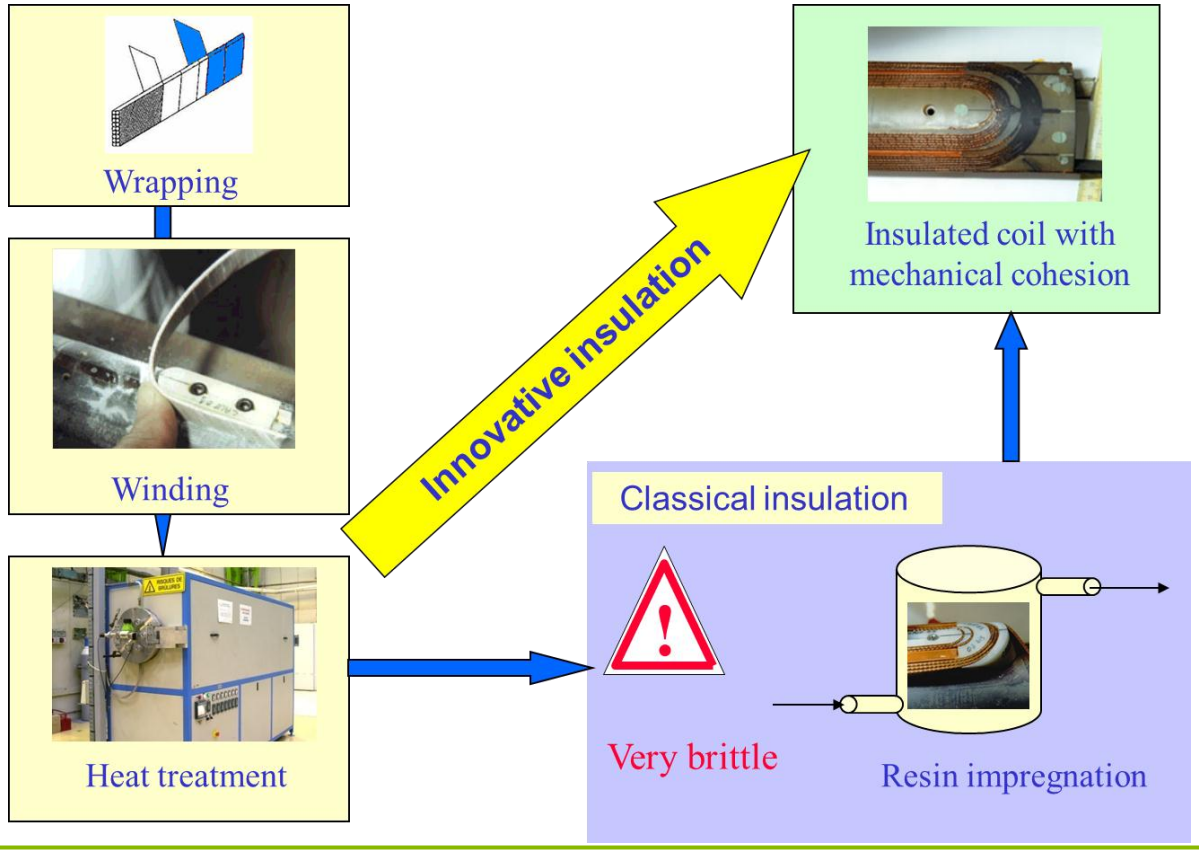
Outline

- Principle
- Technical specifications
- Process
- Insulation properties
- Demonstrators
- Compression tests
- SMC 2 fabrication
- Conclusion

Principle

- At the present time, Nb_3Sn best superconductor candidate for high field magnets (> 10 - 11 T).
- But delicate implementation:
  - Long heat treatment at 650 - 660°C in argon flow ➔ no organic material before treatment.
  - Great brittleness and strain sensitivity of the material after heat treatment ➔ "Wind and React" technique.



Technical specifications for ceramic insulation

- **Follow the heat treatment imposed by the formation of Nb_3Sn** : ramp at 6°C/h, 240 h at 650°C 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 : 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

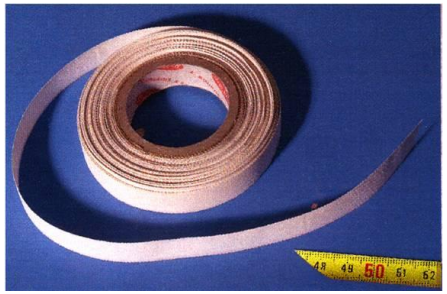
. + conditions for industrial transfer:

- 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

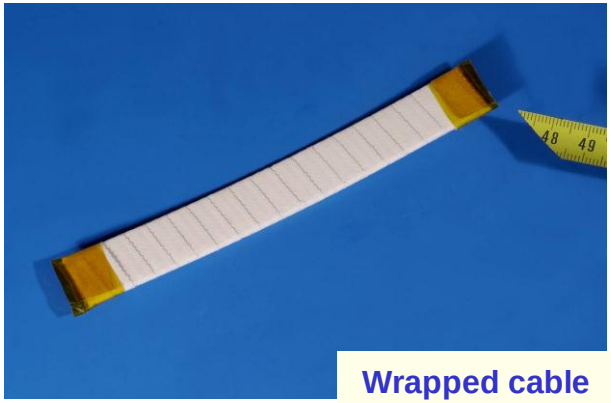
- Glass tape is impregnated with a thick layer of ceramic precursor

Ceramic penetrates entirely the fibers



Insulation tape

- Glass tape is wrapped around the conductor



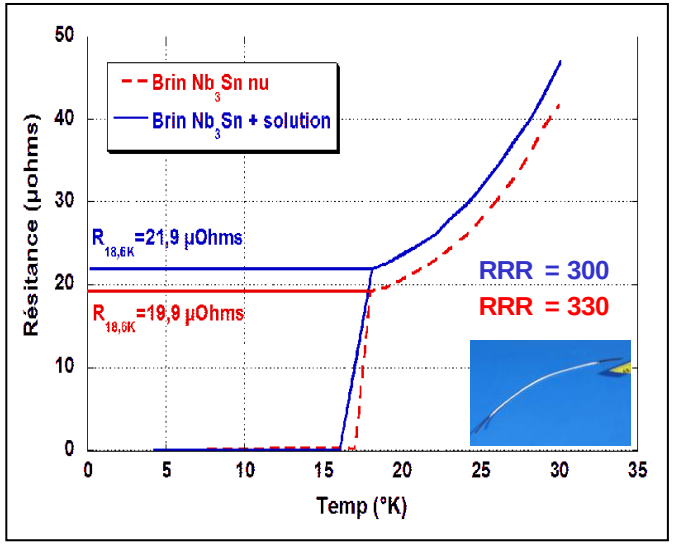
Wrapped cable

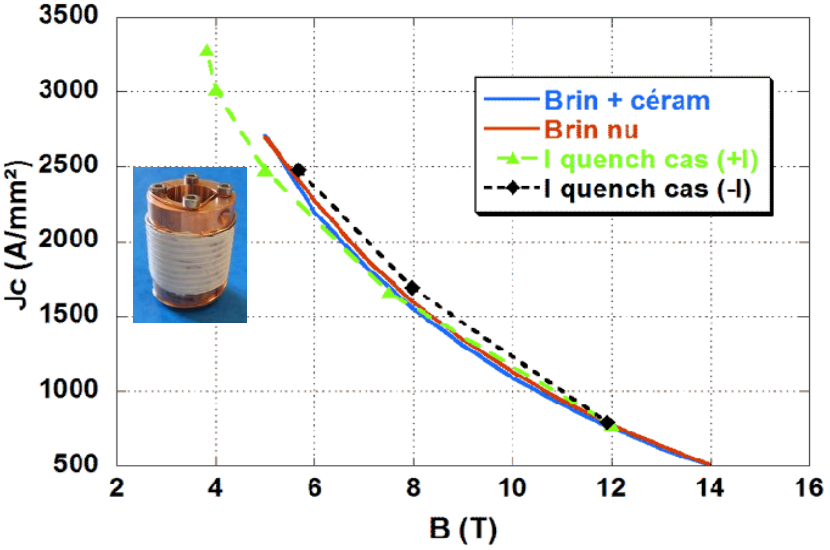
Stack of cables

Insulation properties

- Process well adapted for industrialization:
  - Tape preparation controlled
  - No change in the cable wrapping and coil winding process

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

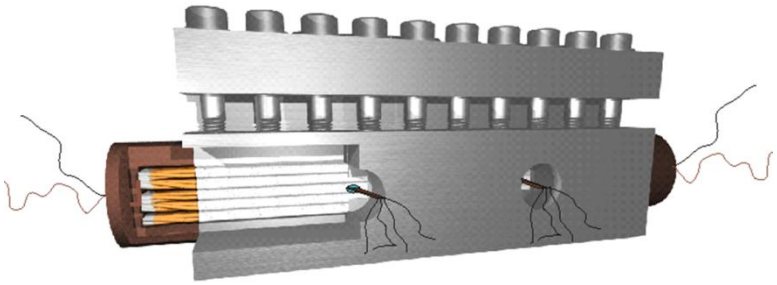


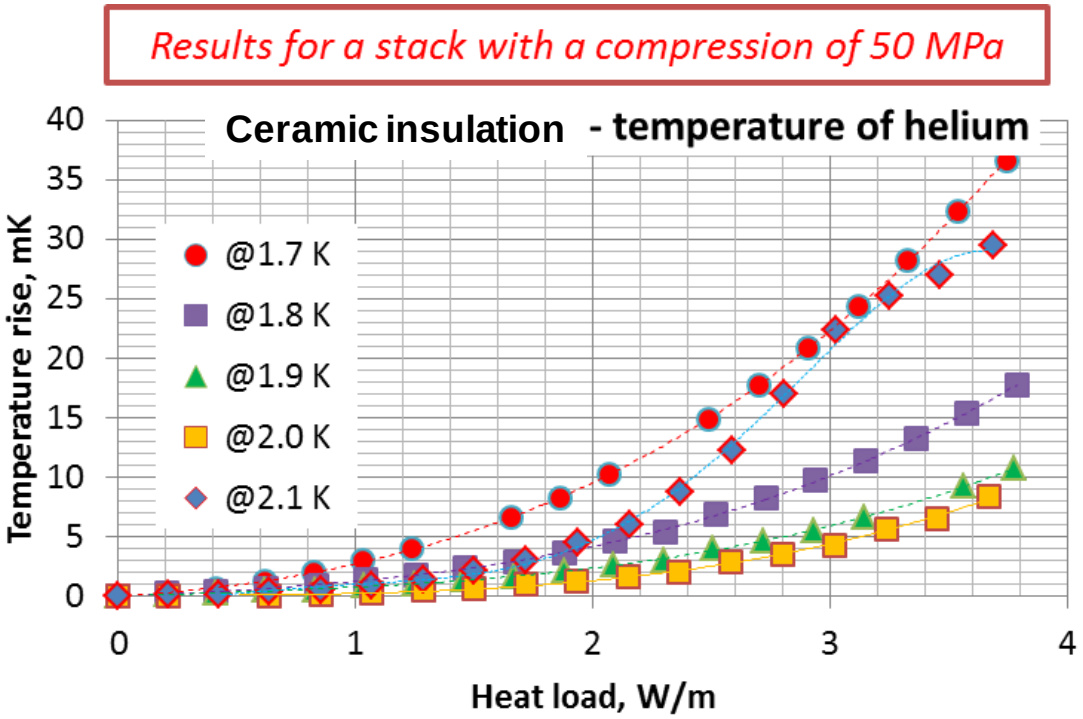


Insulation properties

- Heat transfer measurements:

$\Delta T_{Kapton} / \Delta T_{CI} \sim 30$ if heat load = 2-3 W/m

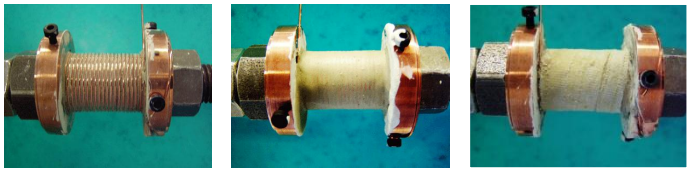




[B.Baudouy, S.Pietrowicz]

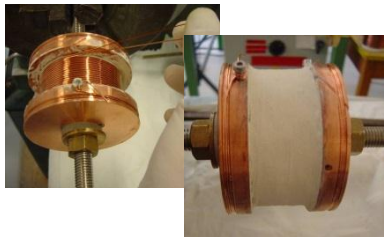
Demonstrators

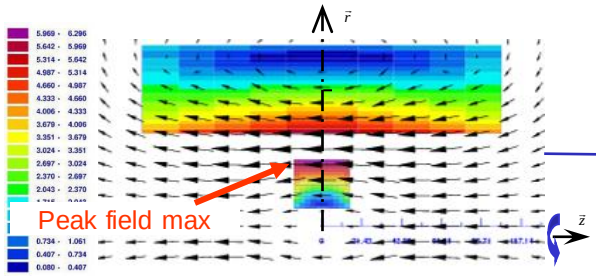
- Solenoid 180 turns ➔ 3.8 T at 740 A
  - *No ageing of the insulation after 2 years*



- Solenoid 400 turns ➔ 5.63 T at 590 A
  - 30 MPa in tension / 65 MPa in compression

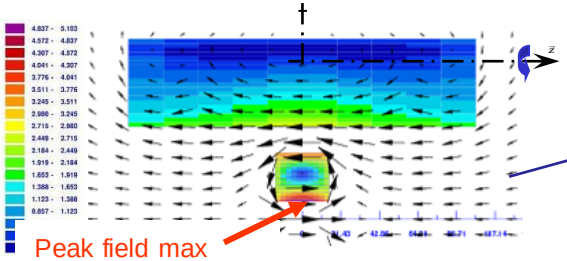
(Stress levels evaluated with simulations in Roxie)





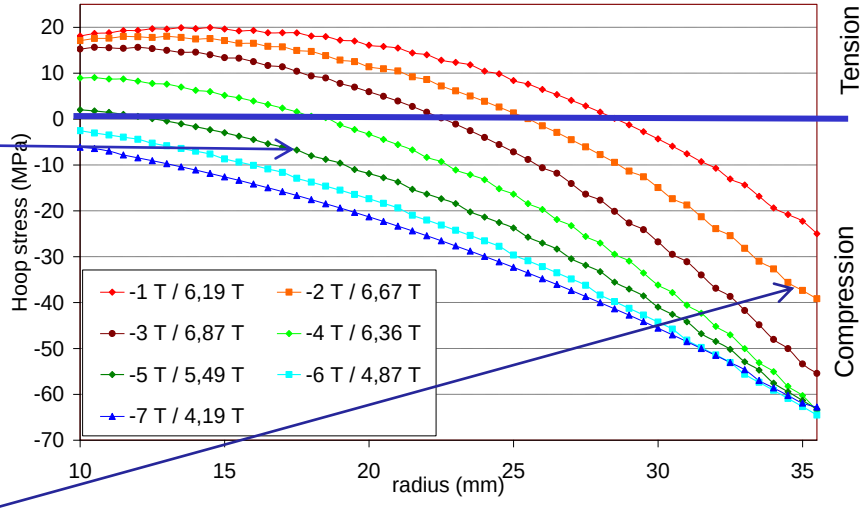
Exemple of field map in configuration B1

($B_{Christiane}$ = -5 T / B_{coil} = 5.49 T)



Exemple of field map in configuration B2

($B_{Christiane}$ = -2 T / B_{coil} = 6.57 T)



Hoop stress vs. radial location (in the plane z=0)

Configuration B : magnets with opposite polarities

B1 : Max. induction located in the external radius / Inward Lorentz force ➔ compression

B2 : Max. induction located in the internal radius / Outward Lorentz force ➔ tension

Mechanical tests

Mechanical characterization = most critical issue

- Specification ➔ transverse compressive tests
- 65 MPa = maximum on demonstrator according to the experimental setup

- To explore higher stress:

  compressive tests on stacks, but the usual stack samples show several limitations.

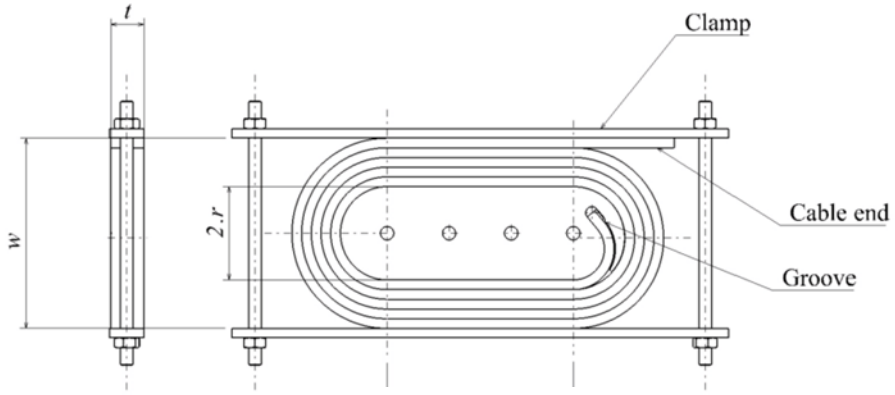
  ➔ new sample design proposed

  ➔ In parallel, preparation of SMC = tests on realistic configuration

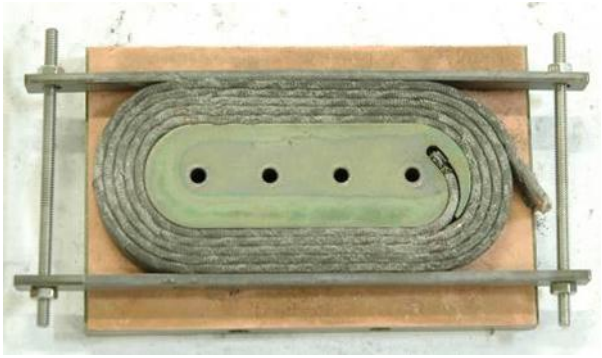
Compressive tests

New sample design proposed = short monolayer racetrack winding

realized by “Wind & React” process.

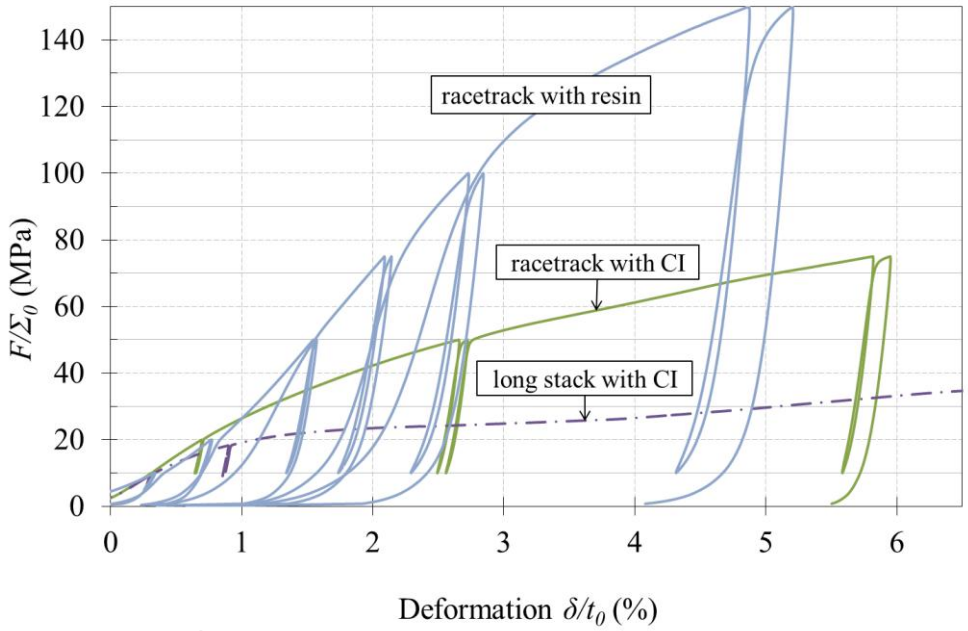


Lss = 60 mm

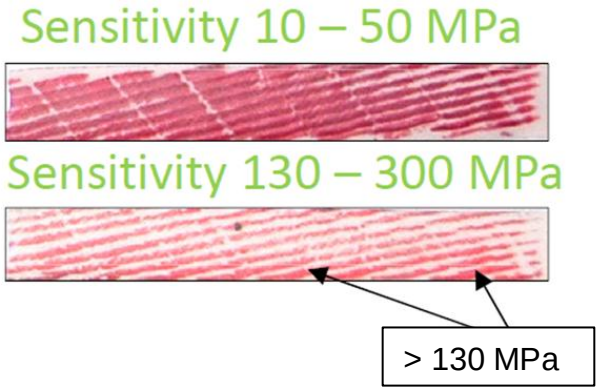


- Tests carried out with an INSTRON™ screw-driven machine, which allows a compressive load up to 300 kN, at room temperature.

Compressive tests - results



Compression curves :
- plastic behavior during the first compression ramp
- elastic behavior during the following cycles for a given pressure



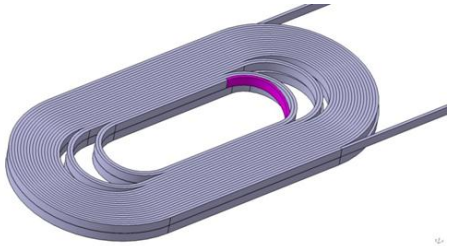
Stress repartition on the contact surface on racetrack with CI for a mean compressive stress of **60 MPa**

- The short racetrack is less deformed than the stacks
- The bare cable deformation remains dominant with the insulation
- Very high local stresses

[Short Racetrack Windings for the Mechanical Characterization of Ceramic-Insulated Cables
P.Manil, F. Rondeaux, IEEE Transactions on Applied Superconductivity – Vol. 20, Issue 3, June 2010, Pages 1658-1661]

SMC 2

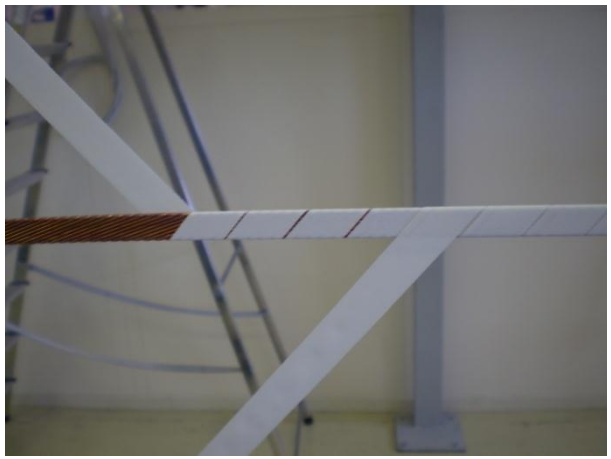
- Model in 3D of the coil and all the needed elements ➔ allows quick modifications.
  - 21 turns
- Tooling
  - adapted from the RAL plans
  - interface for the CERN welding equipment



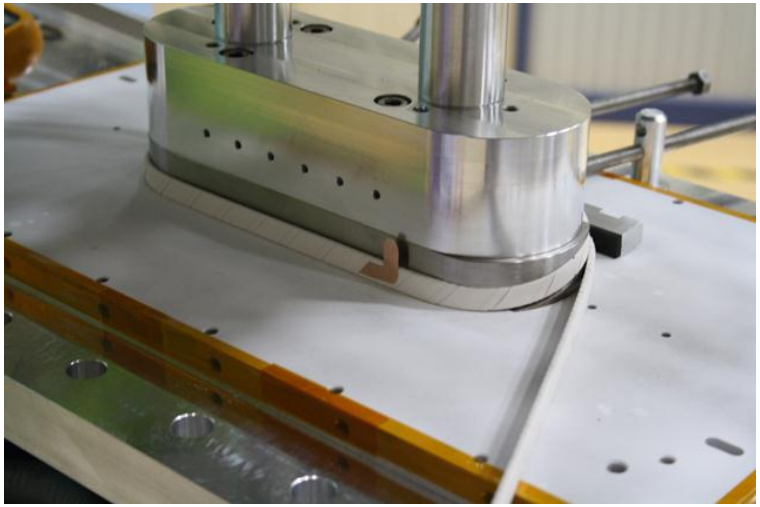
- Conductor = PIT EAS002 14 strand cable (Run 39B) 10 mm * 1.82 mm

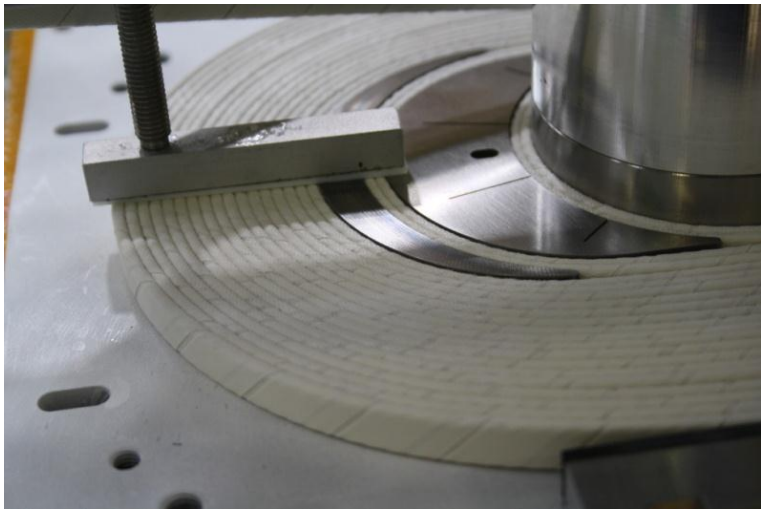
- Insulation = Hiltex S2 glass tape + ceramic precursor (CEA formulation)
  Impregnation of the tape at Saclay on the impregnation setup

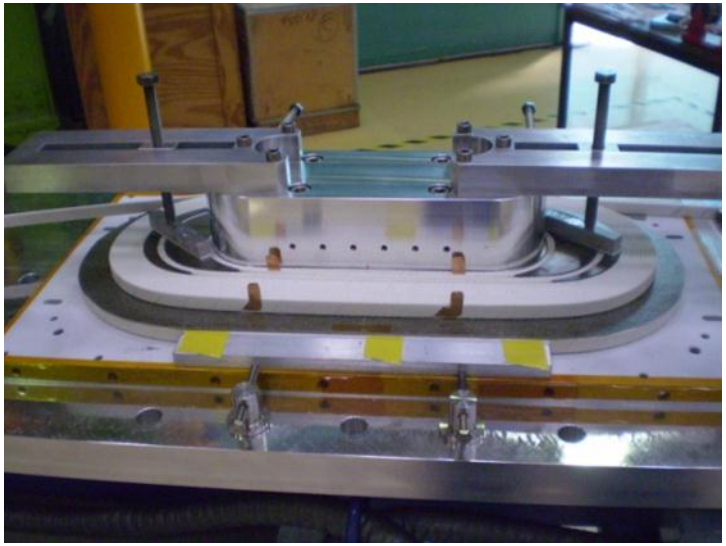
- Cable wrapped at CERN in June 2010 - 2 layers without overlap.

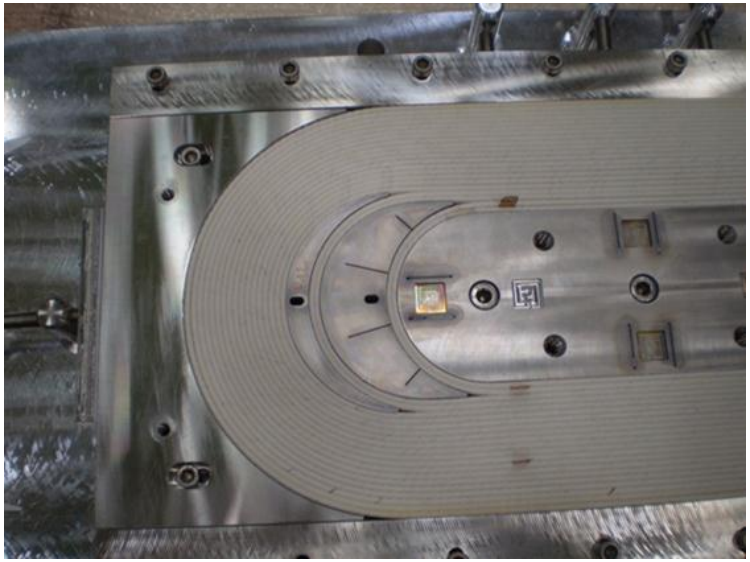


SMC 2 - winding



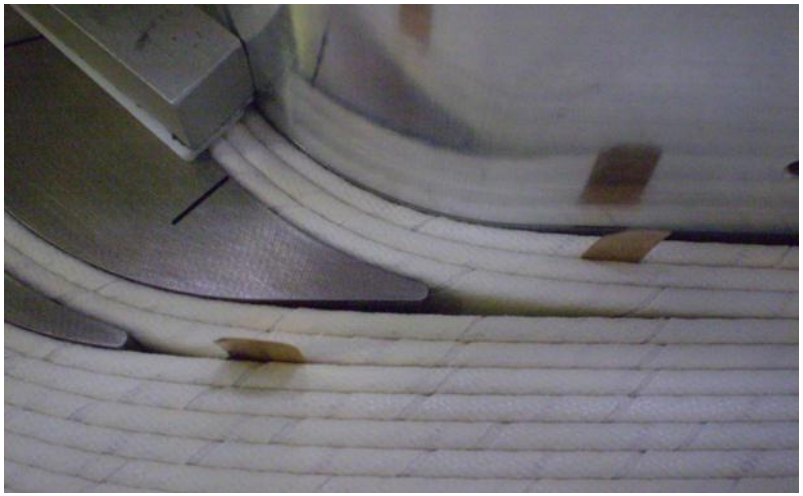






SMC 2

- Final dimensions of the coils smaller than calculated
  - ➔ horseshoes have been changed
  - ➔ but not the head shims



- Some spaces to be filled?
  - ➔ Look at the dimensions after heat treatment

- Coil waiting for thermal reaction

Conclusion

- The process is well adapted for industrialization.
- There is no degradation in the electrical properties of the strand by using this insulation.
- The heat transfer measurements show a comfortable margin for heat loads of 2-3 W/m.
- But the ceramic insulation, in its present form, has a mechanical resistance still too low for high field magnets requirement.

➔can be used in case of compression stress < 60 MPa

Thanks for your attention