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Characterization of edge damage induced on REBCO superconducting tape by mechanical slitting

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This paper describes failure mechanisms in the multilayer thin film structure of a rare-earth bariumcopper-oxide (REBCO) superconductor tape that are due to mechanical slitting of the tape by the manufacturer. We used a variety of imaging and spectroscopy techniques to assess the severity of cracking in the different layers of the thin film structure, and found that the geometry of the mechanical slitter is a key variable in determining crack initiation and propagation. This information is helpful for the tape manufacturers to design a more mechanically robust manufacturing process, which is important due to the large mechanical stresses the tape experiences when in use in a superconducting magnet.

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PAPER

Characterization of edge damage induced on REBCO superconducting tape by mechanical slitting

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Abstract

Rare-earth barium-copper-oxide (REBCO) superconductors are high-field superconductors fabricated in a tape geometry that can be utilized in magnet applications well in excess of 20 T. Due to the multilayer architecture of the tape, delamination is one cause of mechanical failure in REBCO tapes. During a mechanical slitting step in the manufacturing process, edge cracks can be introduced into the tape. These cracks are thought to be potential initiation sites for crack propagation in the tapes when subjected to stresses in the fabrication and operation of magnet systems. We sought to understand which layers were the mechanically weakest by locating the crack initiation layer and identifying the geometrical conditions of the slitter that promoted or suppressed crack formation. The described cracking was investigated by selectively etching and characterizing each layer with scanning electron microscopy, laser confocal microscopy, and digital image analysis. Our analysis showed that the average crack lengths in the REBCO, $LaMnO_3$ (LMO) and Al_2O_3 layers were 34 μm, 28 μm, and 15 μm, respectively. The total number of cracks measured in 30 mm of wire length was between 3000 and 5700 depending on the layer and their crack densities were 102 cracks mm^{-1} for REBCO, 108 cracks mm^{-1} for LMO, and 183 cracks mm^{-1} for Al_2O_3. These results indicated that there are separate crack initiation mechanisms for the REBCO and the LMO layers, as detailed in the paper. With a better understanding of the crack growth behavior exhibited by REBCO tapes, the fabrication process can be improved to provide a more mechanically stable and cost-effective superconductor.

1. Introduction

Coated Conductor (CC) based high temperature superconductor (HTS) technology has advanced significantly in the past few years and CC tapes are now routinely being produced in lengths of several hundreds of meters [1]. High strength Hastelloy alloys have allowed thinner substrates resulting in a significant increase in engineering current density [2, 3], and pinning enhancements in Zr-doped REBCO has increased performance of the wires [4] across a broad range of temperatures and magnetic fields, from 5 T at 77 K [5] up to even 40 T at 4.2 K [6]. These improvements have made REBCO tape a viable option for high energy physics projects [5, 7], fusion reactors such as the SPARC reactor from Commonwealth Fusion Systems [8], and Magnetic Resonance Imaging (MRI) [9, 10]. Although CC tapes provide promise in their electrical performance when compared to their low temperature superconductor (LTS) counterparts, there remain several main challenges associated with REBCO. A key challenge is that, in certain configurations, they are vulnerable to delamination between the different tape layers, due to thermal and magnetic forces experienced during magnet operation [11–13]. REBCO tapes exhibit exceptional axial strength and can withstand up to 700 MPa of stress [14] in that orientation, however when put under a transverse tension, the tape can delaminate under 10–20 MPa of stress [15, 16].