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Frictional Heating Measurements in PBX 9501

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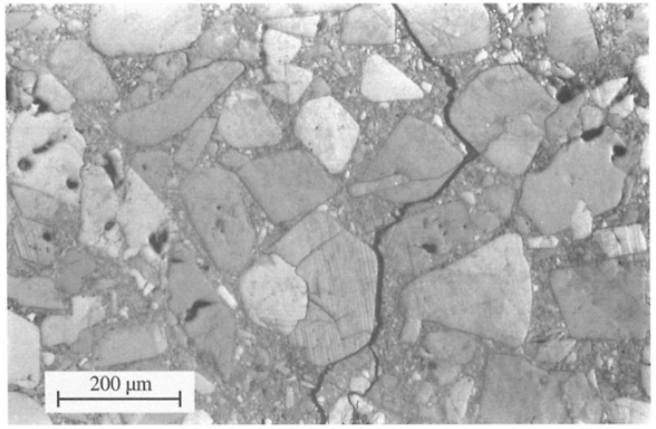
Energetic Materials: A Modeling Challenge

- Complex material structure
- Chemically reactive (fast, exothermic)
- Everything is a function of temperature

Multi-Physics!

Plastic Bonded Explosive [Rae, 2002]



Energetic Crystals [Yarrington, 2018]

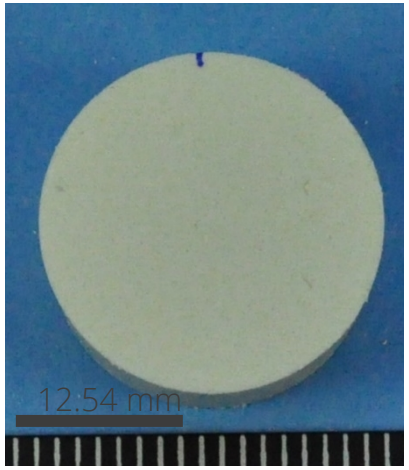
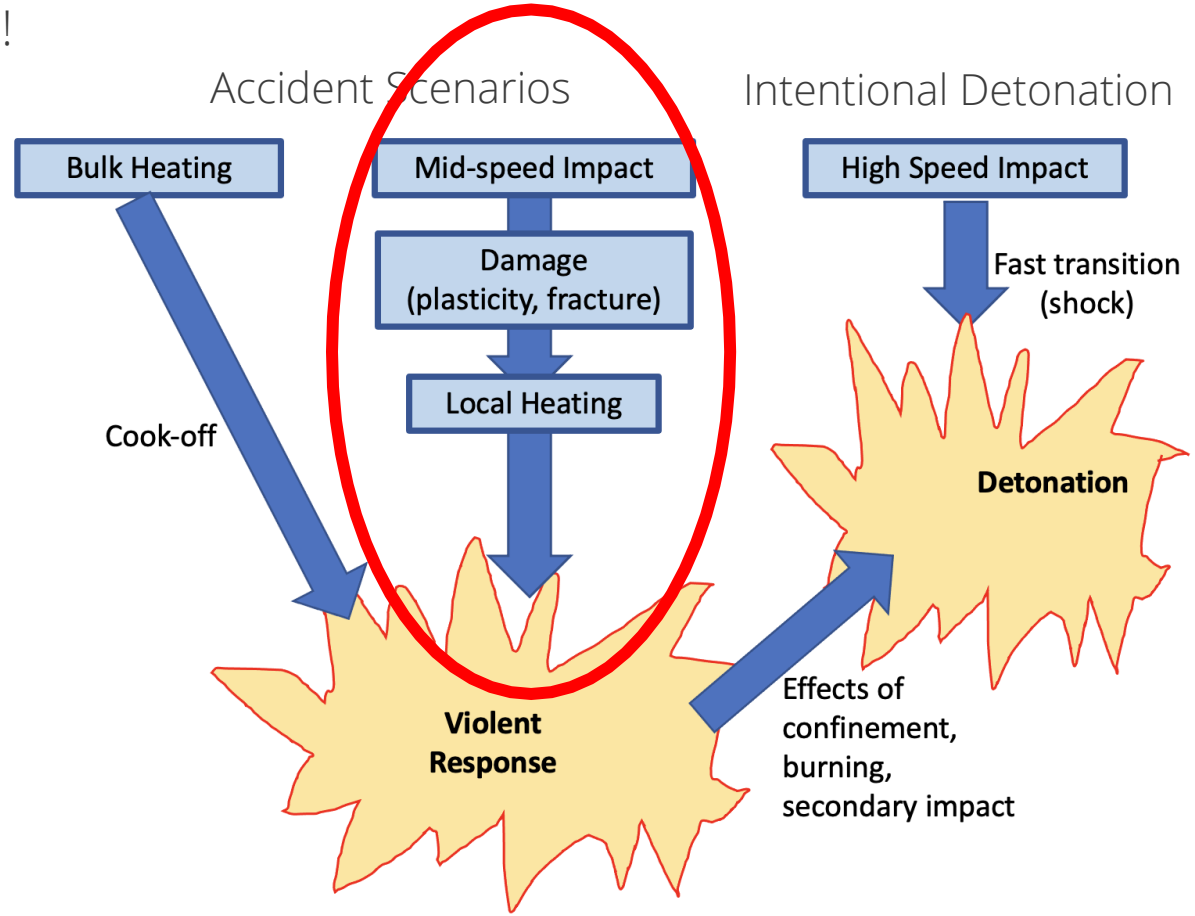


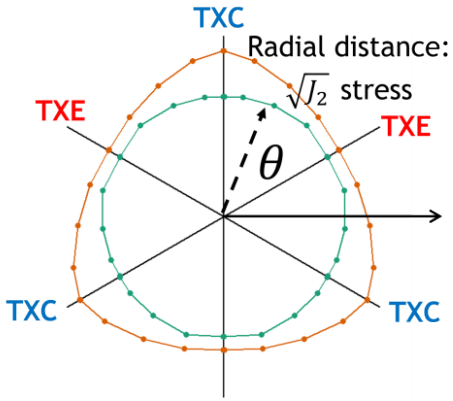
Image: courtesy Marcia Cooper

A few different ways to get an explosion…

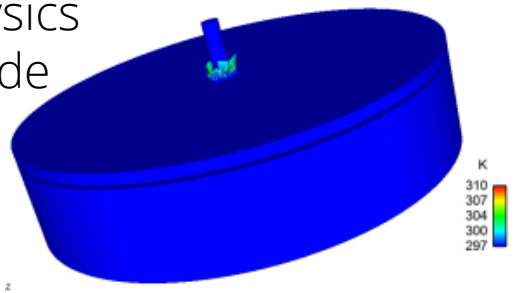


Mechanisms Contributing to HEVR

Continuum Constitutive Model



Multiphysics CRK code



Impact Event

Mechanical Deformation & Damage

Local Hotspot Formation

Heat Conduction

Thermally Activated Chemistry

Go

?

No Go

Interface Debonding

Plasticity

Crystal Fracture

Friction

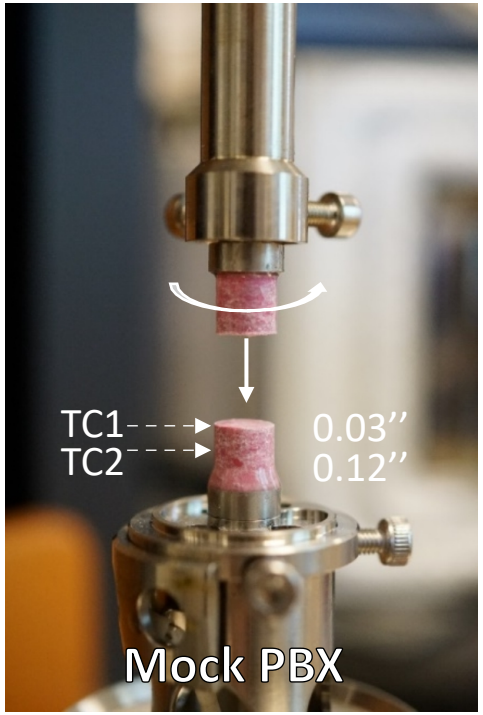
Particle Rotation

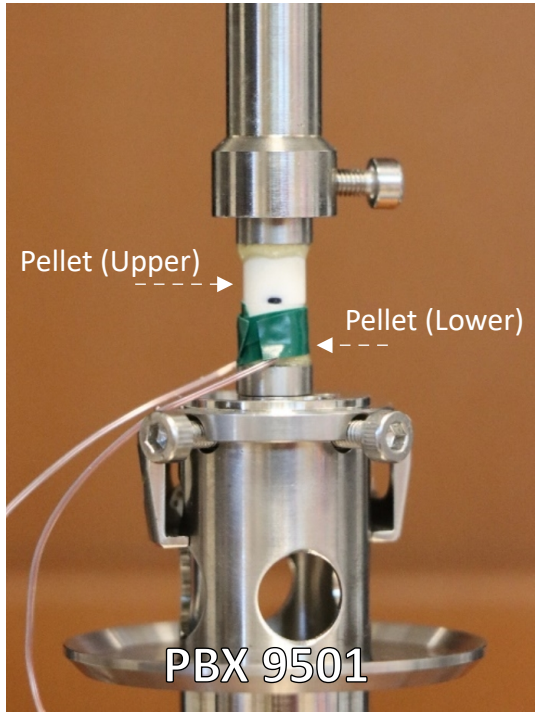
Viscoelastic Heating

Experimental

Objective: Isolate and measure heating due to friction

The *TA Discovery Hybrid Rheometer* was used to frictionally shear two explosive pellets at a controlled angular sliding speed and applied normal force.





Procedure

- Fix pellets to Rheometer fixtures
  - **PBX 9501** (95% HMX, 2.5% Estane, 2.5% Plasticizer)
  - ½" dia. x ½" height pellets
- Insert into rheometer grips
- Place TC in contact with sample surface at known locations and secure with tape
- Wait for thermal equilibrium in Environmental chamber
- Set axial load and run (3 rad/s, 180s)
  - 2.5N, 5N, 10N (triplicate)

Measurements

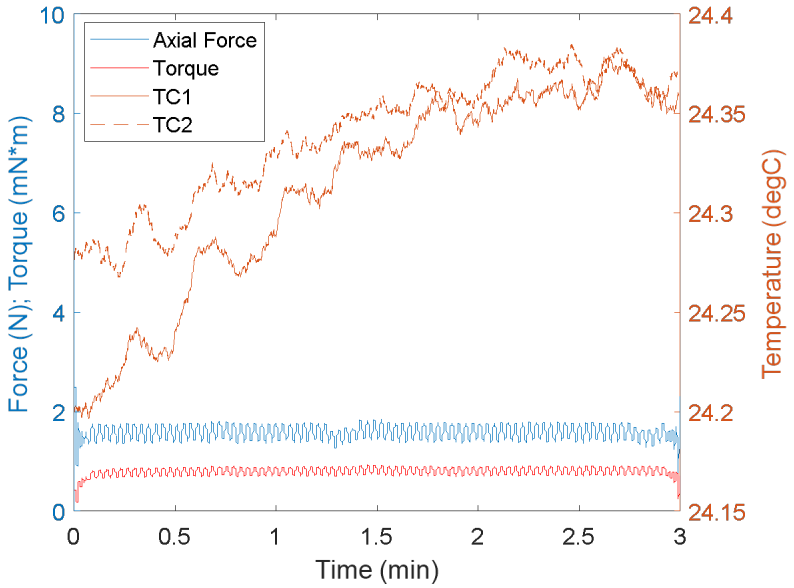
- Normal force
- Torque
- Chamber temperature
- Sample temperature on outer surface using T-type thermocouples (X2)

Outcome

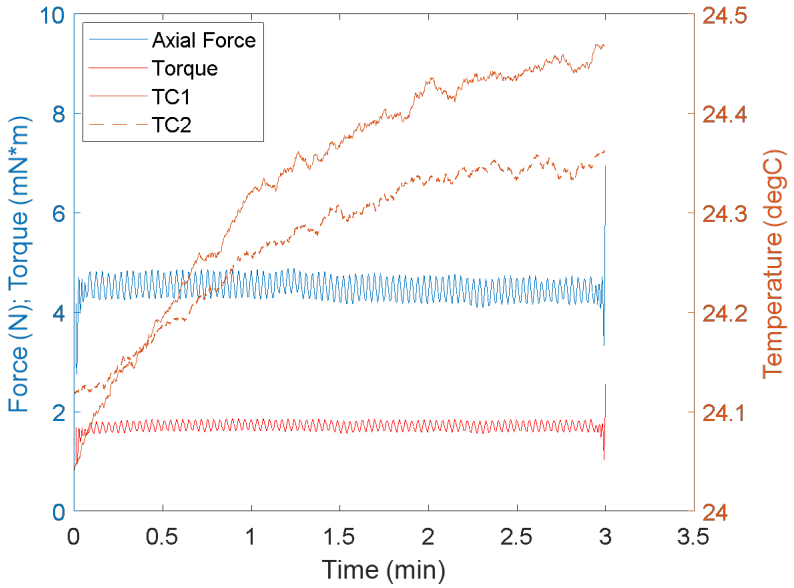
- Temperature rise due to heat generated by friction
- Calculated coefficient of friction

Results – Measurable Outputs from Test

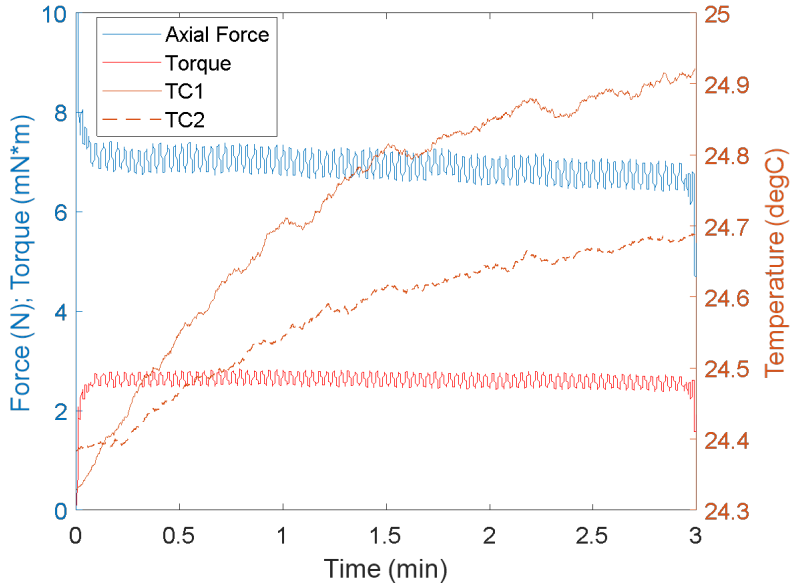
2.5 Newtons



5 Newtons



10 Newtons



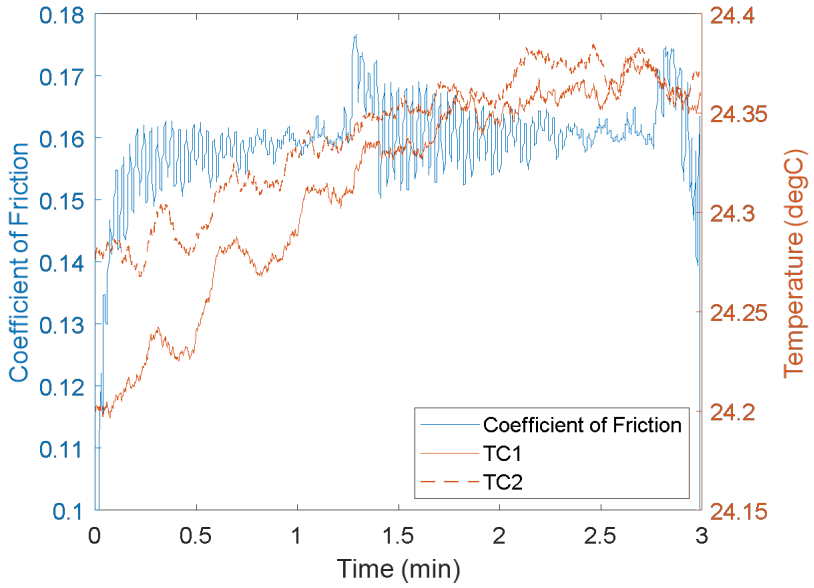
Takeaways

- Measurable temperature rise with heating due to frictional loading for each condition.
- Even loading (axial force and torque) throughout run.
- Measured normal force shifts due to settling, then consistency.

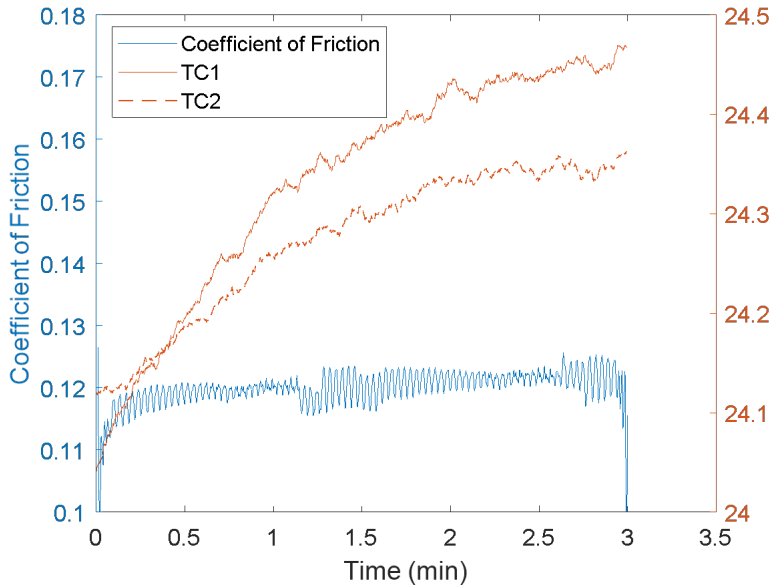
Calculated Coefficient of Friction

$$\mu = \frac{T}{RF_N}$$

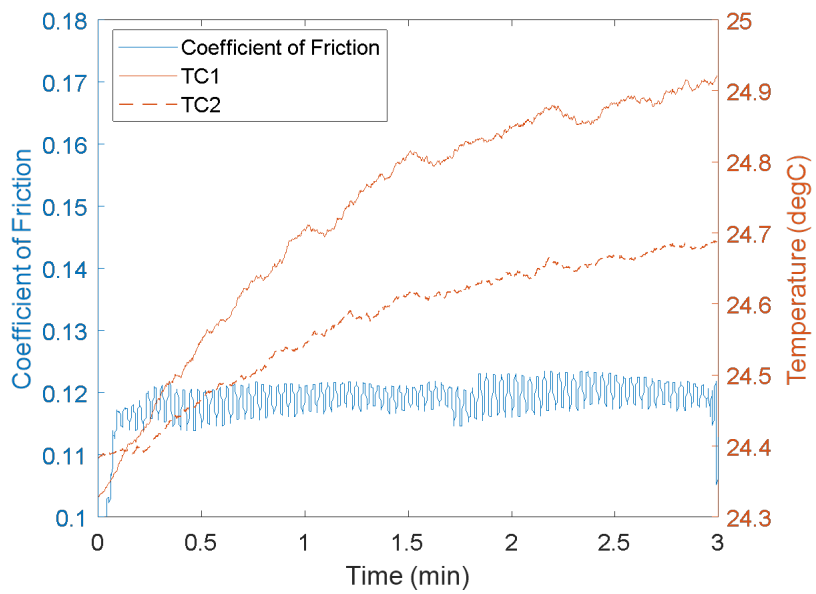
2.5 Newtons



5 Newtons



10 Newtons



Takeaways

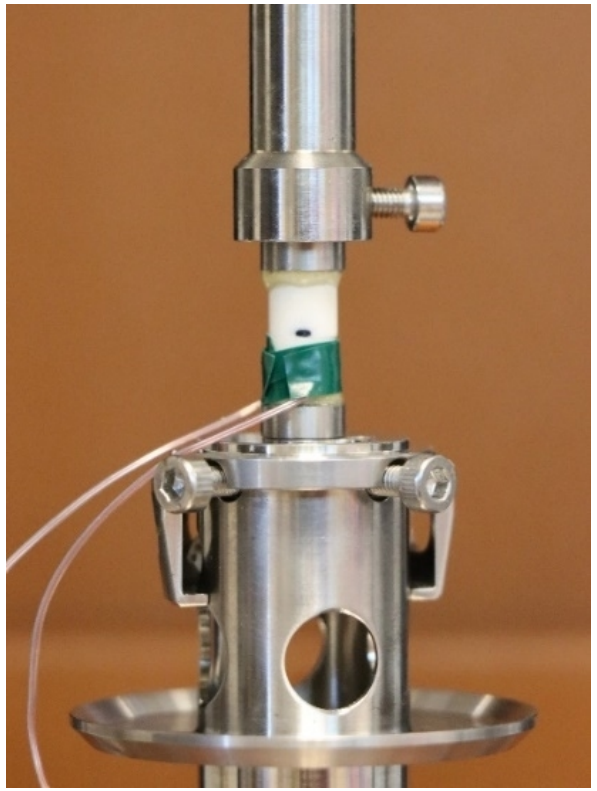
- Coefficient of friction consistently 0.118 for 5N and 10N loading cases.
- Consistent with Polymer on Polymer (~0.1 for PTFE [1])
- What happened to the 2.5 N case?

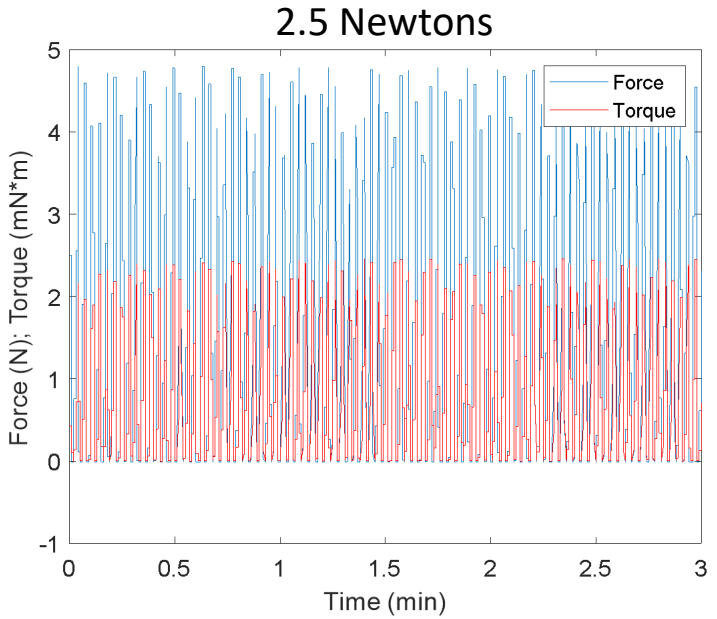
[1] Malcolm Fox, "Polymer Tribology", *Lube Tech,* 2017

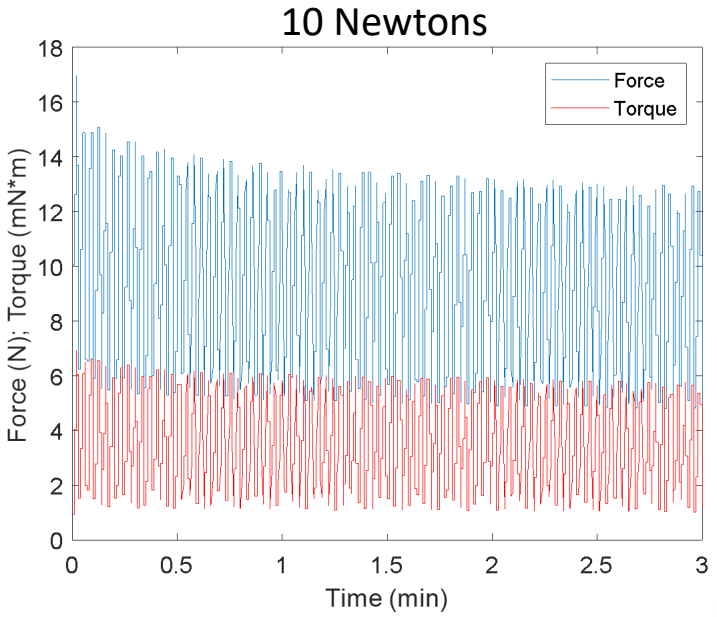
What happened to 2.5 N case?

- Experimental stack up not in perfect alignment.
- Pellets are not in full contact under light loading.
- Result: for part of revolution, zero force/torque is measured.
- At higher loading, pellets are in full contact.

$$\mu = \frac{T}{RF_N}$$



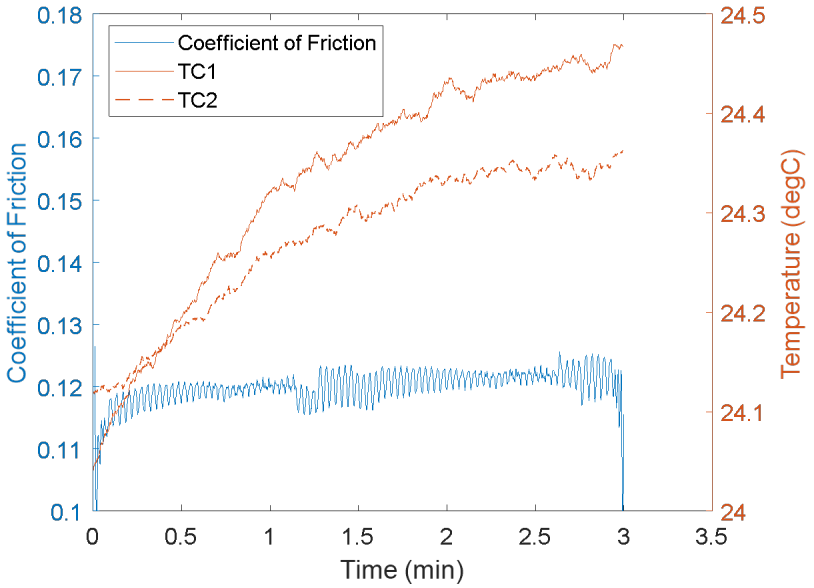


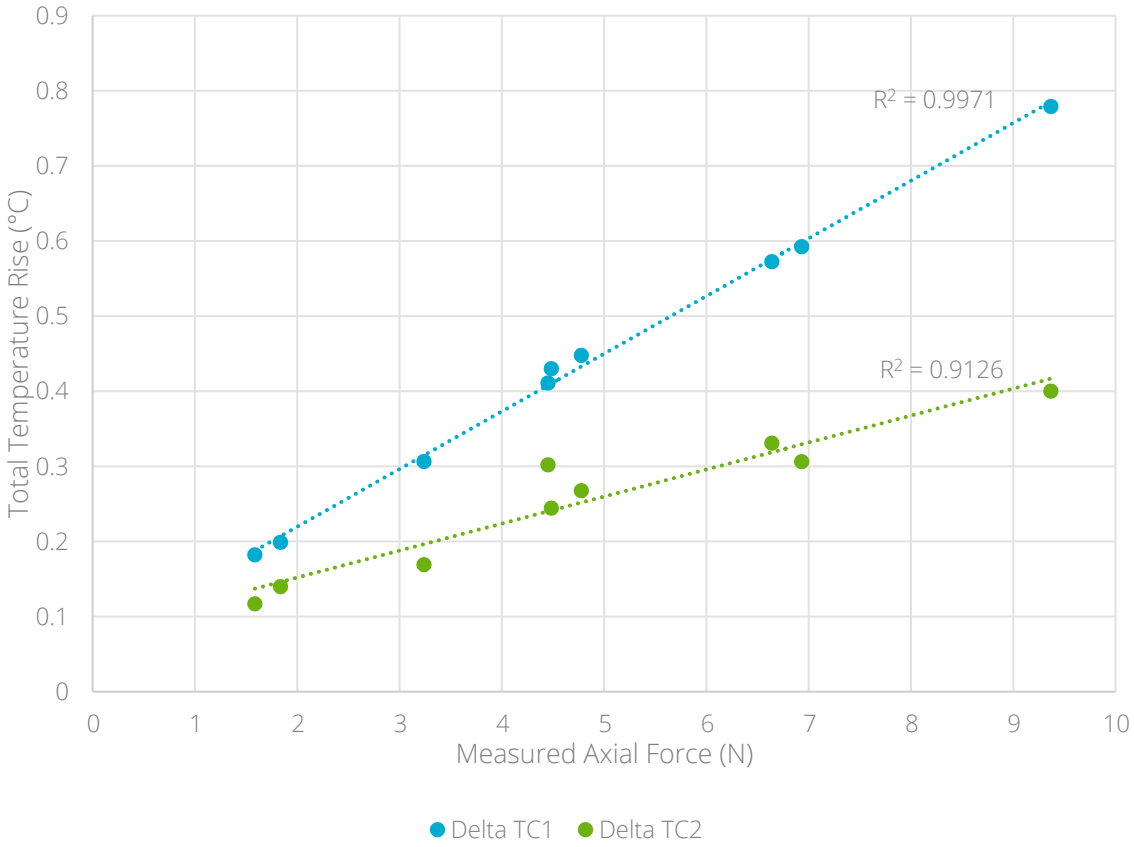


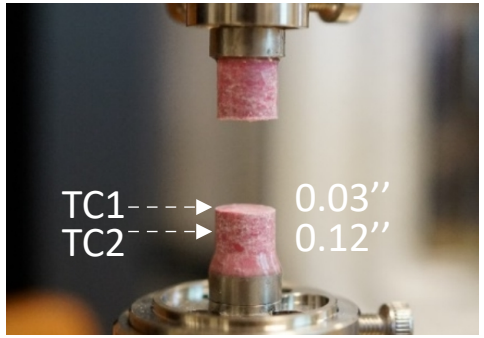
Temperature Comparison

Takeaways

- Linear global temperature rise with axial loading.



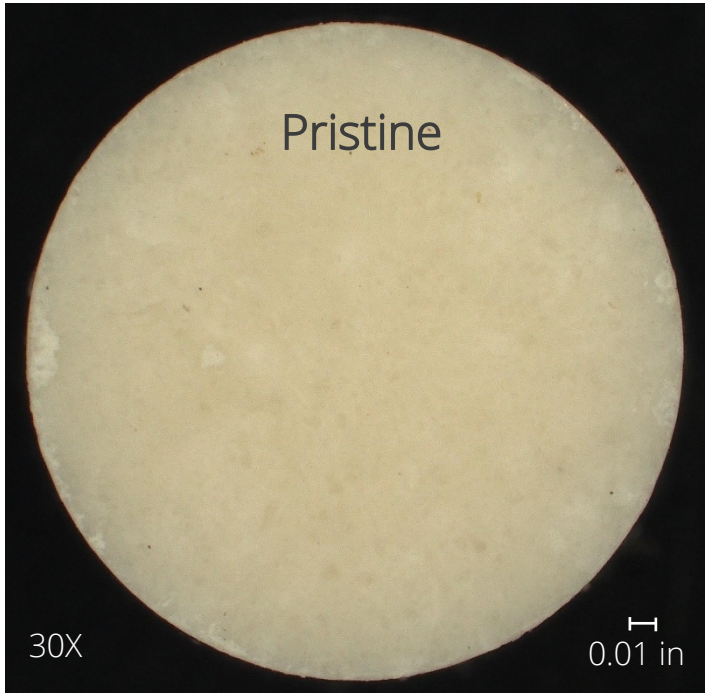


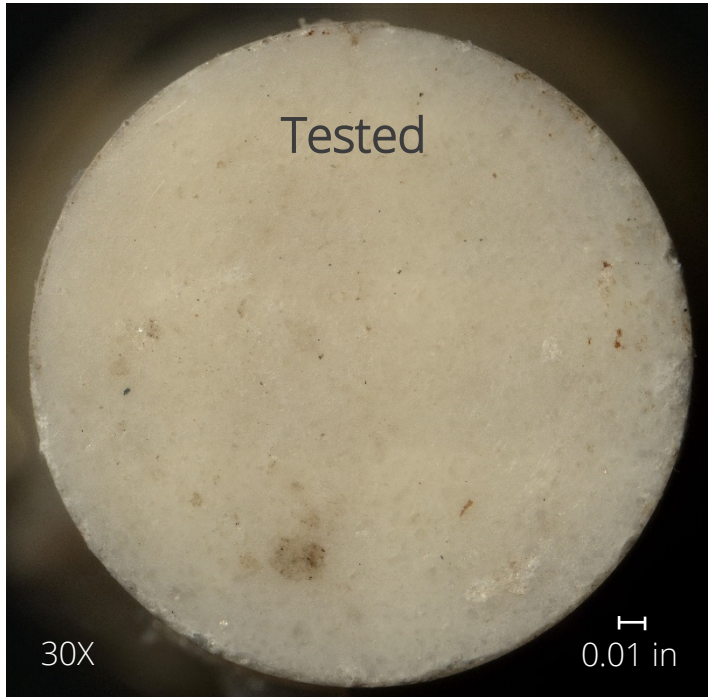


Surface Characterization

Key Takeaways:

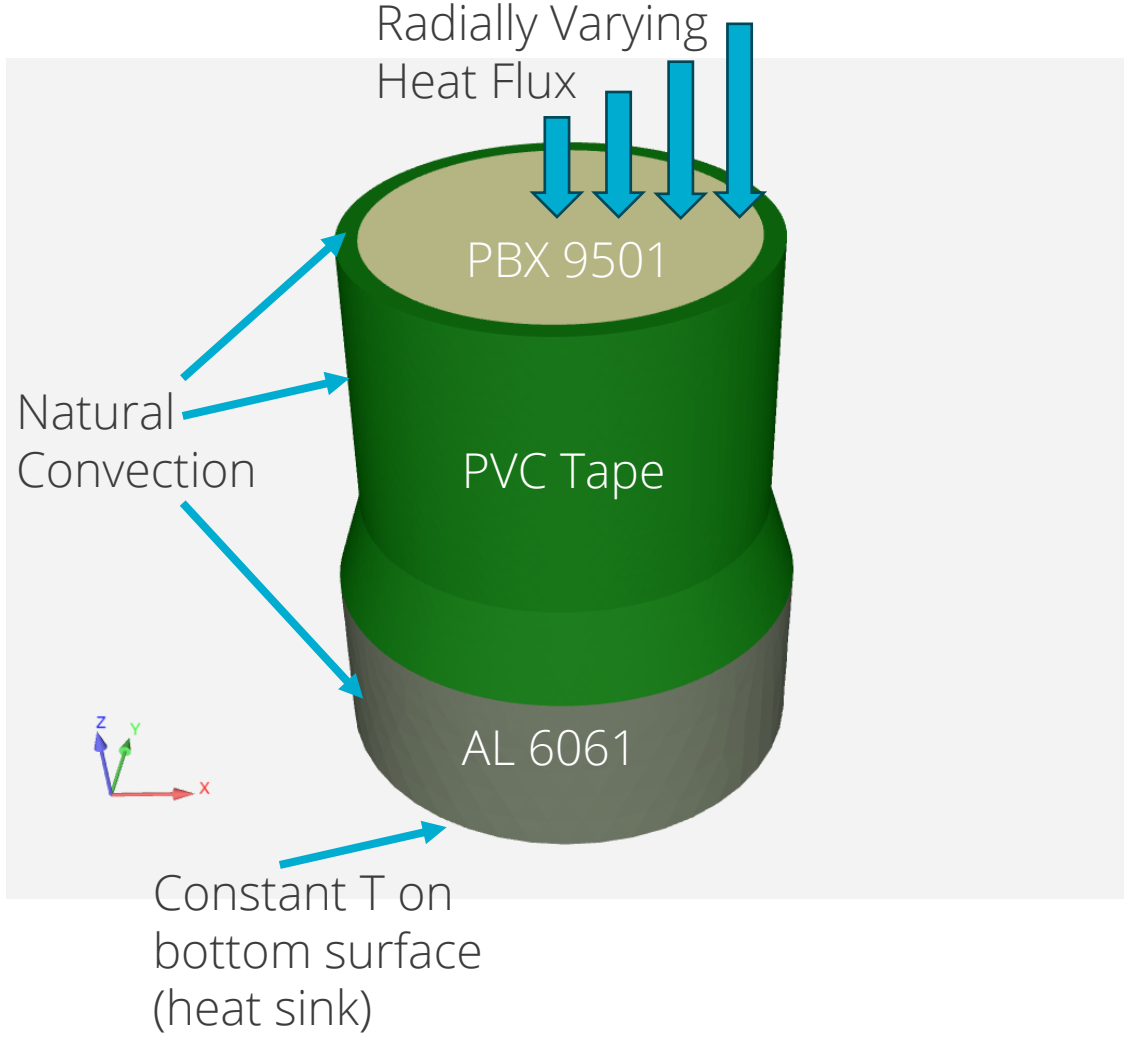
- Very little damage, deformation on surface
- Mild scratching and wear towards outer radius
- No evidence of chemical reaction
- Isolation of friction mechanism

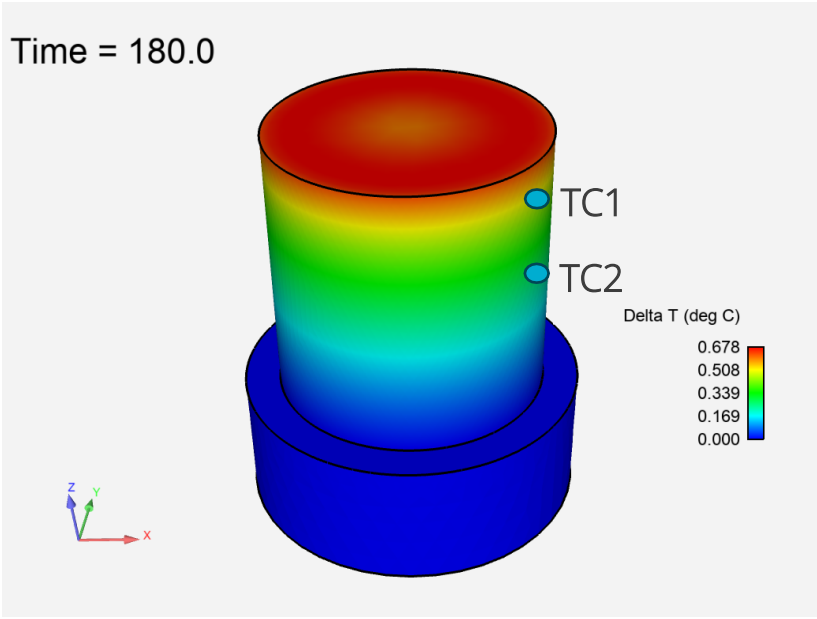


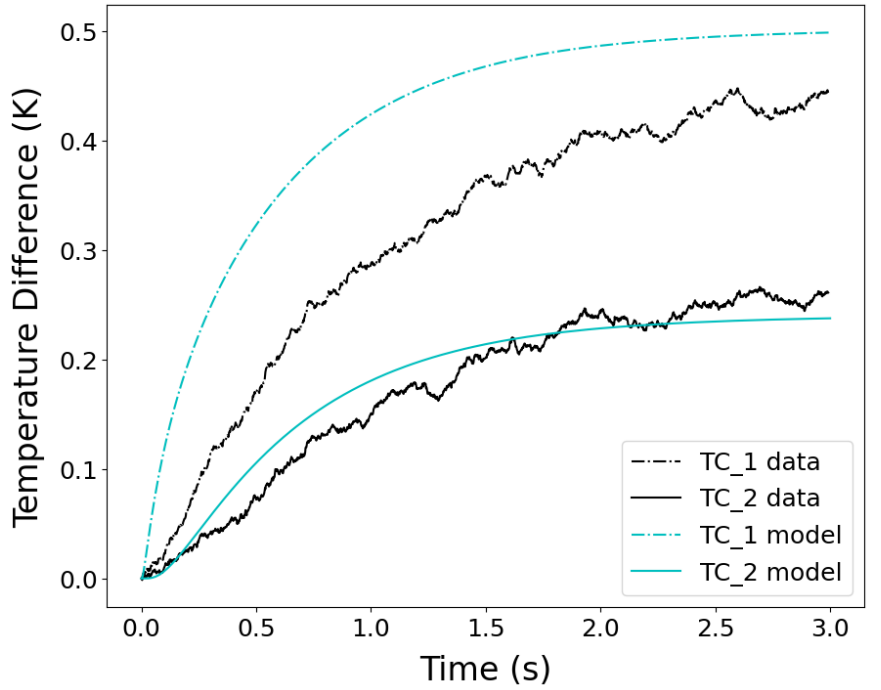


Frictional Heating Model

$$\dot{q} = \delta_E \mu \dot{\imath}$$



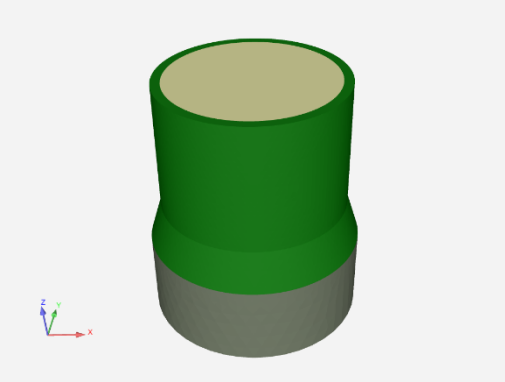


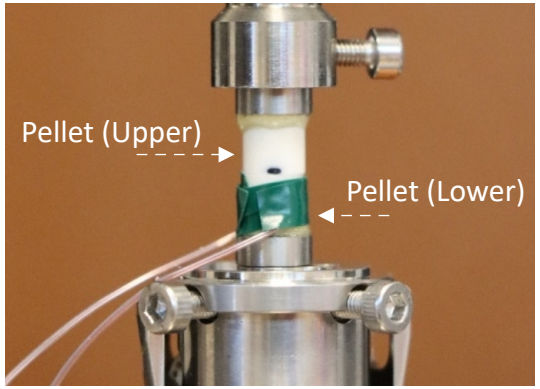


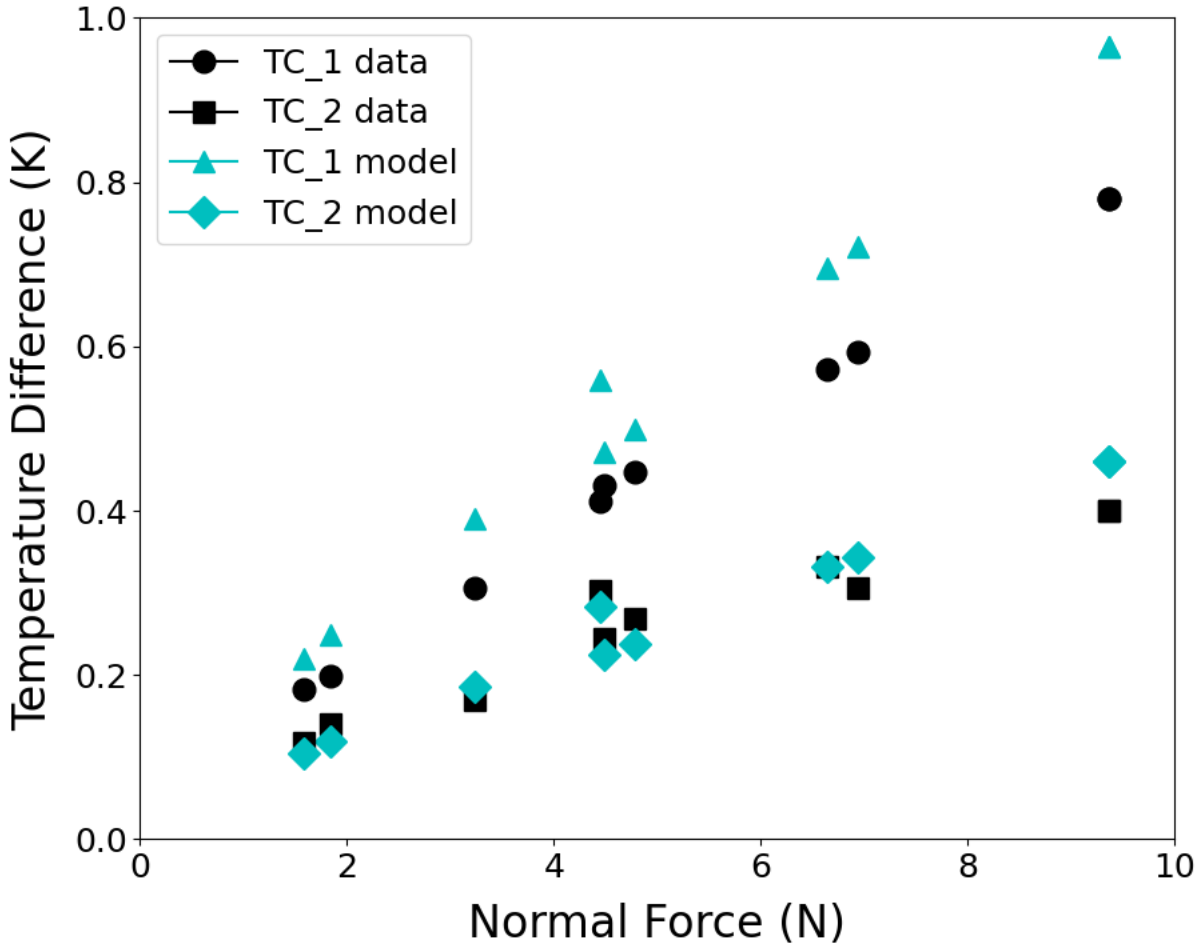
Frictional Heating Model

Takeaways:

- Linear global temperature rise with axial loading predicted by model
- Good match with experimental data considering the modeling uncertainties
  - E.g. properties of PVC tape, convection coefficient, small temperature rises
  - Tape geometry differences
  - Lumping of glue in with the tape







Conclusions

- Novel measurements of frictional heating generated by PBX 9501 sliding against itself
- Friction coefficient measurements
- Good agreement with thermal model and heat flux calculated from the measured friction coefficients
- Temperature rise is linear with respect to normal force—implies Coulomb friction is a good representation of behavior at these loads
- Data and insights useful for modeling frictional heating as a hot spot mechanism, and as continuum damage model inputs (friction along crack surfaces)

Acknowledgements

Experimental

- Hua Wang (rheometry expertise)
- Shane Snedigar (explosives test support)

Characterization

- Jason Phillips (microscopy)