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Root Cause of the Strain Irreversibility Cliff in RRP® Nb3Sn Wires

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Nb3Sn superconducting wires made by the restacked-rod process (RRP®) exhibit a precipitous change of their intrinsic irreversible strain limit $\epsilon_{irr,0}$ with heat-treatment temperature T , called the strain irreversibility cliff (SIC). The occurrence of SIC over a very narrow range of T , within the domain of temperatures typically used for heat-treating magnets made of RRP® wires, can be a challenge for choosing suitable heat-treatment conditions that optimize the wire's transport, strain, and thermal properties all at once. To understand the root cause of SIC, we studied the microstructure of strained samples taken from three RRP® Nb3Sn wires, doped with either Ta or Ti, and having either a standard or reduced Sn content. We used light and scanning-electron microscopy to locate cracks and CuSn phases in strand cross-sections and energy-dispersive spectroscopy (EDS) to measure Sn content in the remnant CuSn phases. We also conducted neutron-diffraction experiments at the Japan Proton Accelerator Research Complex (J-PARC) to identify the various phases in the samples. Samples were reacted at T ranging from 600 to 700 °C. In this paper, we show a strong causality between the SIC behavior and the existence of a brittle CuSn phase in the microstructure. We present the evolution of lattice parameters of the main wire constituents as a function of T and that of Sn content in both Nb3Sn and in the CuSn adjacent phases. Correlations between the nanostructure and microstructure of the samples and their electromechanical behavior will be discussed to unambiguously identify the root cause of the SIC.

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