**Filament Damage in Bi₂Sr₂CaCu₂O₈₋ₓ (Bi-2212) Superconducting Wires as Revealed by External Etching**

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**Introduction**

What are we looking for?
- Bi₂Sr₂CaCu₂O₈₋ₓ (Bi-2212): a superconducting material that is able to produce magnetic fields greater than 20 T.

Why are we looking at it?
- The study of subatomic particles in physics is progressing and needs higher magnetic fields for large particle accelerators.
- Bi-2212 is currently the only superconducting round wire capable of producing magnetic fields in excess of 20 T.

What are we looking for?
- Bi-2212 filaments in the silver matrix are brittle and vulnerable to damage during mechanical testing.
- The research seeks to understand how the damage varies under different mechanical, heat treatment, and wire orientation testing conditions, and how that damage influences the wire’s electrical properties.

**Testing and Analysis**

1 Bar High Compression in Convex Orientation
100 Bar High Compression in Convex Orientation

SEM images taken on the SEM of a Bi-2212 sample at UC Boulder.

Key Results for High Compression:
- Compressively tested Bi-2212 wires at 100 Bar show more damage than 1 Bar samples.
- In the images above, arrow A and B demonstrate filament pieces tended to protrude outward and contained sharp ends, which provides evidence of filament fracture.
- The image from the 100 Bar sample shows less directivity in the filament structure and more sharp edges compared to the 1 Bar sample.

1 Bar No Test
100 Bar No Test

SEM images of a 1 Bar Bi-2212 wire mounted in the convex position after being tensile tested and externally etched for 13 minutes.

Key Results for Heat Treatment:
- Samples which have undergone heat treatment alone (1 Bar and 100 Bar) show little intrinsic damage.
- Both the 1 Bar and 100 Bar untested samples had the same structural characteristics observed in their filaments.

1 Bar vs. 100 Bar OP overview

For microstructural analysis of tested Bi-2212 wires, various etching and mounting techniques to expose Bi-2212 filaments were developed by UW-Eau Claire.

**Conclusion**

Damage As A Result of Applied Heat Treatment:
- Samples which have undergone heat treatment alone (1 Bar and 100 Bar) show little intrinsic damage.
- The analysis indicated the concave orientation was more damaging to the Bi-2212 wire because more prominent jagged edges and sharp ends were seen. The factor of wire orientation has less of an impact on the damage generated compared to mechanical state and the heat treatment.

Damage After High Compression:
- Samples which have been tensile tested show more damage than the microstructurally tested samples.

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(1) Damage As A Result of High Compression
(2) Baseline Structure After Heat Treatment
(3) Damage As A Result of Wire Orientation

1 Bar vs. 100 Bar OP overview

- Bi-2212 wires are coiled on a Cu-Be spring apparatus, then electromechanical tests are preformed as a function of applied strain.
- The electromechanical tests are executed at UC-Boulder and tested wires are examined at UW-Eau Claire.

**For High Tension Compared To High Compression:**
- For Bi-2212 wires which have a specific orientation (concave and convex), there were more broken ends and jagged edges observed in the samples with a concave orientation compared to those with a convex orientation.
- As shown by arrow B and C, the Bi-2212 wires contained jagged edges throughout the samples.
- However, the samples with a concave orientation exhibit more prominent sharp ends (arrow A) and jagged edges.

**For Bi-2212 wires which have a specific orientation (concave and convex), there were more broken ends and jagged edges observed in the samples with a concave orientation compared to those with a convex orientation.**

- In the images above, arrow A and C show the jagged edges observed in the high tension samples.
- Both samples contained small filament pieces broken off, yet the 1 Bar sample was seen to be slightly more damaged because it revealed more sharp ends (arrow B).

**SEM images of a 100 Bar Bi-2212 wire mounted in the concave position after tensile testing, and externally etched for 13 minutes.**

**SEM images of a 1 Bar Bi-2212 wire mounted in the convex position after being tensile tested and externally etched for 13 minutes.**

**SEM images of a 100 Bar Bi-2212 wire mounted in the convex position after being tensile tested and externally etched for 17 minutes.**

**SEM image of a 100 Bar Bi-2212 wire externally etched for 17 minutes and mounted in the convex position after being tested in compression.**