The low temperature thermal expansion of materials used for superconducting magnets

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Outline

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Introduction

- Magnet materials experience large temperature ranges and extreme low temperatures, resulting in large thermal stresses.
- Thermal stresses occur due to differential thermal expansion between various materials.
- Proper designs should consider thermal mismatches to prevent premature failures in magnets.

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Definitions

- The coefficient of thermal expansion (CTE) is defined to be the linear slope of the thermal expansion vs temperature curve.
  - Units of mm/mm/K (in/in/F)
- Ex: A US manufacture uses CTE number in their strain gages for a particular material the strain gage will be bonded to.
  - SK-06-350-CY vs SK-09-350-CY
    - Steel has a RT CTE of 6e-6 in/in/F
    - Stainless steel ha a RT CTE of 9e-6 in/in/F
- Rule of thumb: alphabetical expansions from high TE to low TE.
  - A→B →C→S→T
  - Aluminum, brass, copper, steel, and Ti.

Dilatometer

- Modified vertical tube-type differential dilatometer.
  - Push rods are used to measure expansion (contraction) of the material being tested.
  - Measures a change of length as a function of temperature.
  - Can be used for both high and low temperatures expansion measurements.
- Utilizes the principle of differential expansion between a low temperature reference material (C101 Cu) and the test material.
- Measure two specimens at once.
  - One calibration specimen and one test material.
- Low thermal expansion Ti-6Al-4V push rods.

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Dilatometer

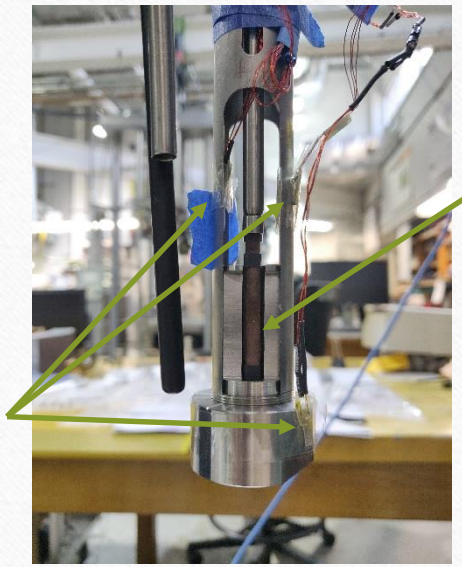
Micrometers are used to measured displacement. Resolution of ± 1e-3mm and an accuracy of ± 2e-3mm.

Linear bearings

Counterweight

Alignment screws

Cooling lines to keep constant temperature.



Temperature Sensors

Specimen

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Dilatometer

Room temperature control environmental chamber for micrometers and rod ends.

Cryostat top flange.

Ti tube housing & Ti rods

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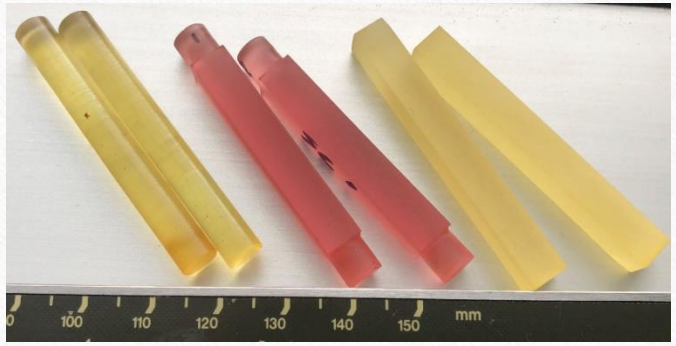
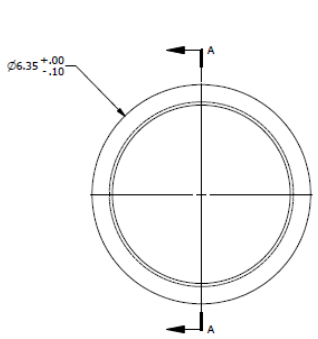
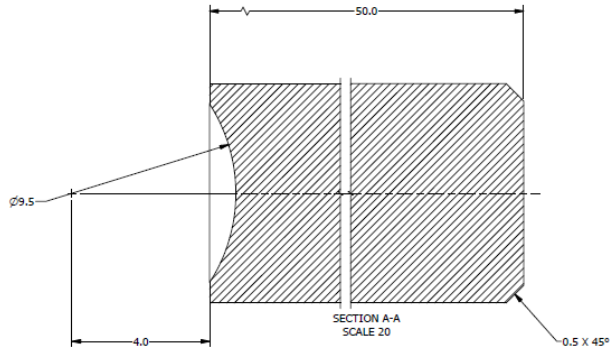
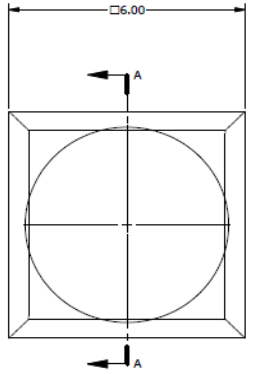
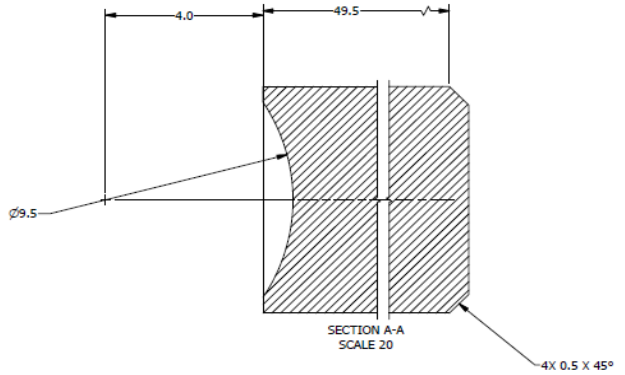
Specimen Geometry











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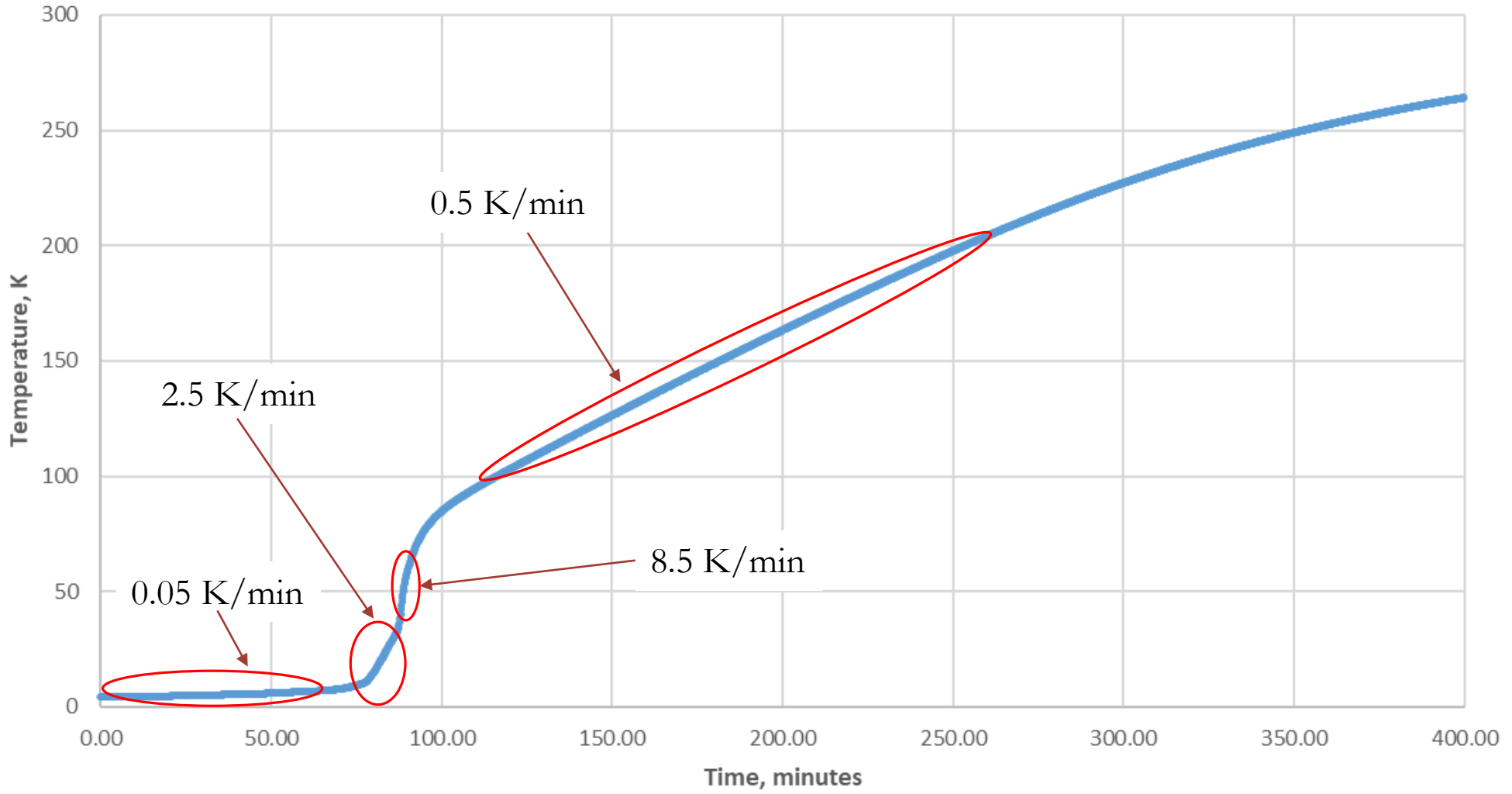
Testing Procedure

- Two separate holders are used, one for square specimens and one for round.
- Rod alignment is checked.
- Fixture is enclosed in a cryostat and then filled with liquid helium at 4.2 K.
- Data is recorded every 10 seconds.
- Specimens passively warm up to 293 K.
  - About 10 hours.

Evaluation of Temperature Rise Rate



Calibration

- C101 copper is used to calibrate the fixture.
- Raw data is zeroed at 293 K.
- Using NIST reference data of thermal expansion for copper is used to determine correction curve for fixture.
- A total of 10 calibrations runs were performed.
- A Polynomial curve fit is then made for thermal expansion of fixture and used to correct for unknown materials.

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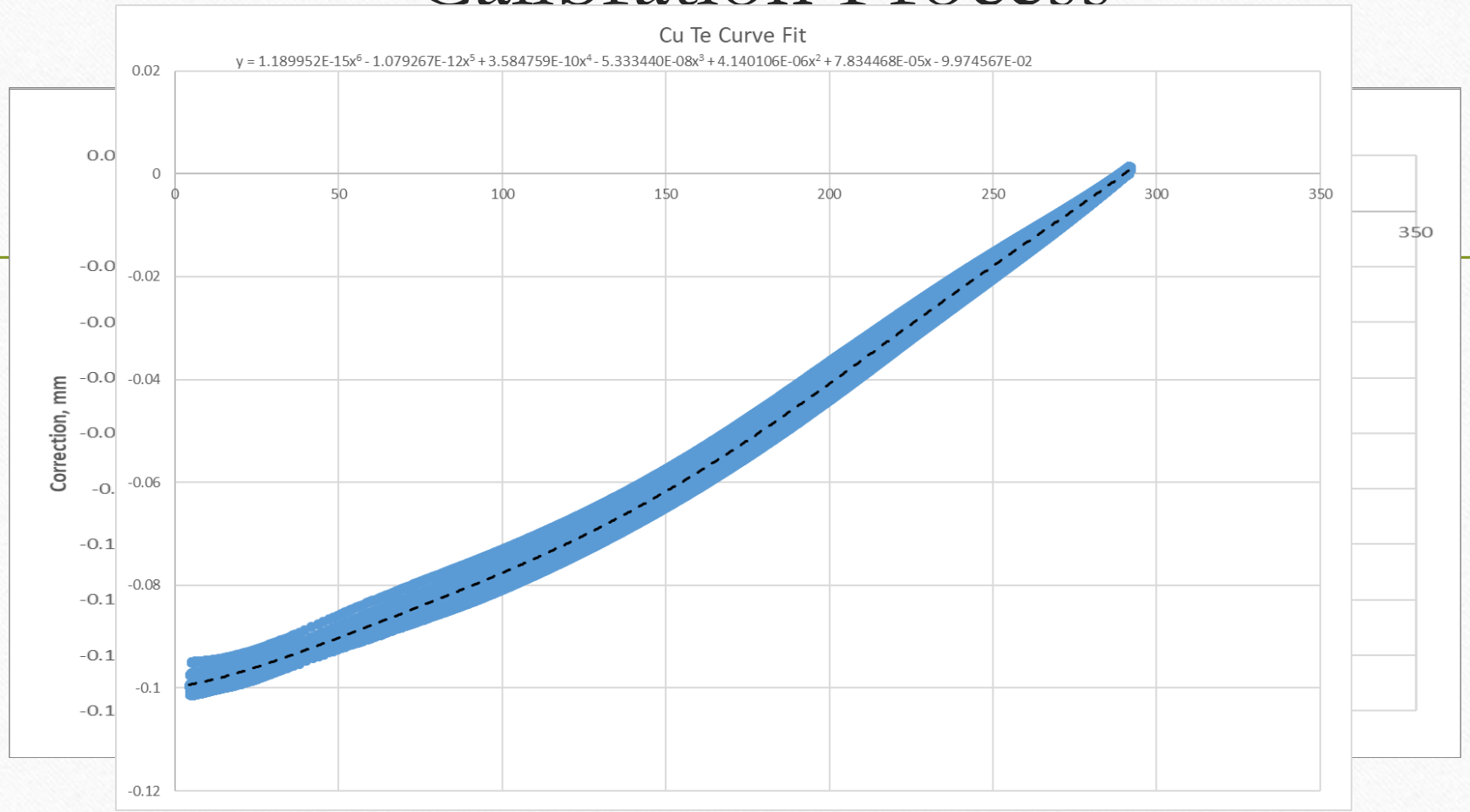
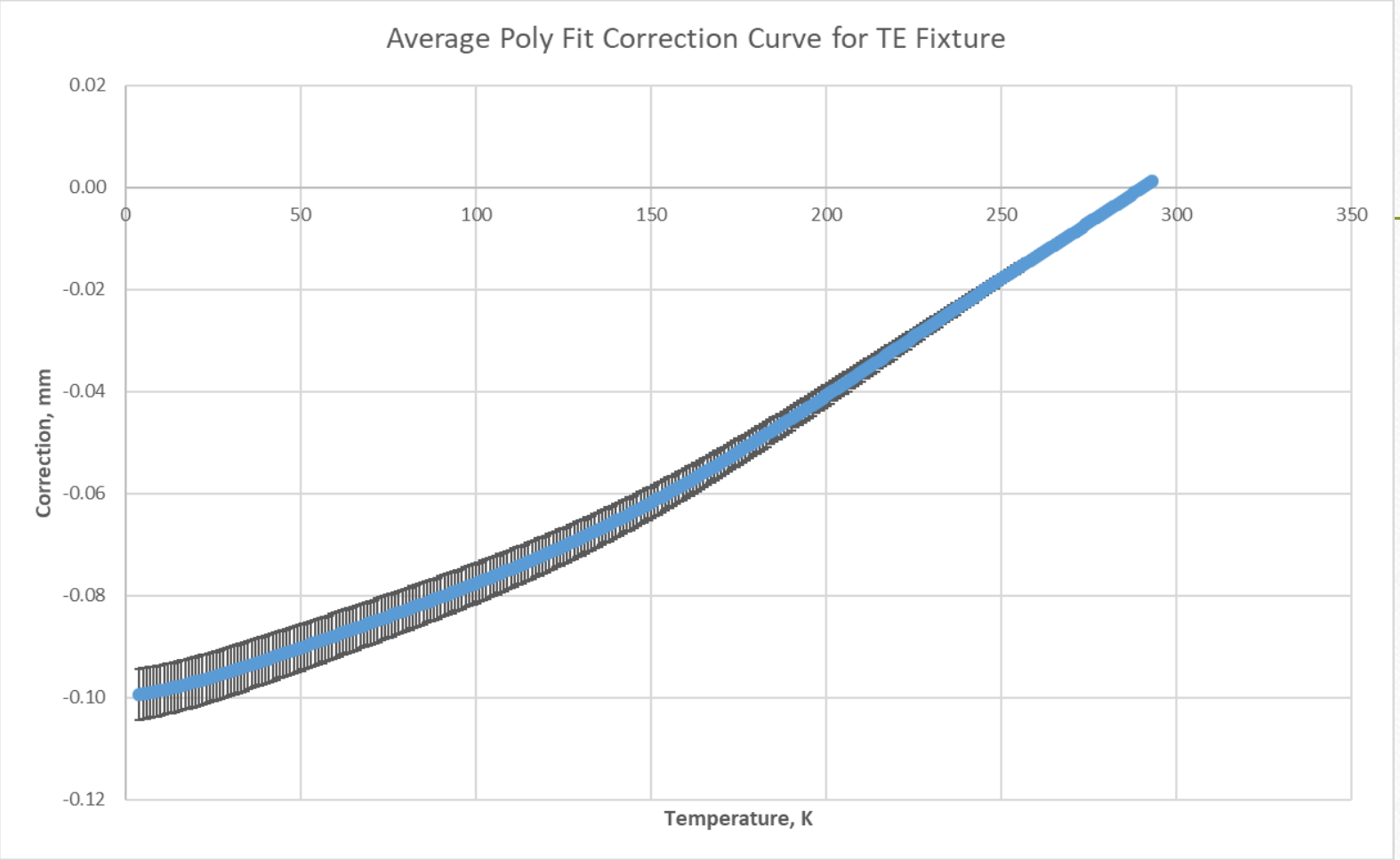
Calibration Process



- Raw data is subtracted from NIST Cu Ref.

- This correction is done for each copper calibration run to get an average polynomial fit.

Correction Curve Fit



- Average polynomial fit for correction curve.
- Error is ± 3 % or ± 5 μm.
- Assume identical station performance and equilibrium temperature conditions for the two specimen stations.
- Sensitive to vibrations.

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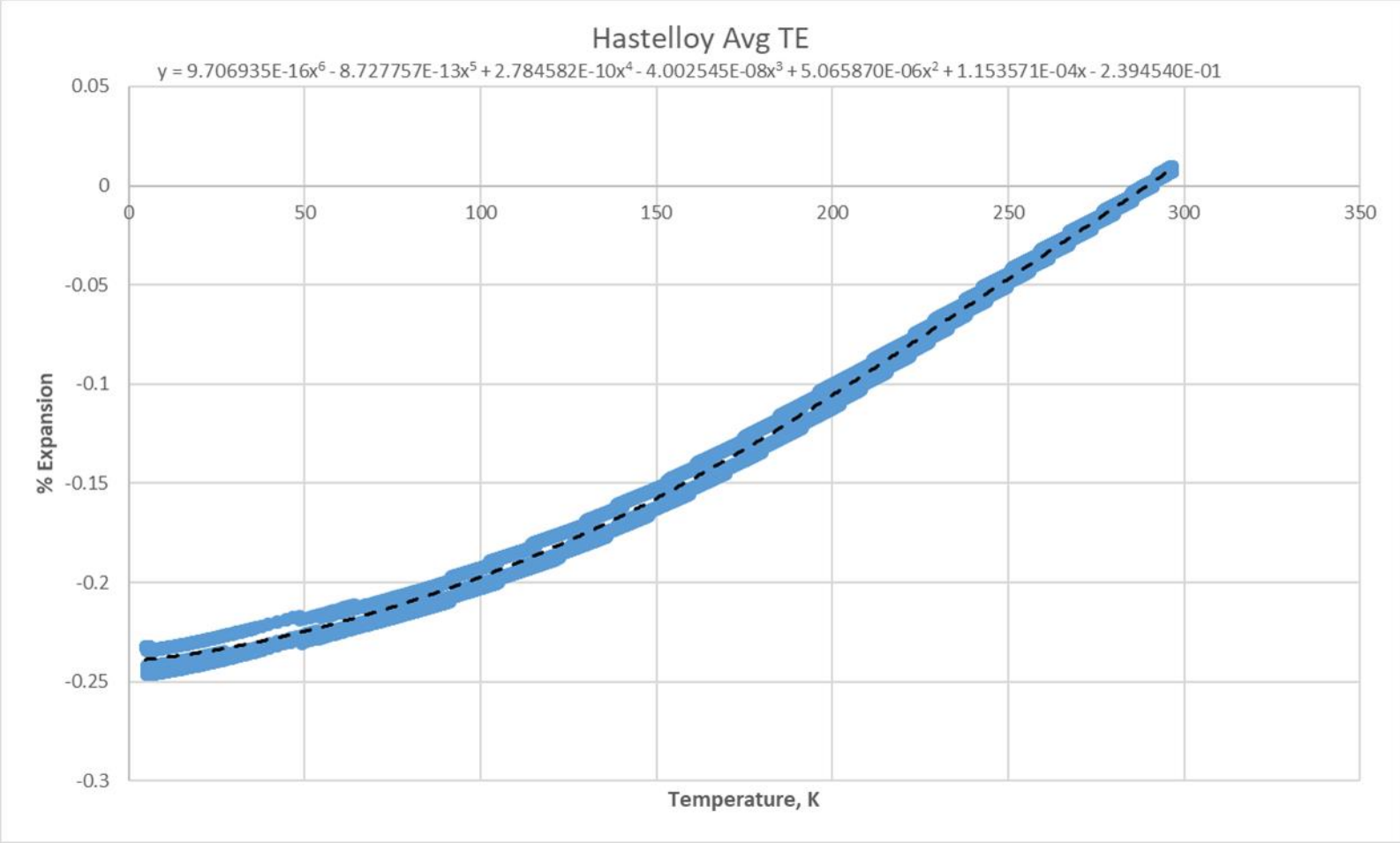
Example of Raw Data



- Average of thermal expansion runs.
- Polynomial curve fit is used to get average thermal expansion from raw data.

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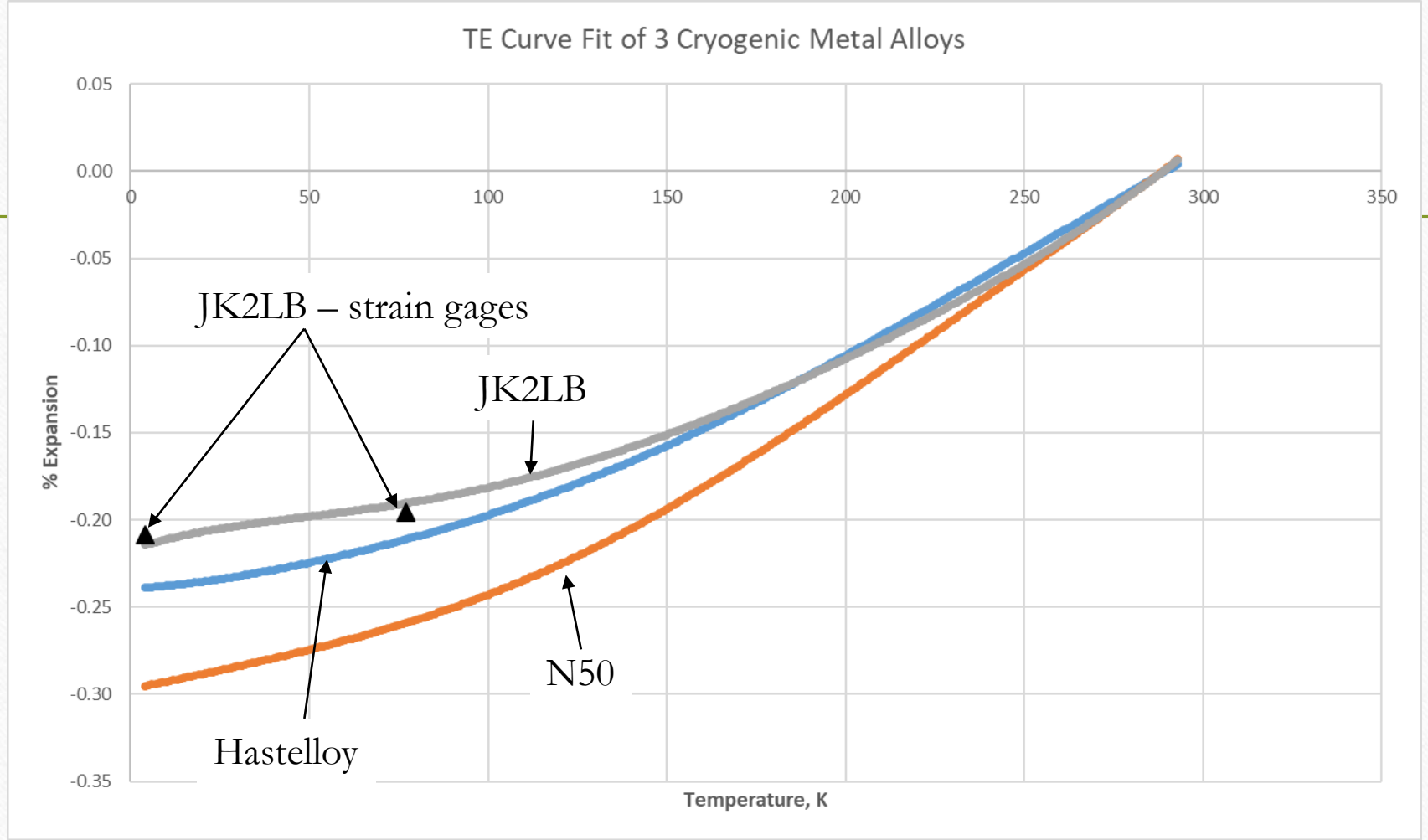
Thermal Expansion of Various Metals



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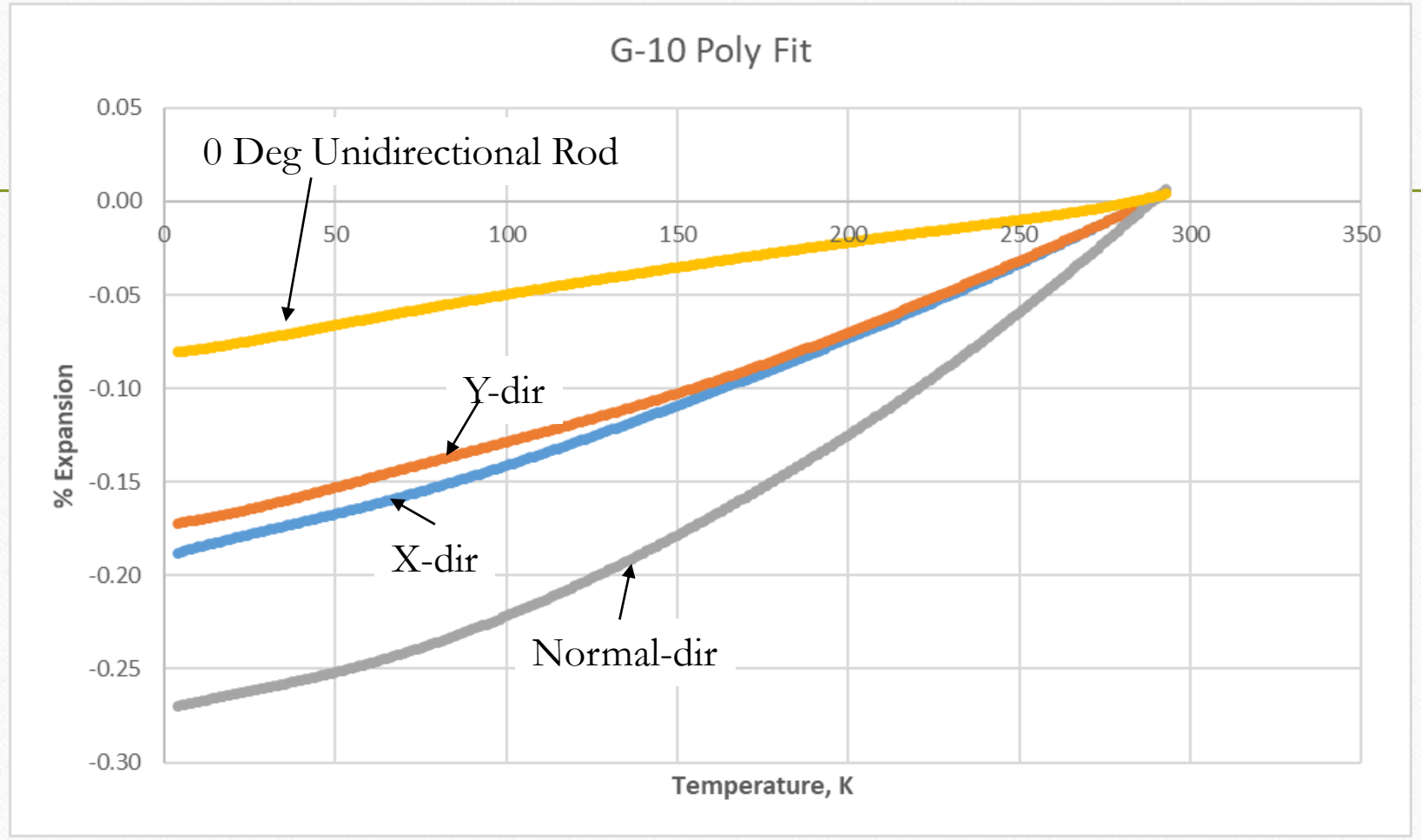
Thermal Expansion of G-10 CR



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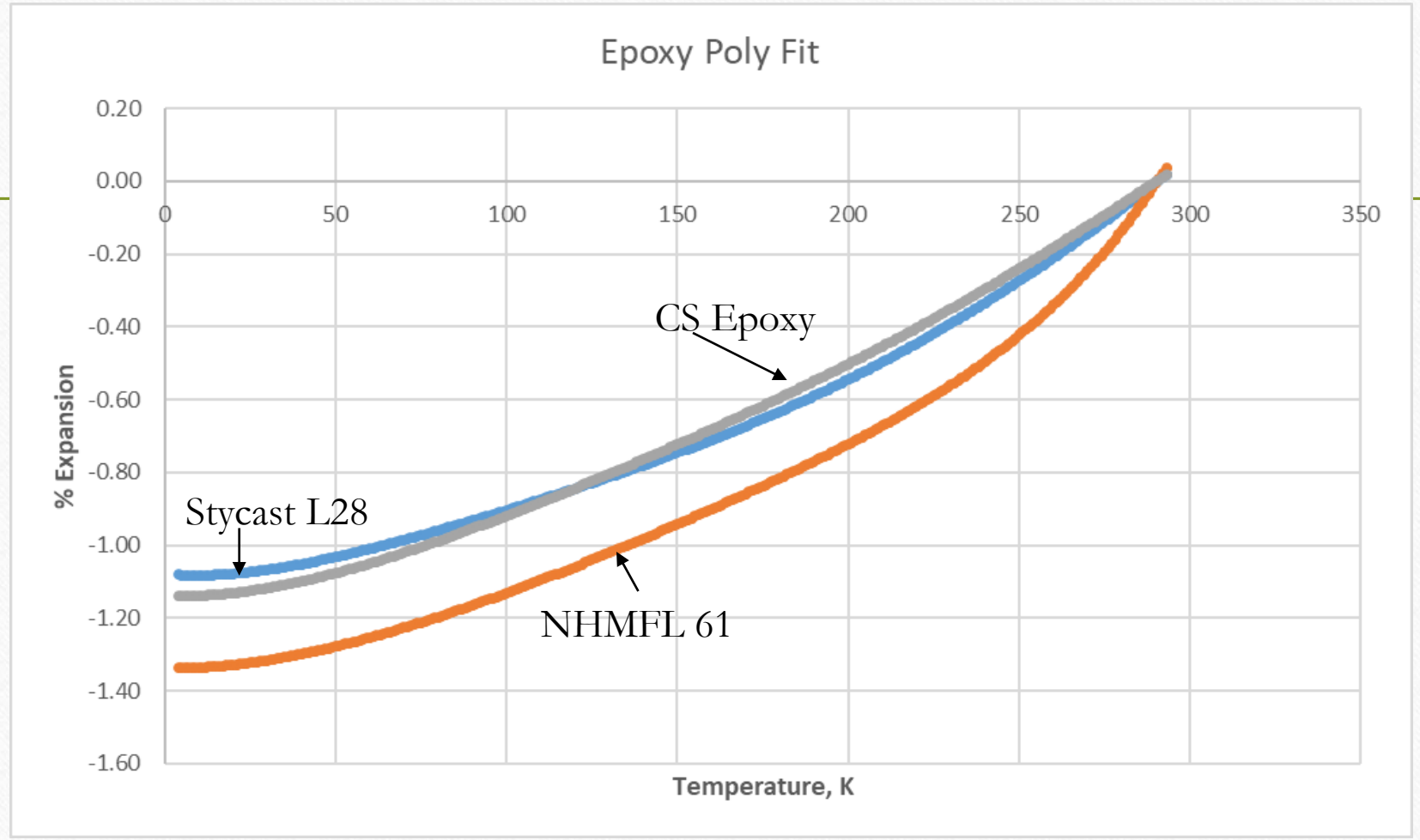
Thermal Expansion of Impregnation Epoxies



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Measuring Bi2223 and REBCO Coated Conductor

- Stacks of Bi2223 and REBCO coated conductor were made to measure their thermal expansion.
- Ends of the stacks were machined to be flat.

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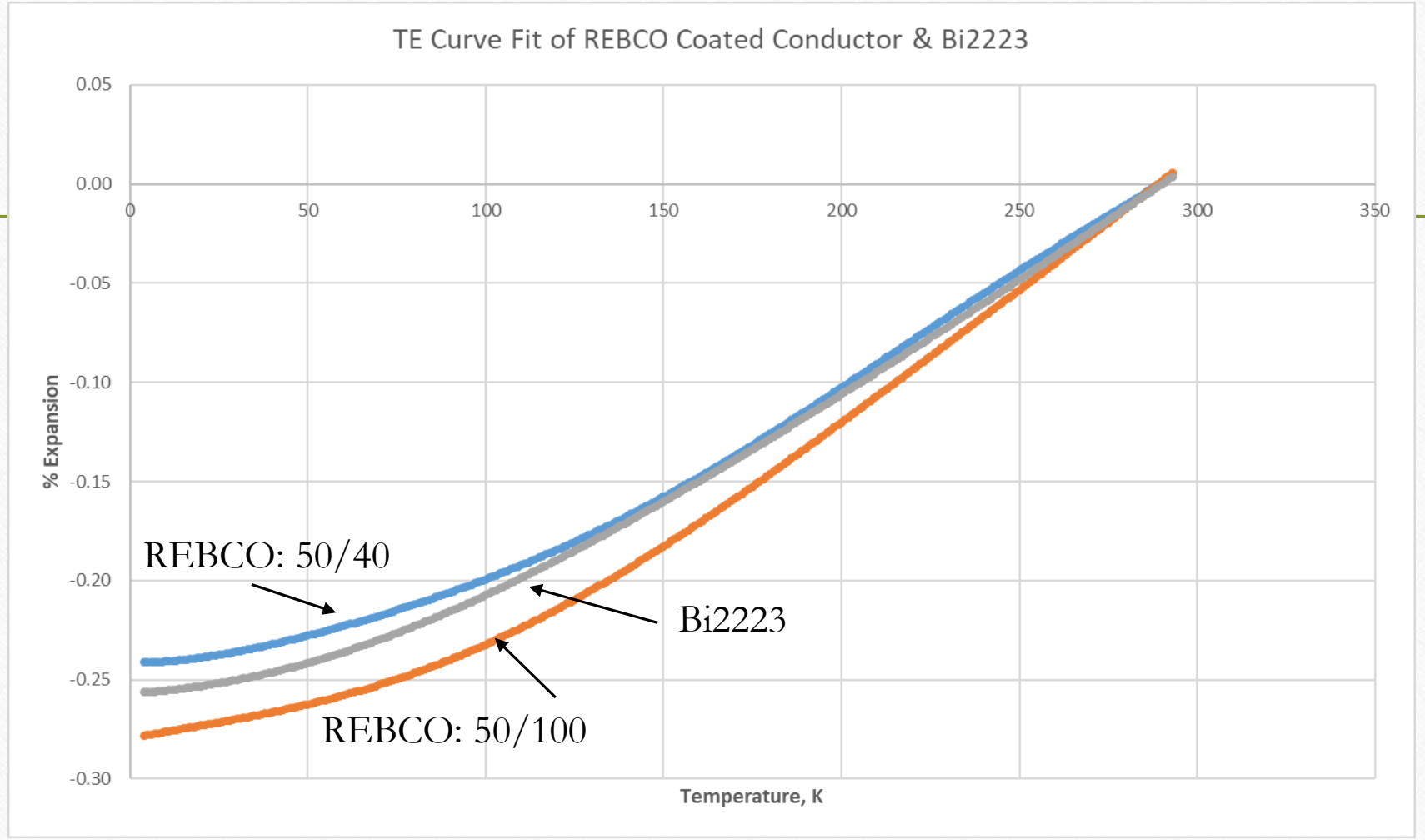
Thermal Expansion of REBCO and Bi2223

Note: 50/40 = 50 μm Hastelloy, 40 μm copper.



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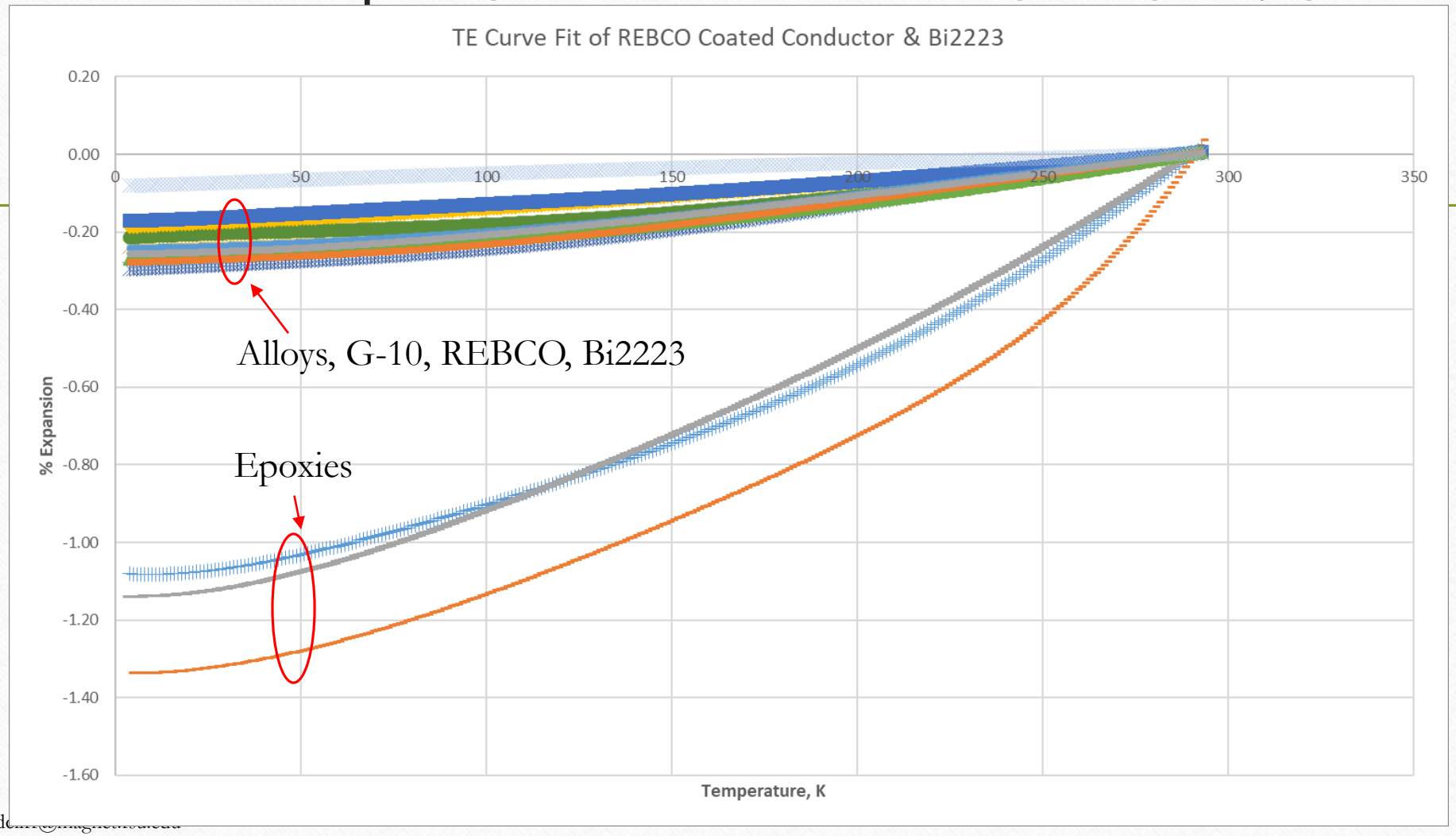
Thermal Expansion of Materials Tested so Far



Summary

- Relatively simply way to measure the thermal expansion of unknown materials.
- A thermal expansion database is being made for magnet designers and other applications.
- Increase accuracy of measurements.
- Improve temperature rise rate.

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