The Effect of Filament Architecture on the Fracture Behavior of Nb_3Sn Composite Strands

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Introduction

Nb_3Sn is a brittle superconducting material used to carry electric current in large superconducting magnets that operate in the 11 – 20 Tesla field range. In a cable-in-conduit configuration such as the experimental fusion reactor ITER or the NHMFL Series Connected Hybrid (SCH), the large Lorentz forces experienced by the Nb_3Sn strand can cause mechanical displacements that result in Nb_3Sn filament breakage, which in turn degrades the current-carrying capacity of the conductor.

The architecture of Nb_3Sn strands (the size, spacing, and distribution of filaments and other components within the wire) is currently designed to maximize critical current density and promote a small effective filament diameter. There is little understanding of how the specific strand architecture affects the propensity of the wire to fracture under Lorentz forces. This work focuses on specifying fracture damage as a function of strand architecture by metallographic examination.

Experimental

We have advanced two techniques for imaging fracture events in brittle Nb_3Sn filaments embedded in composite wires. The first is a traditional metallographic technique, and the second is a novel deep etching technique that provides a 3-D view of the damaged structure. We can image (by SEM or Scanning Laser Confocal Microscopy - SLCM) the distribution of fracture events produced by testing in the TARSIS apparatus at the University of Twente [1] (Figure 1a), or by pure strand bending [2] or microindentation (Figure 1b) at FSU.

Results and Discussion

We have shown that strands with different filament architectures produce different filament fracture patterns after mechanical testing in TARSIS or microindentation. Strands under compression show almost no fracture behavior, regardless of Cu content. Strands under tension always show some crack propagation, but the effect is most severe in strands with highly agglomerated filament structures, such as the high J_c prototype strand shown in Figure 1b. Here, because there is very little interfilamentary Cu, the cracks induced by microindentation propagate over 100 μm.

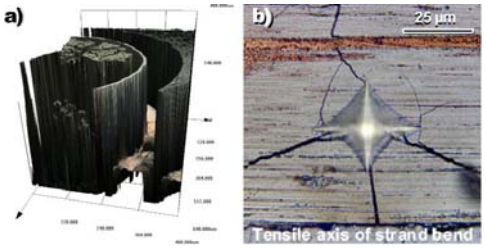

Figure 1. *a) SLCM image of post-TARSIS sample after 300 μm deep etch showing depth distribution of filament fracture. b) Prototype of high J_c Nb_3Sn strand, showing extensive fracture damage after micro-indentation at 300 g.*

Conclusions

The local stress environment and the amount of interfilamentary Cu present in Nb_3Sn composite strands play key roles in determining the extent to which nucleated cracks will propagate across multiple filaments. The clear implication is that if crack propagation can be arrested by manipulating the stress state or introducing more Cu, the strand will be more tolerant of large Lorentz forces and less likely to experience critical current degradation during magnet operation.

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References

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[2] M.C. Jewell *et al.*, *Supercond. Sci. Tech.*, **16**, 1005-1011 (2003)