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Recent progress on CORC® cable and wire development for magnet applications

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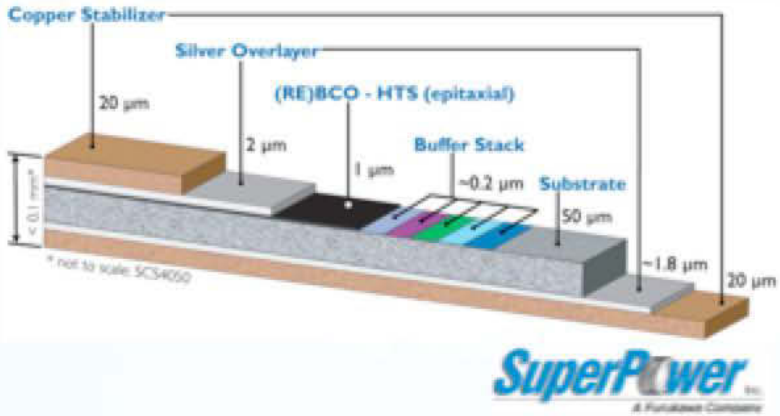
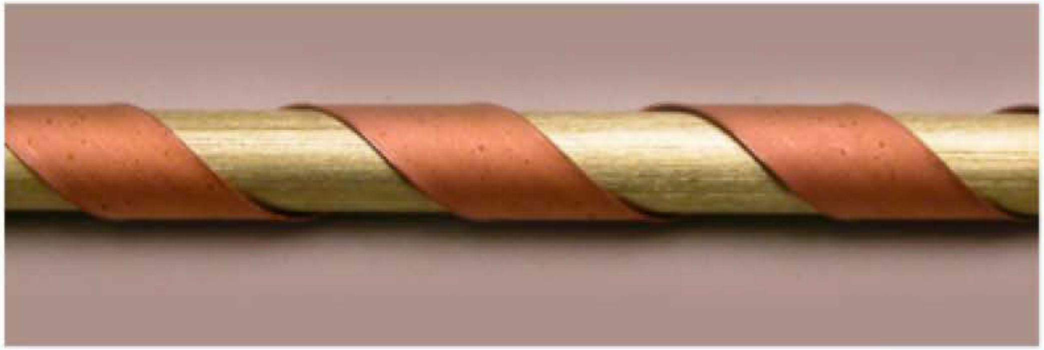
MT26, September 24th, 2019, Vancouver, Canada

CORC® magnet cables and wires





Single tape wound into a CORC® cable

CORC® wires (2.5 – 4.5 mm diameter)

- Wound from 2 – 3 mm wide tapes with 30 µm substrate
- Typically no more than about 30 tapes
- Highly flexible with bending down to < 50 mm diameter

CORC® cable (5 – 8 mm diameter)

- Wound from 3 – 4 mm wide tapes with 30 – 50 µm substrate
- Typically no more than about 50 tapes
- Flexible with bending down to > 100 mm diameter

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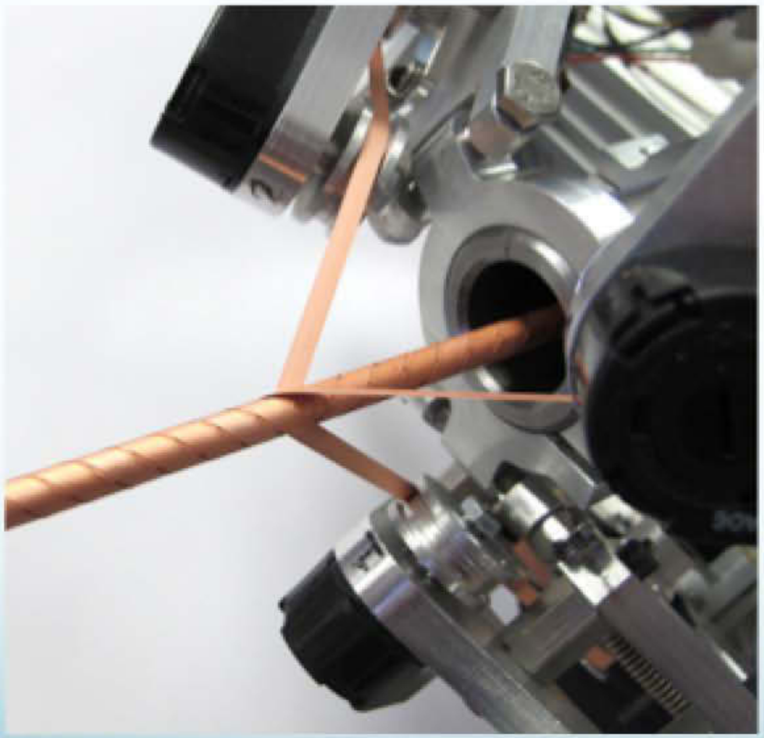
CORC® cable production

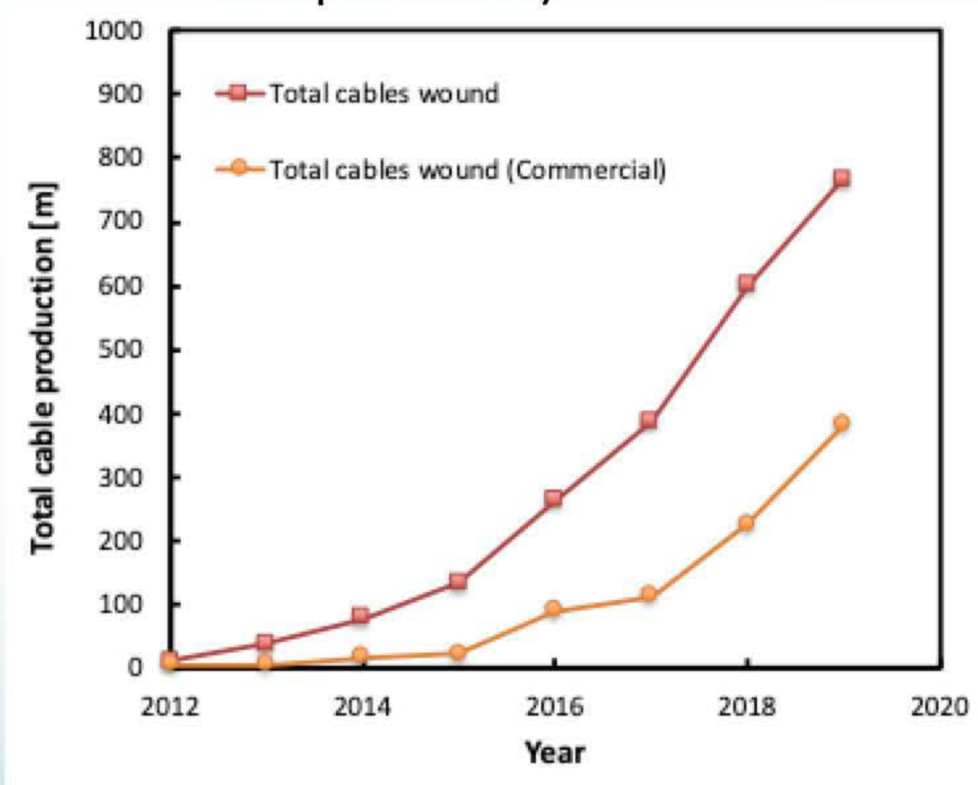
Winding of long CORC® cables with custom cable machine

- Accurate control of cable layout
- Long cable lengths possible (> 100 meters)
- I_c retention after winding 95-100 %



Cumulative CORC® production

- about 800 meters since 2012
- includes 400 meters for commercial orders (including about 130 meters for open orders)



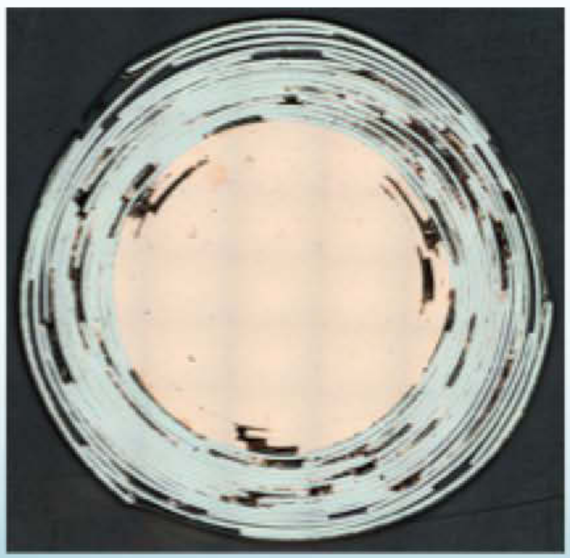
CORC® production expansion

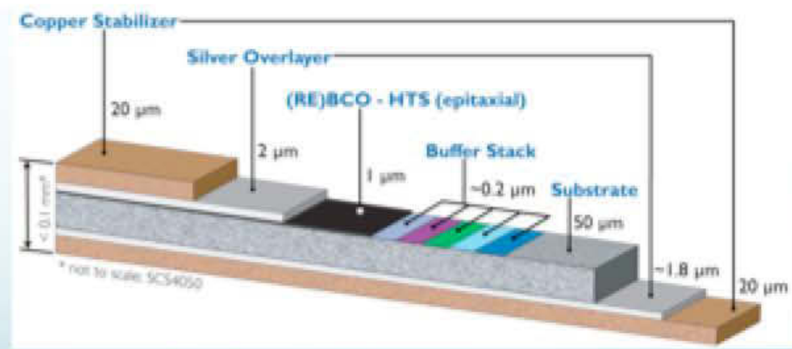
We successfully moved the CORC® cable production to the cloud!

CORC® conductors for accelerator magnets

Increasing J_e (> 600 A/mm^2) and I_c (> 10 kA) of CORC® cables at 4.2 K and 20 T

1. Winding many REBCO tapes, **while not compromising conductor flexibility**
2. Incorporating tapes with the highest performance (I_c) at 20 T
3. Using tapes with thin substrate that allow smaller formers:
   - 50 μm substrate (2012 –)
   - 38 μm substrate (2014)
   - 30 μm substrate (2015 –)
   - 25 μm substrate (2019 –)





37-tape CORC® cable

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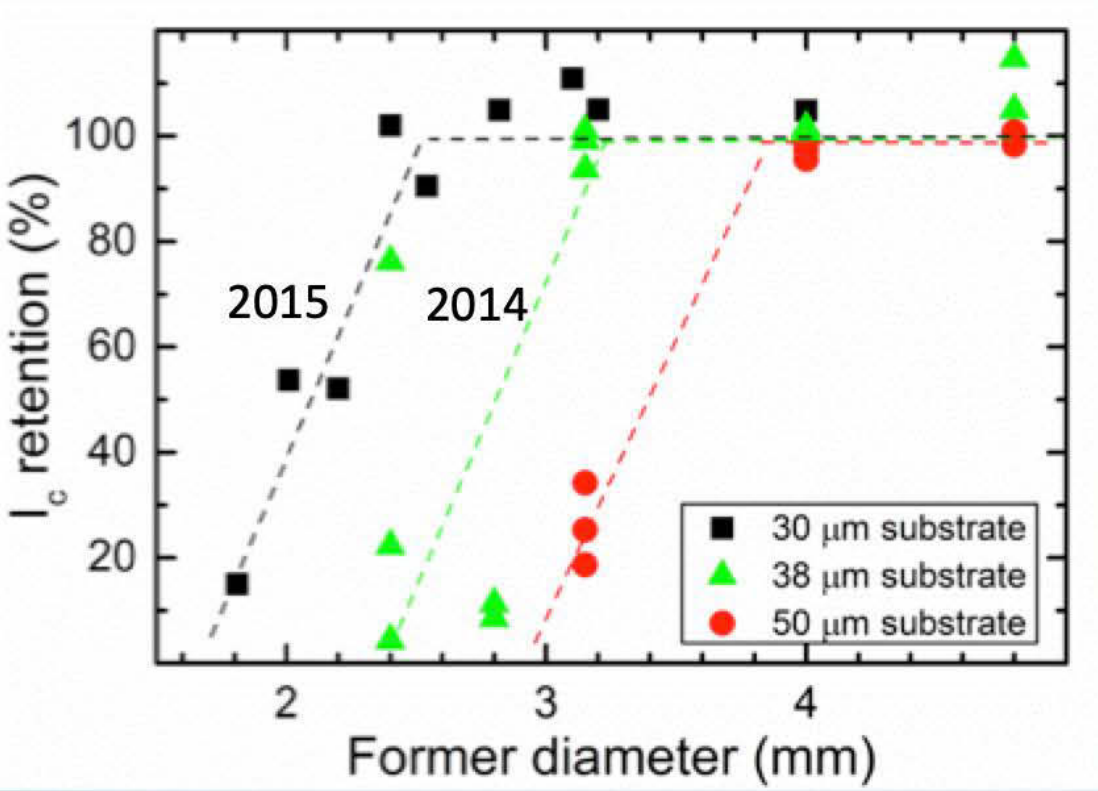
Increase J_e(20 T) by reducing the former size

Thinner substrates allow smaller formers in CORC® cables

- Winding a tape at 45 degrees with the REBCO layer under compression
- Measure I_c at different former diameters



Minimum former diameter

- 4 mm for 50 μm substrate
- 3.2 mm for 38 μm substrate
- 2.4 mm for 30 μm substrate

Increasing J_e(20 T) in CORC® wires

CORC® wires introduced 2016

- Typically smaller than 4 mm thickness
- Wound from 2 and 3 mm wide tapes
- Wound from tapes with 30 μm substrates
- Bending down to 50 mm diameter allows testing in typical superconducting R&D magnets
- Testing now in 12 T solenoid magnet

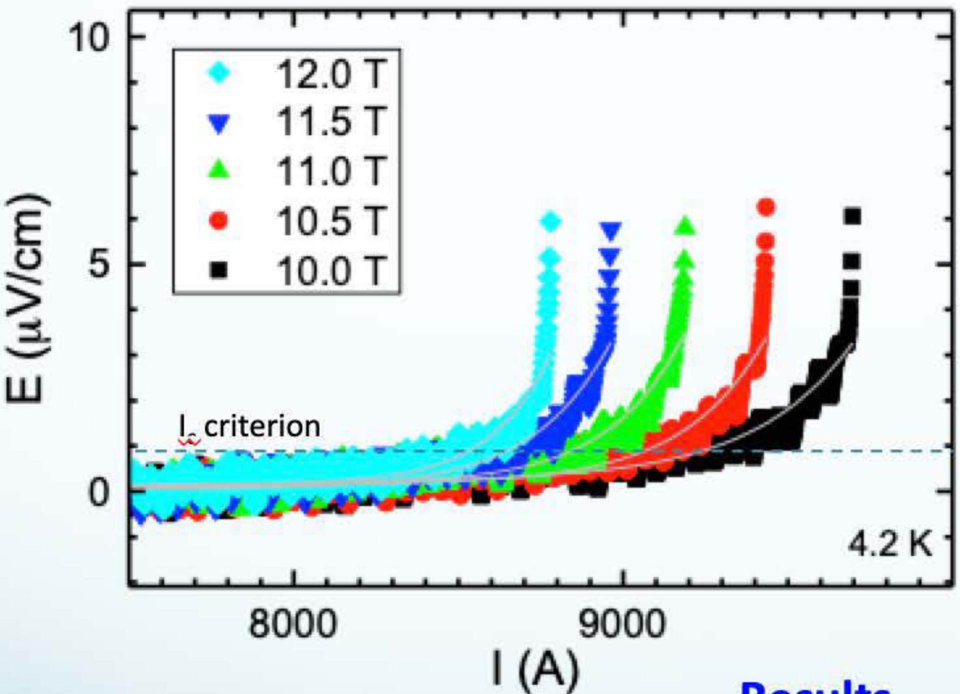
CORC® wire mounted on 60 mm diameter probe

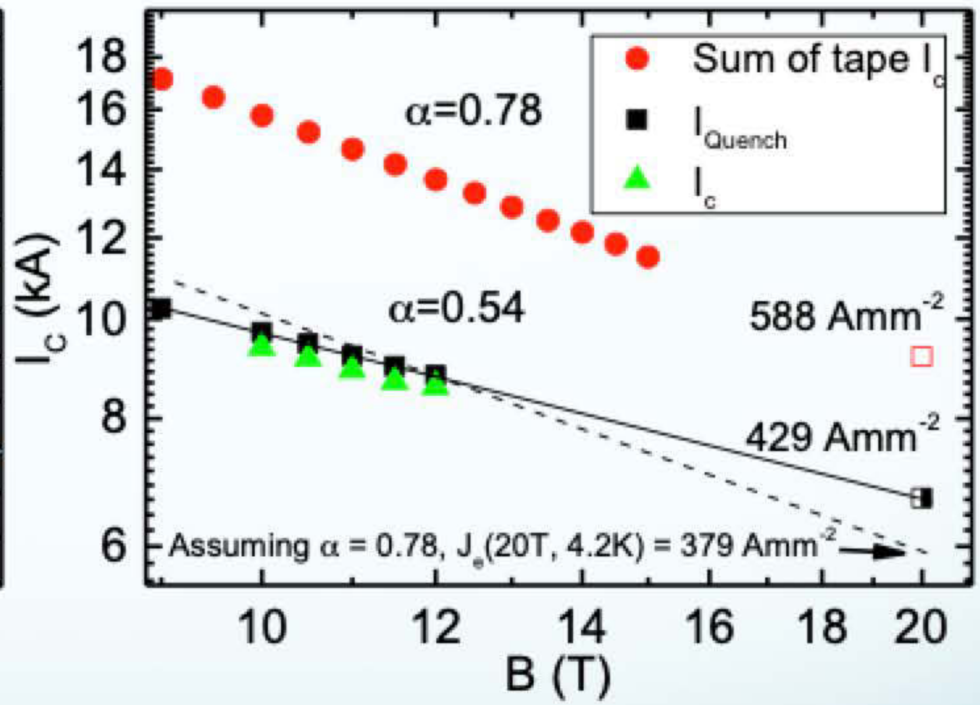
Testing in 12 T magnet

Record J_e(20 T) in CORC® wires with 30 μm substrates

High-J_e CORC® wire layout (pushing the limits)

- 50 tapes, 2 – 3 mm wide, 30 μm substrate
- 4.46 mm CORC® wire diameter
- Relatively inflexible conductor





Results

- I_c = 8,591 A (4.2 K, 12 T, 1 μV/cm)
- Projected J_e(20 T) between 379 and 429 A/mm²
- Retention in I_c only 74.5 %
- Slope of I_c(B) deviates from that of the tapes

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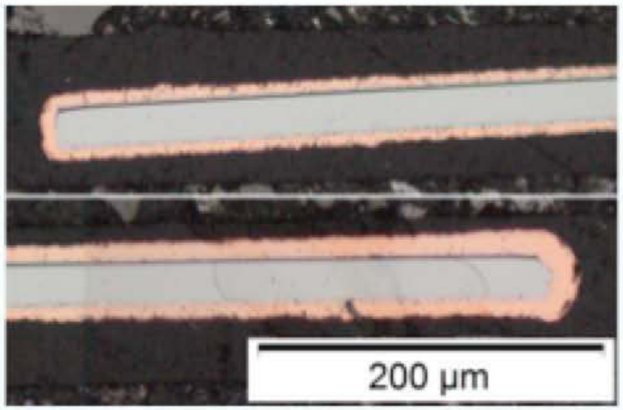
Introduction of REBCO tapes with 25 μm substrates

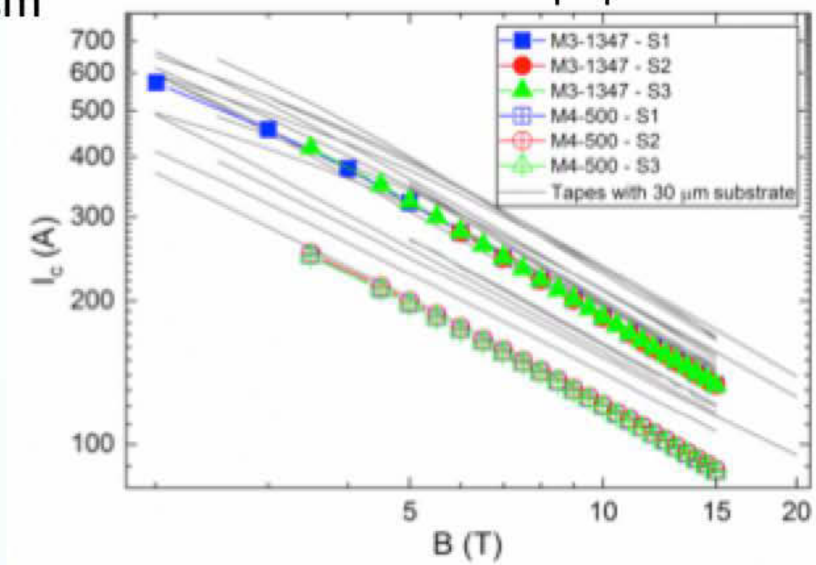
SuperPower produced first batch of tape with 25 μm substrate

- 400 meters of high-quality tape of 2 mm width delivered
- I_c(77 K) = 65 A and 4.2 K pinning similar to 30 μm
- Piece lengths in the order of 30 meters
- Actual substrate 22 – 23 μm thick
- Enables CORC® wires with 2 mm former



Picture courtesy of Michael Small (ASC-NHMFL)

4.2 K tape performance



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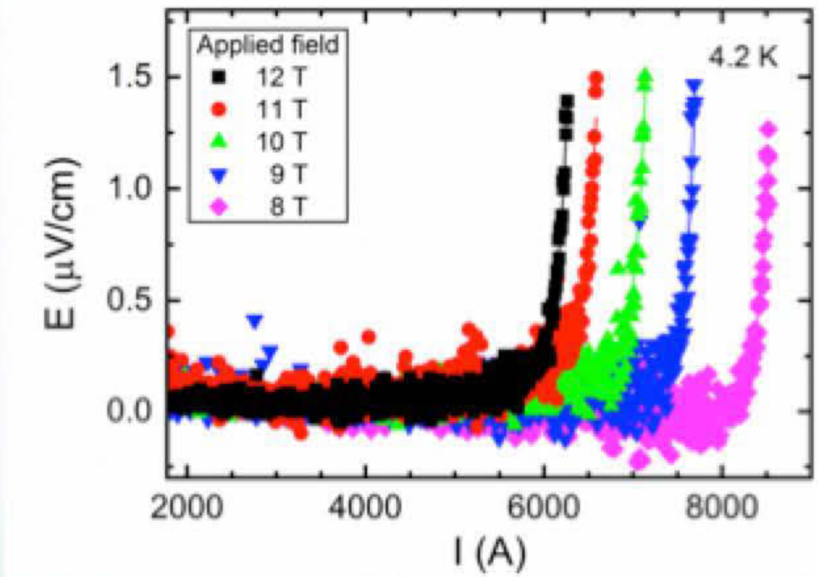
Performance of next generation CORC® wires

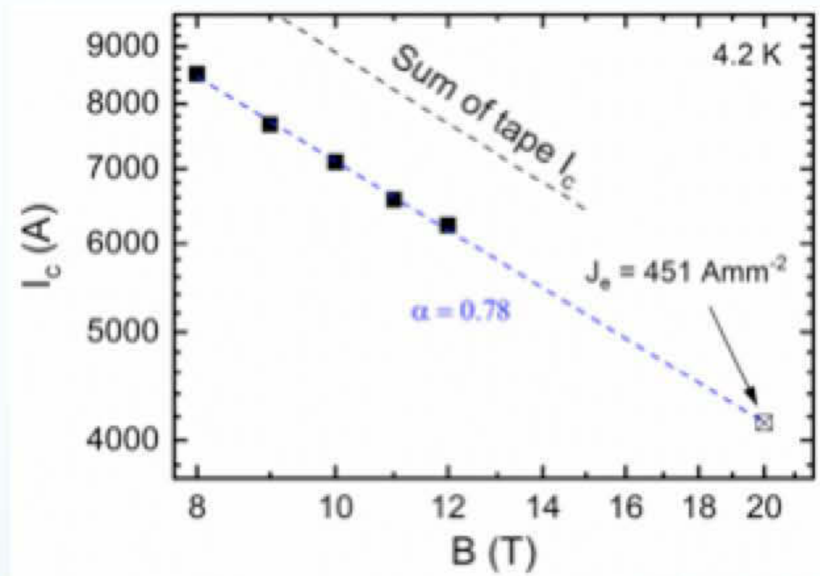
CORC® wire to increase J_e(20 T)

- 32 tapes (2 mm (25 μm) and 3 mm (30 μm) width
- Outer diameter 3.42 mm
- Average pinning

Record CORC® wire (25 μm)

Record CORC® wire (30 μm)





New record J_e (12 T) 678 A/mm^2

Extrapolated J_e (20 T) 451 A/mm^2

I_c(B) closely follows that of the tapes

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Recent progress on CORC® CCT accelerator magnets

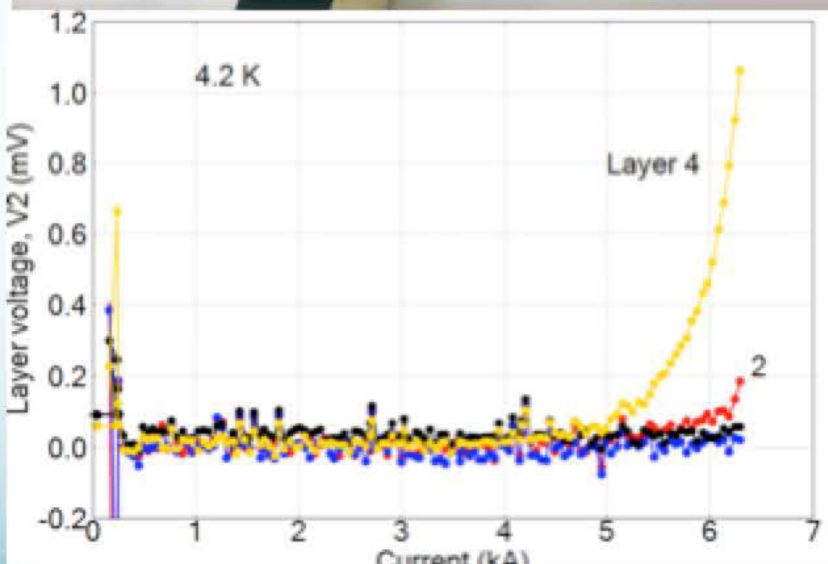
CORC®-based CCT magnet program

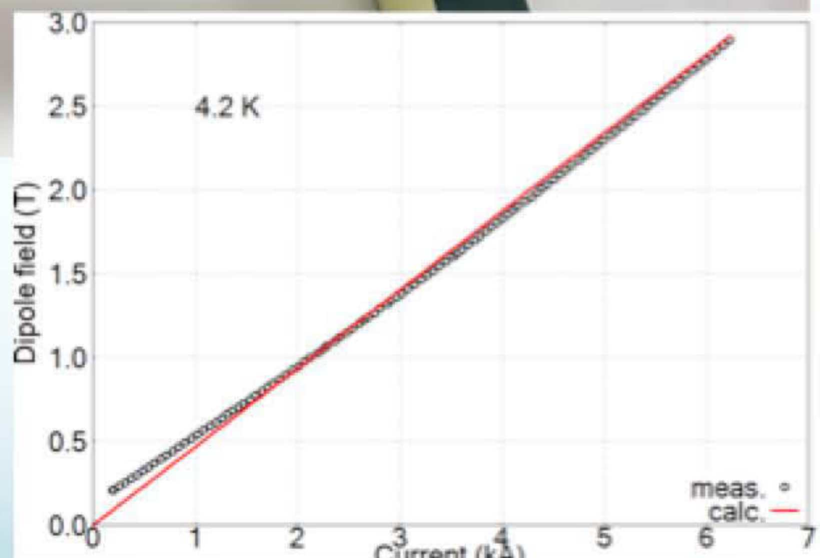
- CCT-C1 => 1 T (successful 2018)
- CCT-C2 => 3 T (2019) →
- CCT-C3 => 5 T (2020)

Successful test of CCT-C2 last week

- Peak current 6.3 kA
- Peak dipole field 2.91 T
- Successfully protected quenches

See Talk Xiaorong Wang tomorrow 17:15 PM (Wed-Af-Or13-04)





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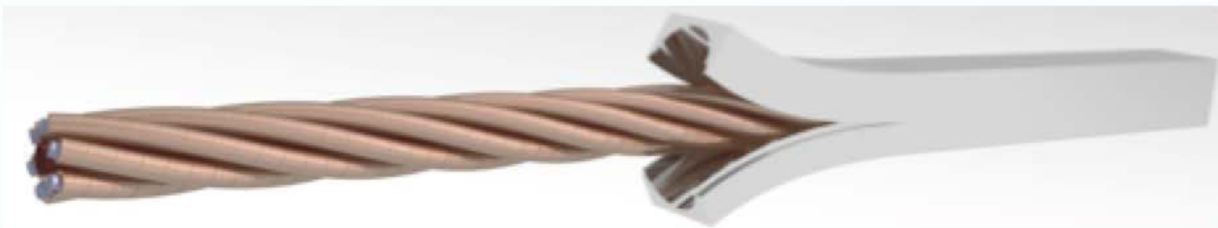
BERKELEY LAB

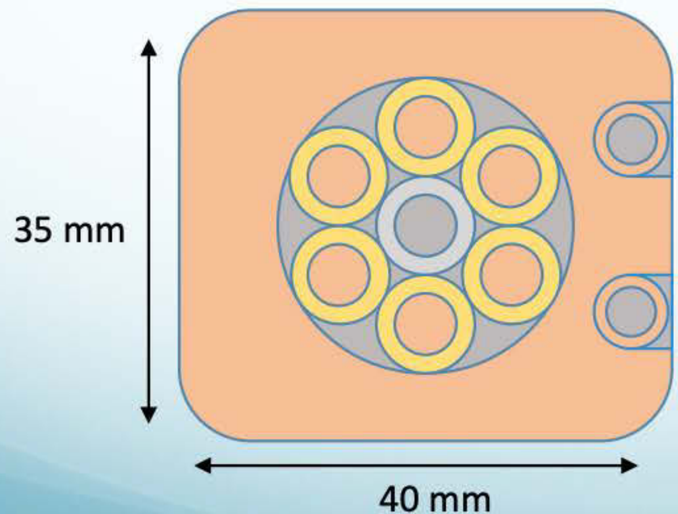
CORC®-CICC development for fusion magnets

Develop CORC®-CICC with operating current 50 – 100 kA at 4.2 K and 12 – 20 T



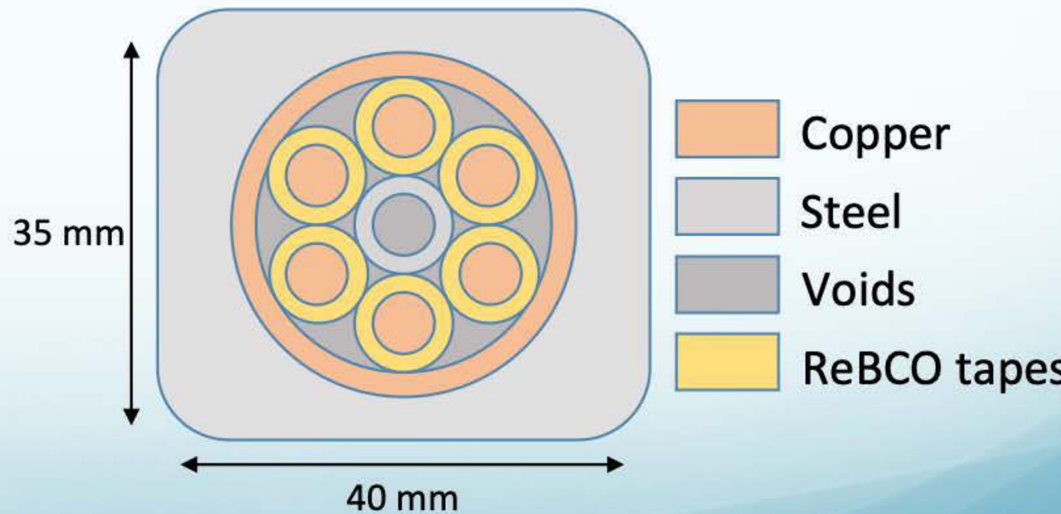
Sample 1 for detector magnets

- High thermal & electrical stability
- Practical cooling
- 80 kA at 12T/4K



Sample 2 for fusion magnets

- Can sustains high stress
- Can cope with large heat loads
- 80 kA at 12T/4K



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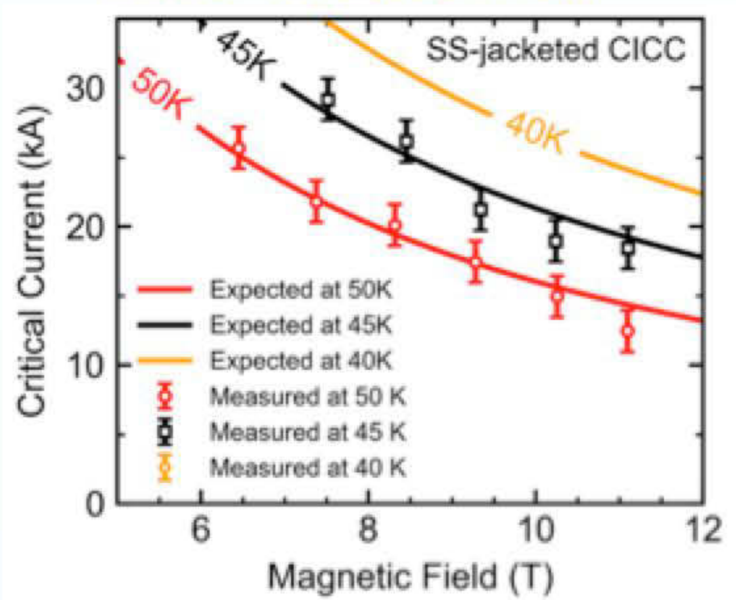
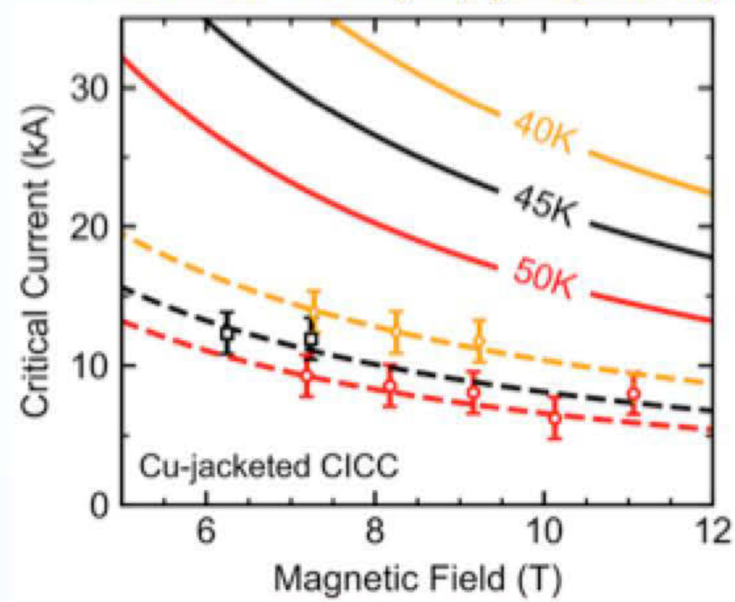
SULTAN Test CORC®-CICC #1&2: Results

Fusion CICC (SS jacket)

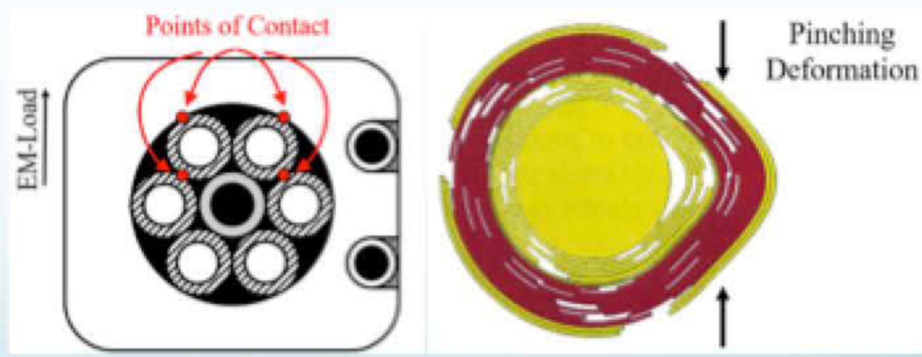


Detector CICC (Copper jacket)



Test range limited by detector sample

- Cooling with helium gas
- Maximum current 45 kA
- Fusion sample performed as expected
- Detector sample degraded



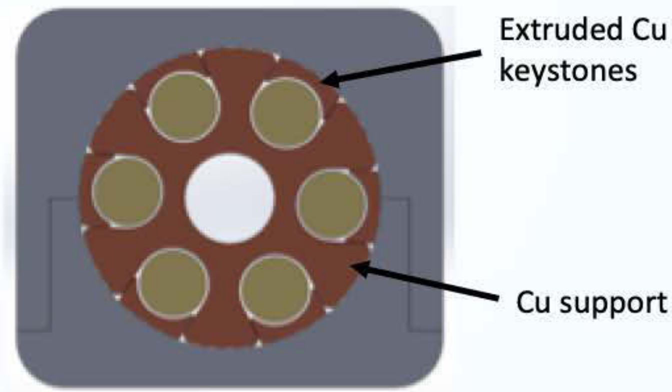
Detector sample being replaced and SULTAN test expected later this year

CORC®-CICC development with internal bundle support

CORC®-CICC #4 for testing in SULTAN

- 6-around-1 CICC based on CORC® cables
- Goal is 80 kA at 10.8 T background field
- Using internal support to decouple CORC® strands
- Improved CORC®-CICC terminals
- SULTAN test early 2020

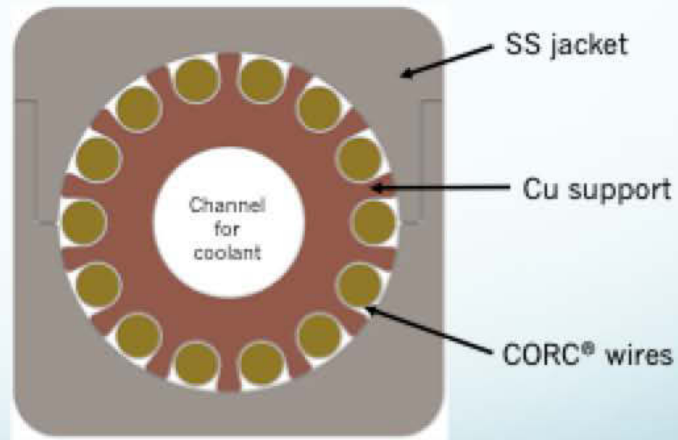
Sample #4



CORC®-CICC #5 for testing in SULTAN

- Based on CORC® 12 – 14 wires for higher degree of transposition and higher flexibility
- Goal is 80 kA at 10.8 T background field
- Using internal support to decouple CORC® strands
- SULTAN test 9 – 12 months from now

Sample #5



Summary

CORC® wires and cables have matured into magnet conductors

- High-quality, long-length CORC® conductors routinely produced for commercial orders
- High currents have been demonstrated: > 8,500 A (4.2 K, 12 T)
- High current densities have been reached: > 450 A/mm^2 (4.2 K, 20 T)
- Introduction of the next generation of CORC® wires based on 25 μm substrates

CORC®-CICC development for fusion and detector magnets is accelerating

- Initial SULTAN test showed degradation due to transverse compression
- Replacement sample is being finalized: test before the end of the year
- Several new CORC®-CICC layouts have been develop to reduce the compressive stress on each strand
- New CORC®-CICC layouts ready for testing in 2020