Combined microstructural and magnetic investigation of pinning force enhancement in Nb_3Sn superconductors

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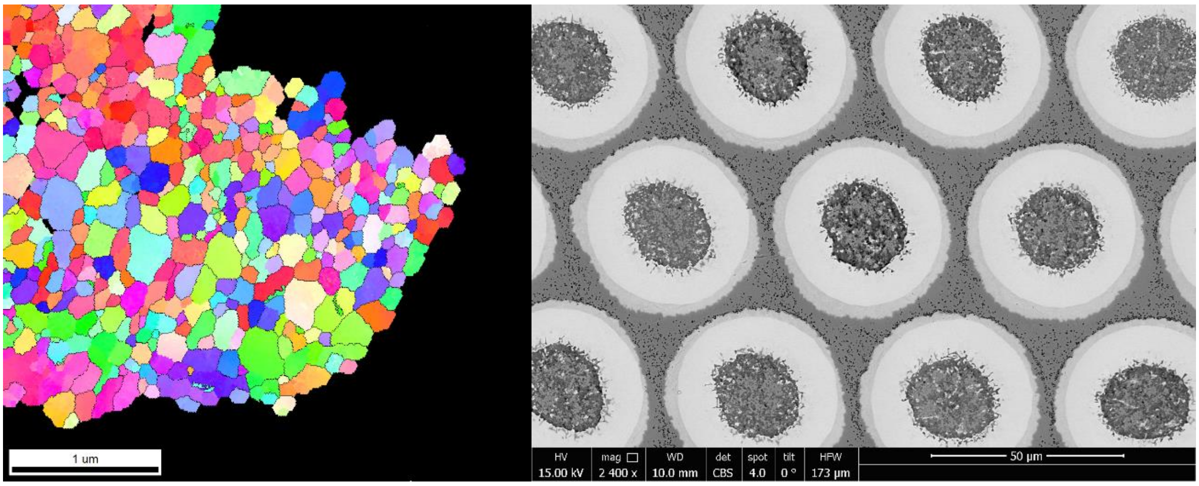
For the design of Future Circular Collider (FCC) superconducting magnets an increase of the high field critical current density in commercial Nb_3Sn wires by about 50 % is required. One possibility of reaching this target is by producing defects in the crystal structure which serve as additional flux pinning centres, as already demonstrated by means of fast neutron irradiation. Another option is grain size refinement by introduction of defects that inhibit grain growth in order to achieve a higher grain boundary density which also increases the pinning force.
In the present study, the underlying mechanisms are investigated through combined microstructural and magnetic analysis in order to establish a correlation between microstructure and superconducting performance. This understanding is required for manufacturing such high-performance superconductors in an industrial process.
We present results of microstructural examinations of grain size distribution, grain geometry, grain boundary morphology, compositional gradients, local texture and defect structure performed on Nb_3Sn wires of various manufacturing techniques. Measurements were conducted using high-resolution transmission electron microscopy (TEM), weak-beam dark-field microscopy (WBDF), energy-dispersive X-ray spectroscopy (EDX) and transmission Kikuchi diffraction (TKD). Findings include residuals of heat treatments and Sn gradients across sub-elements as well as single grains. Examinations of the defect structure were performed on Nb_3Sn wires using weak-beam dark-field microscopy before and after irradiation in a nuclear research reactor to establish a link between defect density and critical current density.
These results are correlated with magnetic measurements, in particular scanning Hall probe microscopy (SHPM) and SQUID magnetometry to determine critical current density and critical temperature. It becomes apparent that Sn gradients across Nb_3Sn sub-elements, defect density and grain size heavily affect the superconducting properties.
This study contributes to a better understanding of the influence of the microstructure on local superconducting properties and ultimately on the macroscopic performance of the superconductor.



TKD inverse pole figure map of a TEM specimen (left) and SEM image of the cross section of a powder-in-tube (PIT) Nb_3Sn superconductor (right).

[1] T. Baumgartner et al., Sci. Rep. 5: 10236, 2015.
[2] T. Baumgartner et al., Supercond. Sci. Technol. 30 (1): 014011, 2017.

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