Damage evaluation in a superconducting magnet winding pack due to an accident

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SCOPE: new failure criterion validation

WHAT?: Damage evaluation in the **TURN INSULATION** of a superconducting magnet winding pack due to an accident

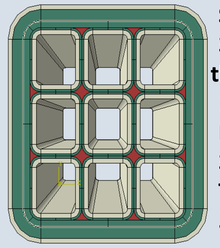
WHY?: **turn insulation cracks** might induce electrical breakdown during a quench, **delaminations** might produce local heating due to friction and then induce a quench

HOW?:
1. Manufacturing mock-ups
2. Set-up of numerical model
3. Tests
4. Numerical model tuning

IN THIS WORK
- Numerical Model Description
- Failure criteria hypothesis
- Results

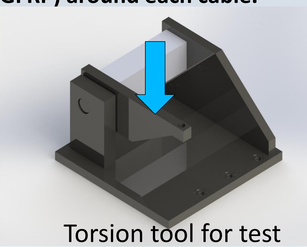
MANUFACTURING MOCK-UPS: geometry

ASG Superconductors samples



Samples 300mm long
3X3 superconducting cable (CICC 26x22 mm) matrix (modeled with AISI jacket 2 mm thick)
1 mm of turn insulation glass fiber reinforced plastic (GFRP) around each cable.
Epoxy resin filler between the conductors
3 mm of GFRP ground insulation around the matrix
Tedlar thin layer to allow the sliding
5 mm of embedding material GFRP
All closed by 2 mm thick AISI

Torsion test has been chosen to induce combination of normal and shear stress in the turn insulation



Torsion tool for test

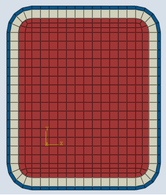
NUMERICAL MODEL DESCRIPTION: 2 different models

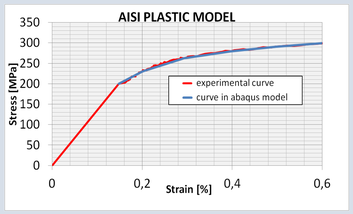
MESH

smeared		refined
nodes: 36288 elements: 29264	linear hexaedral C3D8R	nodes: 203175 elements: 159278

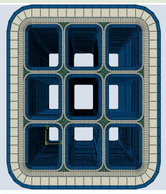
MATERIALS

Material legend:
- AISI 316L
- GFRP
- Epoxy resin Filler
- Smeared WP



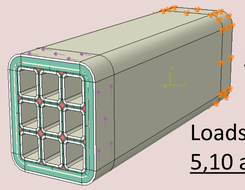


Material	E [GPa]	nu	G [GPa]
Smeared WP	E22=55.27 E11=17.5 E33=20.9	Nu12=0.09 nu13=0.3 Nu23=0.29	G12=13.7 G13=11.47 G23=12.18



Material	E [GPa]	nu	G [GPa]
Filler	7E9	0.3	
GFRP	E22=24 E11=35 E33=35	Nu12=0.33 nu13=0.13 Nu23=0.33	G12=10 G13=10 G23=10

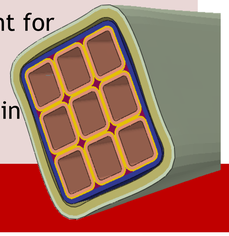
LOAD & BOUNDARY



Fixed boundary

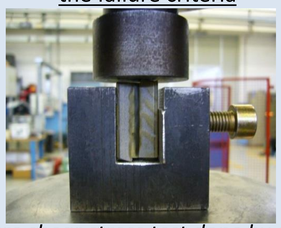
Loads equivalent to torque : 5,10 and 15 kNm

Contact surface: 3 different contact models
- Tie constraint
- Contact with 0.2 nominal friction coefficient for Tedlar layer ("Tedlar")
- Contact with 0.6 static friction coefficient ("Fricion") to take account of the increase in friction due to the manufacturing process

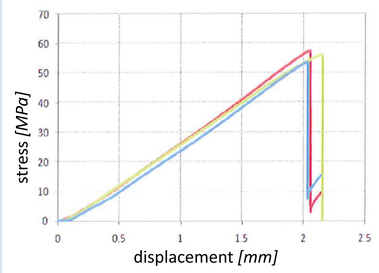


FAILURE CRITERIA HYPOTHESIS

The highest level of pure shear stress value measured, suggested to modify the failure criteria



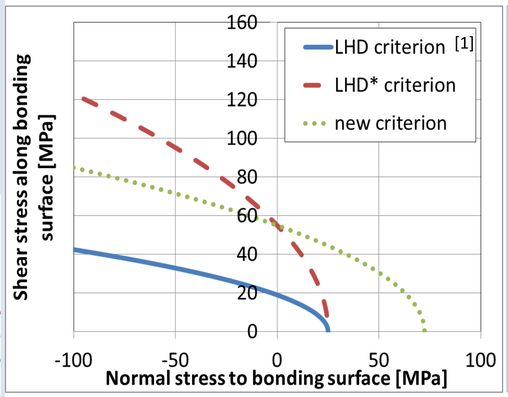
Pure shear stress test done by ASG



$\tau_{max-ASG}$ = 55 MPa

Failure criterion: combination of normal and shear stress

$\sigma/\sigma_{max} + (\tau/\tau_{max})^2 < 1$ with $\tau = (\tau_1^2 + \tau_2^2)^{1/2}$



Defined in ref[1]

LHD: $\sigma_{max-ref1}$ and $\tau_{max-ref1}$ from ref.[1]

Modified from pure shear stress test results

LHD*: σ_{max} from ref. [1]
τ_{max} from ASG test

Modified to keep a realistic trend

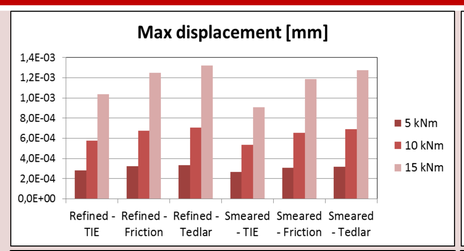
new criterion:

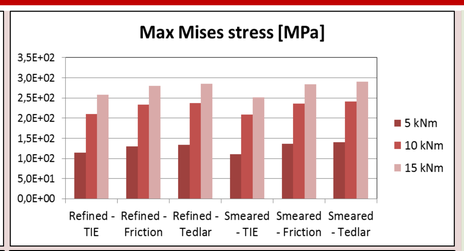
$\sigma_{max} = \sigma_{max-ref1}\ \tau_{max-ASG} / \tau_{max-ref1}$
τ_{max} from ASG test

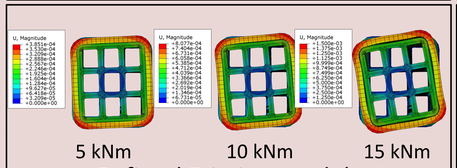
[1] Kitamura, K. et al., ," Cryogenic Shear Fracture Tests Of Interlaminar Organic Insulation For A Forced-Flow Superconducting Coil", IEEE Trans. on Magnetics, vol. 30, no. 4, 1994

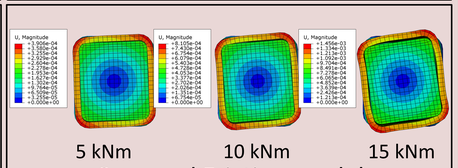
RESULTS

COMPARISON BETWEEN SMEARED AND REFINED MODELS









FAILURE CRITERIA COMPARISON