Irreversibility Field and Magnetization Studies of Pure Niobium PIT Nb_3Sn Conductor

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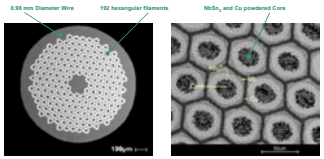
Motivation

- To understand the relationships between microstructure, superconducting properties (T_c, H^* and H_{c2}) and flux pinning (J_c) in the A15 phase
- Powder-In-Tube (PIT) wires are an excellent candidate for this study
  - Thick A15 layers (up to 10 μm) permit chemical analysis
  - Small compositional and grain morphology variations in A15 layers permit cleaner understanding of relationships being studied
- Previous study found:
  - Small, close to stoichiometric Nb_3Sn composition gradient, only falling off very close to Nb-A15 interface
  - Small T_c variation, from 18 K to 16.5 K, over majority of layer
- This study explores how $J_c(B)$, H^*, and H_{c2} change with reaction conditions

Experimental Procedure

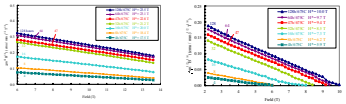
Pure Niobium, Powder-In-Tube Conductor from ShapeMetal Innovation, Holland



- Performed heat treatments from 4 to 128 hours at temperatures of 675°C and 750°C
- Measured the magnetic moment (m) vs. field (B) hysteretic loops up to 14 Tesla, at temperatures of 4.2 K and 12K
- Extrapolated H^* through the Kramer function
  - Plotting $\Delta m^{1/2}B^{1/2}$ vs. B where Δm is the width of the hysterisis loop
- Measured H_{c2} (12 K)
- Measured A15 layer growth and grain size / morphology vs. heat treatment
- Performed resistivity ratio (room temperature and 77 K) measurement to detect Sn poisoning of Cu matrix

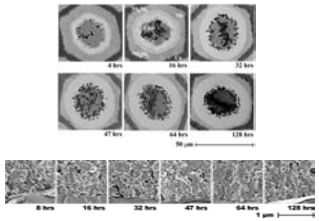
Results

Kramer Plots (4.2 K and 12 K) for 675°C Heat Treatments



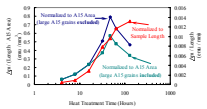
- H^*_{Kramer} increases monotonically with heat treatment time for all wires reacted at 675°C
- H^*_{Kramer} values > 25.5 T observed for 750°C heat treatments (not shown above)
- Practically linear data fits for all heat treatments measured (4.2 K and 12 K)

A15 Layer Growth and Grain Morphology Over Time at 675°C



- Rapid reaction of A15 layer
  - After 4h/675°C layer is primarily Nb_3Sn_2 with small amount of Nb_3Sn present
  - 1:1 mixture of Nb_3Sn_2 and Nb_3Sn at 16h/675°C
  - No Nb_3Sn_2 visible after 32h/675°C
  - Sn breakthrough of Nb barrier detected at 64h/675°C and beyond
- Grain size (~ 120 nm) and morphology remain remarkably uniform through 128h/675°C heat treatment
- Grain sizes of ~ 220 nm observed in 750°C heat treatments

Magnetization Moment vs. Heat Treatment time at 675°C

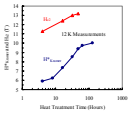


- Δm (= I_c non-Cu J_c) increases monotonically with heat treatment time through 128h/675°C (Red Curve)
- Δm, normalized to measured A15 area (= A15 layer J_c) peaks at 47h/675°C (Blue & Green Curves)
  - Falls ~ 40% from maximum value after 128h/675°C (Blue & Green Curves)
  - Falls ~ 50% from maximum value after 32h/750°C (not shown)

Discussion

Main Points

- Not yet possible to simultaneously optimize the primary superconducting properties (T_c, H^* and H_{c2}) and J_c in PIT conductors
- Several benefits to increasing the A15 reaction beyond 47h/675°C (manufacturer's recommendation)
  1. A 2.4 T advantage in H^*_{Kramer} at 675°C compared to 750°C
  2. H^*_{Kramer} becomes a higher percentage of H_{c2} with increasing time at 675°C
  3. I_c (= Δm) increased monotonically with heat treatment time, through 128 hours, at 675°C



- A15 layer J_c (inferred from Δm normalized to measured A15 area) reached maximum at manufacturer's recommendation of 47h/675°C
- Despite a grain size increase of a factor of 2 between 675°C and 750°C, conductor continued to exhibit strong superconductivity properties at the higher temperature
  - Achieved H^*_{Kramer} values exceeding 25.5 T
  - A15 layer J_c is only ~ 20% less at 32h/750°C compared to the 128h/675°C heat treatment

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