Novel Insulation Designs for Nb_3Sn Rutherford Cables for Particle Accelerator Magnets

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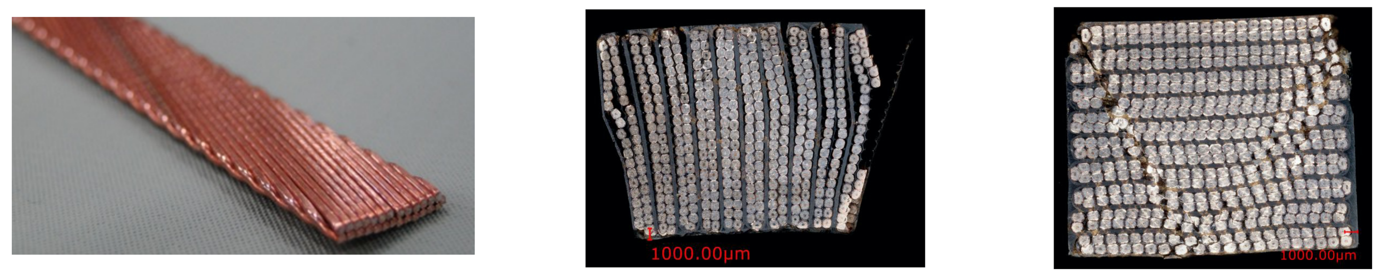
ABSTRACT

The strain sensitivity of Nb_3Sn is considered one of the main challenges that must be solved to use its full potential in particle accelerator magnets application. Significant forces are applied to the superconducting coils both during the assembly and cooldown to cryogenic temperatures, and then during powering. The composite coil reacts to these forces, that are distributed between the insulation and the cables. In most common designs, the cable insulation is made of impregnated glass fiber, which can be significantly damaged during the coil reaction. This paper presents novel stiffer heat resistant insulation designs, that might allow to reduce the stresses applied on the conductor. The potential impact on magnet performances was numerically demonstrated on FE models of cable stacks, and on a reference dipole magnet. The performances of the novel designs are being tested on impregnated 10-stacks. The turn-to-turn resistance was measured at cryogenic temperatures, and the mechanical properties at room temperature.

Potential Advantages of CFRP Insulation

Stiffer and **stronger insulation** schemes can bring the following advantages:

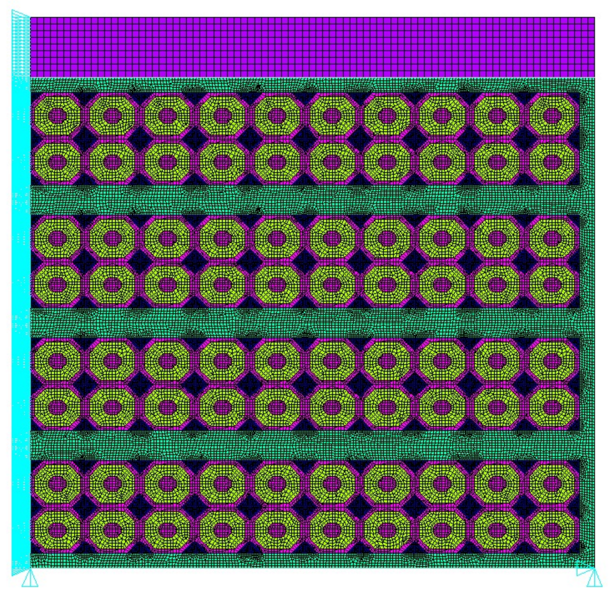
- **Stress management**: strain reduction on the filaments
- **Cable stability** improvement, reducing internal debonding
- **Coil strength** increase, especially on longitudinal/radial loads

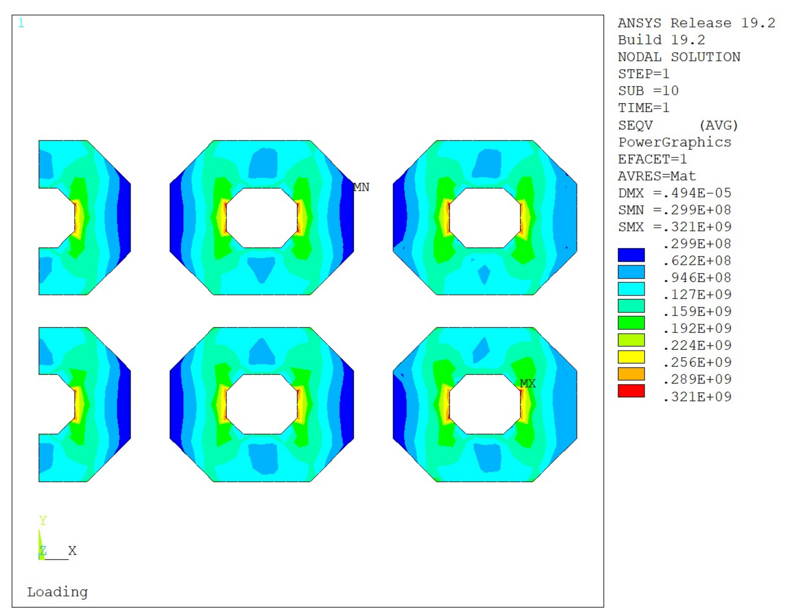


Stress Reduction – 10 Stacks

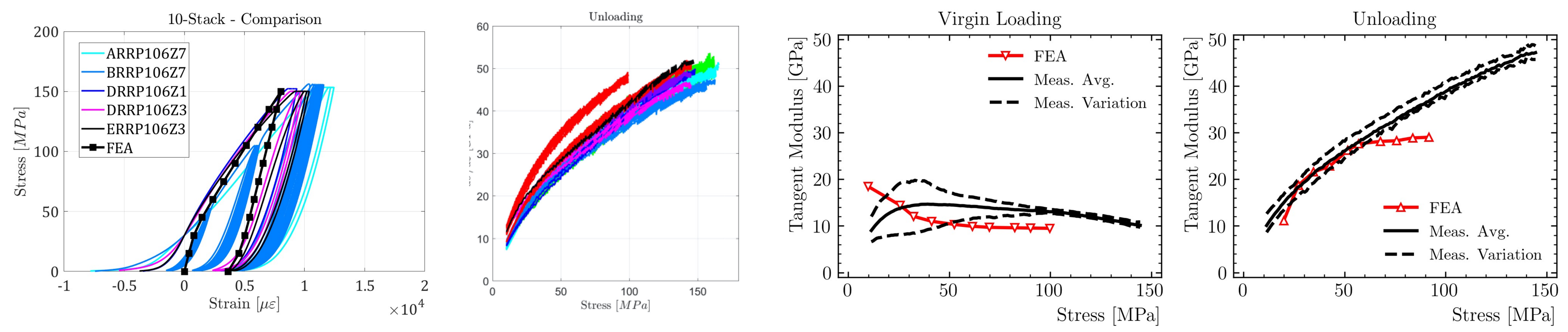
Eins	Superconducting Region Stress						Max. Applied Pressure		
	Center	*Corner*	*Average*	*Center*	*Corner*	*Average*	*Center*	*Corner*	*Average*
GPa	*MPa*	*MPa*	*MPa*	*%*	*%*	*%*	*MPa*	*MPa*	*MPa*
12 (G10)	227	224	228	100%	100%	100%	150	150	150
200 (CFRP)	201	148	179	89%	66%	79%	169	227	191
250	198	138	174	87%	**62%**	76%	172	243	197

- A cable stack **model** at the 'strand' level was created in order to test the potential performances of different insulation designs
- A **transversal load** was applied, and the stress distribution in the cable was computed as a function of the insulation stiffness
- **CFRP/Mica** insulation schemes: **40% stress reduction** at the magnet **corner** with respect to glass fiber, and **13% reduction** in the **center**. This depends also on the cable width (less effective for large cables)
- The current pressure 'limit' is **150 MPa**
- Scaling, this design might be able to withstand up to **243 MPa** with no critical current reduction!

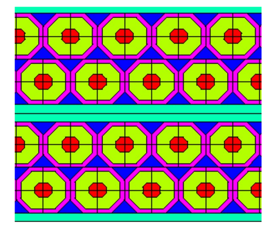




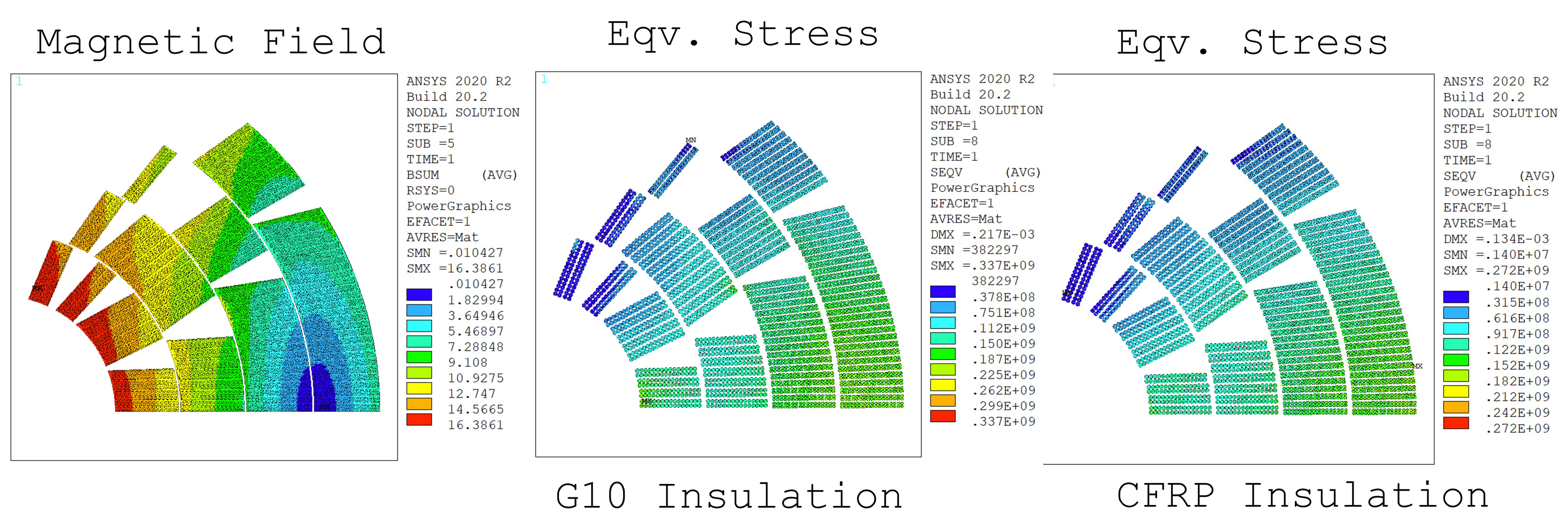
Debonded Cable Stack Model



- On 10 stack measurements, the unloading tangent modulus is continuously decreasing. Non-impregnated 10-stacks show an even more pronounced effect. We tried to reproduce this effect on a FE model, allowing internal sliding.
- **Virgin** loading:
  - Initial 'foot of the press' effect not captured by the model. FE **converges** to the 'final' tangent modulus, suggesting that the inner bonds are progressively breaking!
- **Unloading**:
  - **Initial tangent modulus** 'increase' matched! This is another clue that the bonds break during operation.
  - Are impregnated coils permanently 'damaged' by loading/powering?
  - Measured modulus **higher** for transversal loads greater than 60 MPa. This suggests that the bonds might not be completely broken on the real stack.

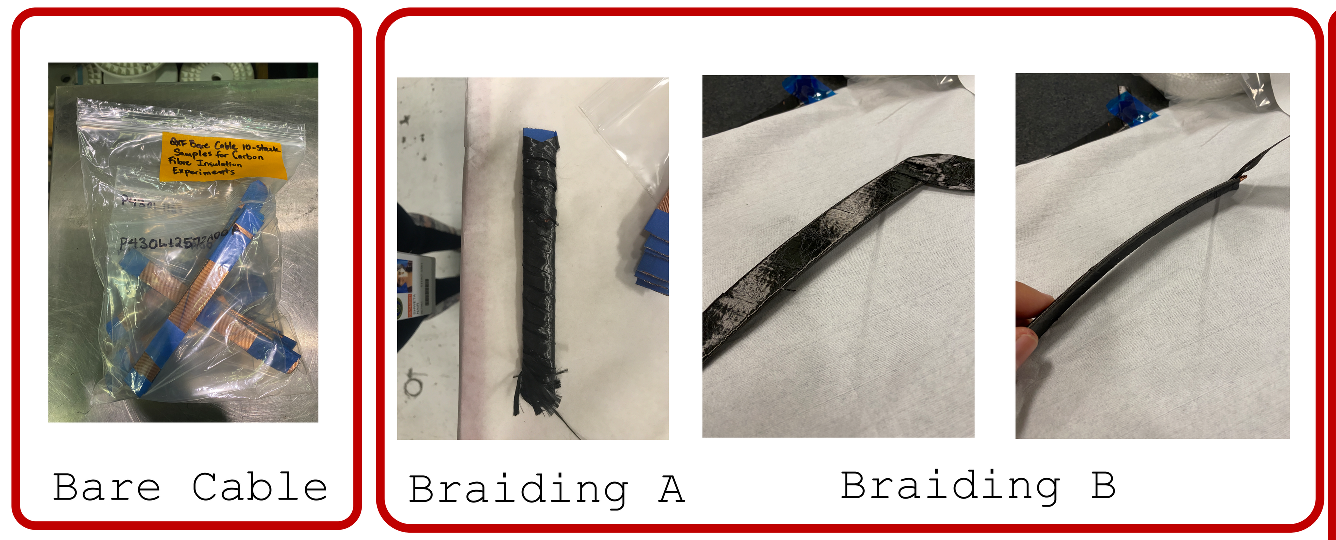


Potential Impact on Dipole Magnet Performances



- Simulation of **4-layer 16** T magnet with a different **insulation** models
- Peak field on conductor: 16.4 T
- Symmetric 2D model, assuming rigid boundaries around the coil pack, opening allowed between coil and pole
- The stiffer CFRP insulation allows to reduce the peak stress on the superconducting regions **from 337 MPa to 272 MPa**.
- The advantage would be even greater with a real (softer) structure.

10 Stacks Production



- Samples production in progress:
  - Fiber **wrapping** was optimized after multiple attempts. Best results obtained applying a **binder** on the cable (B) to keep the dry fibers in place.
  - **Reaction** completed, **Impregnation** ongoing

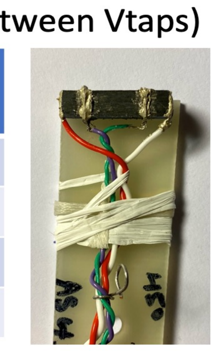
Resistivity Measurement

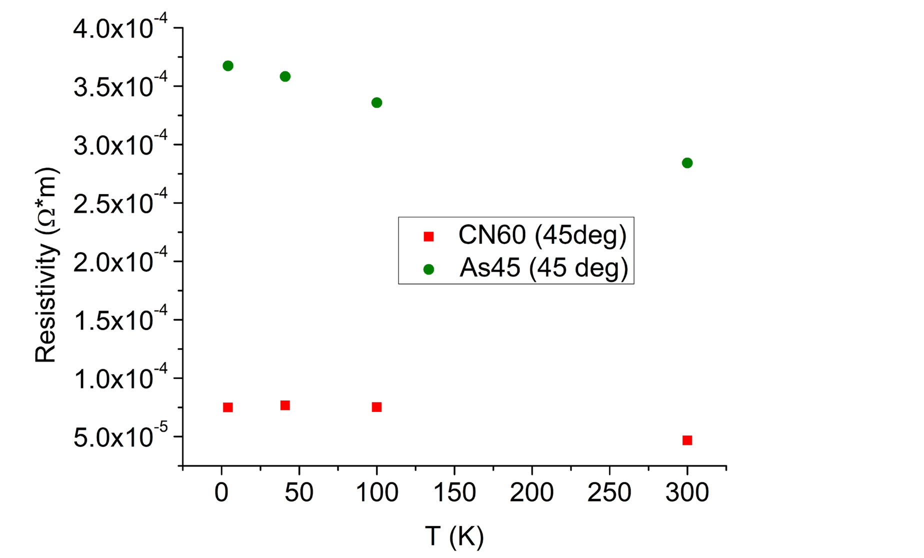
CN60 (45 deg cut) - 5x5x (11.6 mm between Vtaps)

Temperature (K)	Resistance (Ω)	Resistivity (Ωm)
4.2	0.03479	7.49784E-5
41	0.0356	7.67241E-5
100	0.03492	7.52586E-5
300	0.02171	4.67888E-5

As45 (45 deg cut) - 5x5x (10.6 mm between Vtaps)

Temperature (K)	Resistance (Ω)	Resistivity (Ωm)
4.2	0.15578	3.67407E-4
41	0.15188	3.58199E-4
100	0.14239	3.35826E-4
300	0.1205	2.84198E-4





- Samples were measured with current in the 10-100 mA range, typically 5 measurements are averaged for each temperature

Conclusions

- **Stiffer insulation** schemes can allow for a reduction of the stresses on the superconducting regions of the strands:
  - The **reduction** is of 40% in the cable **corners**, and 13% in the cable **center**.
  - This is a **potential 243 MPa limit** in the **coil** corners, which typically sees the peak stresses.
- On a 4-layer 16 T dipole, this would reduce the peak eqv. stress on the superconducting regions from 337 MPa to 272 MPa.
- **Resistivity measurements** show the need of an additional mica layer to provide the required turn-to-turn insulation.

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