Friction Coefficient Measurements for High-Temperature Superconducting Magnet Design

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Introduction

- In dry-wound 40 T superconducting magnets, friction between tape turns is crucial for load transfer and stress distribution across multiple tape interfaces.
- The friction coefficient (μ) varies with surface conditions, pressure, and temperature; static friction (μs) is typically greater than kinetic friction (μk).
- Existing data are limited to room temperature and often inconsistent; no prior measurements exist at cryogenic temperatures.
- A custom experimental setup was developed to measure friction between REBCO and co-winding tapes at 295 K and 77 K under controlled transverse loading.
- Results showed temperature-dependent friction behavior, enabling improved stress modeling and magnet design optimization.

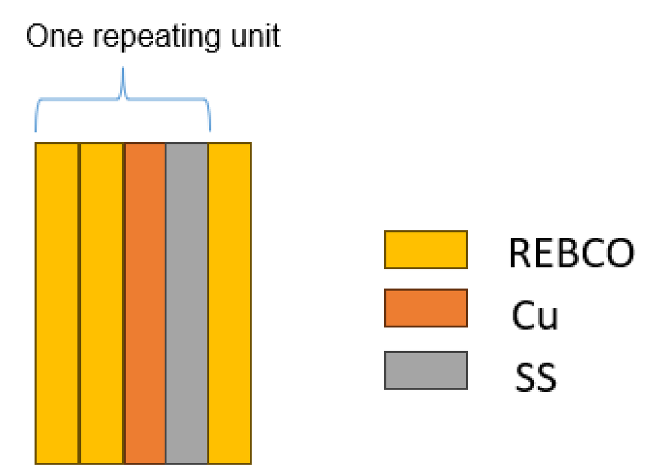

Figure 1: Schematic (not to scale) of the 40 T conductor and cowind.

Material Information

Name	Details
REBCO	SuperPower SCS4050, 4 mm wide
Stainless Steel	Ulbrich 0.006” thick 316 L Half-Hard, with sol-gel insulation, 4 mm wide
Copper	US foil 0.005” thick C101, Half-Hard, RRR=100, 4 mm wide

Test Method

- A 35 N transverse load was applied using a calibrated spring clamp, effective at both 295 K and 77 K, assuming negligible temperature effect on clamp stiffness (Figure 2).
- Tape A was placed between two Tape B strips with 25 mm overlap, aligned using G10 blocks and roll pins. The contact pressure was ~350 kPa.
- Tests were conducted on a 100 kN MTS machine with a 5 kN load cell and 10 mm/min stroke rate.
- Static friction coefficient was calculated using the peak load in the static region of Figure 3, divided by two for dual interfaces.
- Kinetic friction was obtained by averaging the force after the peak in Figure 3, minimizing stick-slip effects.

Test Setup

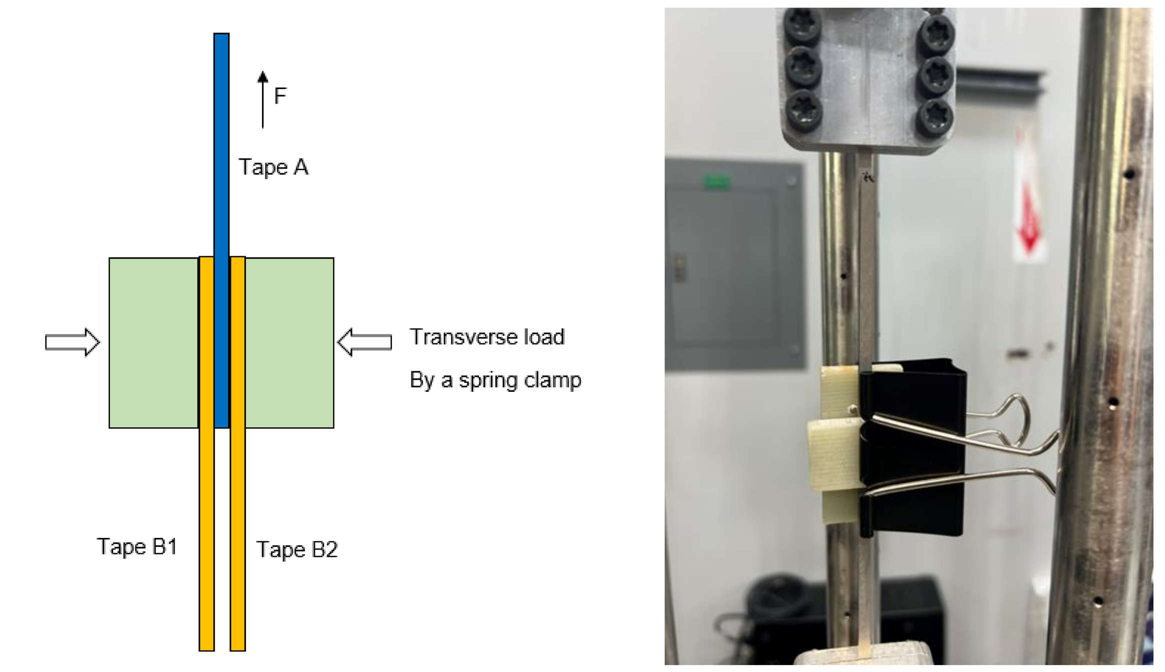

Figure 2: Schematic of the test method and actual setup

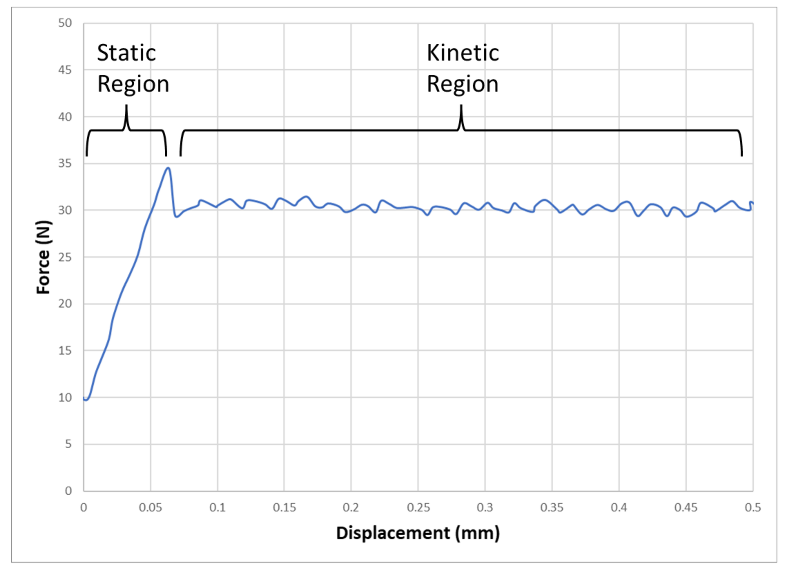

Figure 3: Static and Kinetic region in force-displacement curve

Force-Displacement Curves

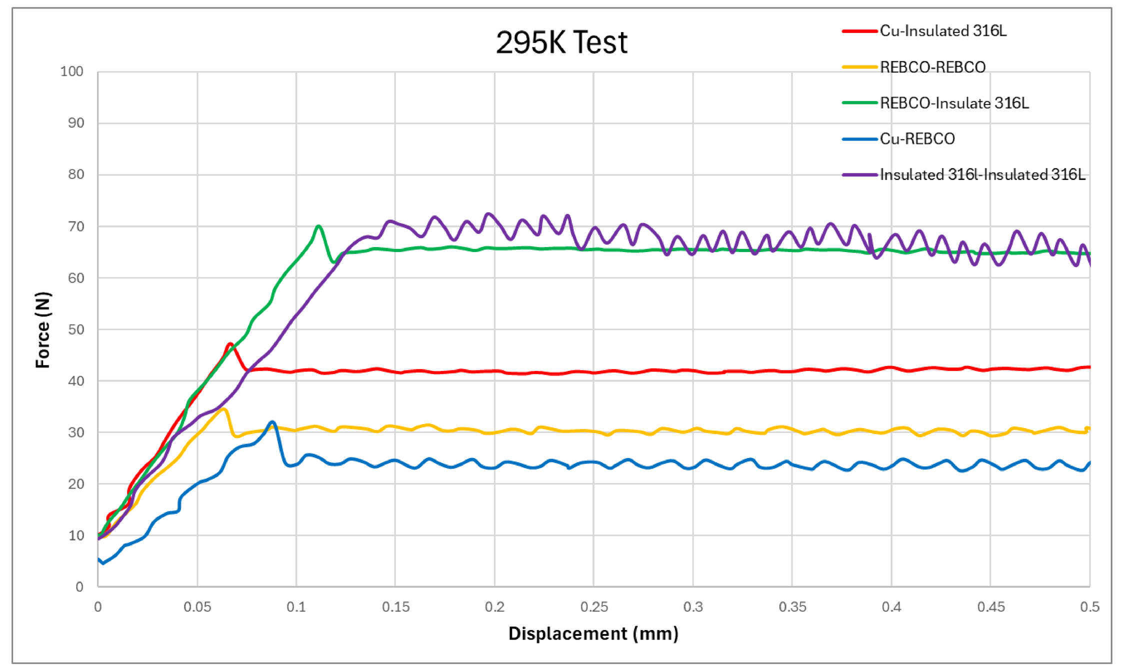

Figure 4: Force-displacement curve at 295K

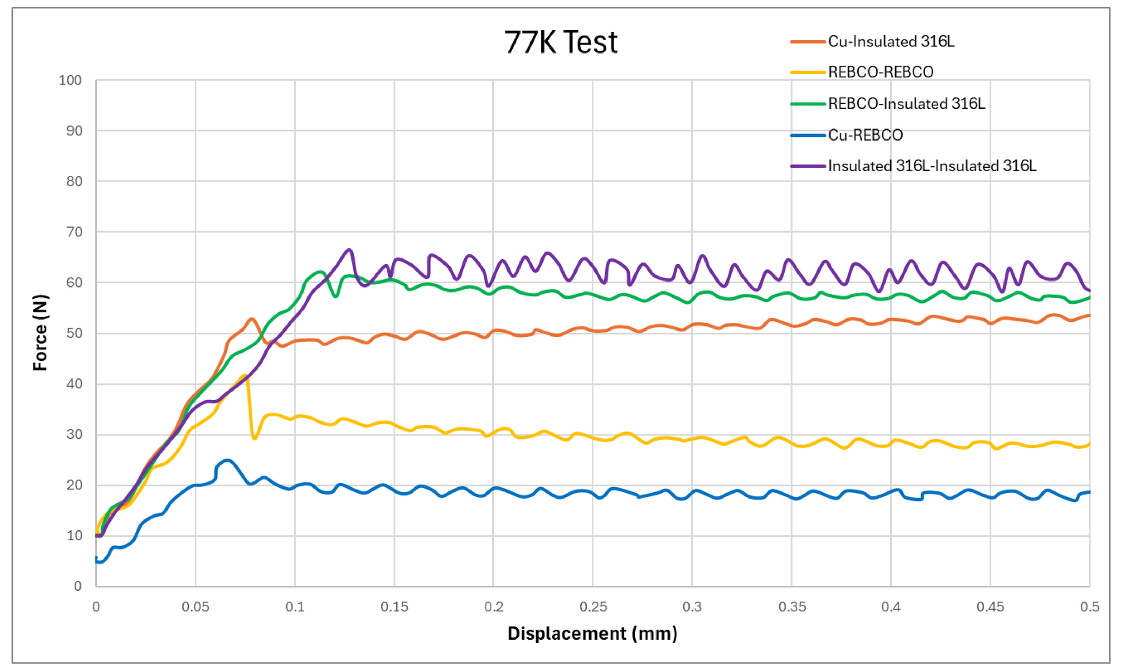

Figure 5: Force-displacement curve at 77K

Results

Contacting surface	Temp	Number of tests	Static friction coef.	Kinetic friction coef.
Copper - Insulated 316L	295 K	5	0.71 ± 0.06	0.67 ± 0.07
	77 K	2	0.76 ± 0.02	0.68 ± 0.07
REBCO - REBCO	295 K	5	0.50 ± 0.07	0.42± 0.07
	77 K	2	0.54 ± 0.07	0.43± 0.00
REBCO - Insulated 316L	295 K	5	0.97 ± 0.05	0.88 ± 0.06
	77 K	2	0.91 ± 0.03	0.84 ± 0.04
Copper - REBCO	295 K	5	0.37 ± 0.06	0.30 ± 0.04
	77 K	2	0.37 ± 0.02	0.27 ± 0.02
Insulated 316L - Insulated 316L	295 K	5	0.97 ± 0.08	0.90 ± 0.07
	77 K	2	0.88 ± 0.09	0.85 ± 0.05

Discussion

- The lower friction coefficient (0.31) measured for uncoated 316 SS tapes compared to literature values (~0.41–0.52) is likely due to ethanol cleaning, smoother surface conditions, the specific transverse pressure used (350 kPa), and differences in test setup compared to standard tribology methods.
- Standard deviations (±0.02–0.09) indicate good overall repeatability, but slight variability is likely due to stick-slip behavior and instrument noise.
- The spring clamp was calibrated at room temperature; thermal contraction at 77 K may slightly alter the actual clamping force, introducing minor systematic error.
- Misalignment between samples and added friction at roll pins may slightly inflate measured friction values.
- Variability in surface roughness, oxide layers, or residual contamination—even after ethanol cleaning—can impact friction measurements between material pairs.
- Future work will focus on improving load control, re-benchmarking with known materials, collaborating with tribology experts, and validating results using commercial friction test systems.

Acknowledgement

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References:

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