Experimental Study of Flux Expulsion and Cold Work

Sam Posen, Fermilab SRF Team
TTC Topical Workshop on Flux
9 November 2018
CERN
Heavy deformation degrades expulsion behavior

• Tantalizing hint that cold work plays a major role in flux expulsion
• This presentation presents new results from an experiment to follow up on influence of cold work
Large Grain Ingot

Cut 2 slices, 3 mm thick

1-cell 1.3 GHz cavity fabrication (now)

Large grains, low dislocation content

Cut 2 slices, 5 mm thick

Roll to 3 mm thickness

Cut down to disc size

1-cell 1.3 GHz cavity fabrication (now)

Large grains, high dislocation content

Large Grain Experiment

Experiment designed to distinguish effects of dislocations independent of grain size: does LG material inherently expel strongly?
Wire EDM from Ingot

- 2 sheets 3 mm thick -> BCP + send direct to cavity vendor
- 2 sheets 5 mm thick -> BCP + send for rolling
Sheets Rolled by ATI

- Thickness reduction from 5 mm to 3 mm (area increase)
- Cold worked so that no longer flat even after roller levelling
- Material sent to cavity vendor
Half Cell Forming

- RI received the sheet material and began deep drawing
- The non-rolled material formed half cells well
- The rolled material tore during the forming process
- This is not entirely unexpected as the material was not annealed at any point during the manufacturing process

Photos courtesy RI
Repair Developed by RI

- RI used the extra rolled material to plug the holes in the half cells
- Some extra beam welds, but should still be representative!
Completed Cavities

Photos courtesy RI
Expulsion Measurement

- Assembled as-received cavities with only vacuum connections (no RF)
- Cavities cooled quickly through range 150-100 K to avoid formation of hydrides
- Thermal cycles to measure expulsion
Material

• Cavities are made:
  – From the same ingot
  – By the same vendor
  – And both have large grains

• Key difference:
  – Cold work

Orientation Map

Local Misorientation Angle

Non-rolled

Rolled

Cold work shows in both maps
Expulsion Measurement

Calculated full expulsion

- TE1RILG001 (not rolled) as received
- TE1RILG001+EP+600 C 3 h
- TE1RILG002 (rolled) as received
- TE1RILG002+EP+600 C 3 h

Non-rolled

Rolled sheets

Full trapping

$B_{SC}/B_{NC}$ vs $\Delta T$ DuringCooldown [K]

Fermilab
Expulsion Measurement

- Cold worked material very strong trapping
- Incomplete expulsion for both LG cavities

Calculated full expulsion

- TE1RILG001 (not rolled) as received
- TE1RILG001+EP+600 C 3 h
- TE1RILG002 (rolled) as received
- TE1RILG002+EP+600 C 3 h

Non-rolled

Rolled sheets

Full trapping

$B_{SC}/B_{NC}$ vs $\Delta T$ During Cooldown [K]
Q vs E Curves after Bulk EP + 600 C 3 hr + Light EP

Note: processing quenches at 2 K led to some $Q_0$ degradation

**TE1RILG001**
(non rolled)

**TE1RILG002**
(rolled)
Expulsion Measurement

Non-rolled sheets showed low expulsion even after 800°C 3 hour heat treatment.
Conclusions

- **Strong trapping behavior** is possible with **large grain material** even after **800 C 3 hour** heat treatment, especially for rolled material.

- These results contribute to a body of evidence that **cold work** in SRF-grade niobium is **crucially important to determining the flux trapping behavior**.

- Implicates rolling steps in producing material that requires very high temperature heat treatment to have acceptable flux expulsion.

- Further motivate studies of dislocations in strongly trapping material.

See also P. Dhakal (JLab), TTC Topical 2017