Filament Damage in $Bi_2Sr_2CaCu_2O_{8-x}$ (Bi-2212) Superconducting Wires Exposed by External Etching

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Introduction

What are we studying?

- **$Bi_2Sr_2Ca_1Cu_2O_x$ (Bi-2212):** a superconducting material that is able to produce magnetic fields greater than 25 T.

Why are we studying it?

- The study of sub-atomic 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.
- This research seeks to understand how the damage varies under different stress and wire orientation testing conditions, and how that damage influences the wire's electrical properties.

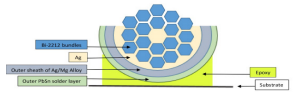
Testing and Analysis

Cu-Be spring apparatus utilized for the electromechanical testing on Bi-2212 wires at UC-Boulder.

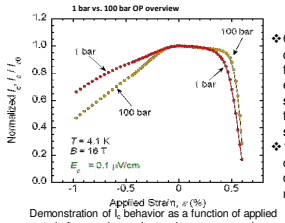
The post-testing examination of the wires: **Concave** shows the inner radius of the tested spiral, **Convex** shows the outer radius, and **Flat** shows the side of the wire.

- 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 microstructural analysis of tested Bi-2212 wires, various etching and mounting techniques to expose Bi-2212 filaments were developed by UW-Eau Claire.
- Scanning electron microscopy (SEM) was used to analyze of microstructural defects caused by testing.

External Etch



External etching gently gets rid of the outer layers to reveal filaments in outer ring.

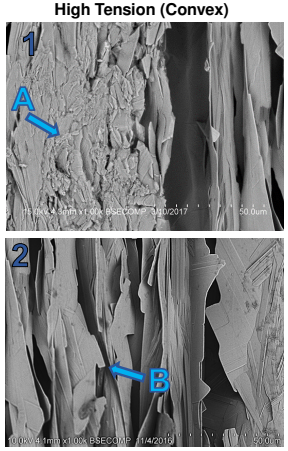


Demonstration of I_c behavior as a function of applied strain for samples under tension or compression.

- Critical current (I_c) degradation happened faster on wires that experienced **tensile strain** compared to those **compressively strained**.
- 1 bar and 100 bar compression samples degraded at different rates.

Damage As A Result of Applied Stress

High Tension (Convex)



SEM images of a Bi-2212 wire mounted in the convex position after being **tensile tested** and externally etched for 16 minutes.

- Image 1 **arrow A** demonstrates the filaments in the high tension sample broke off in small fragments and collected near the middle of the sample.
- Image 2 **arrow B** shows the edges of the filaments were no longer smooth compared to the untested sample, instead they had sharp and broken ends, indicating they were damaged.

Flat (Untested, No Applied Stress)

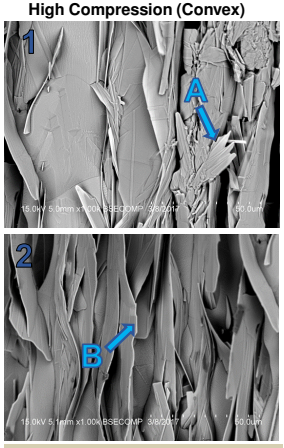
Scanning electron microscopy image of a Bi-2212 **untested flat** wire externally etched for 23 minutes.

- The filaments observed had smooth edges throughout the sample.
- Only a few cracks in the filaments were seen, but the cracks did not indicate severe damage because the filaments continued to maintain their proper structure.

Key Results:

- For Bi-2212 wires which had been stress tested (high tension and high compression), there was **more filament damage** observed in the **high tension sample** compared to the high compression sample.

High Compression (Convex)

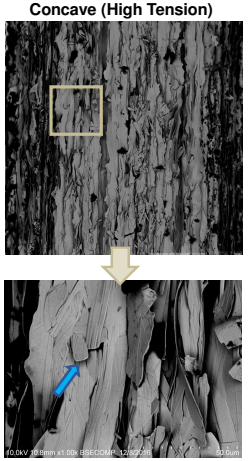


SEM images of a Bi-2212 wire **compressively tested**, etched for 13 minutes, and mounted in the convex position.

- Image 1 **arrow A** shows a variation in size for the filaments that broke off. The illustration indicates the broken pieces of filament tended to exist near the center of the sample.
- Image 2 **arrow B** shows the filaments near the outside of the sample remained intact and resembled the filaments in the untested sample.
- Compared to the high tension sample, there were less broken ends, which indicates high compression sample was less damaged.

Damage As A Result Of Wire Orientation

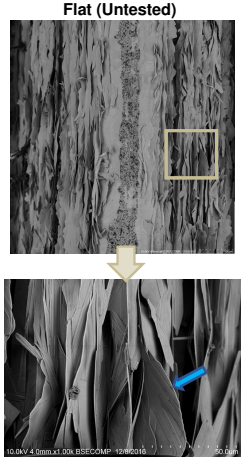
Concave (High Tension)



Images from SEM of a Bi-2212 wire mounted in the **concave** position and externally etched for 13 minutes.

- As shown above, after etching the filaments break off in pieces.
- The etch revealed significant cracks and breakage in the filaments when mounted in the concave position, which indicates damage occurred.

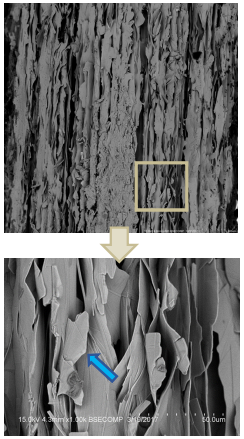
Flat (Untested)



Images of a Bi-2212 wire along with a section of filaments for an **untested flat** sample etched for 23 minutes.

- Filament edges were smooth with few broken ends.
- The filaments proceeded continuously down the sample without severe breakage.

Convex (High Tension)



Images taken on the SEM of a Bi-2212 wire mounted in the **convex** position and externally etched for 16 minutes.

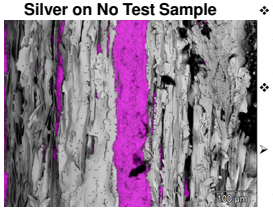
- After the external etch, the filaments showed some jaggedness in the filament structure.
- The edges of the filaments retained better flatness than in the concave samples, indicating less overall damage.

Key Results:

- For Bi-2212 wires with a specific wire orientation (concave or convex), the **concave samples suffered more filament damage** compared to convex samples.
- The pieces of filament that broke off in the middle of the filament were evidence of damage in the concave sample.
- The convex sample shows evidence of damage relative to the undamaged untested wire.
- Exposed **broken ends** were found to be a key marker for filament damage in both concave and convex samples.

External Etching

Silver on No Test Sample



- Three step chemical process of external etching gently removes the silver matrix to reveal the outer filaments for microstructural damage analysis.
- On the SEM, Energy Dispersive X-Ray Spectroscopy (EDS) indicates where silver still remained on the sample.
- **Results:** The pink coloring on the image of the wire (to the left) expresses where the silver matrix was located on the sample.

Acknowledgements

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Conclusion

Damage As A Result of Applied Stress:

- The damage on the high tension and high compression samples was characterized into two categories, the surface and filament damage. Overall, the **high tension was more damaging** to the Bi-2212 wire.

Damage As A Result Of Wire Orientation:

- The concave and convex samples produced different characteristics for the filament damage. The analysis indicated the **concave orientation was more damaging** to the Bi-2212 wire because numerous cracks were formed and it suffered physical breakage of filament pieces.

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