Changes proposed to heat-treatment of Large Hadron Collider Nb_3Sn magnets for optimal results

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Restacked-rod-process Nb_3Sn superconducting wires will be used in the high-luminosity (HL) upgrade of the Large Hadron Collider particle accelerator at CERN in order to increase the rate of particle collisions. However, the brittle nature of Nb_3Sn superconducting wires requires proper of stress and strain management in magnets to be made for the HL-LHC upgrade.

Systematic studies of Nb_3Sn axial-strain properties enabled this collaboration to discover the *strain irreversibility cliff*, an abrupt change of the intrinsic irreversible strain limit $\varepsilon_{irr,0}$, presumably the strain at which cracks start to form in Nb_3Sn, as a function of heat-treatment temperature, θ, for forming Nb_3Sn (see Figure). The strain irreversibility cliff imposes restrictions on the heat treatment that conflict with those required to maintain the conductor's residual resistivity ratio above 150, as required to ensure stability of magnets against quenching. This collaboration combined studies of strain and residual resistivity ratio properties. These specific measurement capabilities have now permanently relocated from NIST to the MagLab's Applied Superconductivity Center.

The study led the team to introduce an electro-mechanical stability criterion that takes into account both strain and residual resistivity ratio requirements. It is a valuable tool to inspect Nb_3Sn wires *before* considering them for usage in magnets to achieve optimal cost and performance outcomes.

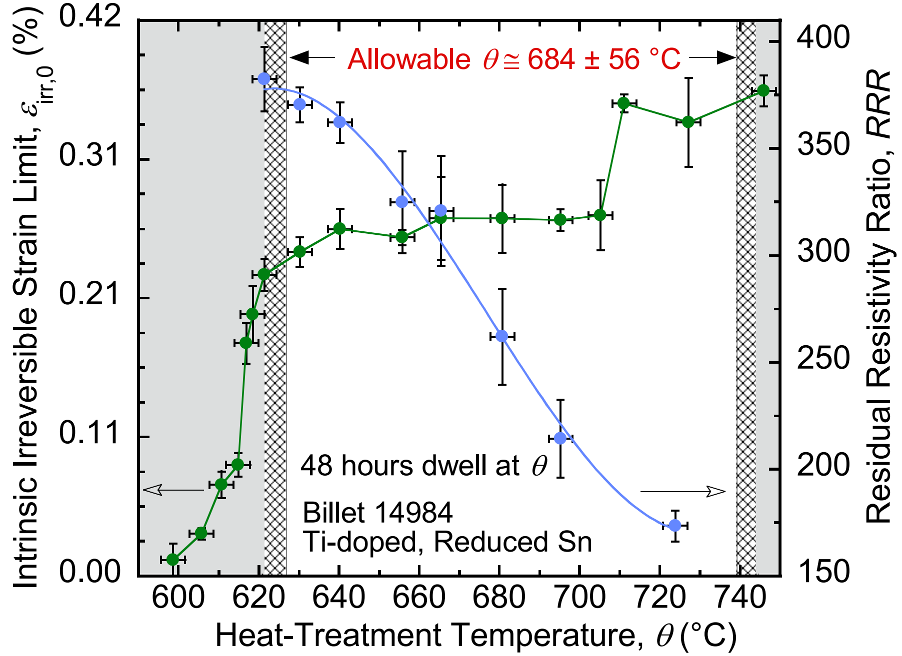

Figure: $\varepsilon_{irr,0}(\theta)$ and $RRR(\theta)$ dependences for a particular Nb_3Sn superconducting wire. Area shaded in gray on the left is where θ is below the cliff onset temperature (determined by the sharp drop in $\varepsilon_{irr,0}(\theta)$ (green). Area shaded in gray on the right is where the residual resistivity ratio (blue) drops below 150. The residual domain between the hatched areas defines the allowable temperature window for an optimal heat treatment. For this wire, the allowable θ of 684 ± 56 °C is very wide.

Instrumentation used: Strain and *RRR* apparatuses from NIST, now relocated to Applied Superconductivity Center at the MagLab (ASC-NHMFL). Furnaces at ASC-NHMFL.

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