Critical current retention of potted and unpotted REBCO Roebel cables with transverse pressure

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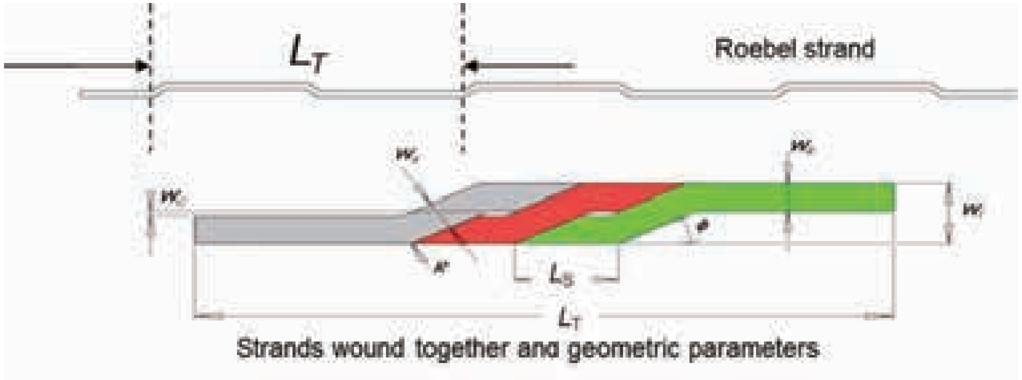
Introduction

- ReBCO Roebel cable
  - Fully transposed cable/ equivalent topology to Rutherford cable (with $R_c = \infty$)
  - High J_e
  - High bend tolerance
- Manufacturing facility at Robinson Research Institute, VUW (GCS – in transition, parent company sold)
  - Can use 10 mm or 12 mm ReEBCO tape to make strands
  - Can punch and wind long lengths

Introduction (cont)

- Pressure experiments reported here use 5/5 cable
- Geometry



Parameter	Name	2 mm Cable	4.5 mm Cable	5 mm Cable
L_{TRANS} (=2L)	Transposition length	90 mm	300 mm	300 mm
W_R	Strand width	2 mm	4.5 mm	5 mm
W_X	Crossover width	1.7 mm	5.0 mm	6.0 mm

Background – transverse pressure issues

- Requirements ~150 MPa in a dipole magnet
- Pressure concentration due to Roebel shape

- The geometry of Roebel assembly concentrates pressure in non-trivial patterns [1].
  - The 'blue' areas are thicker
  - Shifts can concentrate stress further – not reported here

  - Odd or even strand #s behave quite differently

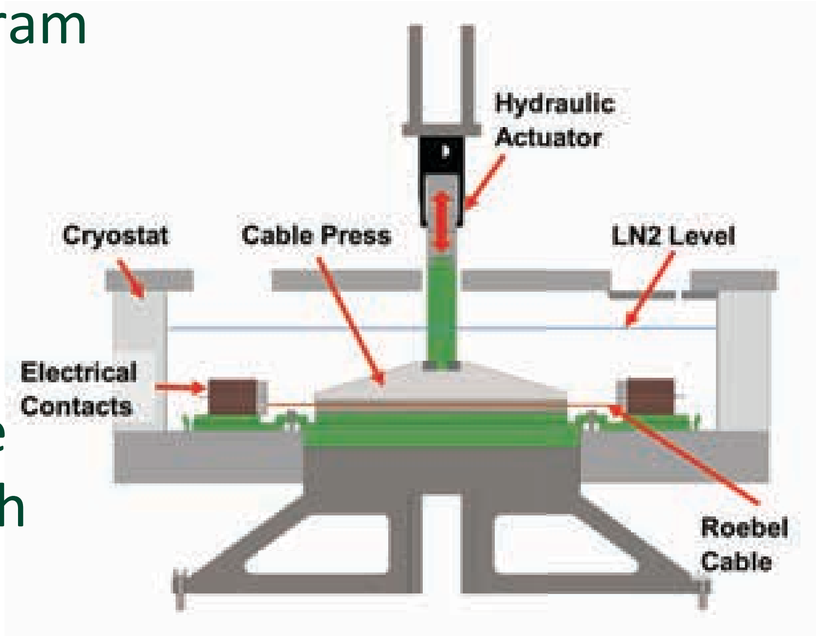
[1]. J. Fleiter, et al. *IEEE Trans. Appl. Supercond.* 25, 4802404 (2015).

Objectives

- Measure transverse pressure performance of unpotted Roebel cable
  - Previous results have been variable
  - Find critical pressure for irreversibility
    - Understand variability and mechanisms
  - Important for preparing coils pre-impregnation
- Improve pressure performance by encapsulation
  - Reproduce successful previous results (CERN, KIT, Twente) on our cable geometry
  - Find critical pressure
    - Understand variability and mechanisms

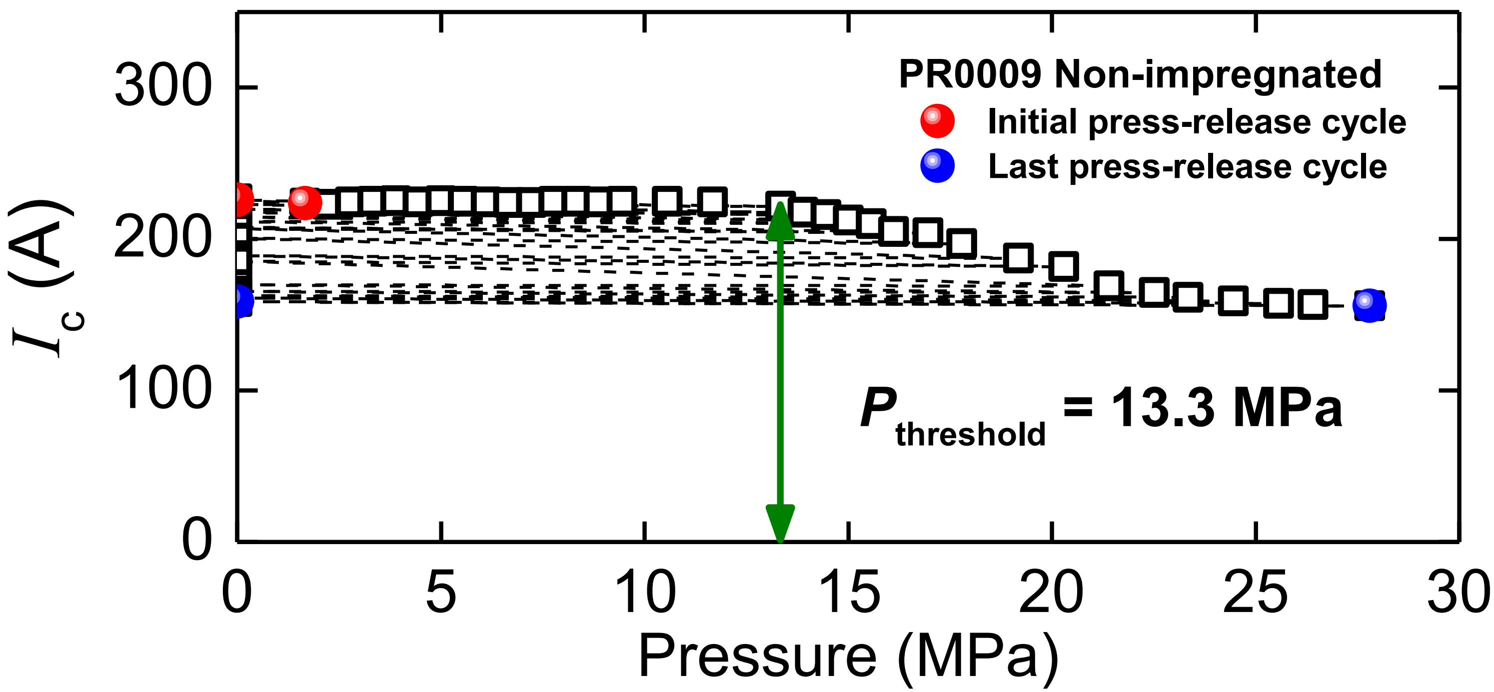
Experimental

- Planar face compression
  - Simulate effect of hoop stress
  - Pressure applied via hydraulic ram
  - Rotational coupling between ram and platen
- Liquid N_2 immersion
- Strand I_c testing
  - Single strand energised
  - Incremental pressure increase
  - I-V curves were measured with cycling of pressure (pressure/ release/pressure/…)
  - I_c checked after each pressure cycle (@ P=0)



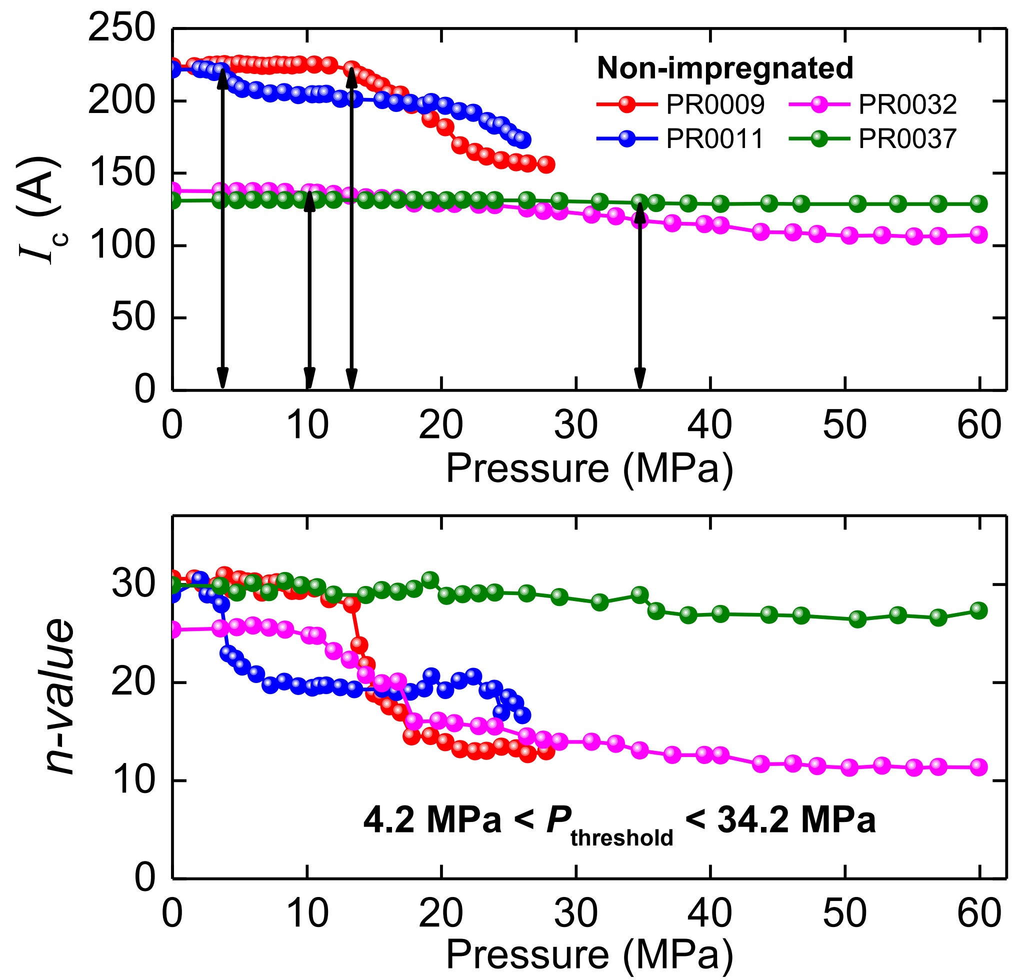
Roebel cable pressure test

- Point of initial irreversible I_c degradation
  - Criteria I_c changes by 1%

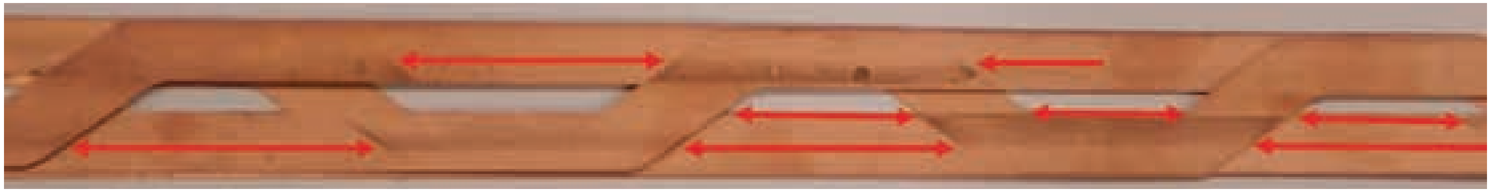


Results: unpotted 5/5 cables

- $P_{threshold}$ = 4.2 – 34.2 MPa
- *n*-value more sensitive to damage than I_c

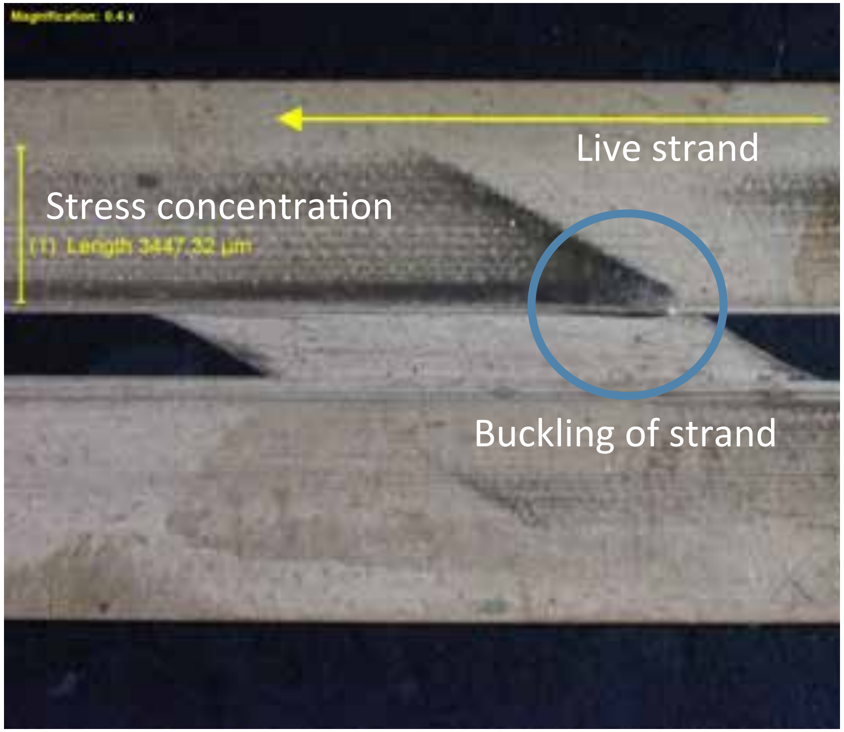


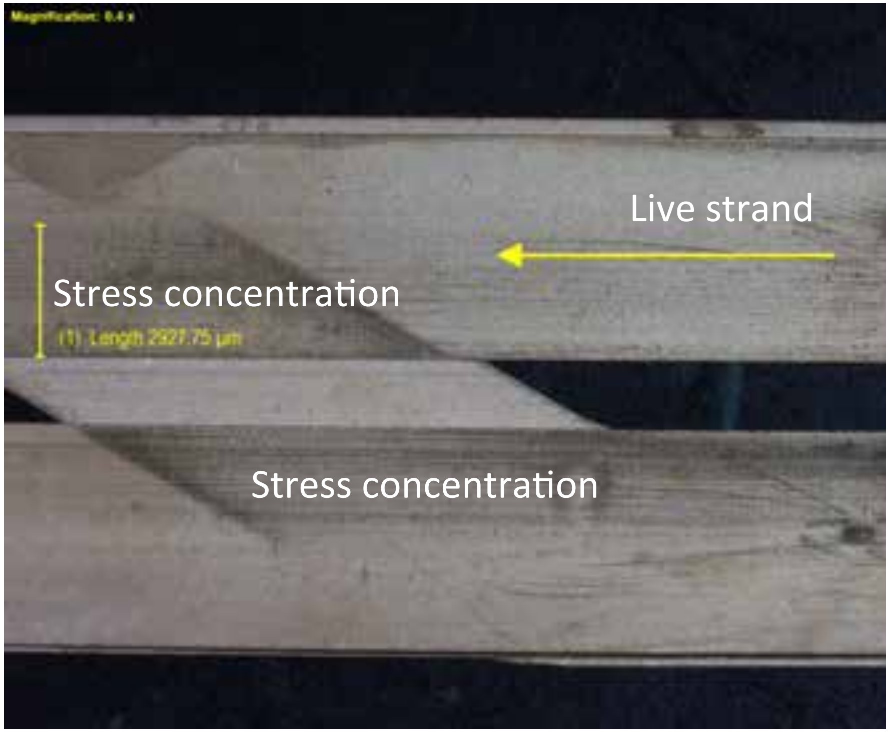
Evidence of pressure concentration



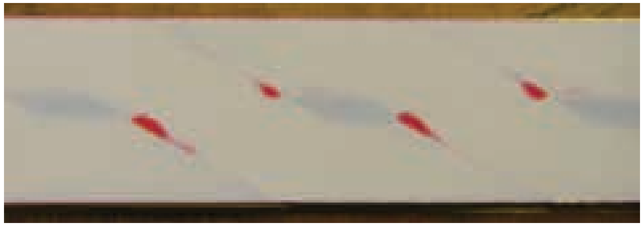
- After transverse pressure of 60 MPa was applied to 5/5 cables
  - Change in surface finish over part of surface
    - Seen as darker in picture
    - Light reflection more specular
  - Implies pressure concentration

Optical microscopy



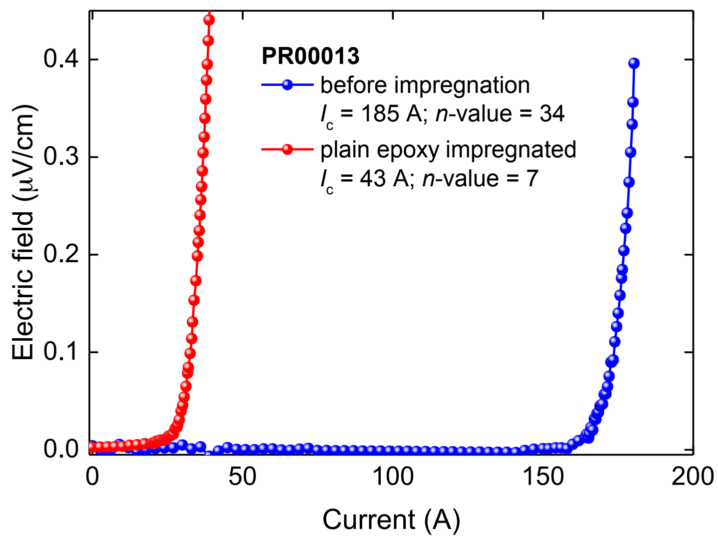


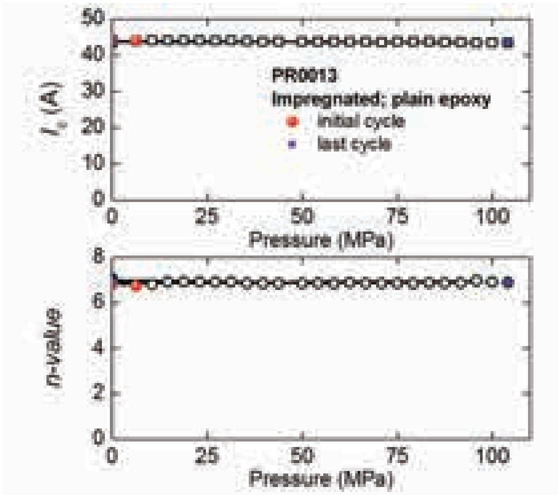
Stress concentration



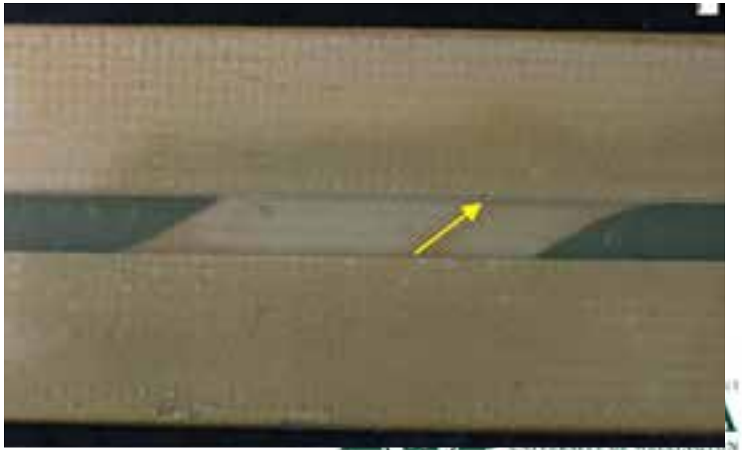
- Concentrated pressure region
  - Overlapping edges
- Mitigation
  - Distribute the pressure evenly
  - Investigate cable impregnation

Epoxy impregnation





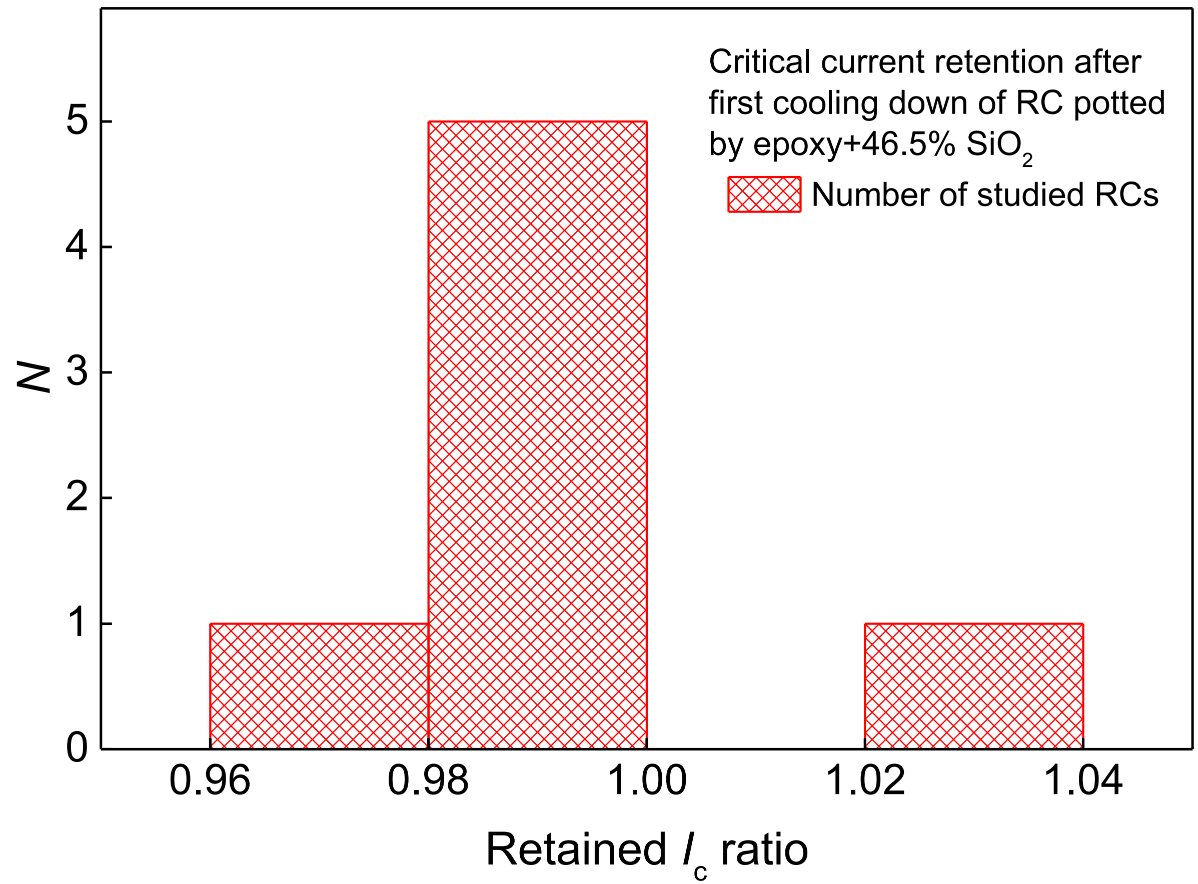
- Molded planar cable
  - Bisphenol-A epoxy resin system
    - Araldite CY5538 + HY5571
- I_c degraded on cooldown
  - (but not further degradation)
  - Believed due to thermal mismatch



Matching CTE

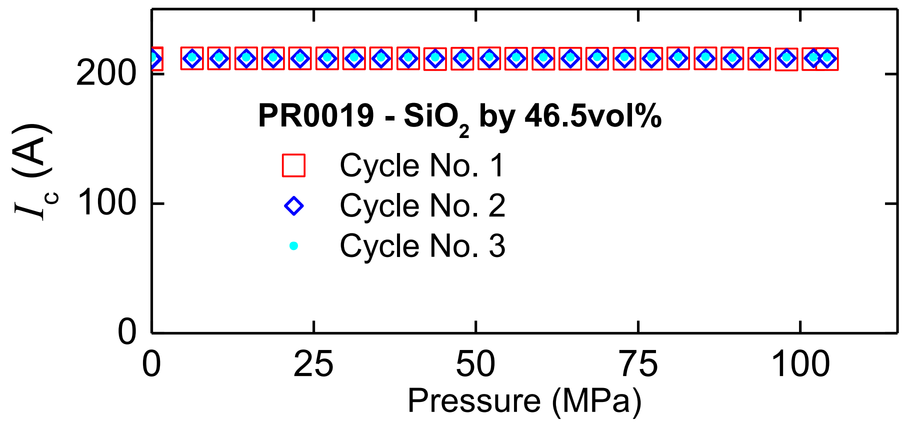
- A mismatch of the coefficients of thermal expansion of the epoxy and the 2G wire
  - which causes mechanical degradation of HTS layer, is likely the cause of this failure.
- SiO_2 / Epoxy composites
  - Closely match CTE of the Roebel cable strands.
  - Epoxy+SiO_2-nanopowder (< 1 um) 46.5% Vf
    - Highest vol. fraction that still allows resin flow
    - American Elements SI-OX-02N-P.01UM
    - 1:1:3 resin: hardener: silica powder by weight
- Thermal cycling also investigated

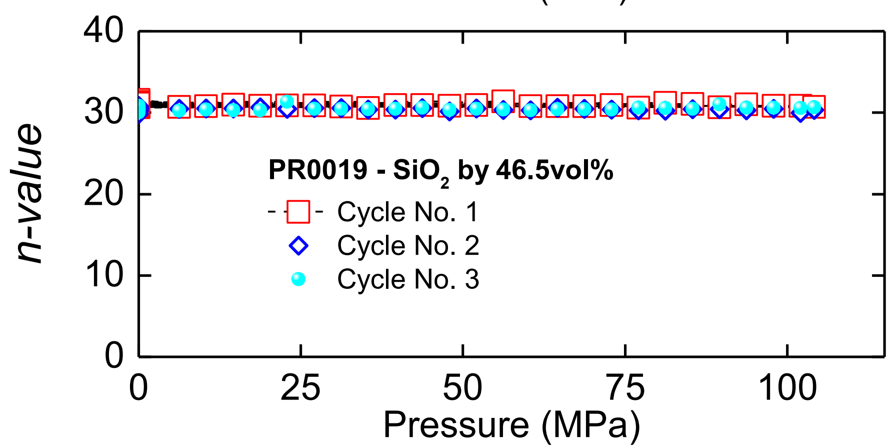
46.5% V_f SiO_2



- Good retention of I_c at 46.5%.

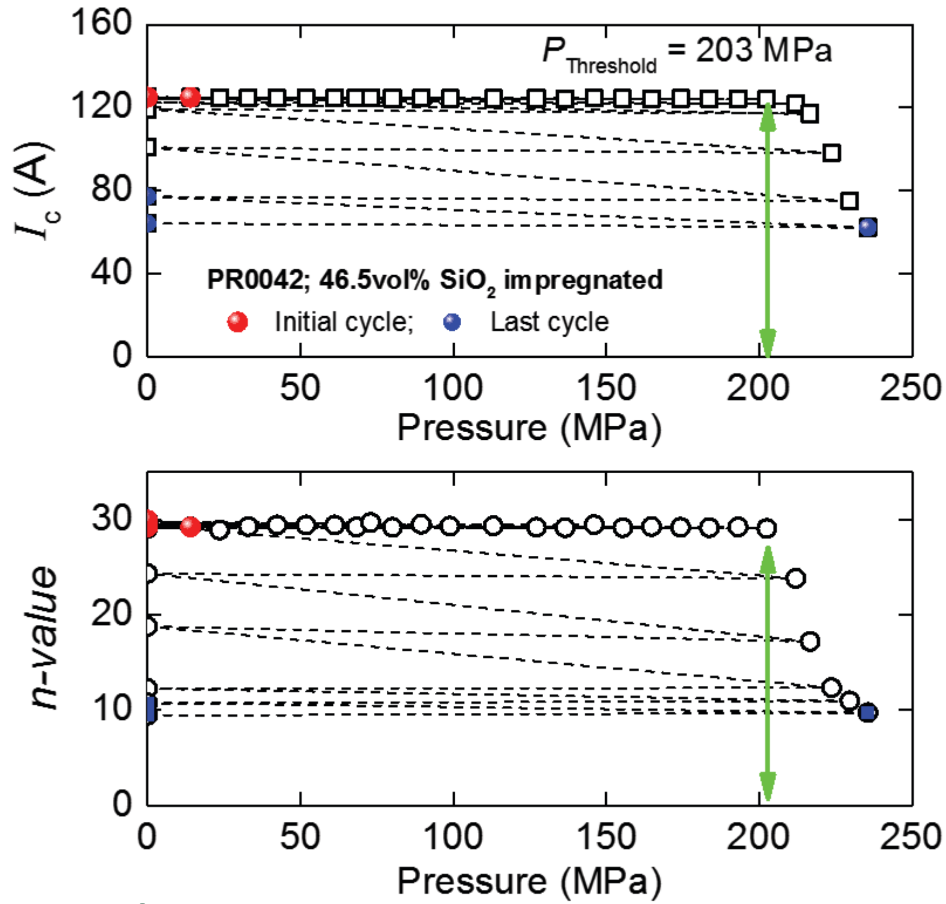
Pressure and thermal cycling





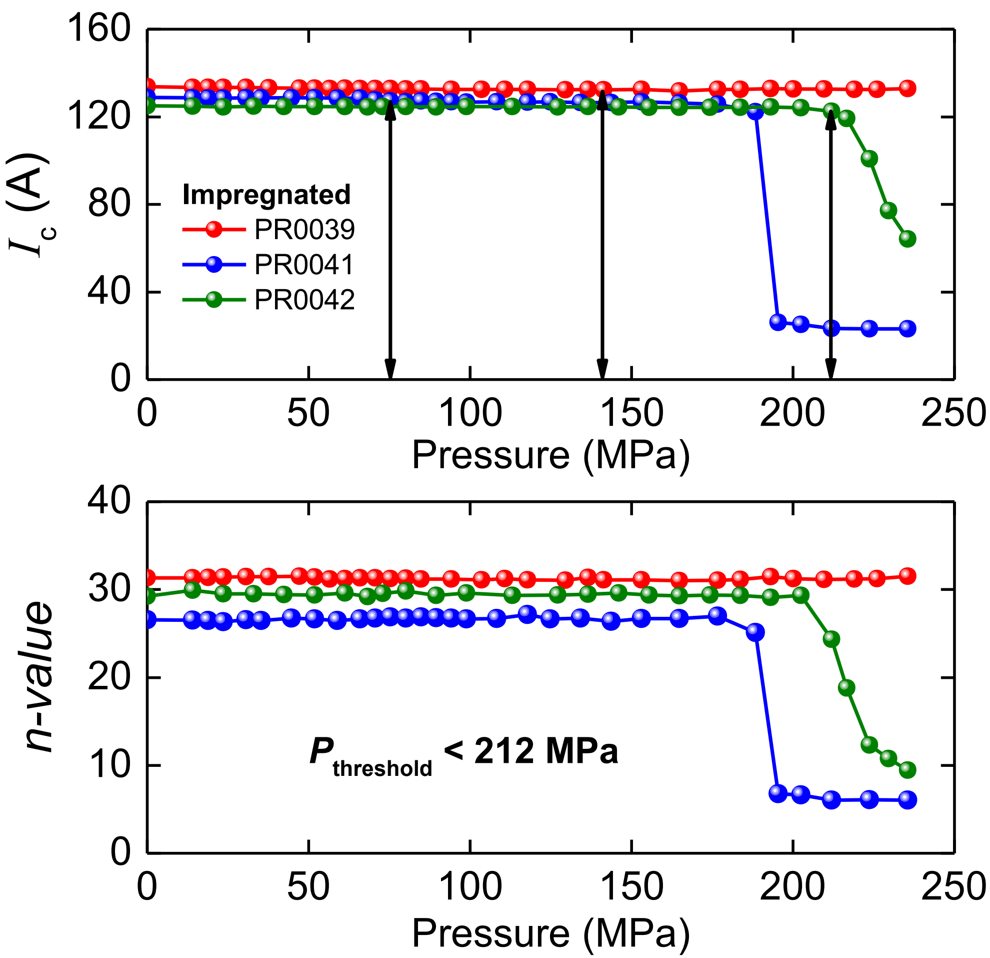
- I_c retained with combined pressure and thermal cycling (to 100 MPa)

Pressure testing to irreversibility point



- Potted length 80 mm

Irreversibility point for tested cables



Cable ID	$P_{threshold}$ (MPa)
PR0019	127
PR0020	96
PR0038	80
PR0039	141
PR0040	75
PR0041	75
PR0042	212

- Some evidence of mechanical damage
  - Cracks in epoxy

Conclusions

- Non-impregnated cable is susceptible to damage at low transverse pressures
  - Evidence for stress concentration (different from simple models)
- We can epoxy impregnate and retain I_c with thermal and mechanical cycles
- Increase in irreversibility to 75 - 212 MPa
  - Variability may be due to non optimised sample production