Image Analysis to Further the Development of Tube Type Nb_3Sn Conductors

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Motivation

The next generation of high-field magnets and particle accelerators requires improvements in the critical current density J_c, while not sacrificing stability. While rod-restack process wires (RRP®) currently hold the record for high-field J_c (>3000 A/mm^2 at 12 T and 4.2 K), the complex geometry makes wire drawing to fine filament diameters difficult. The Tube approach, developed at Hyper Tech Research, Inc., has the advantage of a simple design: a Cu-clad Sn rod in a Nb-Ta tube. These strands typically achieve 2000-2500 A/mm^2 but can be drawn down to finer filament sizes: 217-restack strands are routine and filament counts up to 919 have been reported.

To keep improving the design, inhomogeneities should be characterized. This study seeks to determine the location where defects are more likely to occur.

In this study we examine an experimental 271-restack wire, named T2525, as a case study for future wire development.

Electron Microscopy

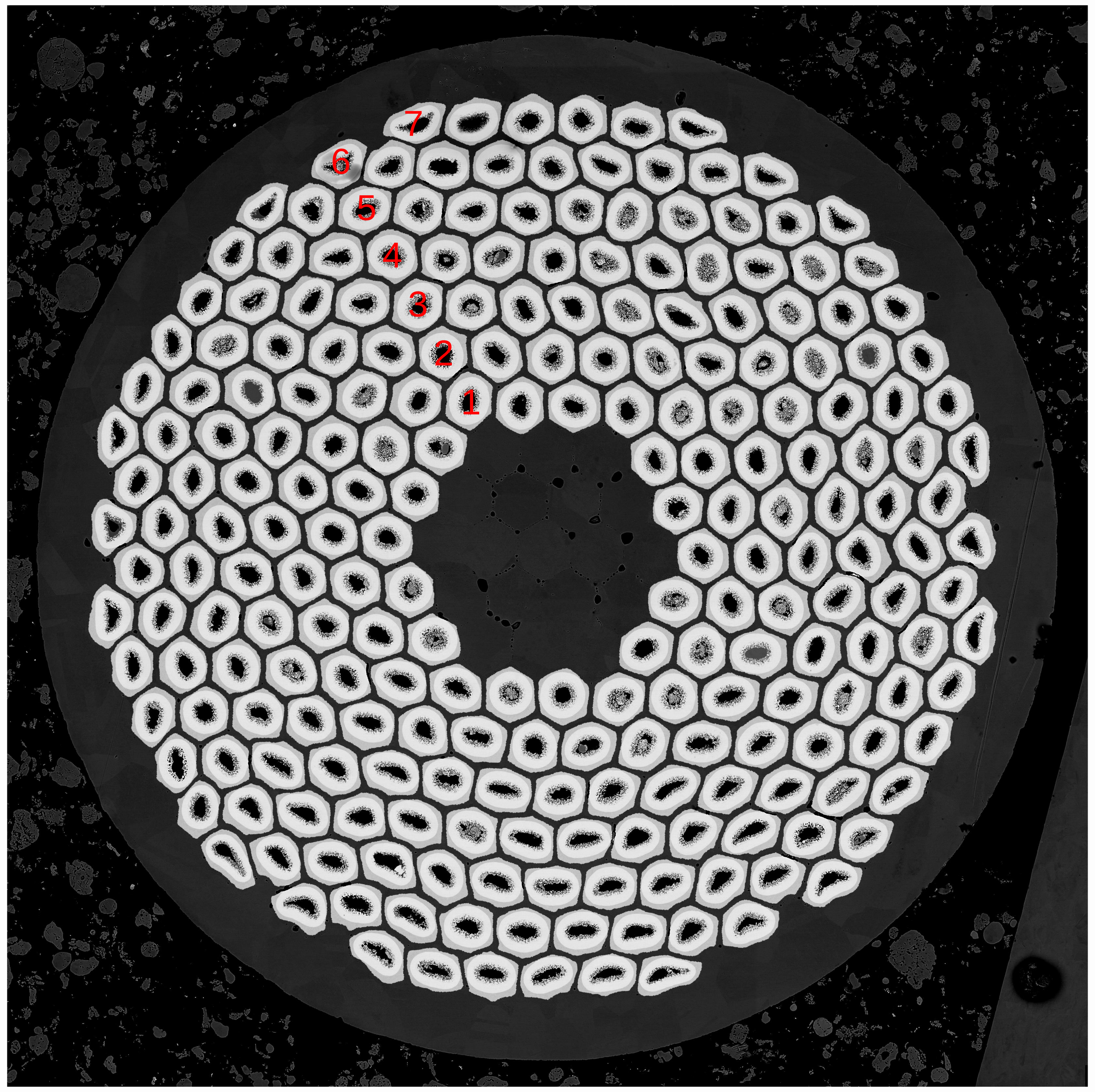

Fig. 1 Representative BSE SEM cross section of wire T2525.

Wire Specifications

Table 1: Strand Specifications	
Strand Name	T2525
Nb-Sn Atomic Ratio	3.15
Filament Shape	Hexagonal
Filaments	234/271
Strand Diameter	0.85 mm
Heat Treatment	625 °C x 350 h

Defect Analysis

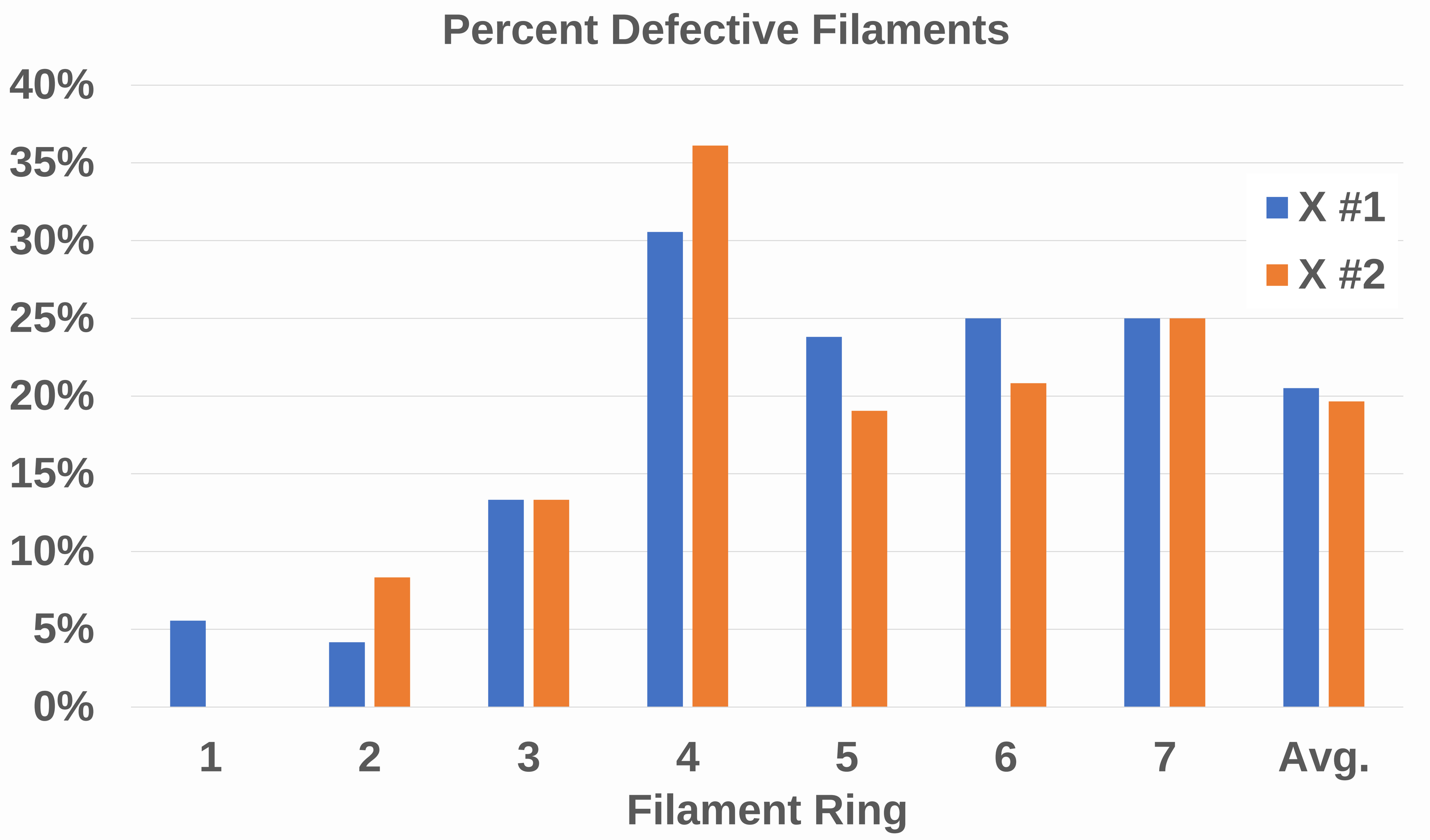

Fig. 2: Percent of filaments in each ring with Sn leaks. Ring 1 is nearest the Cu rods on the inside of the strand, while ring 7 is the outside filaments. X #1 and X #2 refer to sequential cross-sections 5 mm apart longitudinally.

Discussion

In the presently studied wire, it is clear that filaments nearer the center of the strand are much less likely to experience damage than those in the middle and outer rings. It is hypothesized that the softer Cu in the wire core might reduce drawing stresses and reduce the likelihood of defects.

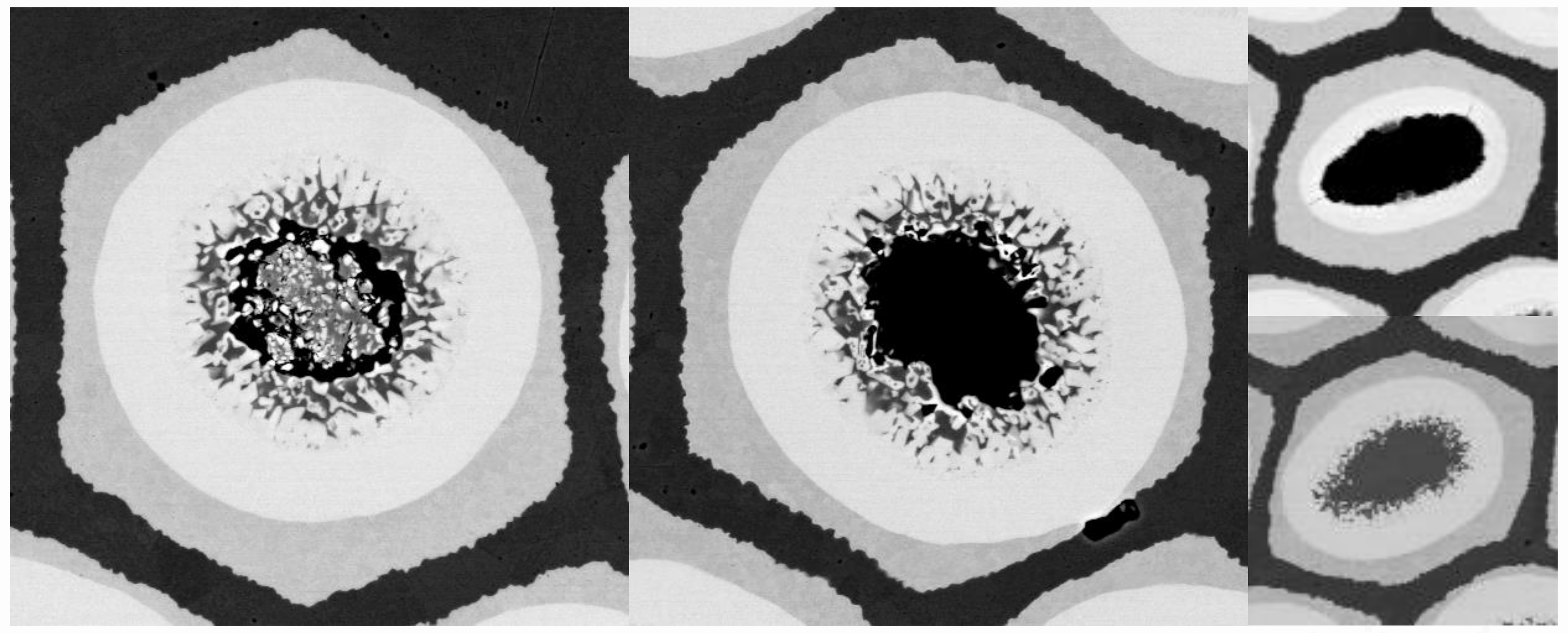

Fig. 3: Left: A good filament in which Sn diffusion has completed without breaching the Nb-alloy tube.

Center: A filament in which Sn has leaked into the Cu matrix. A Kirkendall void can be distinguished due to the density difference in α-bronze vs. Sn and Cu.

Upper Right: Much rarer, a filament from ring 2 with thin Nb_3Sn layer, which has been included in the statistics.

Lower Right: The cross-sections 5 mm on either side of the above filament from ring 2 show no sign of Sn leak.

Conclusions

Sequential cross-sections of an experimental tube-type wire were made, 5 mm apart. The presence of Sn leaks was quantified, which revealed that Sn leaks are more likely in the filament rings towards the outside of the strand than towards the inside.

This data will support ongoing improvements to the wire-drawing process and to the precursor billet recipe in order to reduce hardness mismatches and wire-drawing instabilities.

References

[1] Sumption, M. D. et al. Critical current density and stability of Tube Type Nb_3Sn conductors. Cryogenics 52, 91–99 (2012).

Acknowledgments

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Electron microscopy was performed at the Center for Electron Microscopy and Analysis (CEMAS) at The Ohio State University.