On the Mechanisms Behind the Irreversible Degradation of Nb_3Sn Wires Under Mechanical Loads: Effects of the Filament Microstructure and of the Stress Redistribution

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High performance niobium-tin (Nb_3Sn) wires are characterized by extremely high critical current density but also reduced mechanical strain tolerance. Thus, the electro-mechanical limits of the wires become a parameter of the highest importance for the design of the next generation accelerator and fusion magnets, whose large sizes and intense magnetic fields will result in increased electro-magnetic forces compared to the existing machines. The stress level that determines the irreversible degradation of the critical current, I_c, results from a combination of different factors, intrinsic and extrinsic to the wire.

An intrinsic factor is the presence of voids in the Nb_3Sn filaments and in the wire matrix. Voids are formed during the wire fabrication and the reaction heat treatment and result in localized stress concentrations that can lead eventually to the formation of cracks. By combining the results of I_c measurements under axial stain, X-ray micro-tomography experiments and finite elements method (FEM) simulations, we demonstrate a quantitative correlation between the void morphology and the irreversible strain limits measured on different Bronze Route Nb_3Sn wires. Furthermore, we propose to use our modeling tool to predict the possible enhancement of the irreversible strain limits in Powder-In-Tube (PIT) and Restacked-Rod-Process (RRP) wires following a reduction of the void fraction.

The way the mechanical stresses are exerted is an extrinsic factor that influences the stress tolerance and the irreversible limits of the wire. Here we present the results of I_c measurements as a function of transverse loads performed on PIT and RRP Nb_3Sn wires, which are deformed and resin-impregnated similarly to the Rutherford cables in an accelerator magnet. We observed substantial differences in the irreversible stress limits between round and deformed wires as well as between wires impregnated with different types of resin (epoxy, glass fiber+epoxy, stycast). The correspondence between the present results and the operational conditions of the 16 T dipoles designed for the Future Circular Collider study at CERN is reported.

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