Recent innovations in Nb_3Sn wire technology for the next generation of accelerator magnets

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The aim of our research is to push Nb_3Sn wires towards their ultimate performance in view of future particle-physics experiments at the energy frontier. In particular, the design of 16 T dipole magnets for the CERN Future Circular Collider (FCC) relies on the development of next-generation Nb_3Sn wires with outstanding properties in terms of critical-current density and mechanical strength. Our contribution to the advancement of the Nb_3Sn technology relies on two pillars: at the nanoscale level, tailoring the vortex-pinning landscape and enhance J_c; at the microscale level, predicting the properties of the conductor under large stress. The first focus is on inhibiting the Nb_3Sn-grain growth by means of nanoparticles (typically ZrO_2) that form through internal-oxidation processes during the reaction heat treatment. Grain boundaries act as pinning centers in Nb_3Sn, therefore smaller Nb_3Sn grains enhance J_c. We are currently manufacturing internally-oxidized rod-type multi-filamentary wires made from binary and ternary Nb-alloys. Beyond an improved J_c, our wires exhibit record-high upper critical fields above 29 T at 4.2 K [1]. At the microscale level, we developed a method to characterize the wires' internal voids and cracks, which play a crucial role for the electromechanical properties [2]. X-Ray tomographies were acquired at the European Synchrotron Radiation Facility (ESRF) on Nb_3Sn wires used for prototype accelerator magnets. Samples were submitted to mechanical load, simulating real conditions during magnet operation. Convolutional Neural Network (CNN) analyses allowed us to identify wire components (Nb_3Sn sub-elements, copper matrix) and defects (voids, cracks). The trained CNN was able to analyze, quickly and autonomously, large volumes of tomographic images, thus enabling a systematic investigation of the mechanical damages in Nb_3Sn wires and, eventually, the development of reinforcement strategies.

[1] F. Buta et al., Journal of Physics: Materials 4, 025003 (2021).
[2] T. Bagni et al., Sci. Rep 11, 7767 (2021).