# THERMOELECTRIC MEASUREMENTS OF SLIDING ASPERITY CONTACT FLASH TEMPERATURES*

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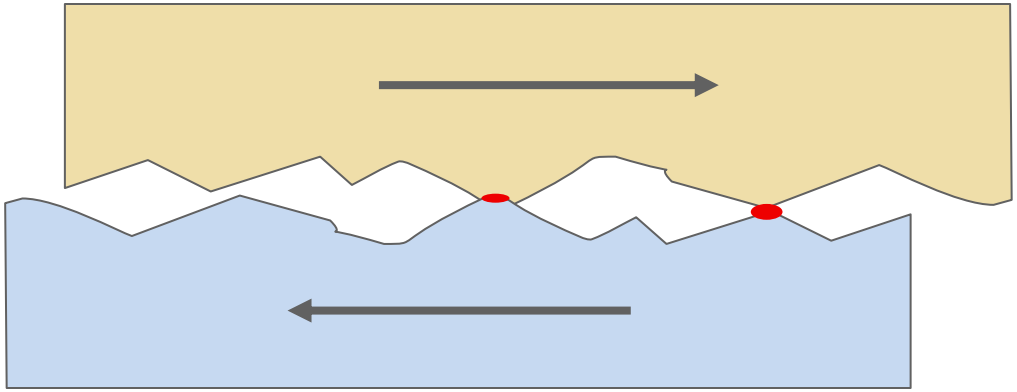
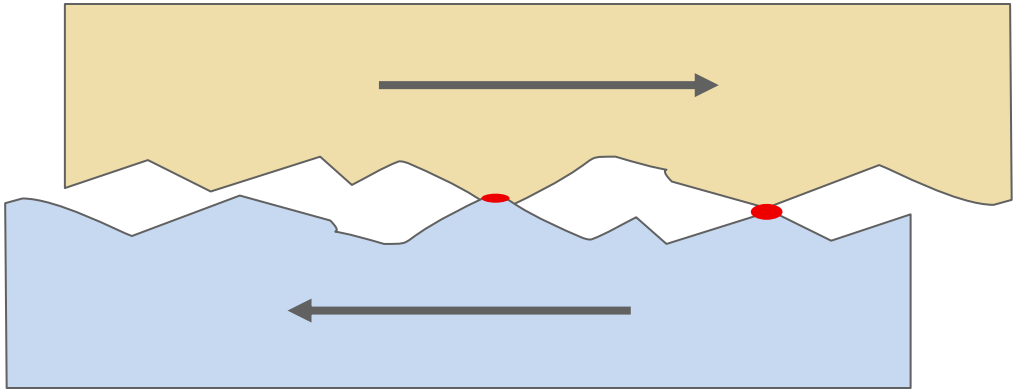
# Goal

- The temperature of sliding components is of essential importance for the understanding friction, wear, and the generation of chemical reaction films that may form in oil-lubricated systems.
- In boundary regime sliding, most of the load is carried by the surface asperities
- Real area of contact << apparent area of contact → high localized stress → large frictional heating
  - deformation of asperities can be plastic or elastic
- Temperature of microscopic asperities in area of sliding is difficult to measure
  - Brief
  - Localized



# Background

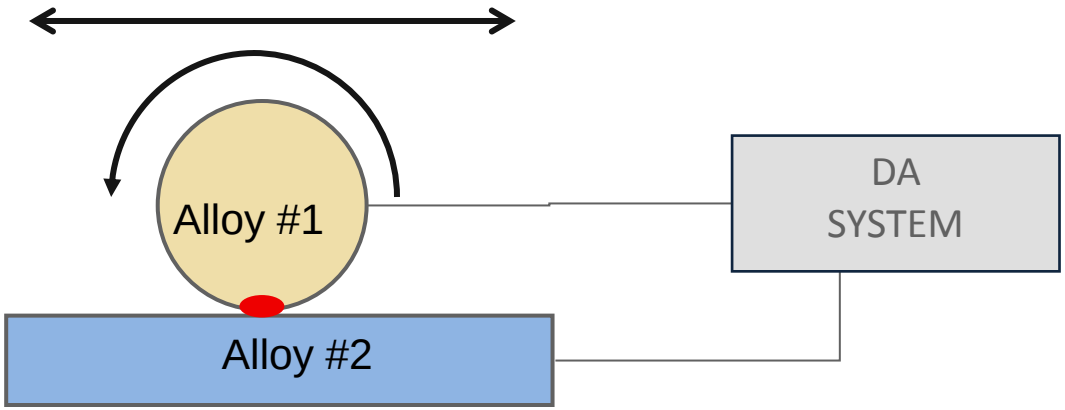
- Thermoelectric or “dynamic thermocouple” approach can be used to assess temperature of the sliding contact
- Makes use of electric potential generated when dissimilar metals are in contact with each other at elevated temperature: thermocouple junction
- Electric potential generated only at point of touching tips of asperities - essentially instantaneous response time
- *Indicated temperature is average of all asperities in contact at any specific moment*
- Data acquisition system continuously  measure  temperatures directly with several degree accuracy



# Experiment

- Part 1 : low speed reciprocating measurements (strip on plate)
- Part 2: high speed rotating measurements (block-on-ring)

- For this work, type K, “Chromel-Alumel™” (Ni90%/Cr10%-Ni95%/Al2%/Mn2%/Si1%) metals are available in bulk form



# Background

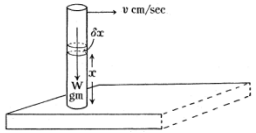
Temperature rise above ambient, ΔT, during sliding is a function of geometry and material's thermal and mechanical properties

Most models find $\Delta T_a$ proportional to

$$\frac{\mu * \text{relative speed} * \text{load}}{\text{real area of contact}}$$

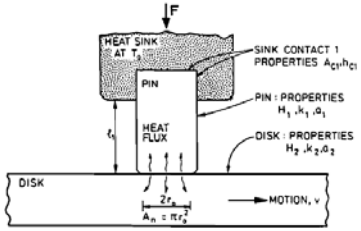
Bulk (Bowden[1])

$$T - T_0 = \frac{\alpha \mu W g v}{J \cdot \pi r} \sqrt{\frac{1}{2\sigma k r}}$$




Flash (Ashby[2])

$$T_f - T_b' = \frac{\mu F v}{A_r}\left[\frac{1}{\frac{k_1}{l_{1f}} + \frac{k_2}{l_{2f}}}\right]$$

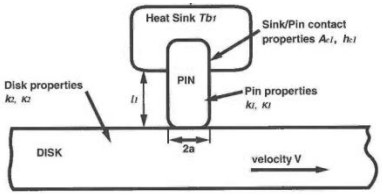



Flash (Gesim[3])

$$T_{s,av} = T_B + 1.064 \frac{F(V_C - V_T)}{A_a} \frac{\sqrt{a}}{b_C\sqrt{V_C} + b_T\sqrt{V_T}}$$

Flash (Kennedy[4])

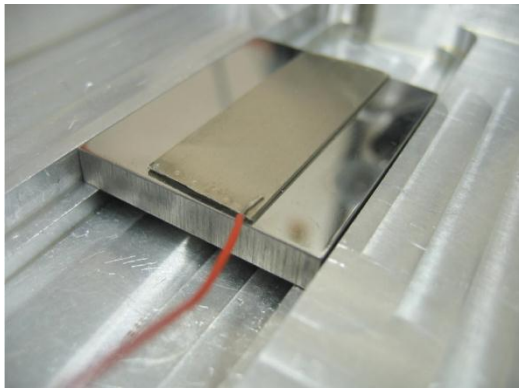
$$T_{c\,max} = \frac{1.31 a \mu \bar{p} U}{\sqrt{\pi}\left[k_1\sqrt{(1.2344 + Pe_1)} + k_2\sqrt{(1.2344 + Pe_2)}\right]}$$



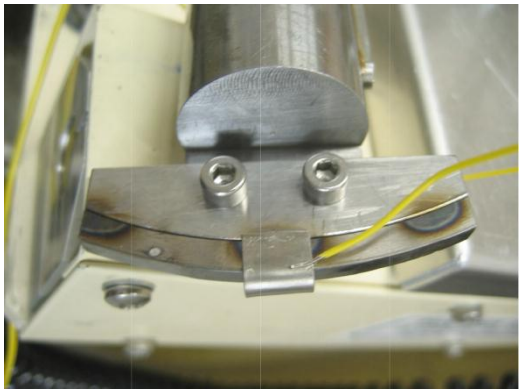


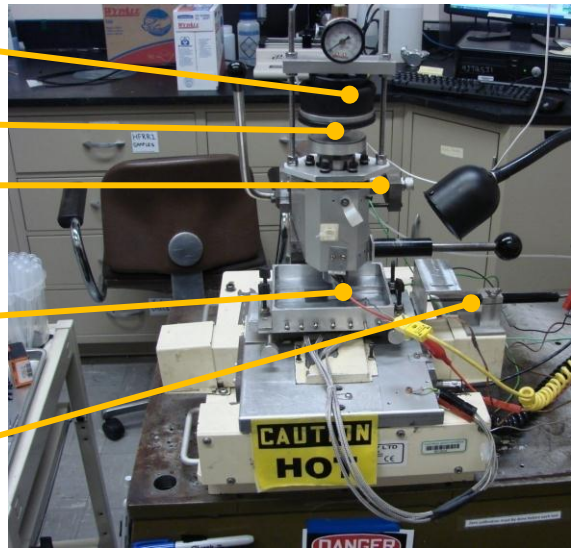
1. F. P. Bowden, and K. E, W. Ridler, Proc. R. Soc. Lond. A 1936 154, 640-656
2. M. F. Ashby, J. Abulawi & H. S. Kong, Tribol. Trans., 34:4, 577-587
3. B. A. Gecim, Tribol. Trans., 35:2, 225-234
4. F. E. Kennedy, in Mod. Tribol. Hbk., B. Bhushan ed, 2000, 235-271

# Low-speed reciprocating



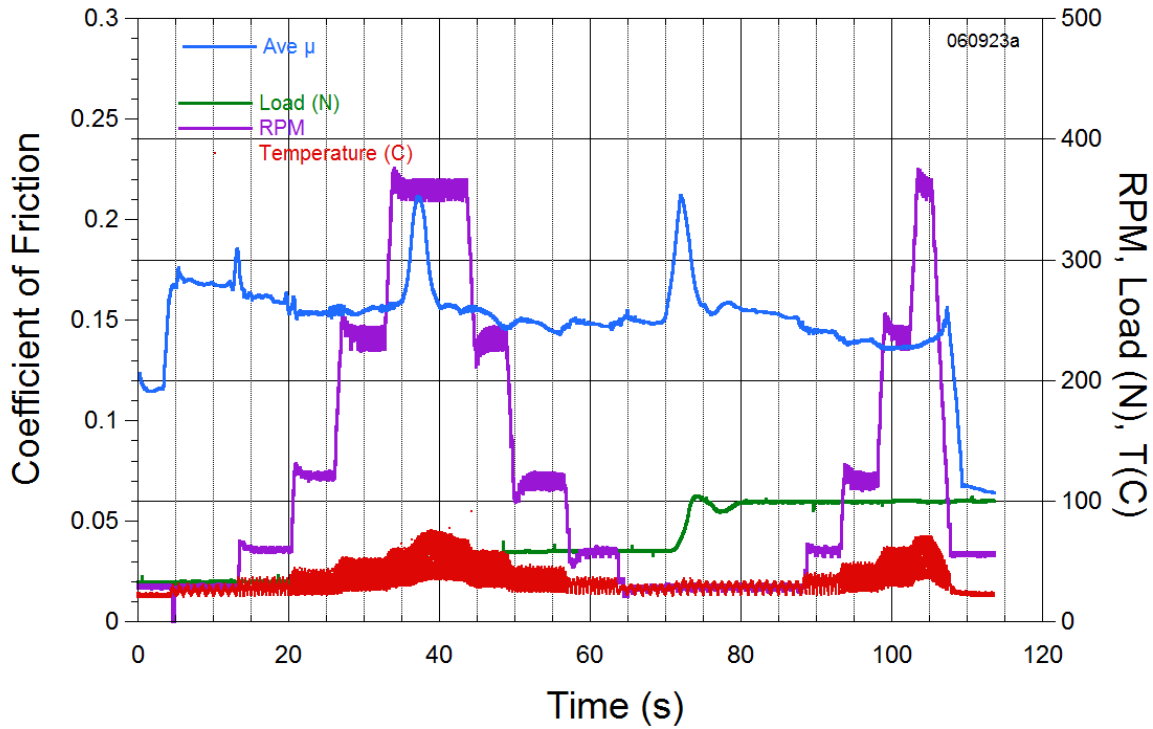
- Alumel™ strip was spot welded to flat
- Chromel ™ strip was spot welded to jig
- Electrical insulation needed to reduce 60 Hz noise
- Data acquired at 500 sample/s
- 1” stroke
- Thermoelectric potential was measured by DA system and converted to °C





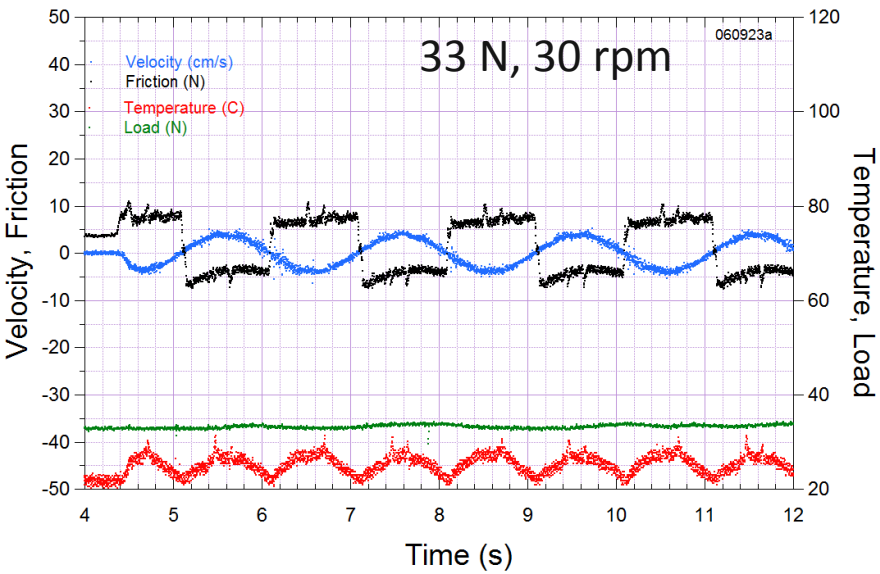
# Low-speed reciprocating

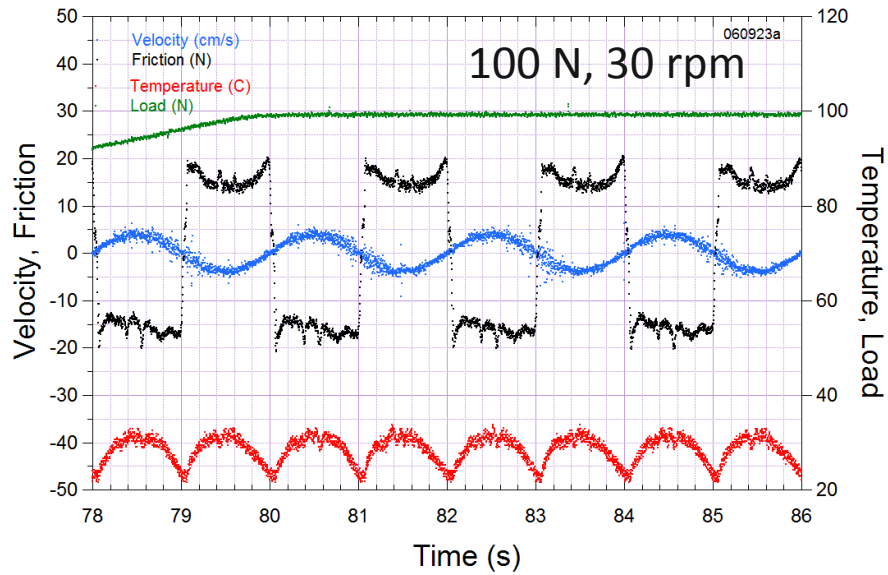
- Experimental conditions for first tests
  - Sliding was done in SAE 10w30 fully formulated motor oil
  - Normal load < 100 N to avoid scuffing of nickel-based materials
  - 22°C at start of test and returned to 22°C after test



# Low-speed reciprocating

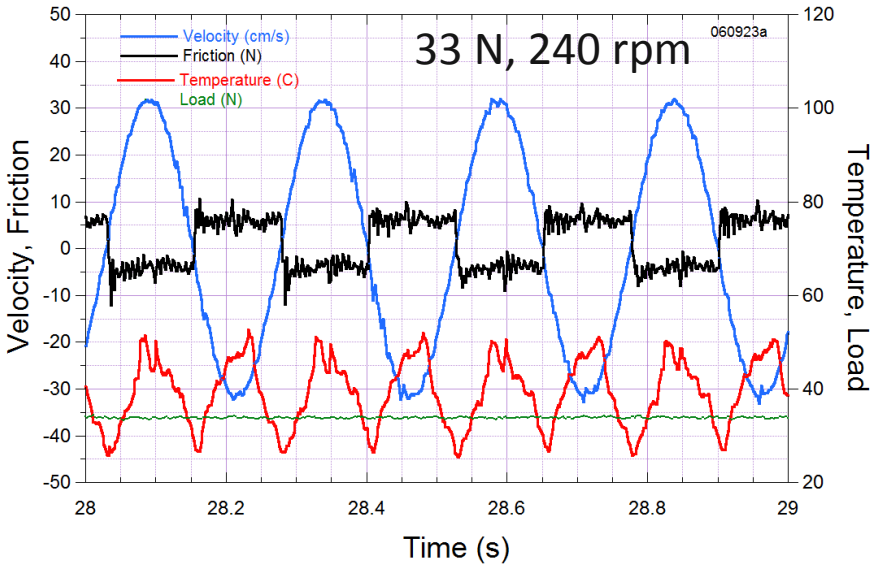
- Expanding graph at a load of 33 N, 30 rpm, temperature rises were a few degrees above RT during sliding in each direction
- At a load of 100 N, 30 rpm, ΔT is still small, but friction is much larger

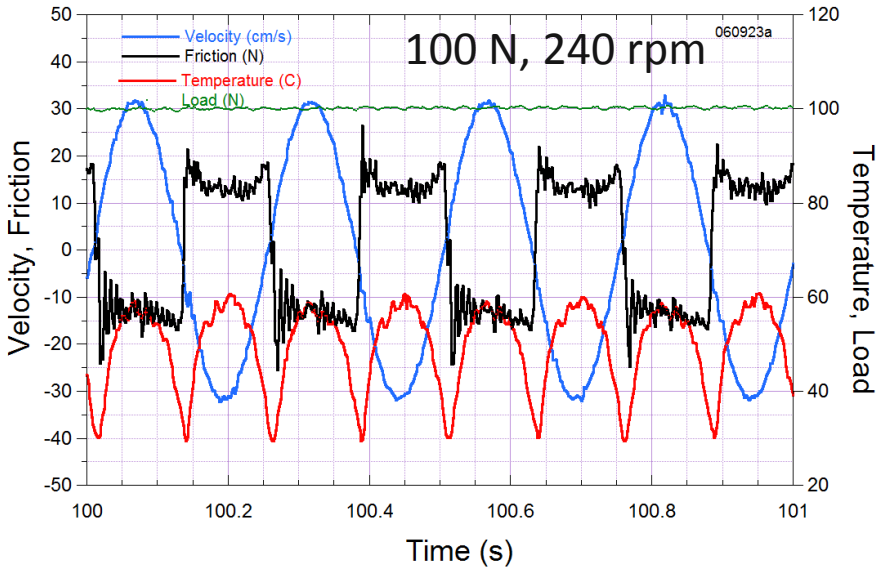


# Low-speed reciprocating

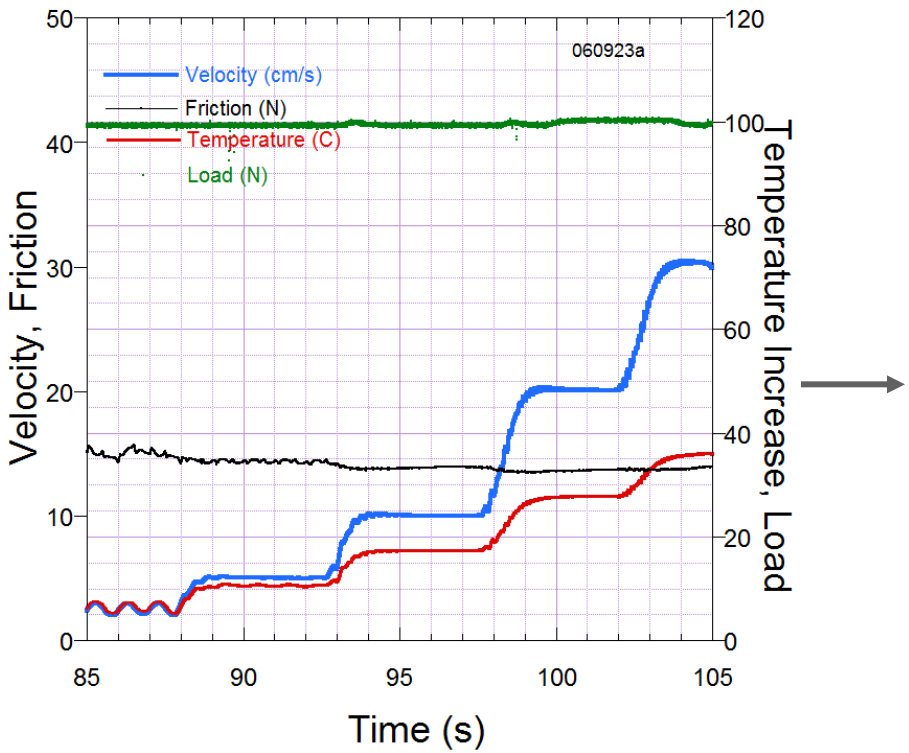
- At a load of 33 N, 240 rpm, ΔT is much larger than at 30 rpm
- Repeatable fine details in ΔT from cycle to cycle due to variations in surface topography

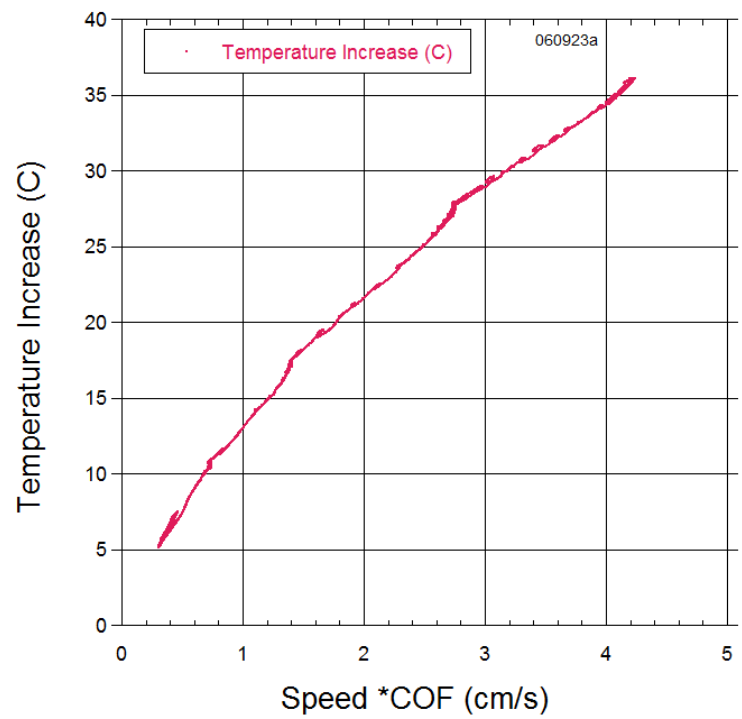


# Low-speed reciprocating

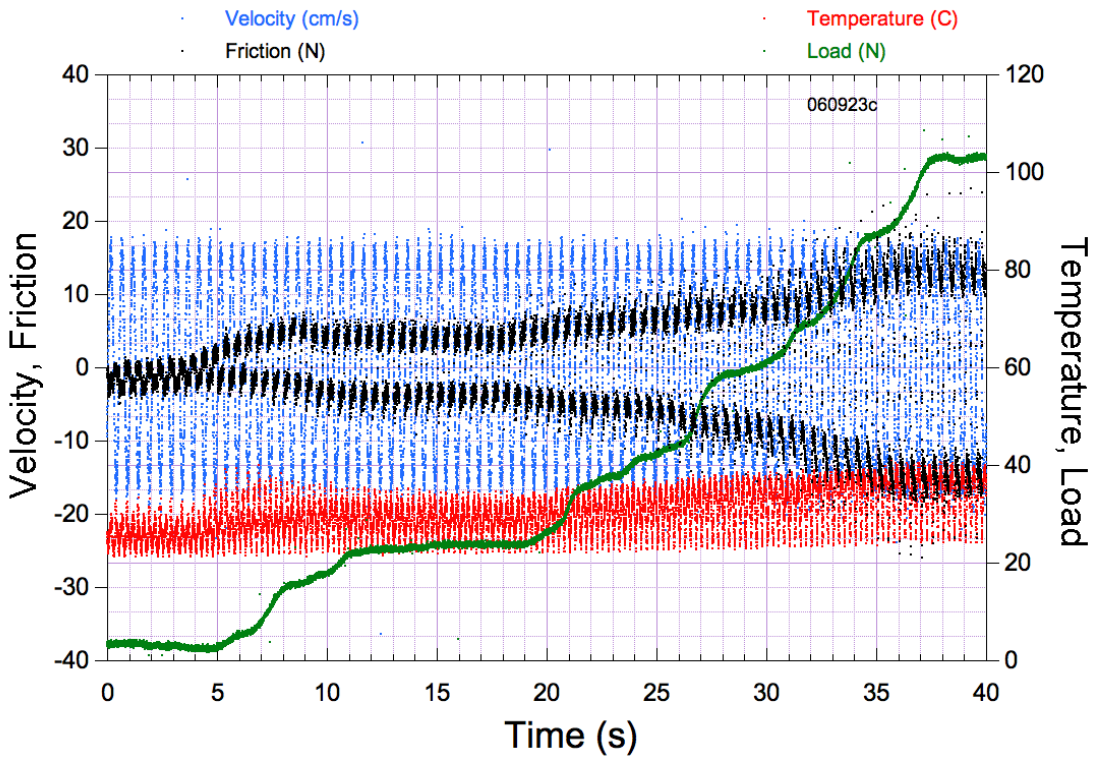
- $\Delta T_a$ as function of average speed * COF is graphed and behavior is less than linear



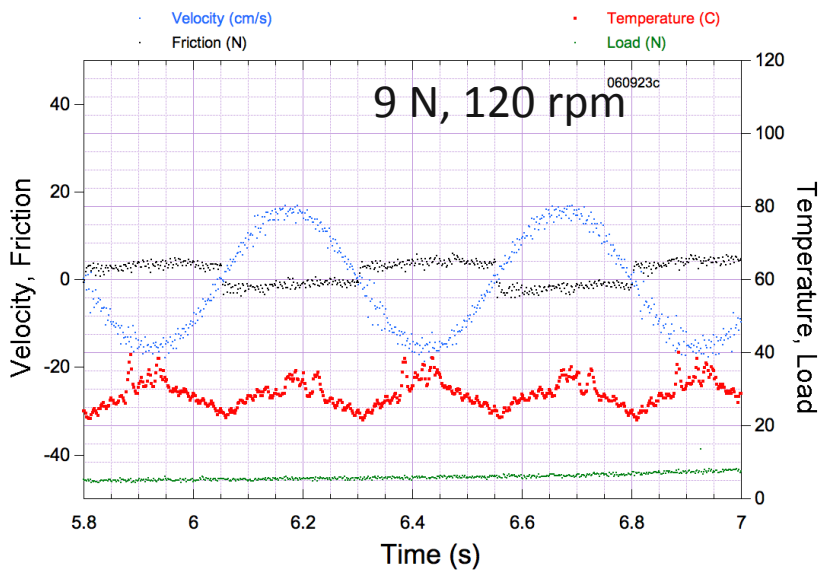
# Low-speed reciprocating

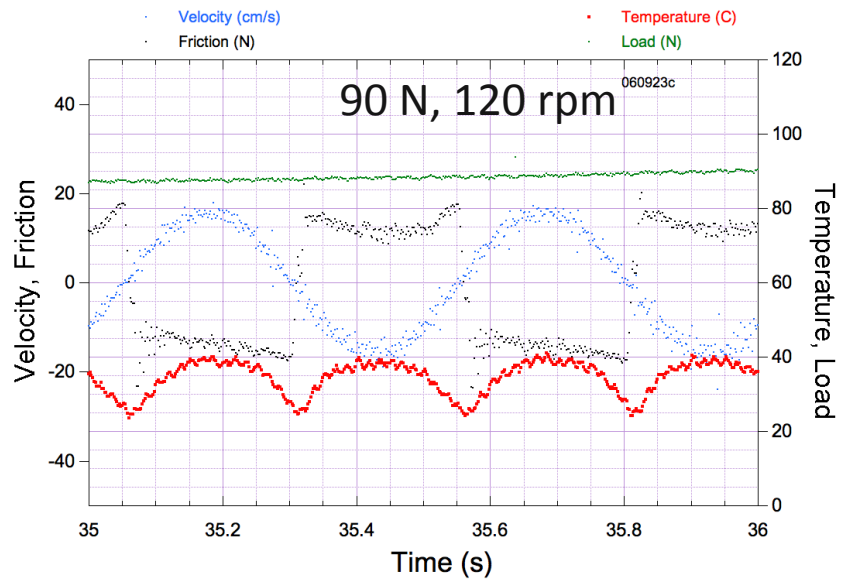
- A test was performed  at constant 120 RPM with increasing normal load to examine load dependence, for load from 4 N to 105 N
- Small increase ΔT for large increase in load



# Low-speed reciprocating

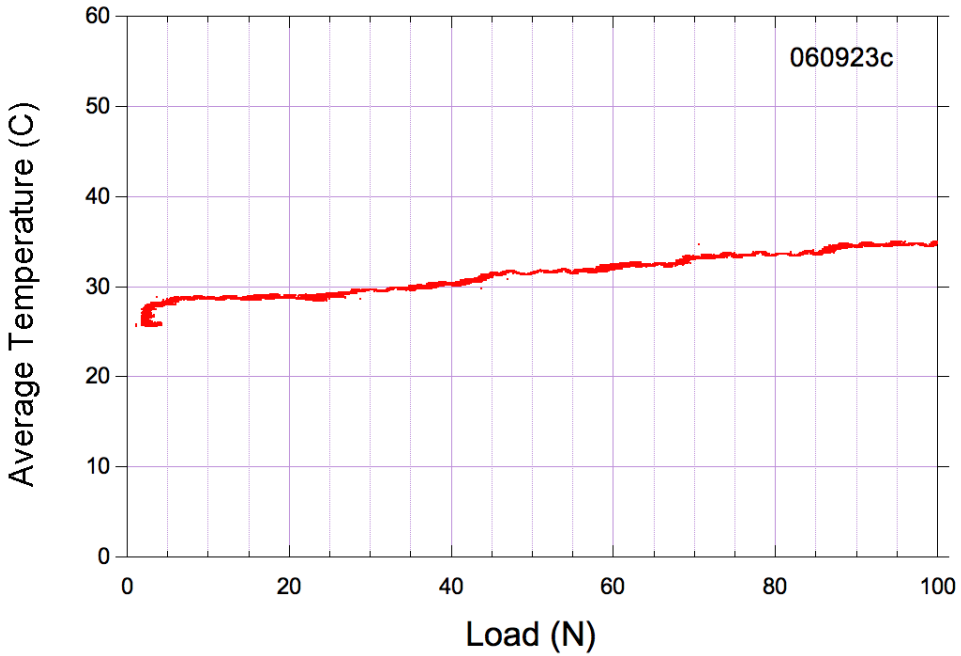
- Instantaneous temperature rise at 9 N and 90 N are different in shape but not extremely different in magnitude
- Friction waveforms are similar
- Peak temperatures at center of stroke are similar



# Low-speed reciprocating

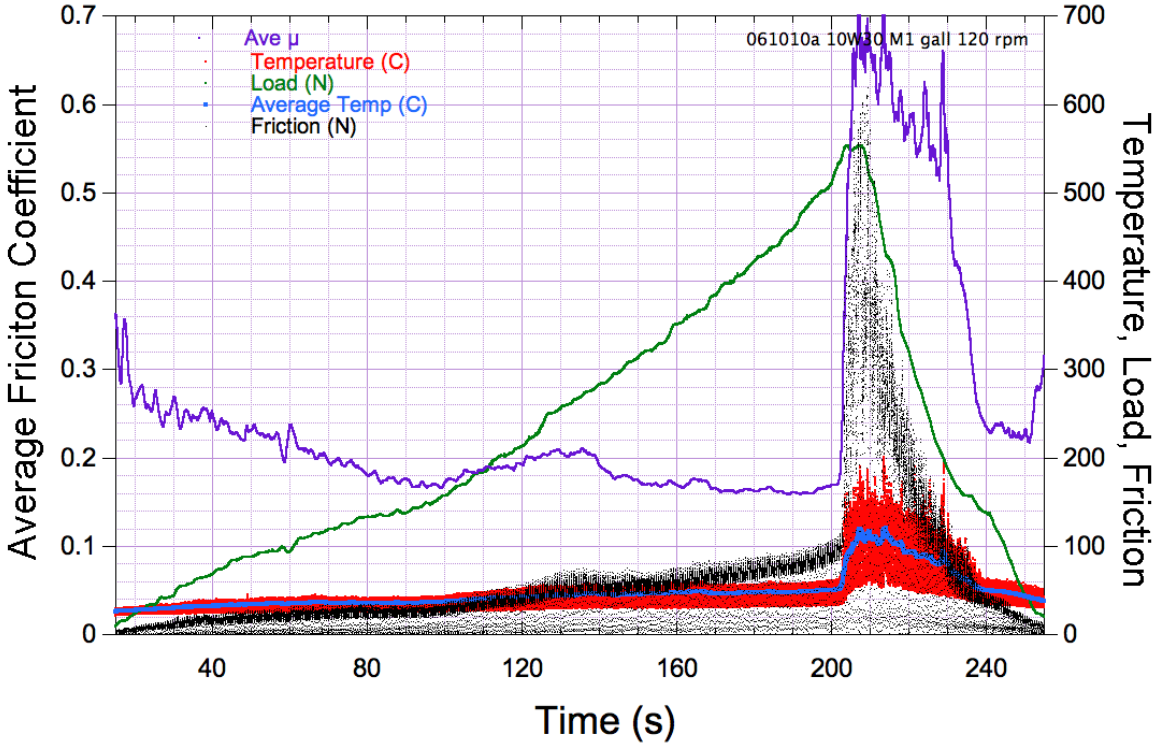
- $\Delta T_a$ is weak function of load for 25:1 change in applied load
  - Bulk heating
  - Real area of contact reasonably proportional to load




- …what about dependence of $\Delta T_a$ on coefficient of friction?

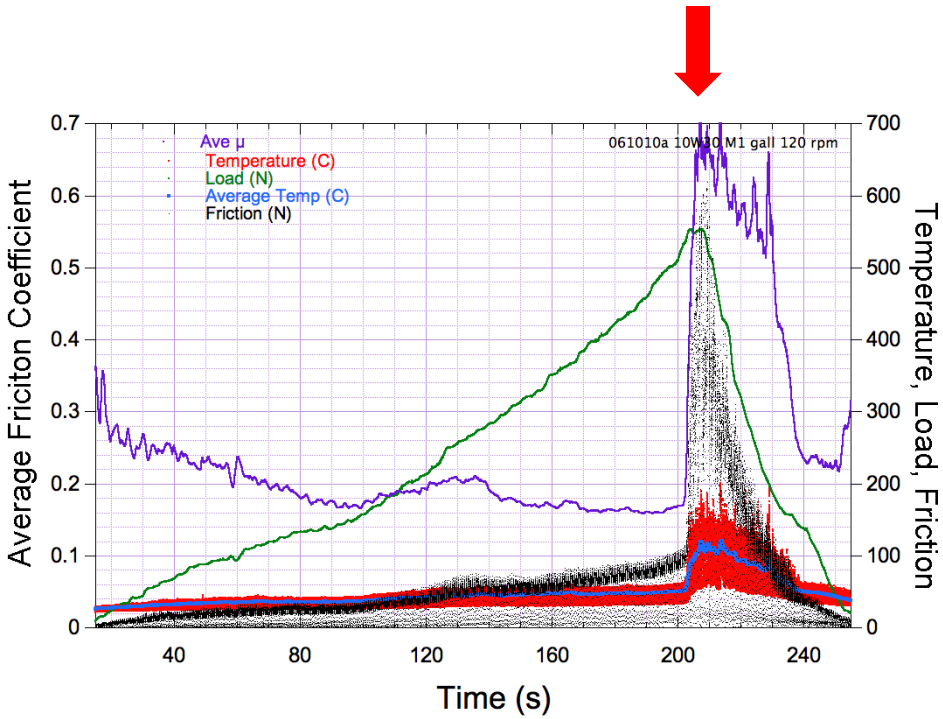
# Low-speed reciprocating

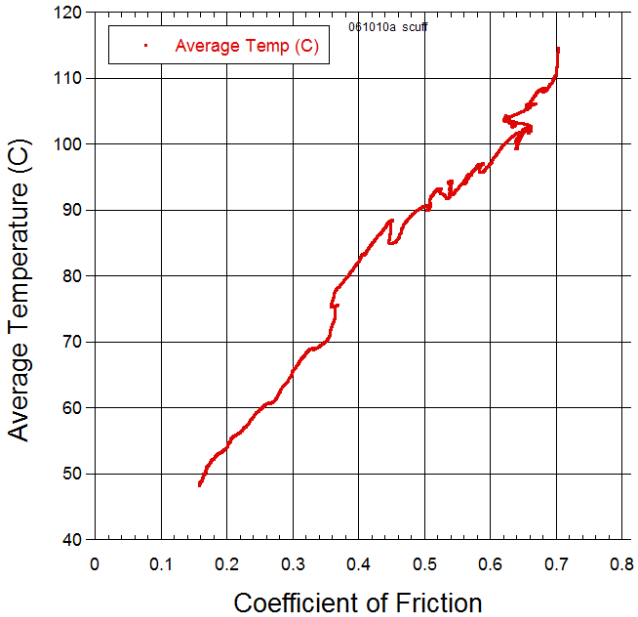
- At steady 120 rpm, load was increased to induce scuffing
- Large jump in μ and ΔT at 550 N, and load was ramped down to prevent specimen destruction



# Low-speed reciprocating

- Transition at 200 s can be used to test relationship between sliding parameters and ΔT caused by change in μ while holding sliding speed and load relatively constant, showing $\Delta T_a$ proportional to μ

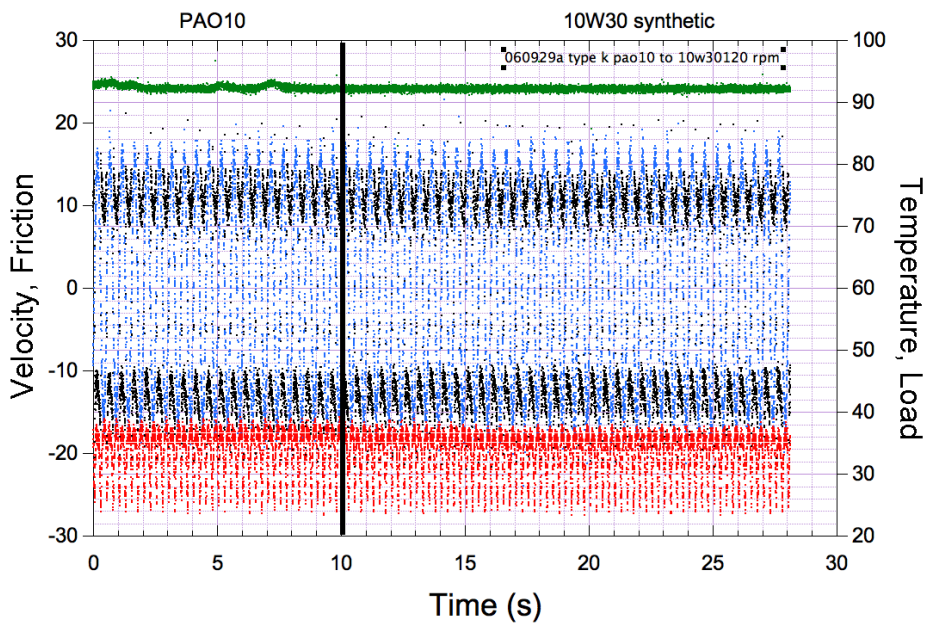


# Low-speed reciprocating

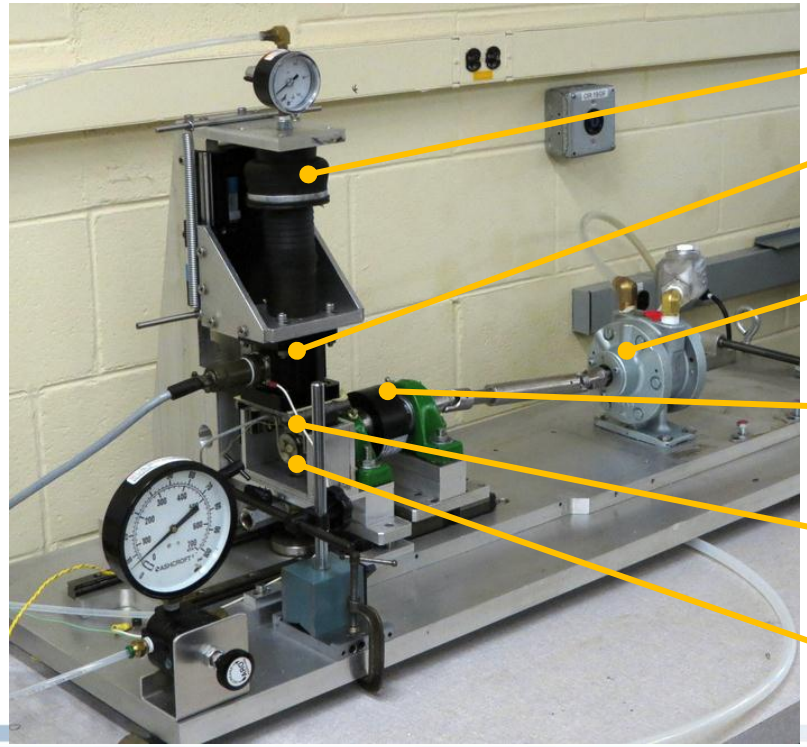
- What effect do changes in lubricating fluid have on $\Delta T_a$ ?
- Unadditized PAO basestock oil was changed to fully formulated oil by flooding the sliding contact
  - No obvious change in $\Delta T_a$ or $\Delta T_p$ or COF
  - F *V → Power → heat

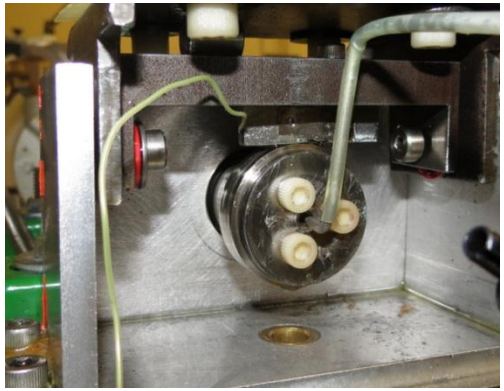
Basestock Fully formulated



# High speed rotation

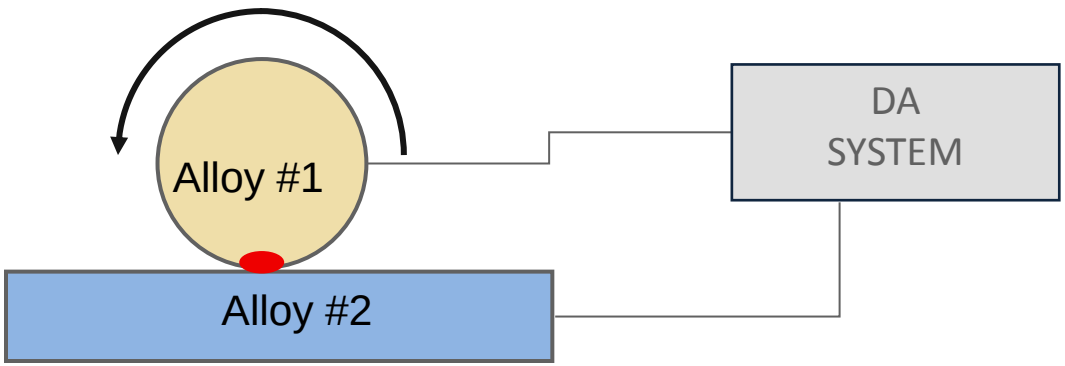
- "Block on Ring" test machine modified to enable "dynamic thermocouple" measurements
- Air motor, preamplifier, and insulators needed to reduce electrical interference
- Alumel™ ring, Chromel™ block
- Rotating center voltage pickup
- 2,600 rpm → 480 cm/s sliding speed
- 50,000 samples/s  typical



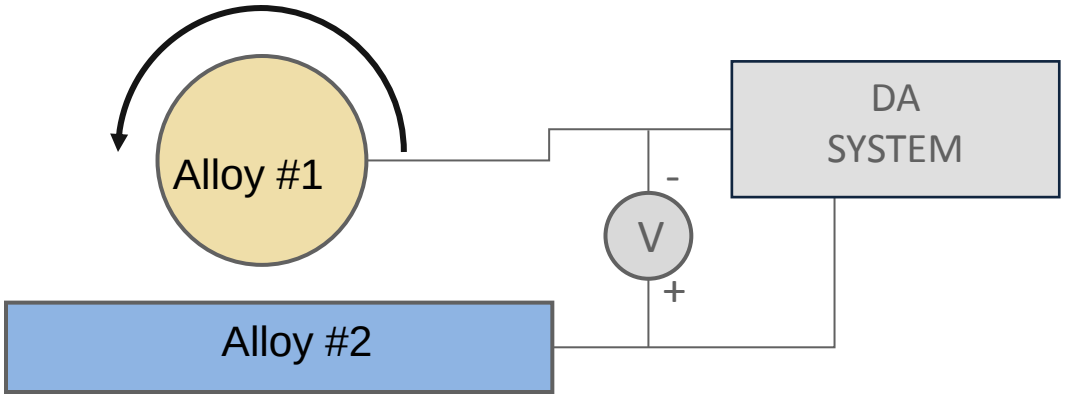
# High speed rotation

- Ni-base materials have poor tribological durability and are prone to rapid surface damage at high sliding speed
  - Polyalphalolefin (10) basestock oil for some tests
  - Run-to-scuff tests required 70W-90 gear oil
  - Controllable load/speed tests required SAE 10w30 fully formulated engine oil to prevent damage



# High speed rotation

- At high speeds surfaces may become momentarily separated
  - Temperature → RT
- Continuity detection added

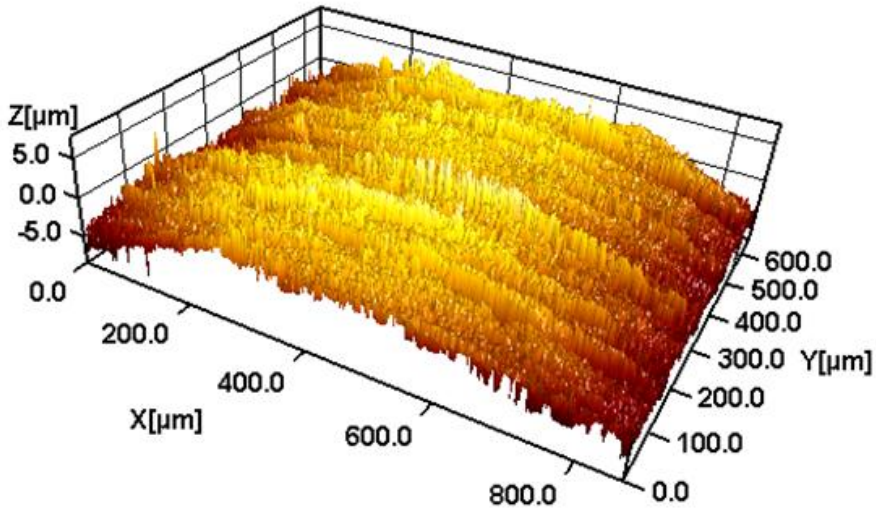



Contact: T → T

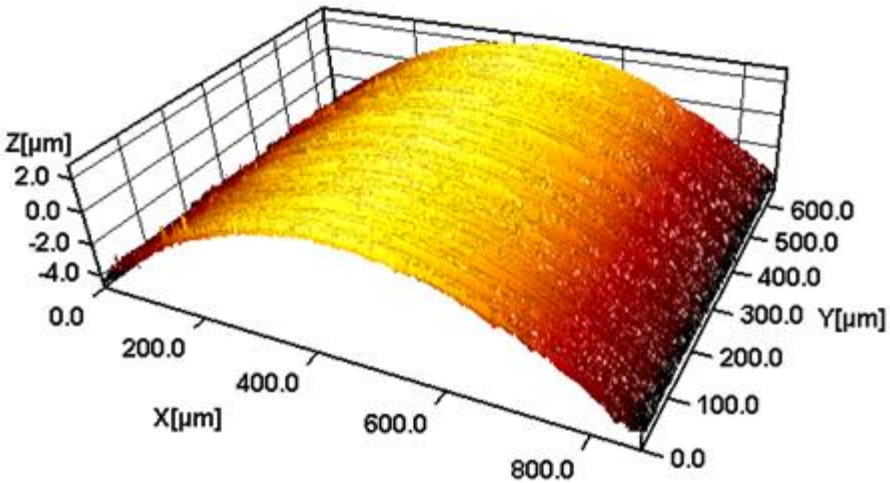
Open: negative temperature (masked in software)

# High speed rotation

- Polishing before testing




Sa=1483 nm Sq=1808 nm



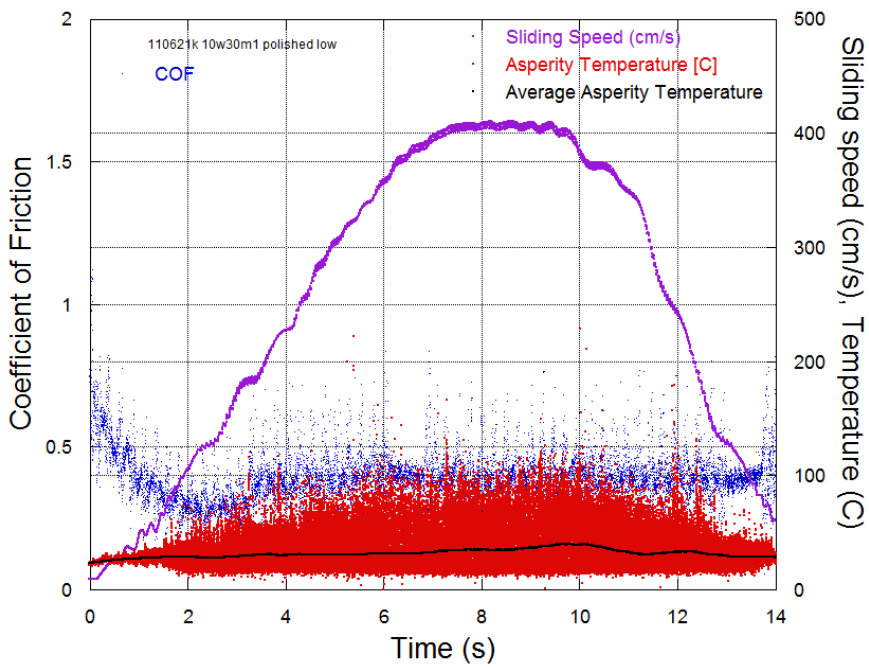

Sa=144 nm Sq=181 nm

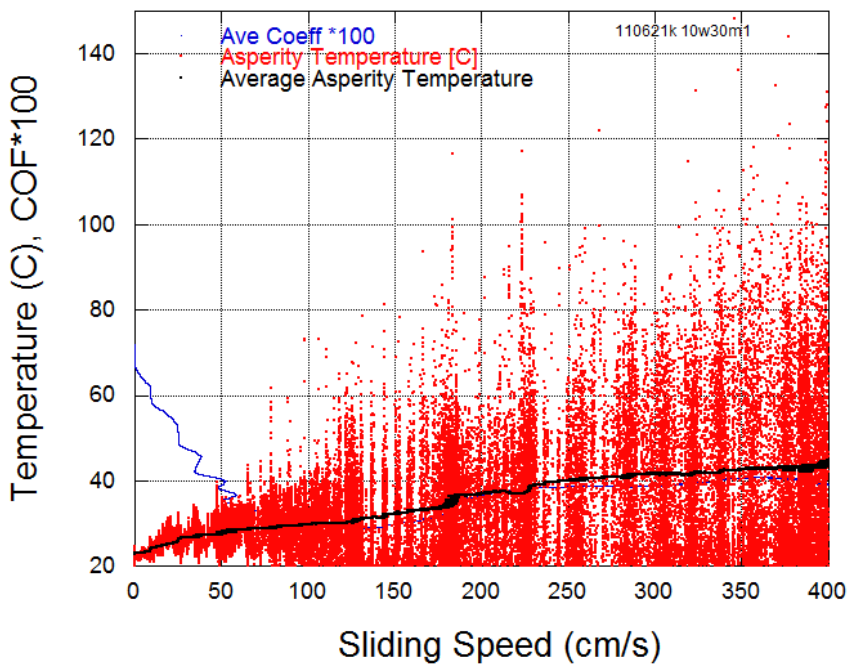
120 grit dry

1200 grit in oil

# High speed rotation

- Light 13 load, smooth polished block and ring,

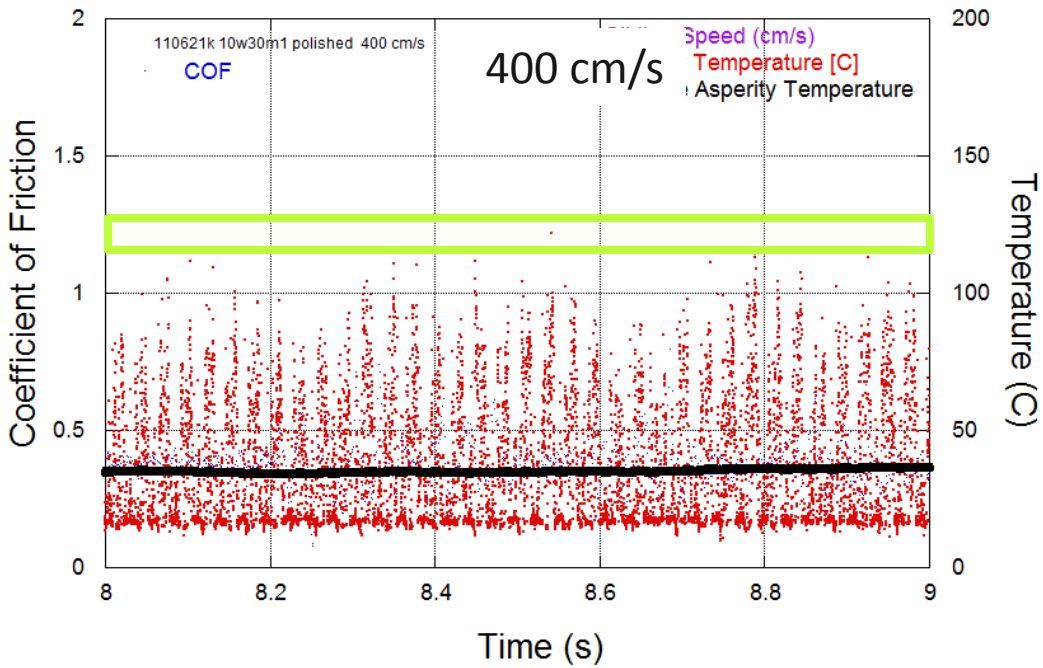



13 N load 0-400-0 cm/s test

# Reciprocating vs unidirectional

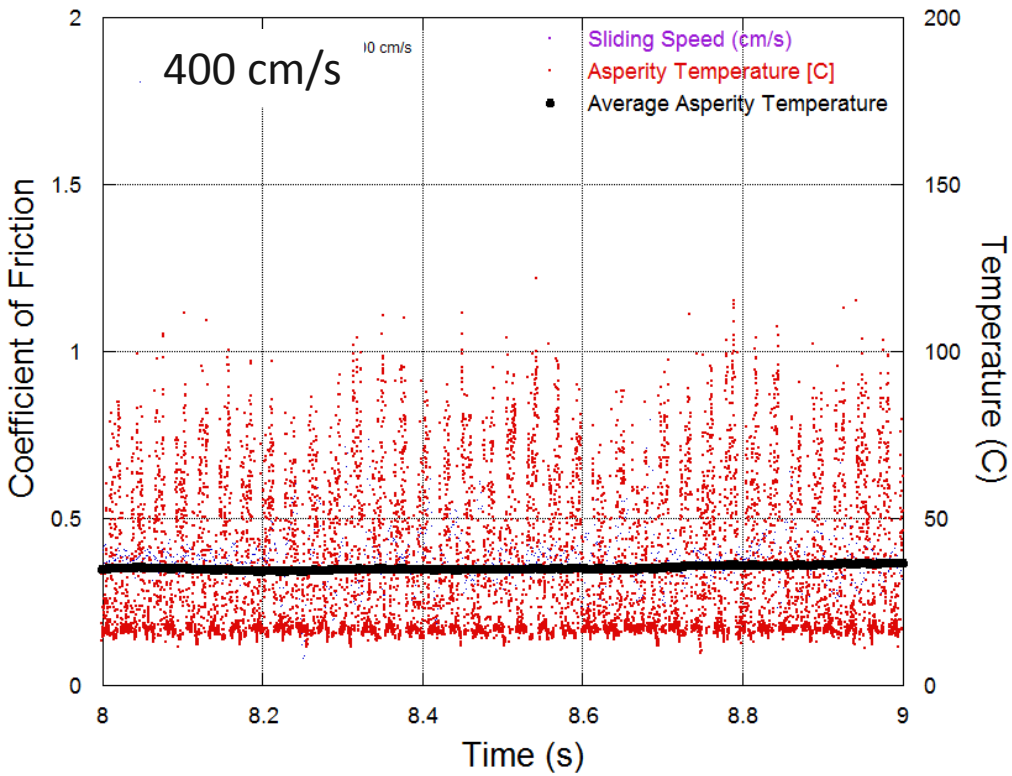
- Average flash temperature vs peak flash temperature
- Spectrum of measured asperity temperatures
  - Wide range of actual asperity temperatures (25-110 C)
  - Multiple asperity contacts, 1, 2…..,10, ???

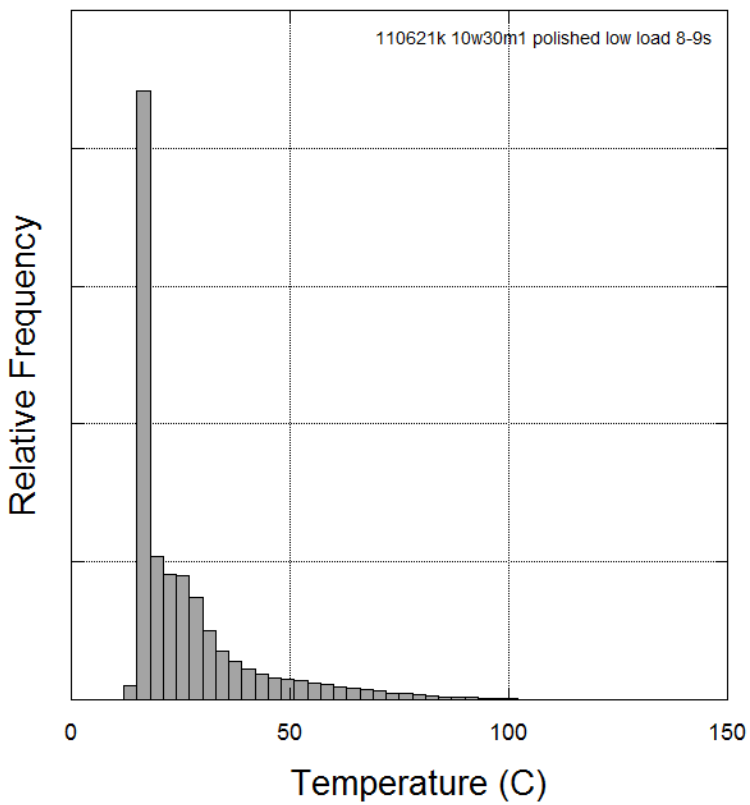



Rotating – constant speed

# Histograml

- Histogram gives picture of range of measured temperatures

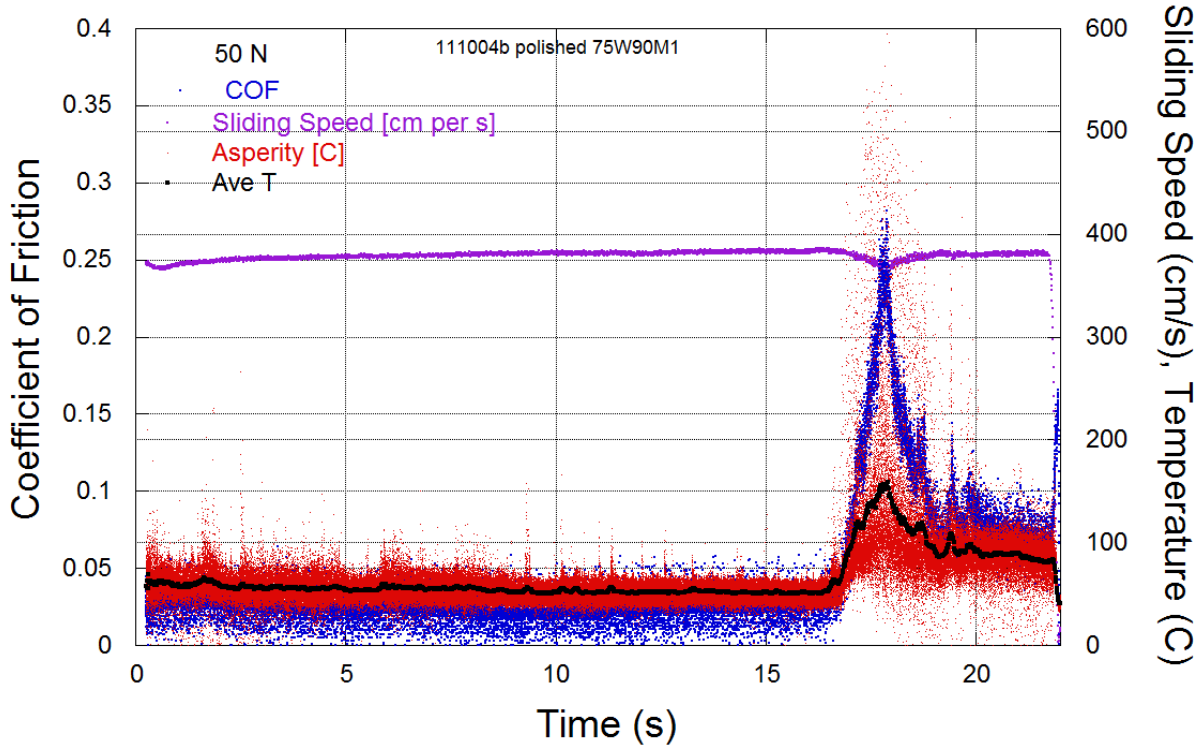


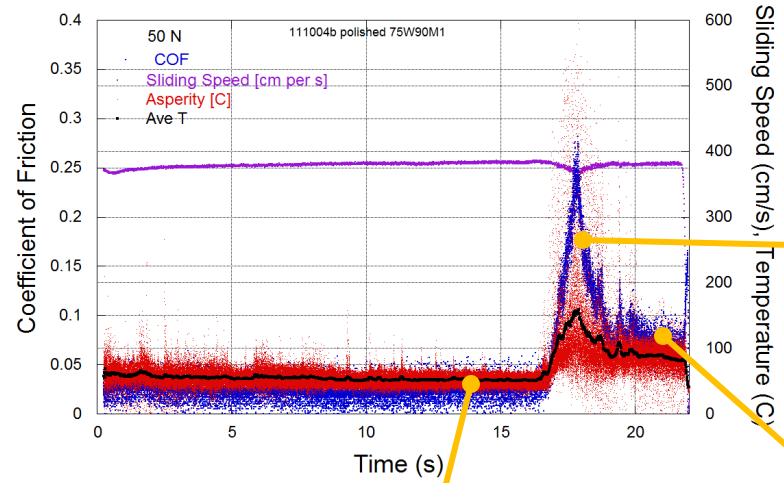
# High speed rotation

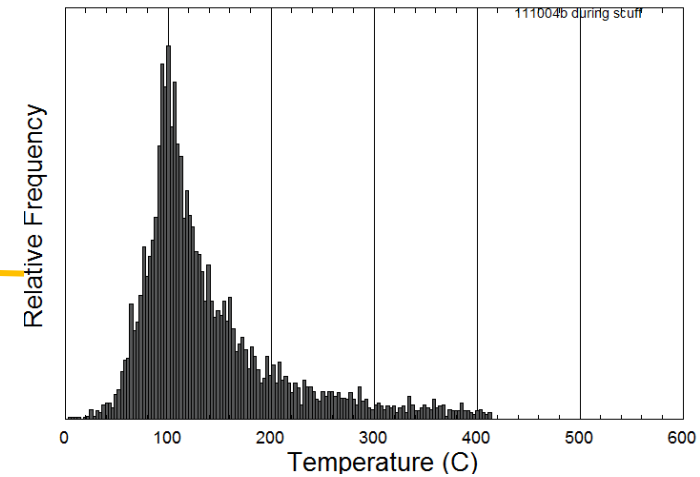
- How can coefficient of friction be varied while keeping speed and load constant?

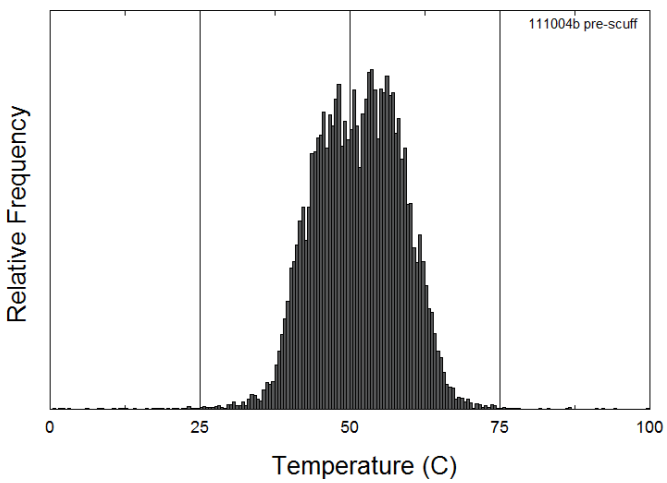
Run to scuff test using 50 N, SAE 70W90

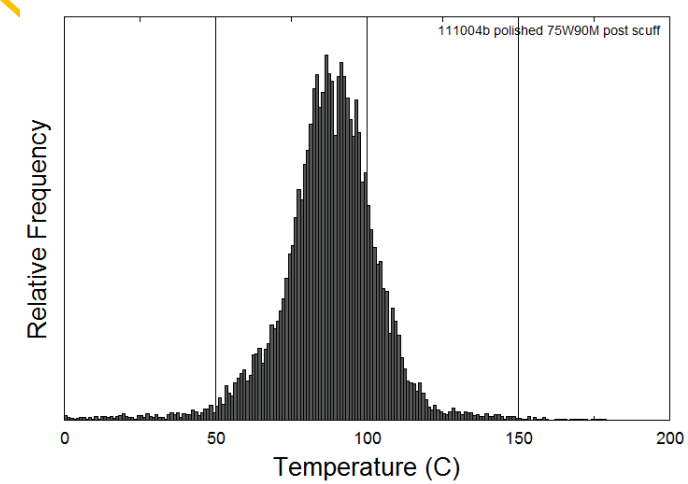


# High speed rotation



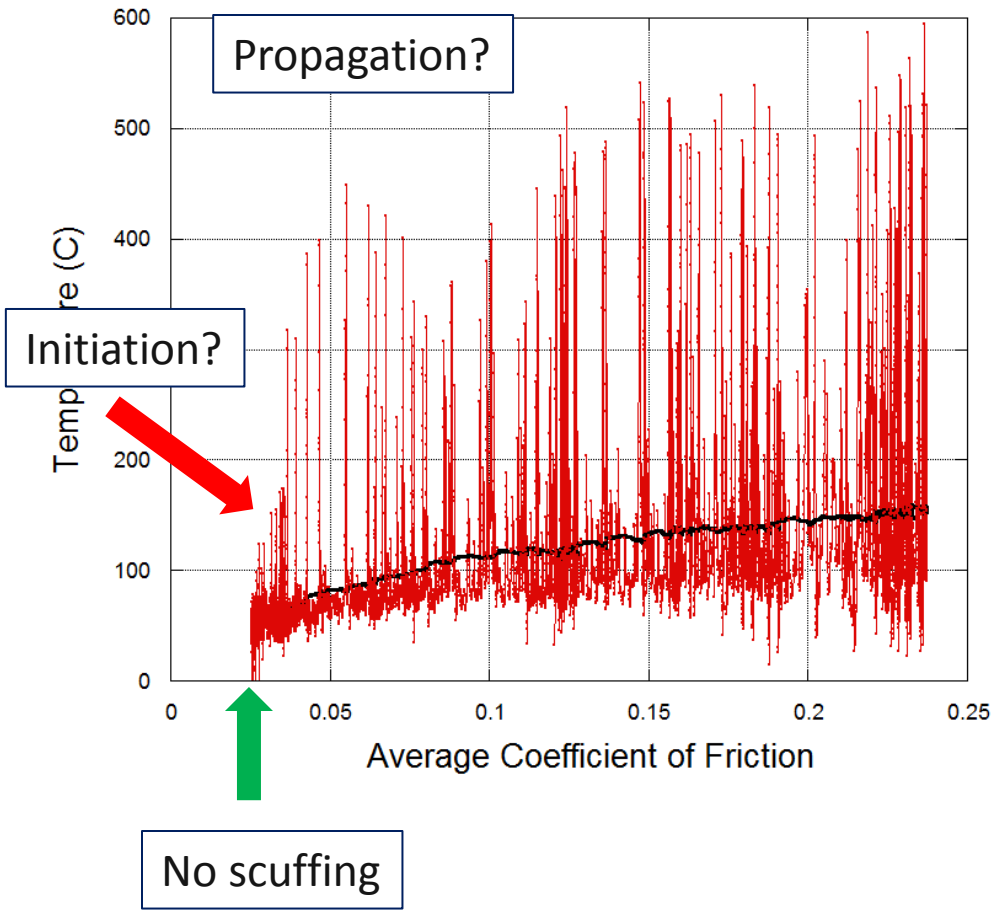



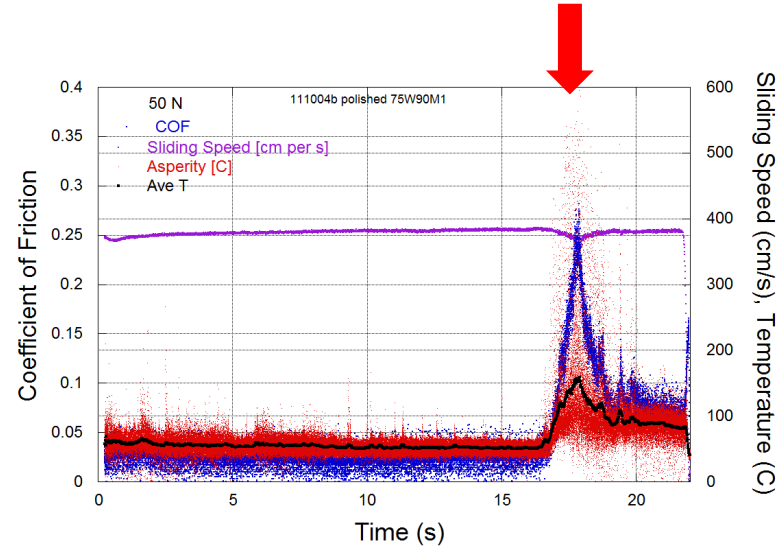



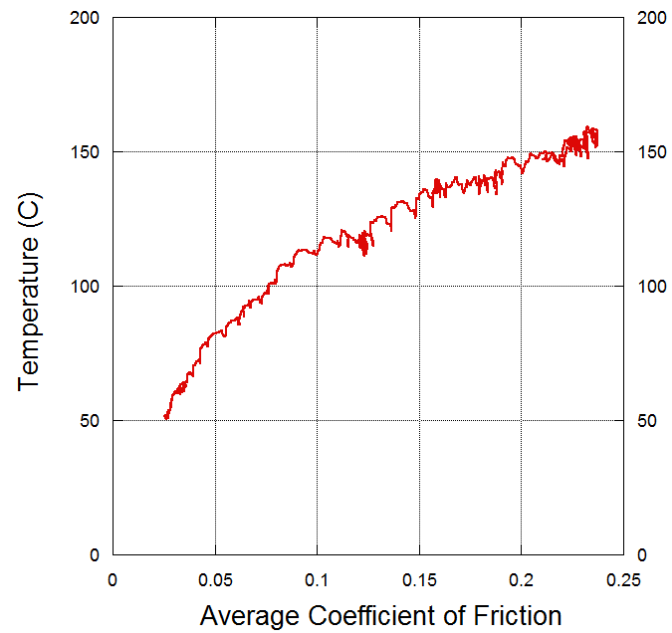

$\Delta T_a \neq \Delta T_p$

# High speed rotation

Detail of scuffing event

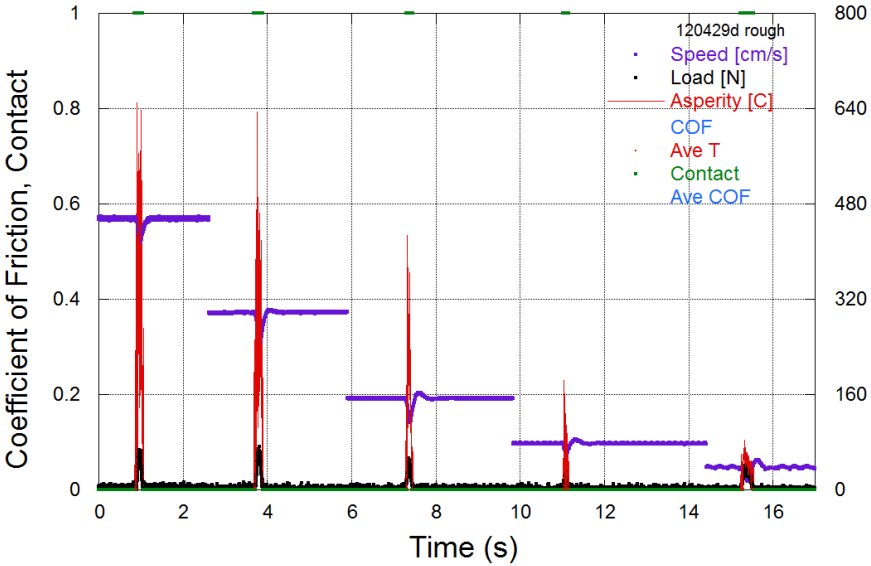


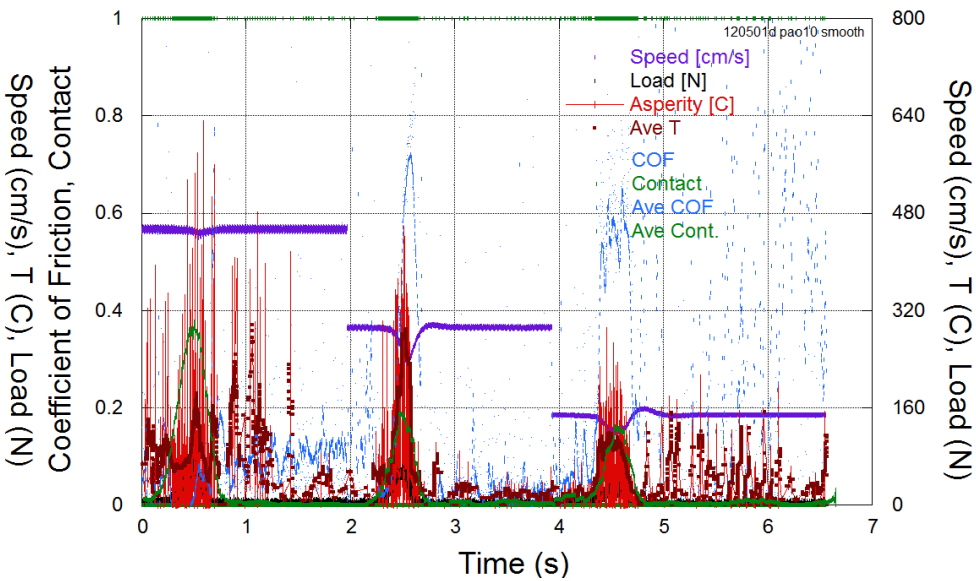



# High speed rotation

Polyalphaolefin 10 base stock



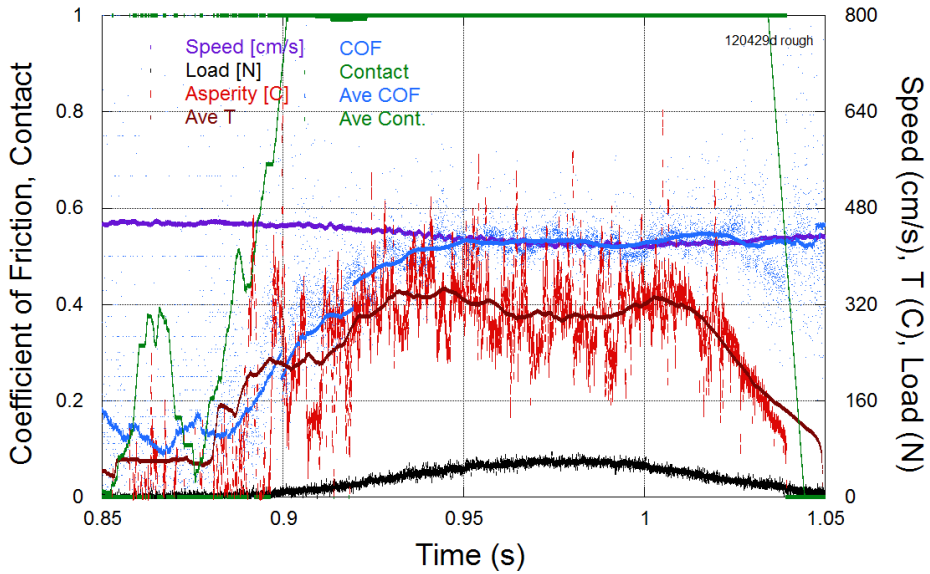

Initially rough surface

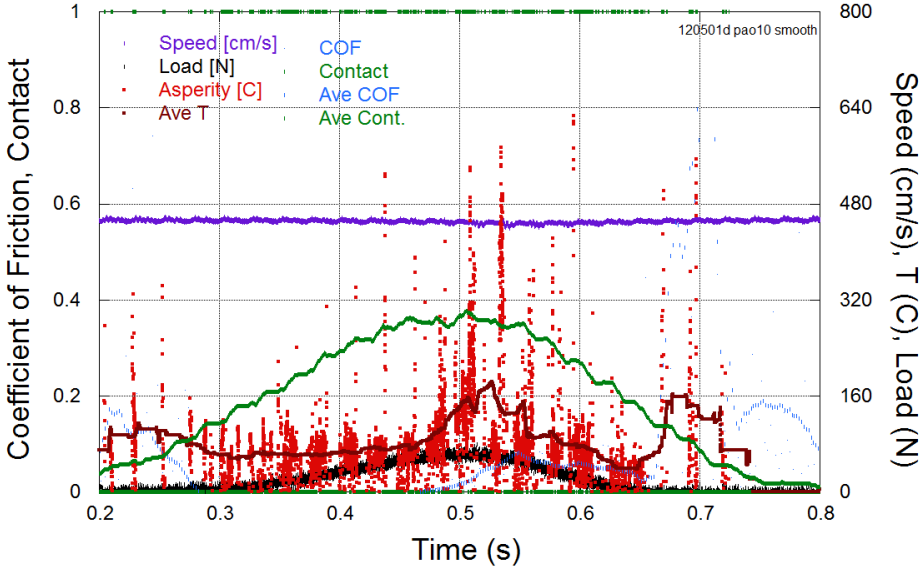


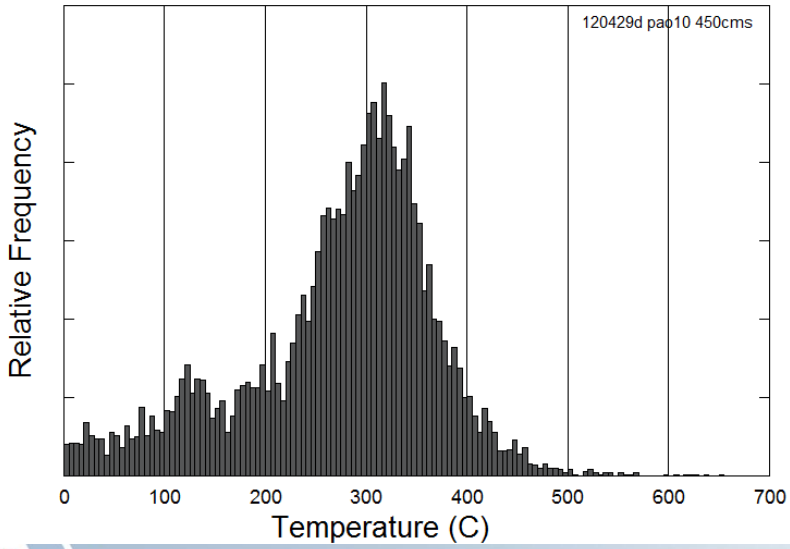

Initially smooth surface

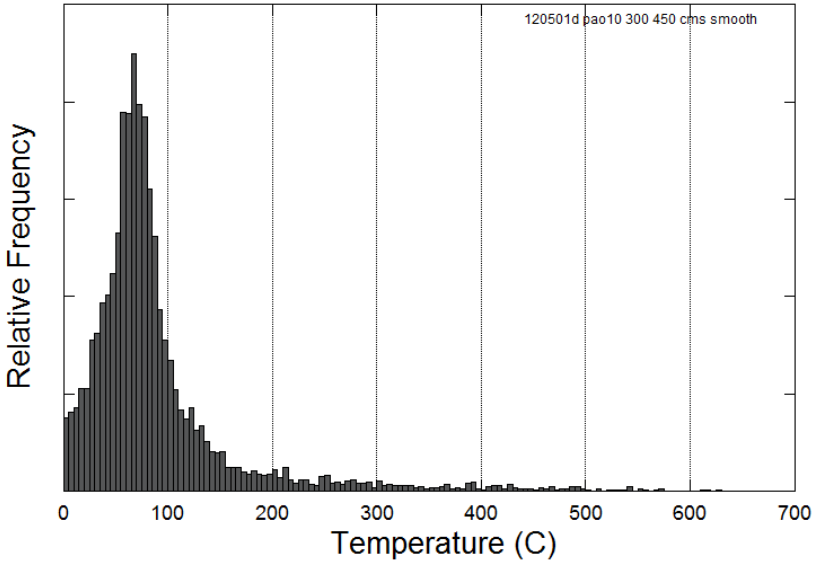
# High speed rotation

- Rough compared to smooth



# Summary

- A thermoelectric method was used to measure “flash” temperature rise in a variety of sliding conditions
- The *distribution* of measured temperatures depended greatly on the sliding conditions
- $\Delta T_a$ was a strong function of sliding speed – nearly linear, for the conditions studied
- Surface contact heating was a weak function of load in all cases
- Surface contact heating was strong function of coefficient of friction - not linear
- The type of oil appeared to have little direct influence on asperity temperatures, but only secondarily as lubricant influenced sliding regime: mild wear, severe wear, or scuffing
- High rate temperature measurement may offer a means, in parallel to low rate friction force monitoring, to understand initiation and propagation of a scuffing event

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# Block on Ring

Questions?