Effect of the sub-elements layout on the electro-mechanical properties of high J_c Nb_3Sn wires under transverse load

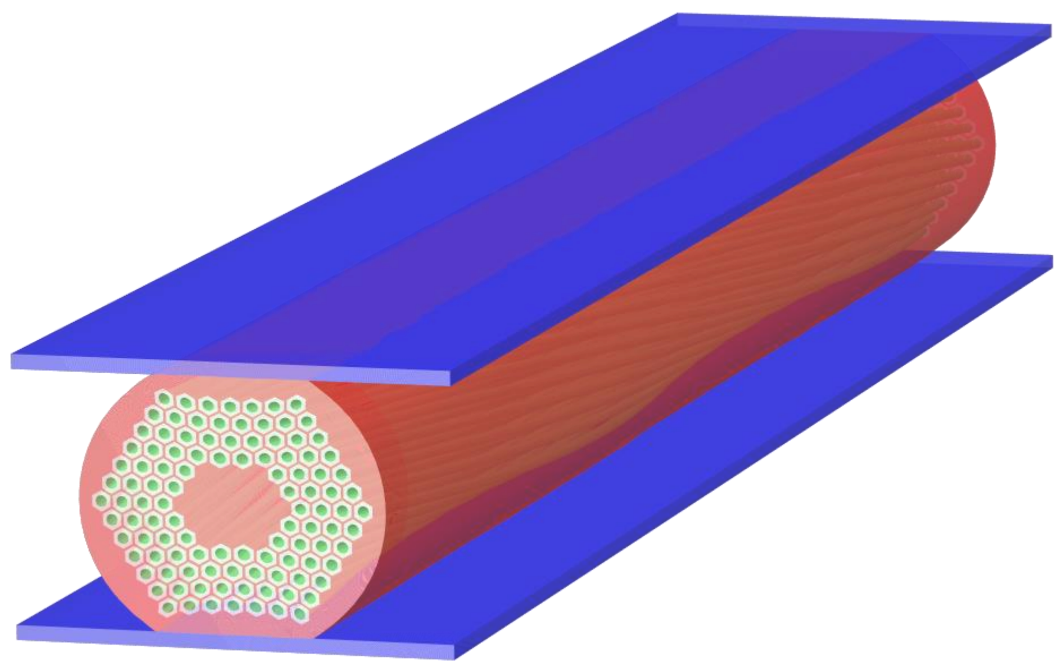
Dario Baffari, Bernardo Bordini, Alessandro Cattabiani
European Organization for Nuclear Research (CERN), TE-MSC-SCD

Abstract

The brittle intermetallic Nb_3Sn superconductor is currently being used to develop high field magnets in the framework of the Hi-Luminosity upgrade of the Large Hadron Collider at CERN. Despite its excellent superconductive properties, Nb_3Sn wires suffer from significant critical current I_c reduction due to the transverse load applied during the magnets' assembly and energization. In high critical current density J_c RRP and PIT wires (J_c >1200 A/mm2 at 15 T, 4.22 K), the I_c is reduced by about 20 % at 12 T (and 40% at 19 T) when applying a transverse load of 150 MPa because of the strain state on the superconductor.

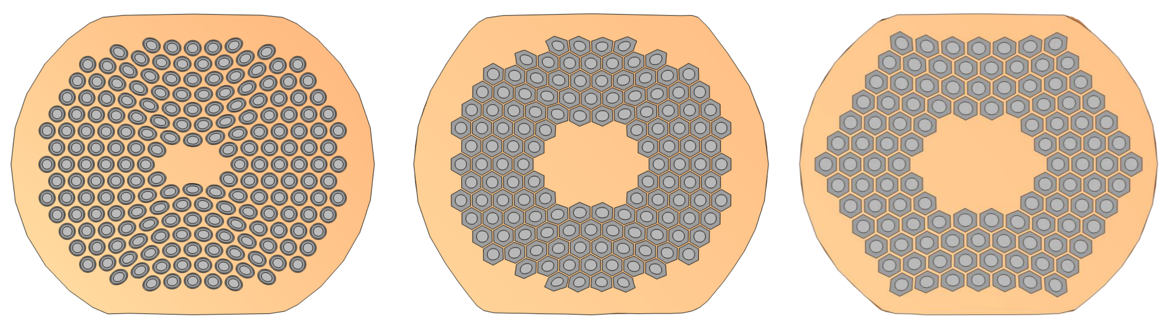
A dedicated FEM 3D numerical model coupled with a J_c scaling law has been developed to predict the electro-mechanical behaviour of RRP and PIT wires under transverse loads. By using this model, the effects of different geometrical factors have been studied to identify the key parameters that allow limiting the effect of transverse loads on the I_c reduction under transverse load. In particular, this poster deals with the role of the: production technologies, diameter, sub-elements layout, heat treatment and precompression.

Model setup

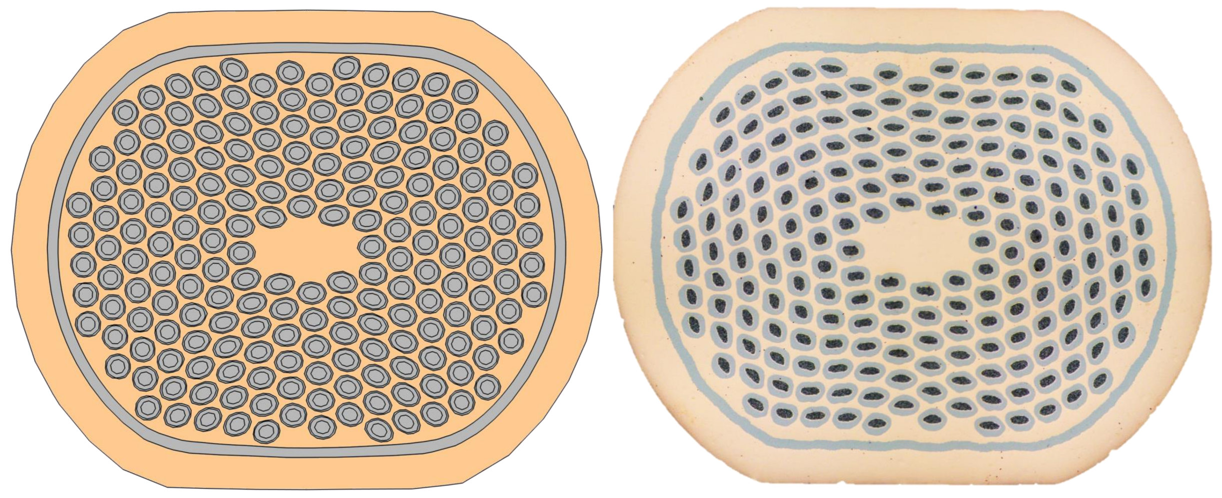


Full detailed 3D geometry of the strand (**no homogenization**).

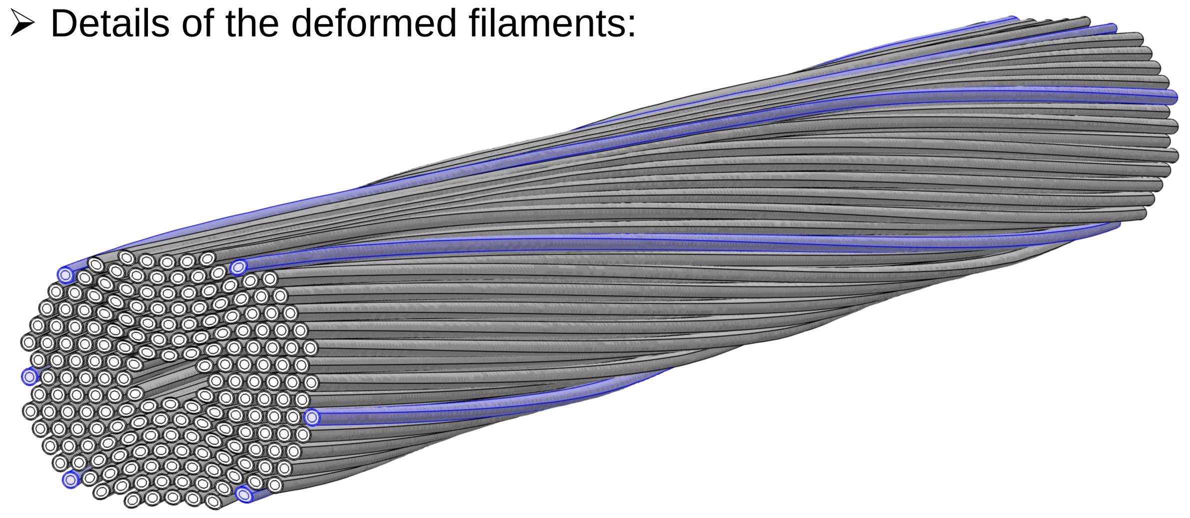
- Mechanical simulation to obtained deformed geometry after **15% flat rolling**, to mimic the deformation due to the cabling operations.
- Only the deformed geometry has been transferred to the electro-mechanical model (**residual strain** after reaction were considered **negligible**).
- A variety of strand layout has been investigated:



PIT 192 | RRP 132/169 | RRP 108/127

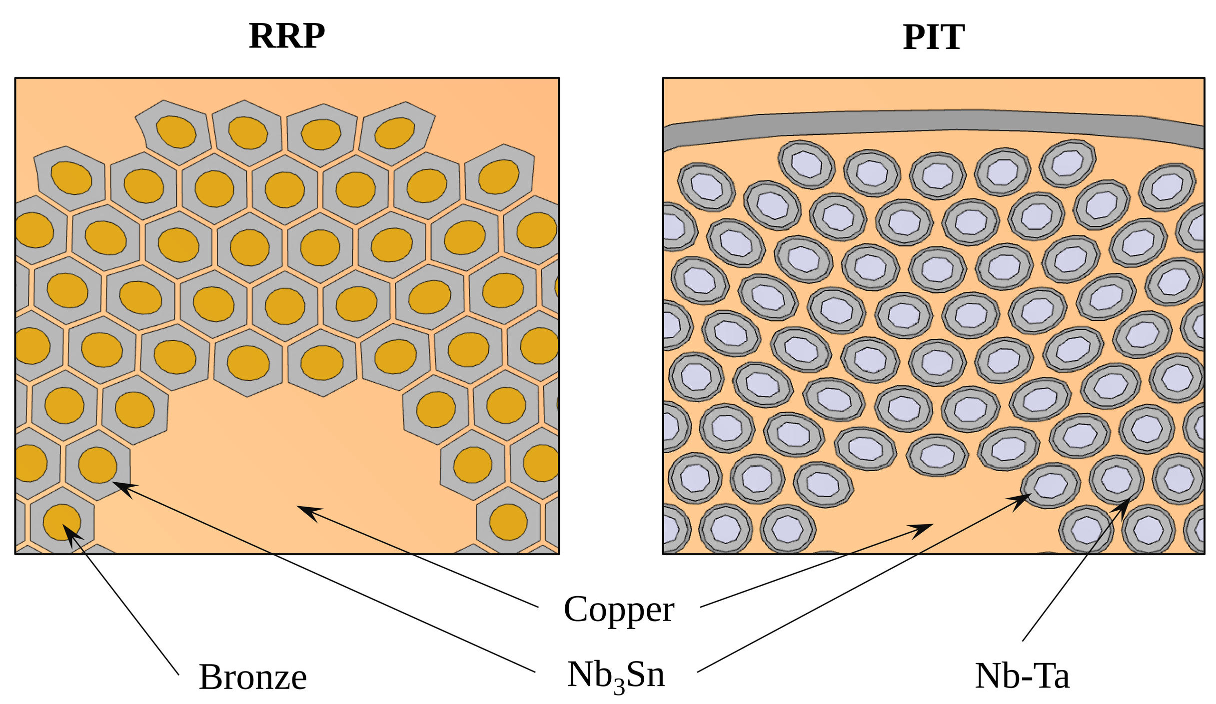


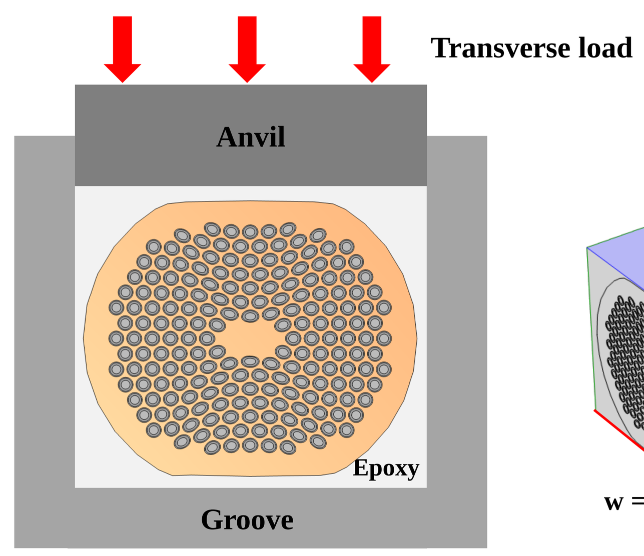
- Comparison between FEM calculated geometry and cross section of a 0.85 mm PIT192 strand with **bundle barrier**.
- Details of the deformed filaments:

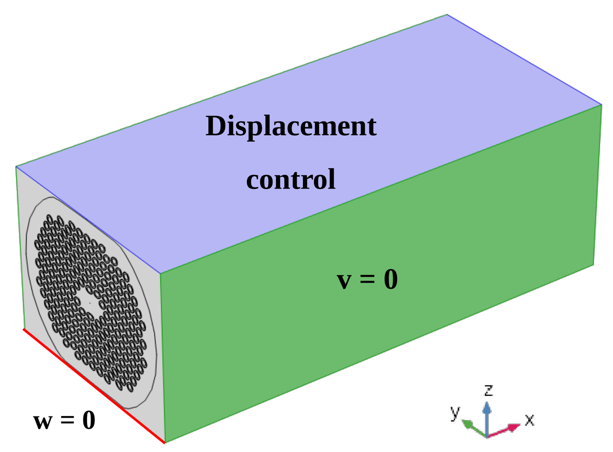


Detailed cross section compositions has been simulated

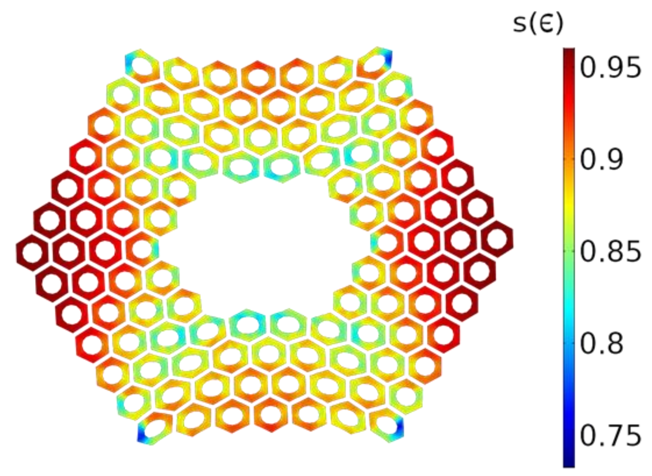
- **Elastoplastic** material model for copper stabilizer.
- **Orthotropic** elastic model for the SC filaments.
- **Solid Bronze** in the **RRP cores**, no material in the PIT cores (resistance of the porous Nb-Sn intermetallic reaction residual is considered negligible).







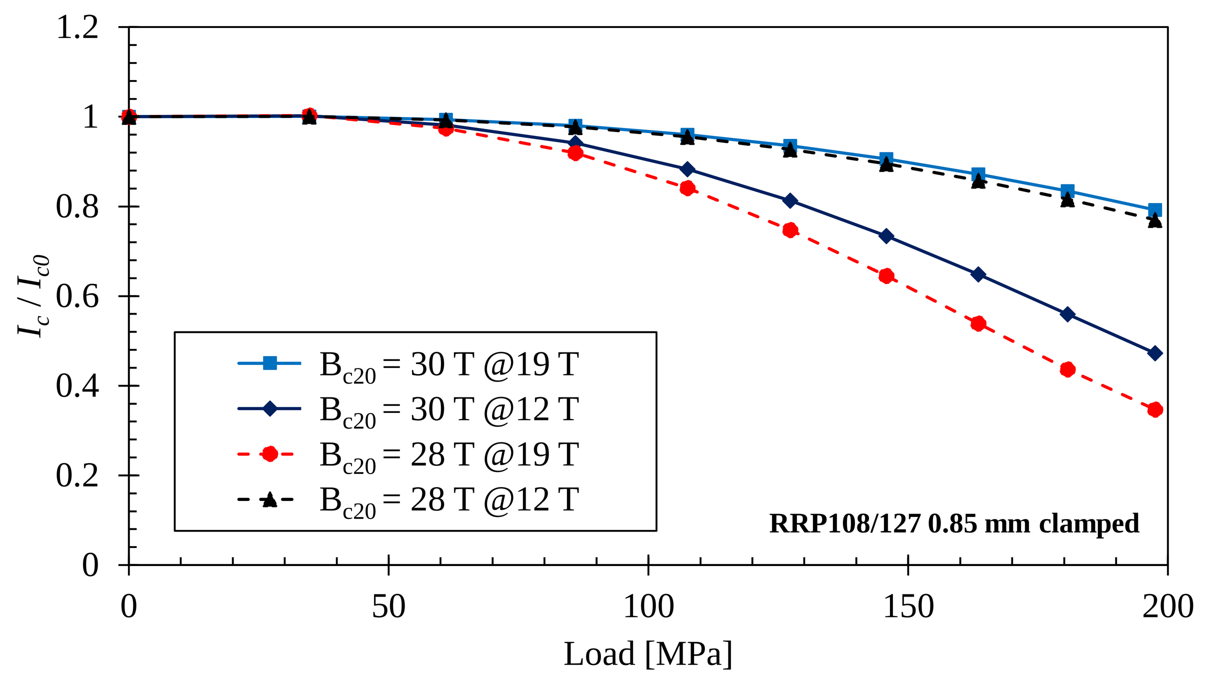
Strain function calculation



$$s(\varepsilon) = \frac{1}{2}\left(e^{-C_1\frac{I_1^2+3}{I_1^2+1}I_1^2} + e^{-C_1\frac{I_2+3}{I_2+1}I_2}\right)$$

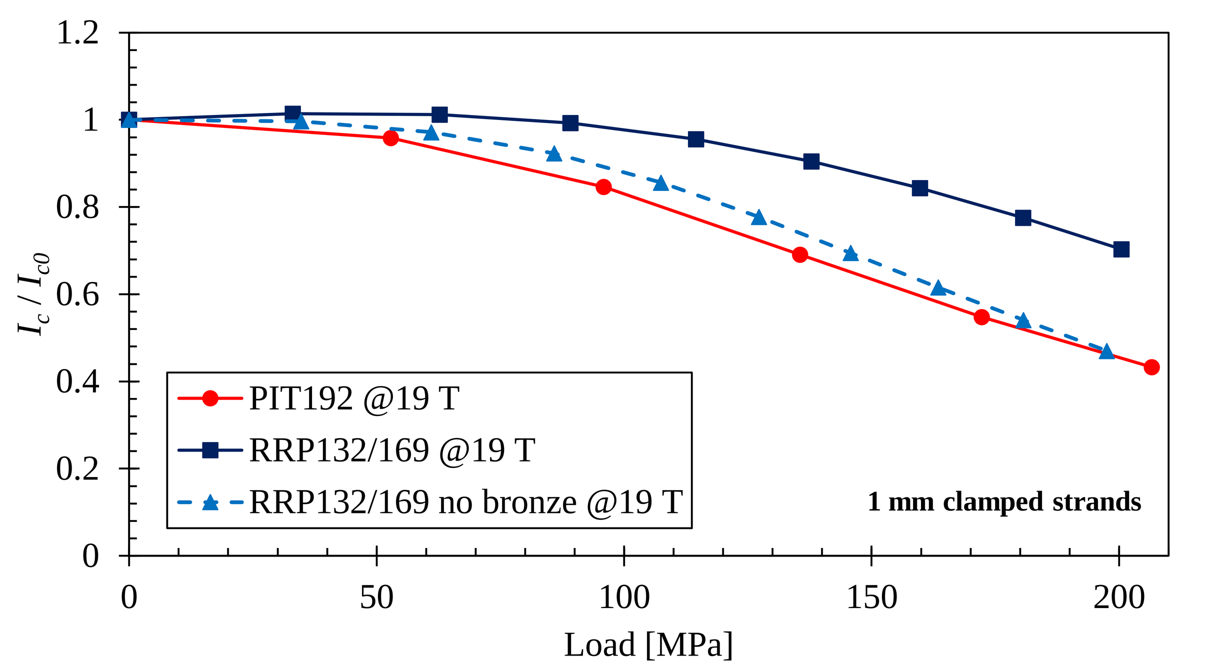
- FEM mechanical model coupled with J_c exponential scaling law by Bordini et al.
- Precompression added during data post-processing

Influence of B_{c20} and applied field



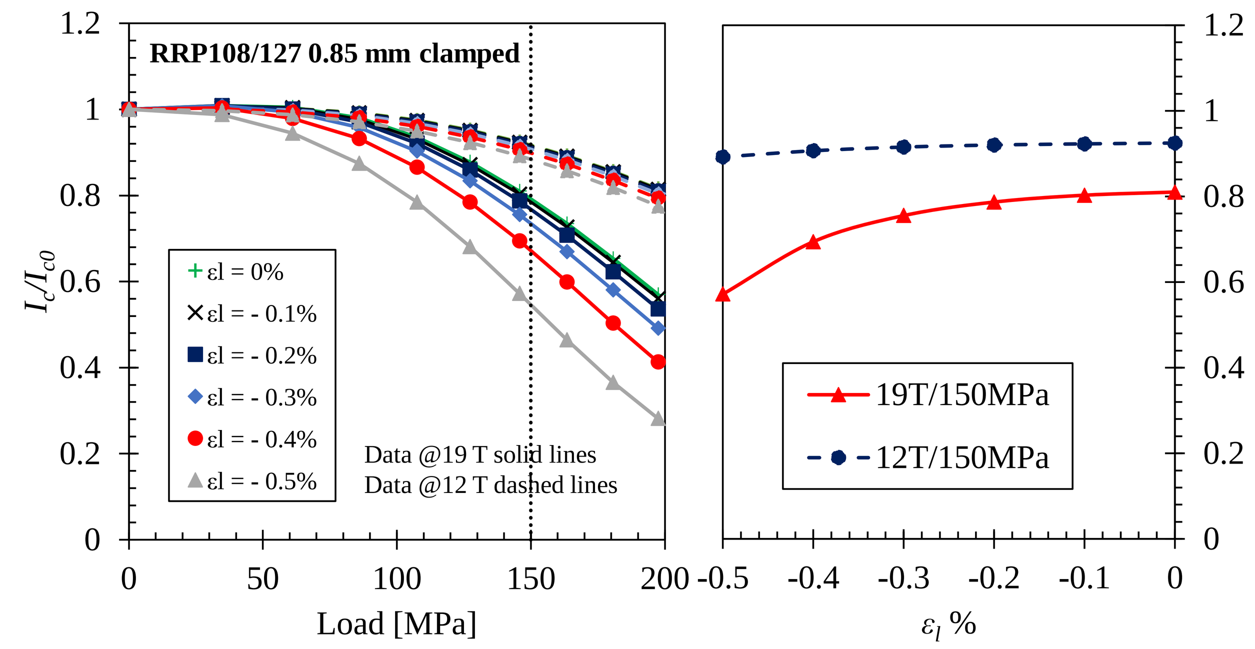
- The model can predict the influence of both the externally applied field and the conductor B_{c20} on the I_c reduction.
- At 12 T the reduction is relatively low, since the B_{c2} reduction plays a smaller role being the applied field far from the critical level.

Influence of the production technology



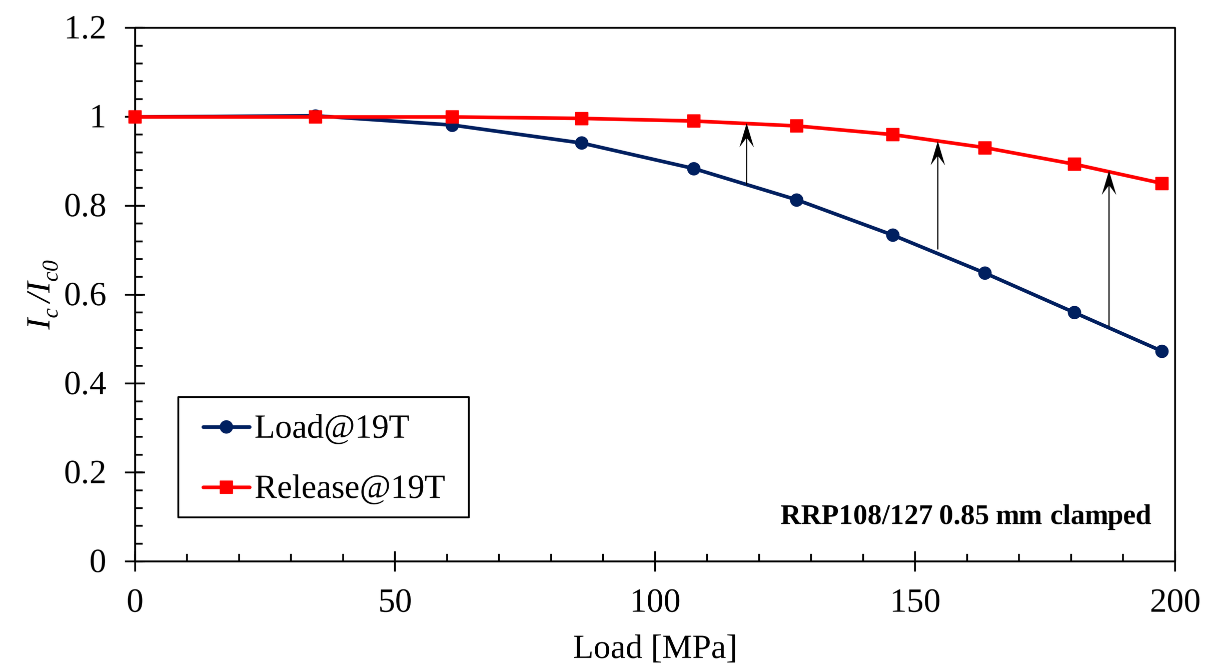
- Relevant influence of the **bronze core within** the sub-elements on the reduced strain sensitivity of RRP compared to PIT.
- When the bronze core is **removed** from the RRP strand the simulation data show **higher I_c reduction**, in line with the PIT case studies.

Influence of precompression



- The effects of the precompression on the I_c reduction **at high fields** are particularly relevant for ε_l < - 0.3%.
- The I_c reduction increases significantly for higher compression levels due to the **initial lower B_{c20}** (for P = 0 MPa), leading to a lower margin for B_{c2}.

Residual reduction after unloading



- Persistent plastic deformations of the copper matrix in the transversal direction can explain alone the **permanent I_c reduction** (before filament cracking) observed experimentally even at moderate load level.

Conclusions

- This poster presented an overview of the effects of different geometrical and technological parameters on the critical current reduction of Nb_3Sn strands under **transverse pressure**.
- Comparative analyses have been carried out on a 3D FEM model to highlight the **contribution of different parameters** on the overall critical current reduction.
- The **lower strain sensitivity of RRP wires** with respect to PIT strands has been linked with the reinforcing effect of the bronze cores within the sub-elements.
- The model has shown the relevant **effect of copper plasticization on permanent I_c reduction** after unloading.
- The obtained results show the **potentials of the proposed modelization strategy** to simulate and predict the behaviour of superconductors under transversal pressure.

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