Nb3Sn coils: impregnation at CERN

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Workshop on Nb_3Sn technology for accelerator magnets
Paris, 11-12 October 2018

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4. Impregnation process
5. Resin system: CTD 101K
6. Baseline and challenges
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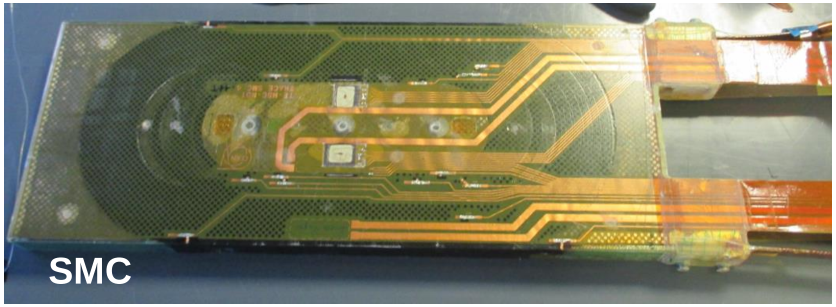
1. Introduction

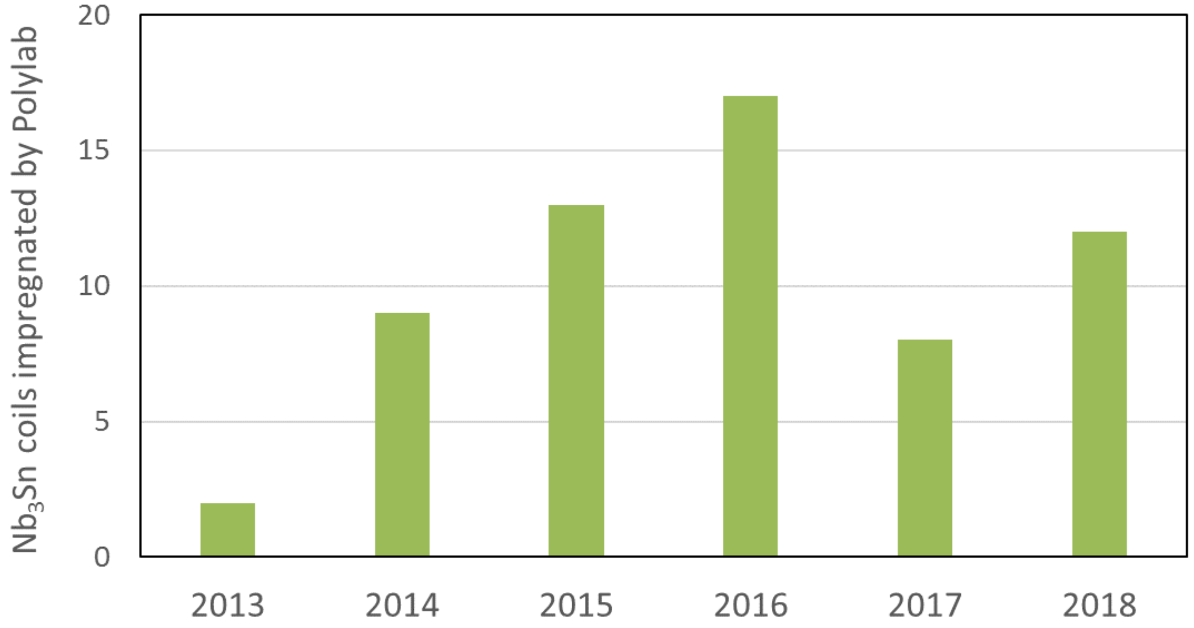


2. Nb_3Sn coils impregnated at CERN

Impregnation of model coils

Polymer lab: +60 impregnated Nb_3Sn coils over the past 6 years

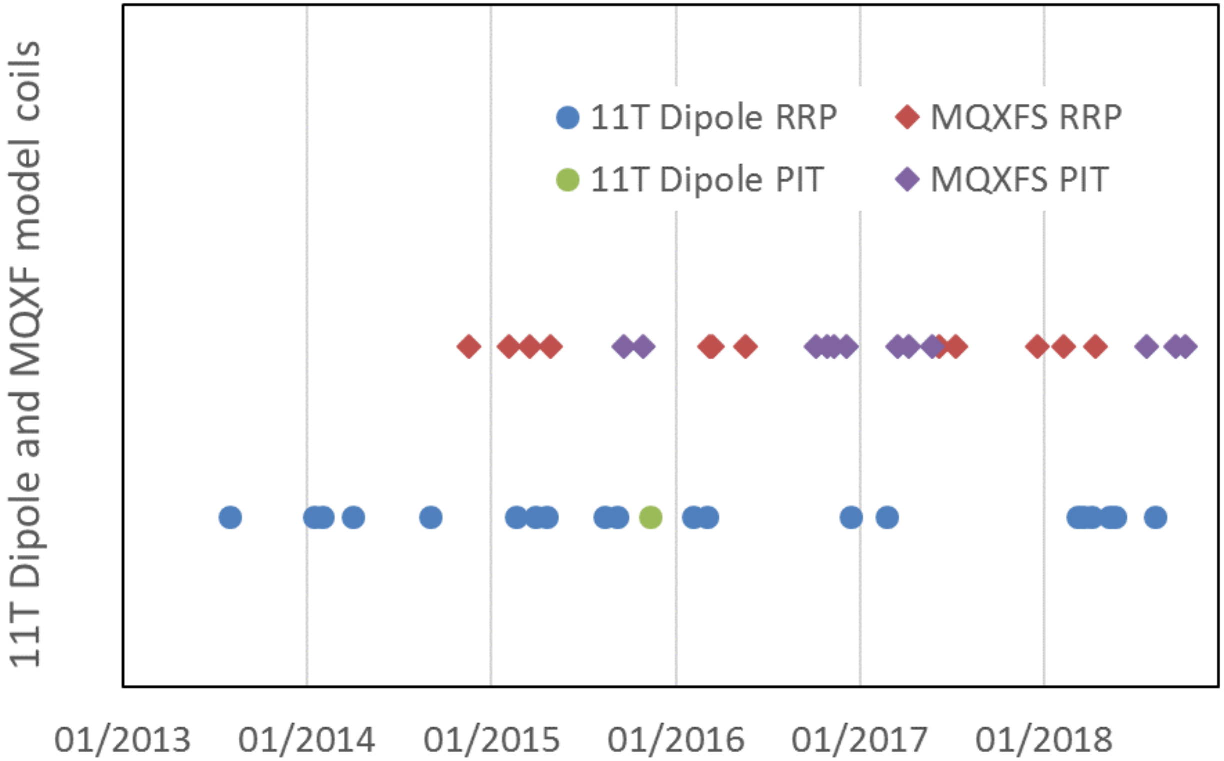
Coil	#
11T Dipole	19
MQXFS	24
FReSCa2	6
SMC 11T Dipole	5
RMC FReSCa2	4
RMC MQXF	2
E-RMC	1



2. Nb_3Sn coils impregnated at CERN (cont.)

Impregnation of model coils

Polymer lab: +40 impregnations of 11T Dipole and MQXFS coils



2. Nb_3Sn coils impregnated at CERN (cont.)

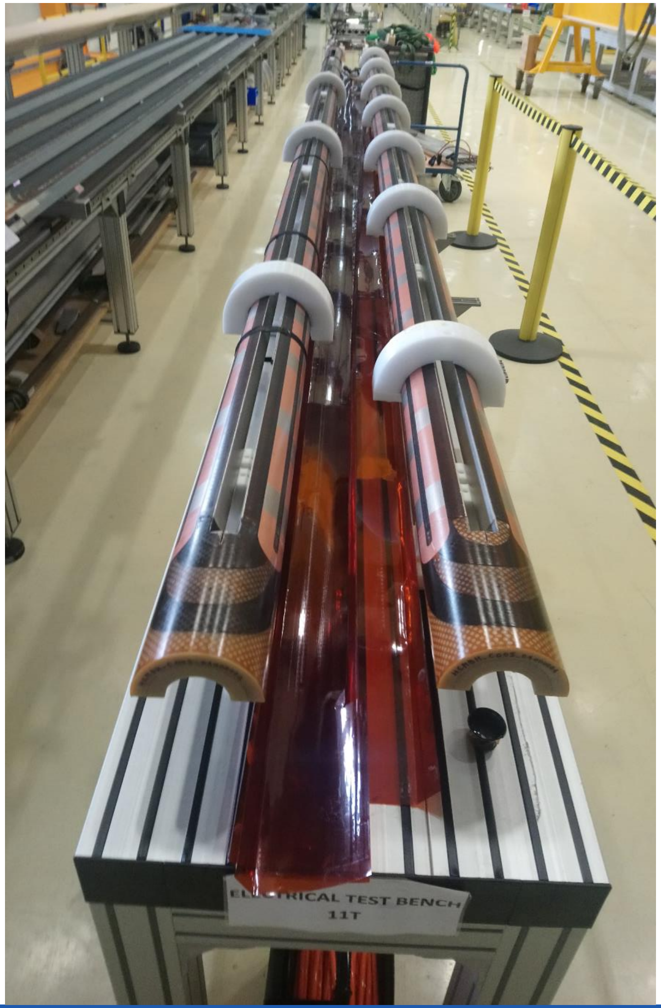
Impregnation of prototype and series coils

LMF @180: ~20 impregnated Nb_3Sn coils (including 2 model coils 11T Dipole)

Practice coils	#
11T Dipole	2
MQXFB	3

Prototype coils	#
11T Dipole	5
MQXFB	5

Series	#
11T Dipole	3
MQXFB	0



3. Impregnation Facilities

TE/MSC-MDT, Polymer laboratory (@927):
Model coils up to 2m

Telstar machine @B927

TE/MSC-LMF (@180):
Prototype and Series coils up to 7.5m

Elytt machine @B180

4. Impregnation process

Preparation for impregnation

Coil inside the mould → RT tests: • Leak tightness • Obstruction • Pressure hold → Mould inside chamber, connect heating system, purge with N_2 → 80°C/110°C tests: • Leak tightness • Obstruction • Pressure hold → Pumping of vacuum chamber & mould bakeout

Leak tightness:
- the mould is pumped at RT. The vacuum lost after 10 minutes should be less then 100 mbar.

Major obstruction:
- Mould pumped at RT; time to recover atmospheric pressure: <10s (varies with coil)
- N_2 is injected at resin inlet. N_2 shall flow out at resin outlet.

Pressure hold (11T Dipole):
- Inject N_2 up to nearly 2 bars. Pressure shall hold for 10 min.

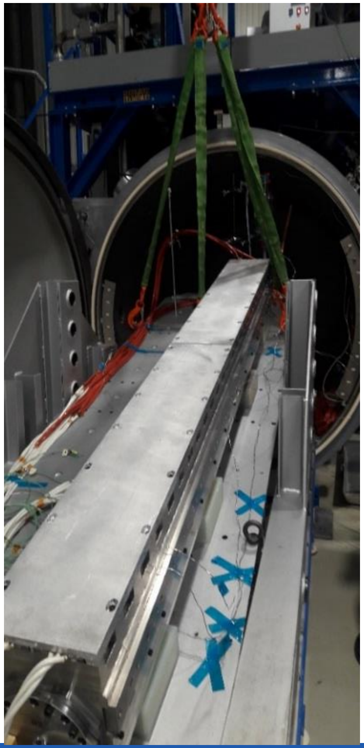
4. Impregnation process (cont.)

Preparation for impregnation

- Coil inside the mould
- RT tests:
  - Leak tightness
  - Obstruction
  - Pressure hold
- Mould inside chamber, connect heating system, purge with N_2
- 80°C/110°C tests:
  - Leak tightness
  - Obstruction
  - Pressure hold
- Pumping of vacuum chamber and mould bakeout

Telstar machine:

1. Place mould on the tray
2. Tilt tray to 12 degrees
3. N_2 mould purge for 3h



4. Impregnation process (cont.)

Preparation for impregnation

Pumping of vacuum chamber & mould bakeout

Ok for resin mixing and degassing

Pirani sensor connected to injection channel and monitored during bakeout

Criteria for impregnation:

$P_{chamber}$ ~3x10^{-3} mbar

P_{mould} ~3x10^{-1} mbar

4-5 days of mould bakeout

4. Impregnation process (cont.)

Impregnation

Pumping of vacuum chamber & mould bakeout → Resin mix and degassing → Resin injection → Vacuum-pressure cycle and/or apply pressure → Curing cycle → Impregnated coil

Mixing tank

1. Transfer of premixed resin to the mixing unit with peristaltic pump
2. Resin mix is heated to 60°C and degassed under agitation
3. Resin degassed to a lower pressure level than mould: ~9×10^{-2} mbar
4. Mixing tank pressure increased to 400mbar, to inject the resin through the flowmeter and into the mould

11T Dipole mandrel with channels for resin injection along coil length:

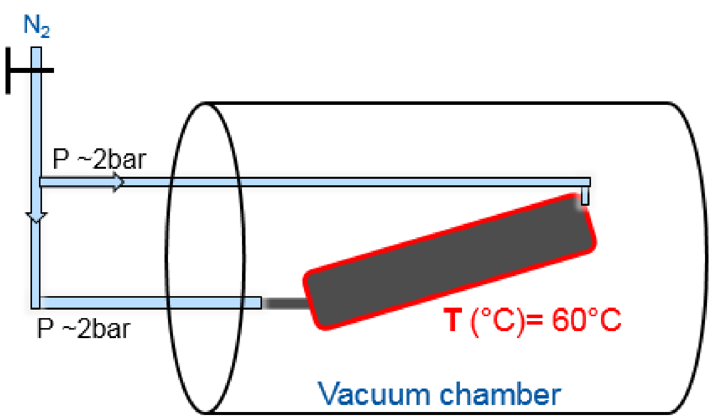
4. Impregnation process (cont.)

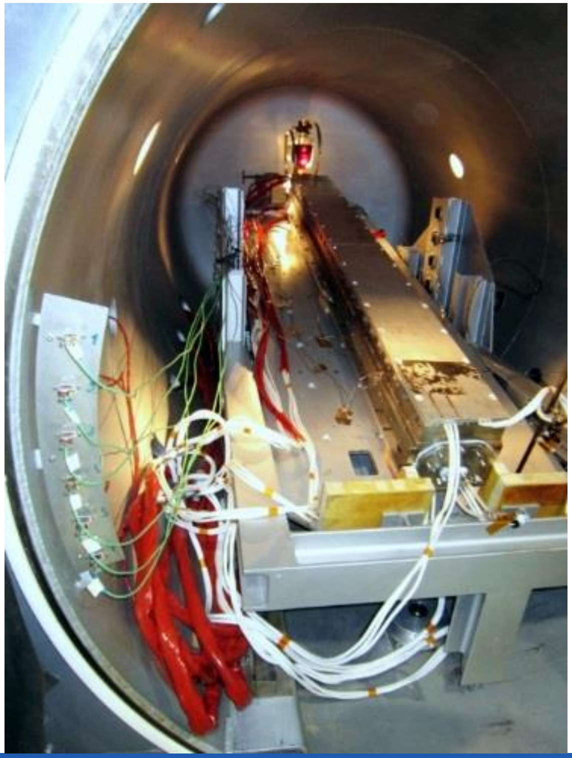
Impregnation

Pumping of vacuum chamber & mould bakeout → Resin mix and degassing → Resin injection → Vacuum-pressure cycle and/or apply pressure → Curing cycle → Impregnated coil

At the end of the impregnation:

1. Increase mixing tank pressure 1 bar to force the resin into the mold and release voids
2. Break and restart the vacuum for 3 hours to complete wetting of fibre glass and drive out voids
3. Apply 2 bars of pressure onto resin of impregnated coil (@927 only for 11T Dipole)



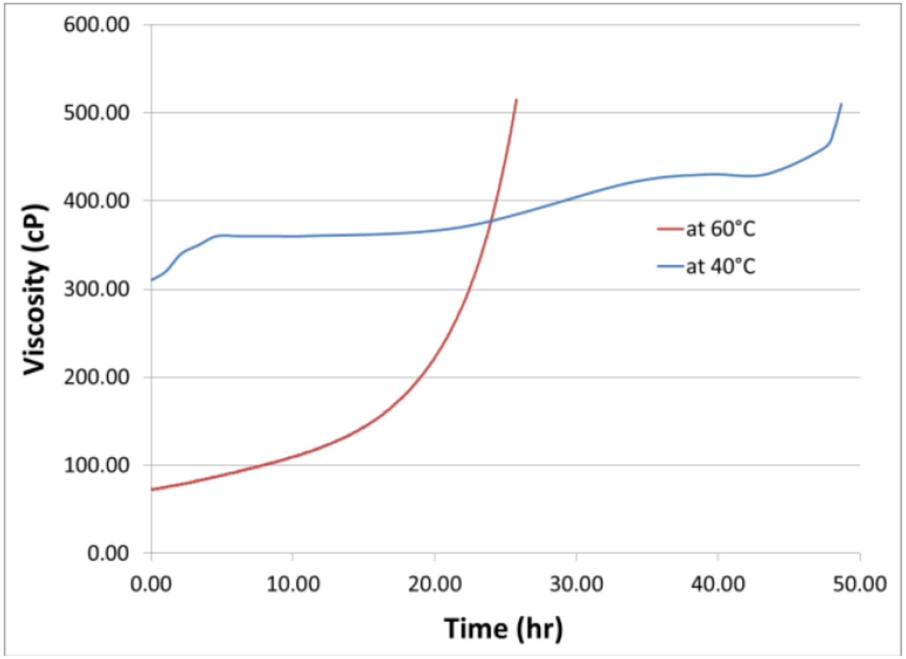


5. Resin system: CTD 101K

Three component system formulated for long pot life:

- Resin: Bisphenol A diglycidyl ether (DGEBA) epoxy
- Hardener: anhydride
- Accelerator: amine

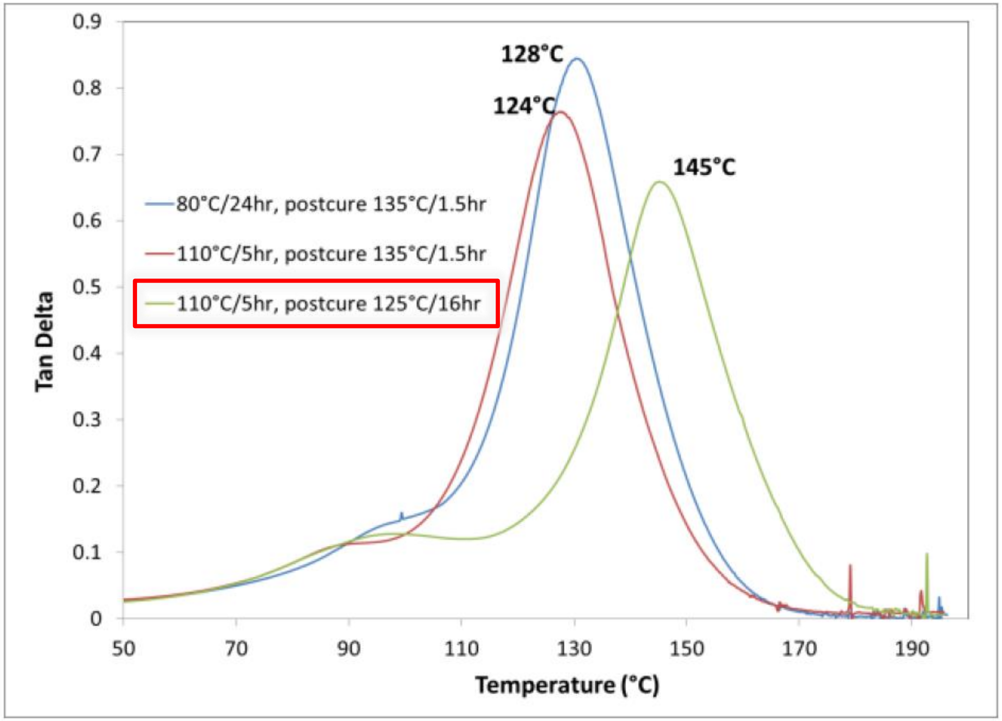
Temp. (°C)	Pot life (h)	Viscosity (mPa·s)
25	145	1300
40	60	400
60	20	100



CTD-101K Viscosity Profile at 60°C and at 40°C

Data from CTD, Composite Technology Development Inc.

5. Resin system: CTD 101K (cont.)

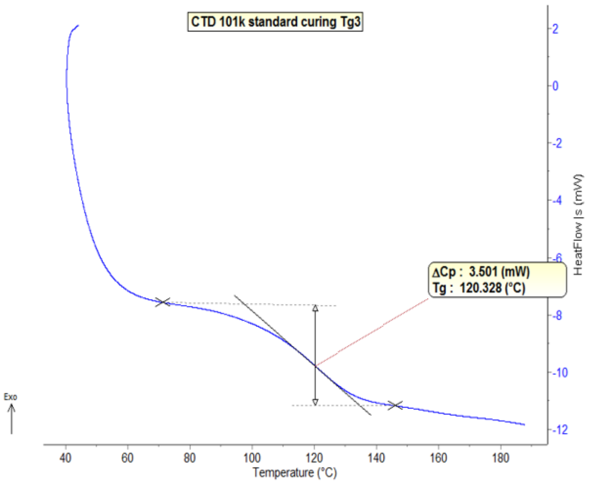


Resin glass transition temperature (T_g) as a function of cure cycle. (Expressed as DMA tan δ) .

Data from CTD, Composite Technology Development Inc.

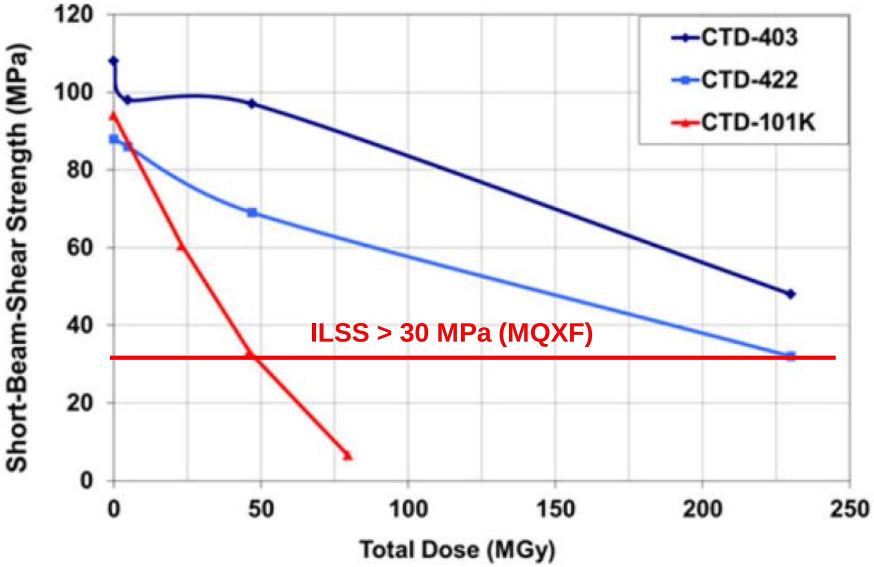
Measured by the Polymer lab with DSC:

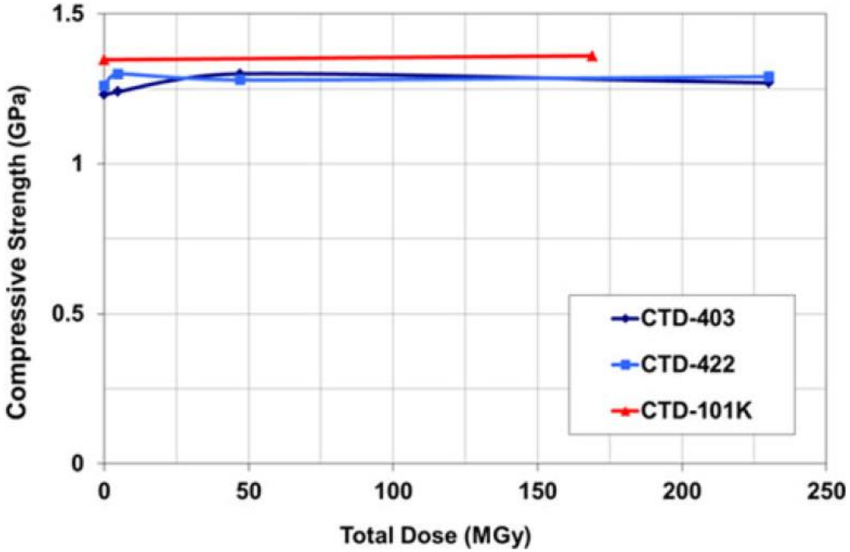
$Tg_{\ average} = 121 \pm 2°C\ (1\sigma)$



5. Resin system: CTD 101K (cont.)

Mechanical properties at 77K of laminates with S2 Glass, vf= 50%





CTD 101K: DGEBA epoxy
CTD 422: Cyanate ester/Biyphenol A epoxy 60:40
CTD 403: Cyanate ester

Irradiation conditions:

- TRIGA reactor at ATI (Vienna)
- 80% gamma, 20% neutron
- 340 K irradiation temperature

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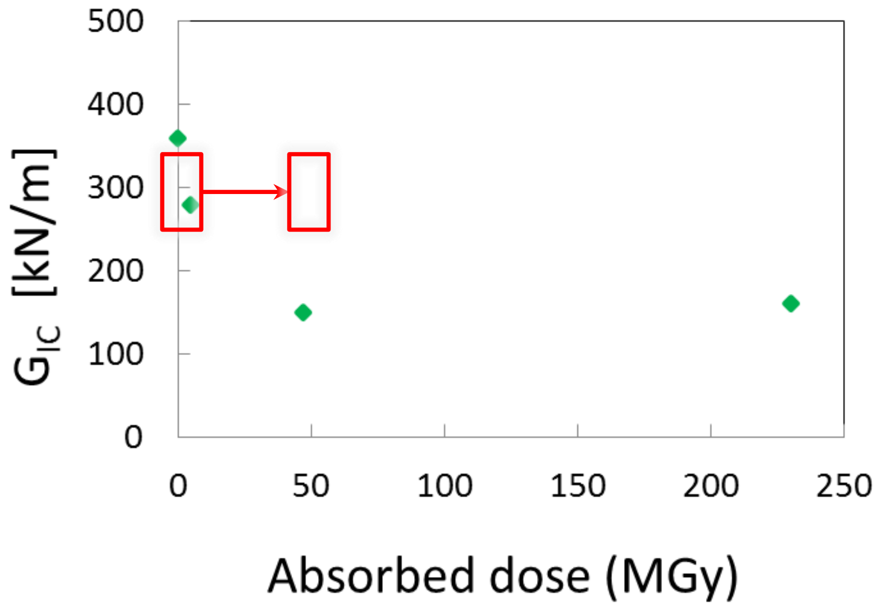
5. Resin system: CTD 101K (cont.)

Fracture toughness of CTD 101K at 77K, laminate with S2 Glass, vf= 50%



Fracture toughness of CTD 101K at 77K, laminate with S2 Glass, vf= 50%

Data from CTD 101K technical datasheet, irradiation conditions unknown

6. Baseline and challenges

HL-LHC: inherited insulation scheme from US LARP

- Resin: CTD 101K
- Glass fibre S2
- Binder for winding: CTD 1202
- Mica tape (11T Dipole)
- Heat treatment reaction cycle

This insulation system works, but can be improved, e.g:

- Carbon remaining from the binder degradation with the reaction cycle
- Glass fibre degradation with reaction cycle
- Brittleness of resin – contributing to magnet training

7. Work in progress

Radiation program at QST Takasaki (JP)

KEK collaboration

Materials selection

VPI resins
- Bisphenol A epoxy - CTD 101K
- DGEBA epoxy – Araldite F
- DGEBA epoxy - Damisol 3418
- DCBE cyanate ester/Bisphenol F & Bisphenol A epoxy 40:60 - CTD 425
- Polyesterimide - Damisol 3340

Glass fibres
- S2 glass 493 66 Tex fibres

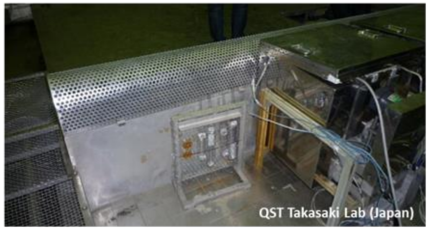
Hot press composites

For Decapole Spacers & wedges (INFN & KEK)
- Bismaleimide triazine - BTS2 (S2 glass fibres)
- Polyetherimide - Duratron (E glass fibres)

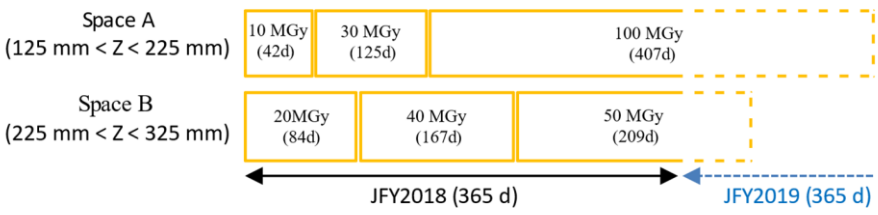
Irradiation facility selection

Gamma-ray irradiation	QST Takasaki Lab (Japan)
Fixed Box [cm³]	40x30x100
Irradiation dose [MGy]	0-100
Dose rate [kGy/h]	10
Atmosphere	Air
Temperature	RT
ESTIMATED cost (€)	~ 1000 (“competitive fund”)

QST Takasaki conditions:
- KEK collaboration
- Publish results



Estimated Irradiation time (days)



Characterization tests

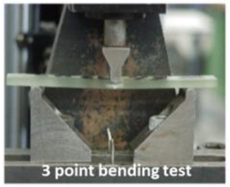
Mechanical properties

Interlaminar shear strength (ASTM D2344)
Flexural strength (ISO 178) → CERN, EN-MME-MM

Charpy impact properties (ISO 179) → LTA, Laboratoire de Technologie Avancée (Geneva)

Chemical / polymer properties

Tg, Heat flow (DSC, IEC 61006) → CERN, TE-VSC-SCC



Test temperature: RT, 77K

Thank you for your attention