The Role of Contact Mechanics on the Fretting Corrosion Performance of PEEK-Metal Taper Junctions

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Disclosures (Gilbert)

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Editor-in-Chief: Journal of Biomedical Materials Research – Part B: Applied Biomaterials

Council: Society for Biomaterials

Introduction

Total joint replacement & modularity

- in situ degradation of metal alloys

→ Mechanical factors + crevice geometries + biology = ???

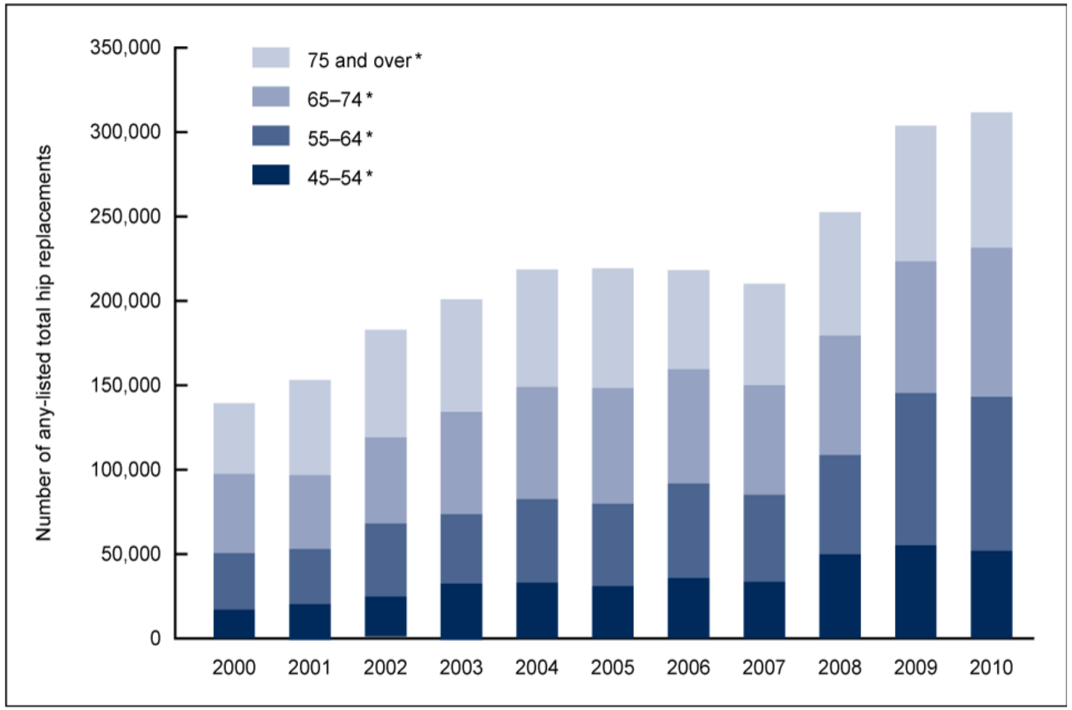
FDA medical device databases (as of 2013):

- >100 implant components 'substantially equivalent'[1]
- 5 components recalled for material/design reasons[2]

→ How does implant design affect performance?

http://friction.engr.wisc.edu/home/projects/wear-analysis-of-modular-hip-implants

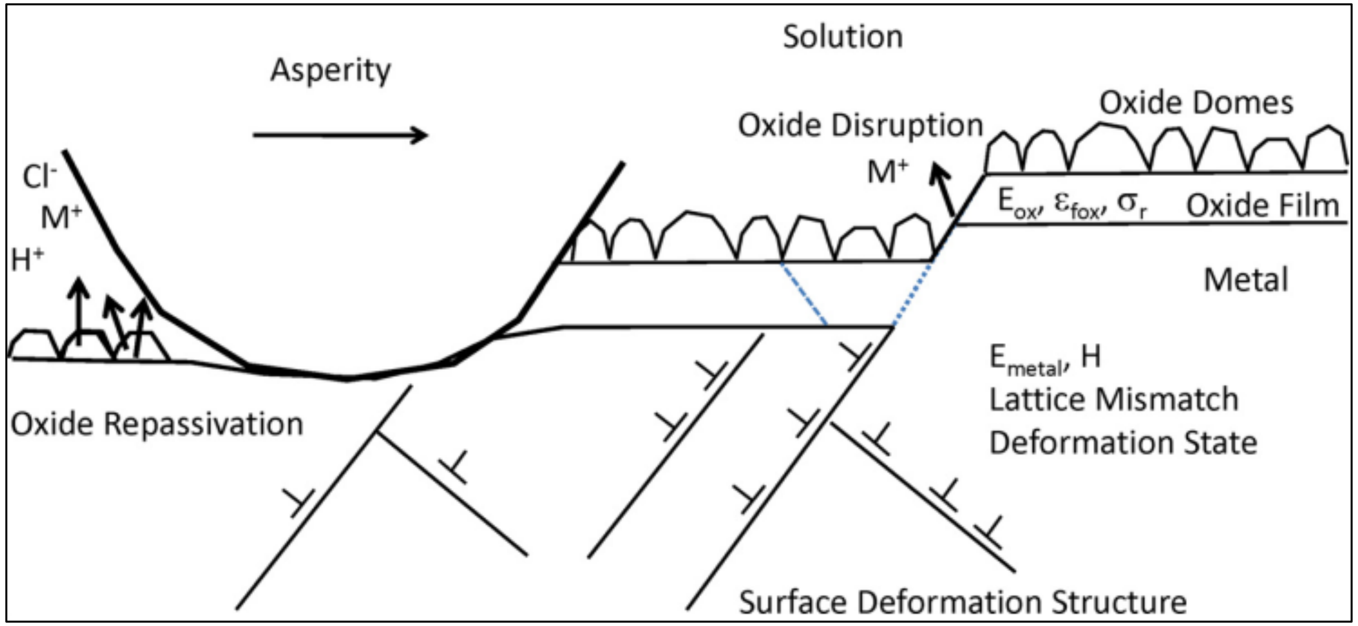
Figure 1. Number of total hip replacements among inpatients aged 45 and over, by age group and year: United States, 2000–2010



* Significant linear trend from 2000 through 2010 among all age groups and total number.
SOURCE: CDC/NCHS, National Hospital Discharge Survey, 2000–2010.

1. https://www.accessdata.fda.gov/scripts/cdrh/cfdocs/cfPMN/pmn.cfm
2. https://www.accessdata.fda.gov/scripts/cdrh/cfdocs/cfres/res.cfm

Fretting Corrosion



Gilbert et al. (2015)

http://danieli.wikidot.com/2-failure-mechanisms-in-total-joint-and-dental-implants

→ Surface damage is mainly dictated by **contact mechanics, friction & surrounding electrochemical environment**

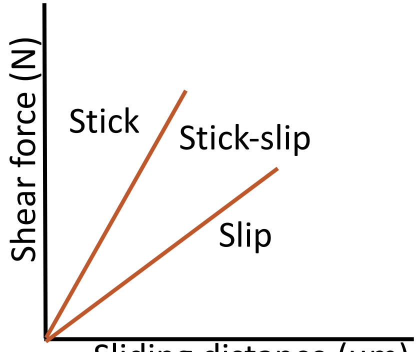
Fretting & Contact Conditions

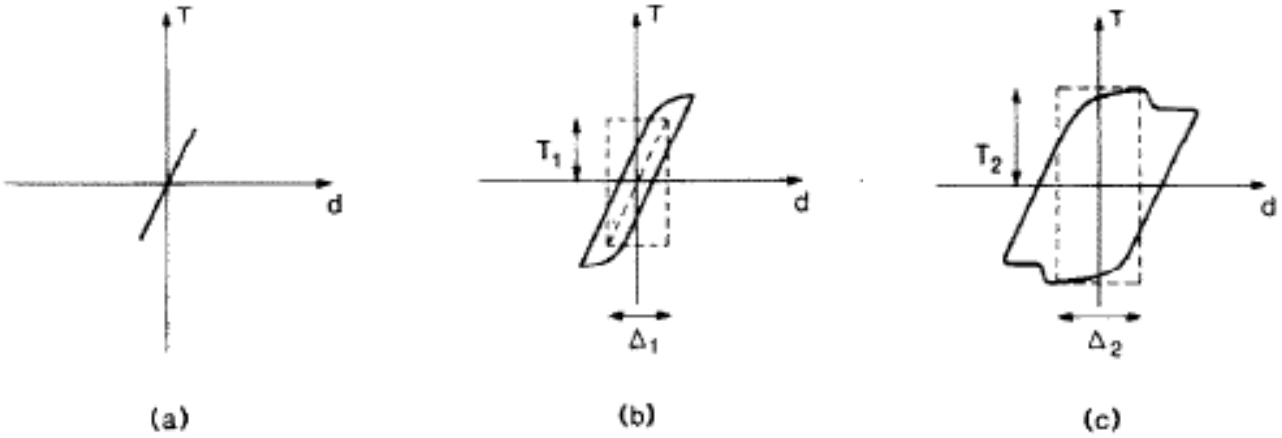
3 fretting regimes:

- Stick: minimal surface damage
- Stick-slip: some wear, fatigue
- Slip: severe surface damage

Contact conditions depend on:

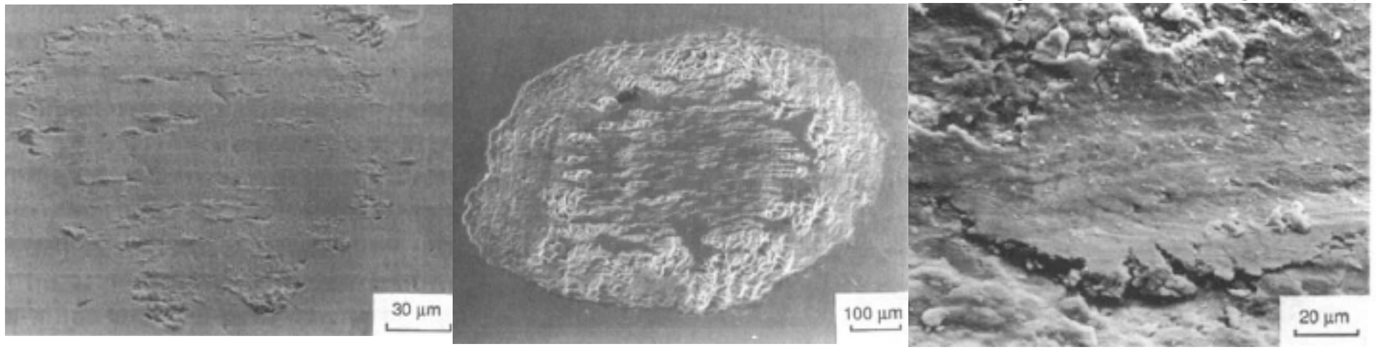
- Normal/tangential forces
- Displacement
- Frequency
- Environment
- Geometry[3]
- Material/Lubrication[3]





(a) (b) (c)

Vingsbo, O., & Söderberg, S. (1988).

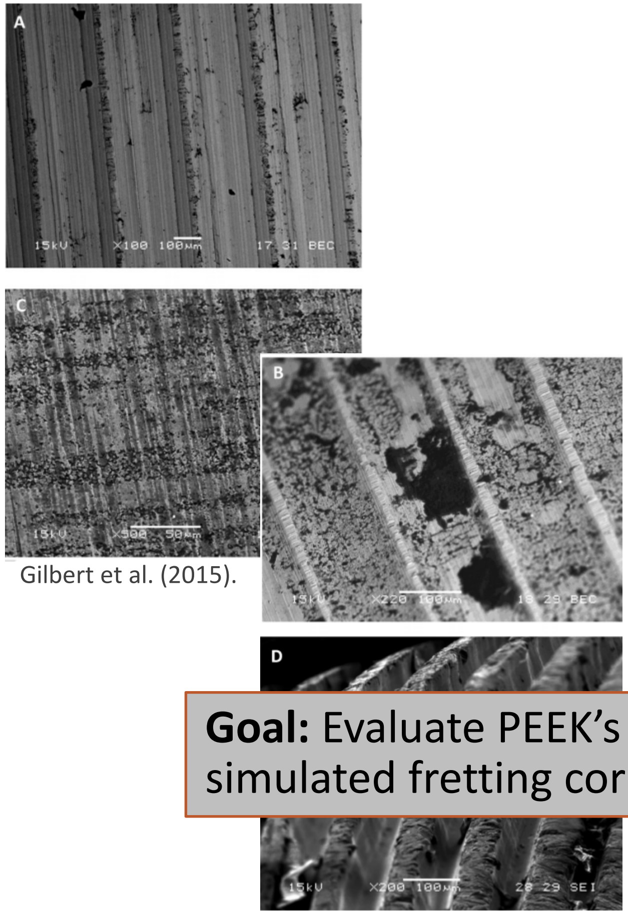


stick stick-slip slip

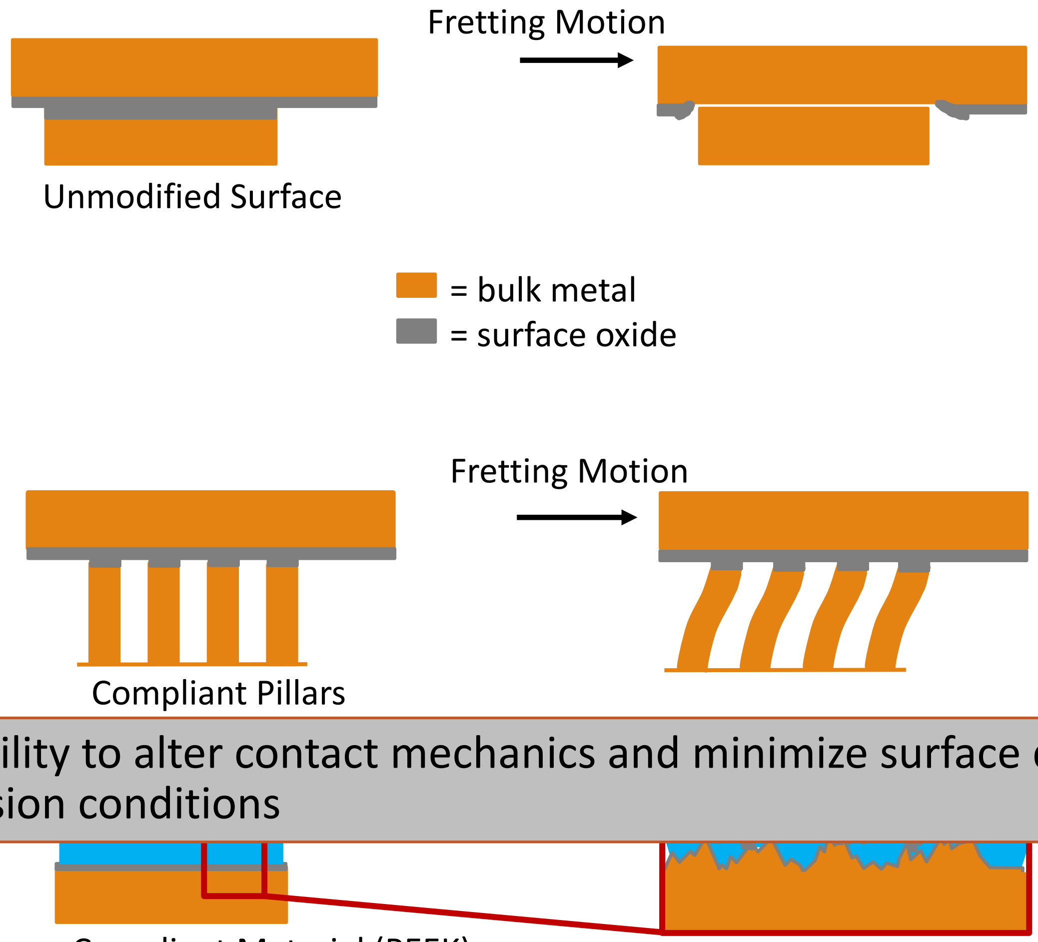
3. Jauch, S. Y., Huber, G., Haschke, H., Sellenschloh, K., & Morlock, M. M. (2014). Design parameters and the material coupling are decisive for the micromotion magnitude at the stem–neck interface of bi-modular hip implants. *Medical engineering & physics*, *36*(3), 300-307.

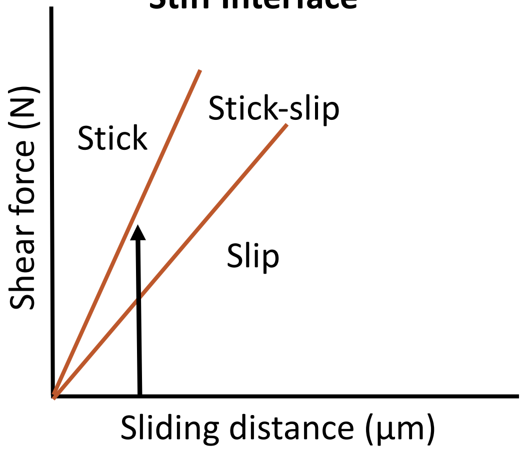
Motivation: Taper Compliance/Stiffness

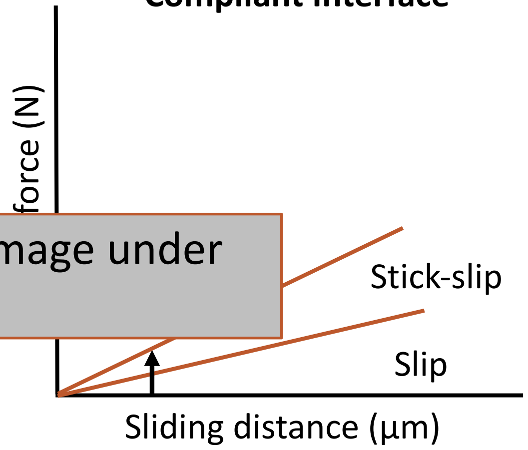
Stiffness is directly involved in seating mechanics[4]



Gilbert et al. (2015).







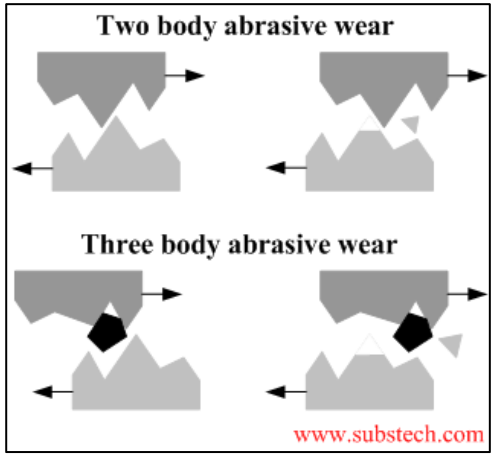
Goal: Evaluate PEEK's ability to alter contact mechanics and minimize surface damage under simulated fretting corrosion conditions

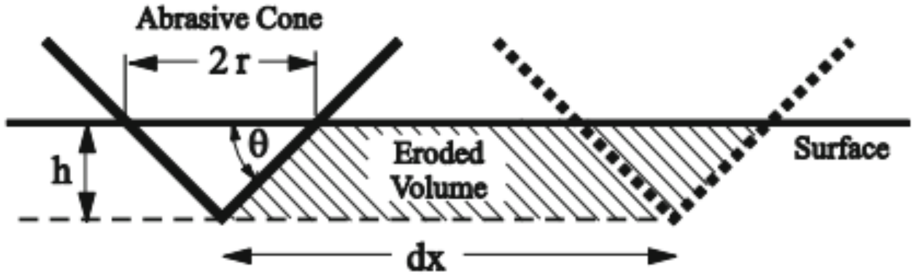
4. Ouellette, E. S., Shenoy, A. A., & Gilbert, J. L. (2018). The seating mechanics of head-neck modular tapers in vitro: Load-displacement measurements, moisture, and rate effects. *Journal of Orthopaedic Research®*, *36*(4), 1164-1172.

Counterface Hardness & Oxide Film Disruption

Current research on hardness & wear performance under fretting corrosion conditions is conflicting

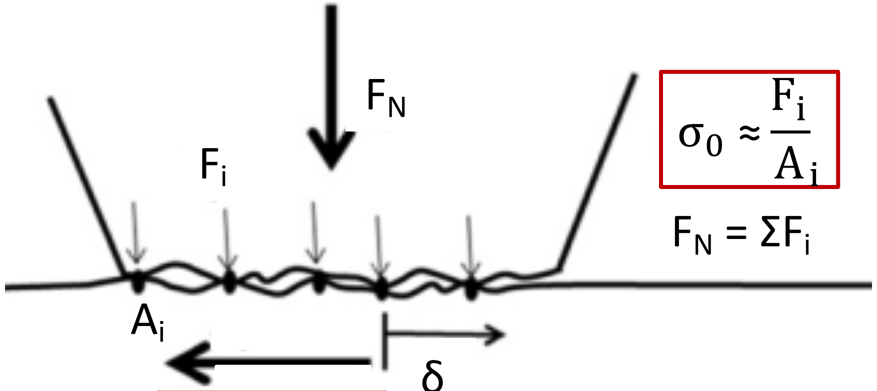
Low-hardness materials may play role in preventing fretting corrosion damage[5,6]





$$V = \frac{k_{abr} F_N}{\sigma_0} x$$

Assuming elastic-perfectly plastic material, pressure in each asperity is ≈ σ_0



$$\sigma_0 \approx \frac{F_i}{A_i}$$

$$F_N = \Sigma F_i$$

$$F_s = \mu F_N = \frac{\tau_c}{\sigma_0} F_N$$

5. Swaminathan, V., & Gilbert, J. L. (2012). Fretting corrosion of CoCrMo and Ti6Al4V interfaces. Biomaterials, 33(

6. Ouellette, E. S., & Gilbert, J. L. (2016). Properties and corrosion performance of self-reinforced composite PEEK for proposed use as a modular taper gasket. Clinical Orthopaedics and Related Research®, 474(11), 2414-2427.

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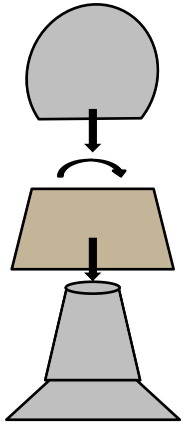
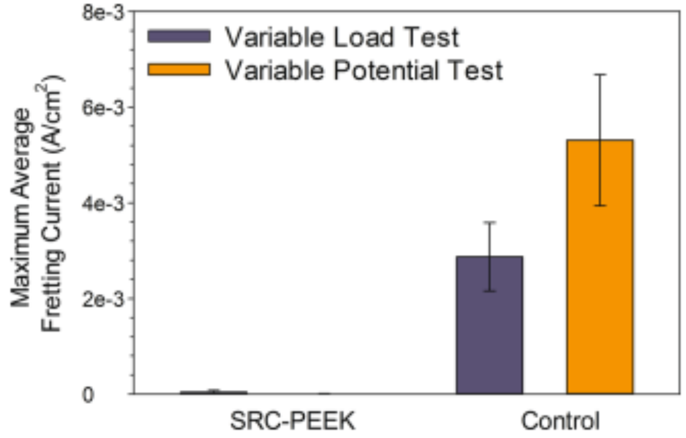
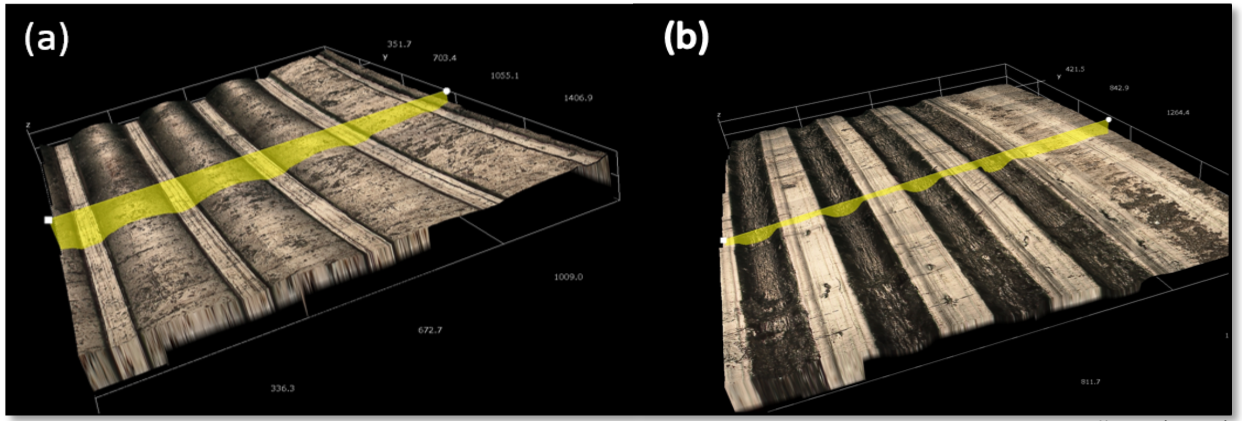
SRC-PEEK Gaskets

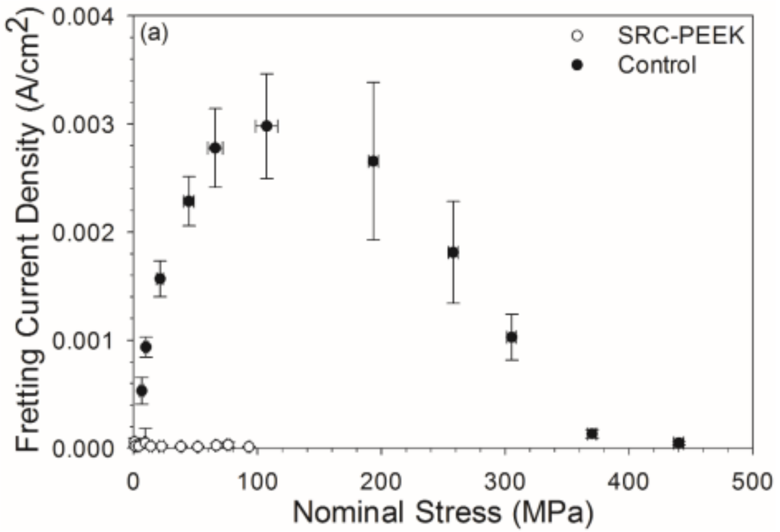
Ouellette & Gilbert (2016): Properties and corrosion performance of self-reinforced composite PEEK for proposed use as a modular taper gasket [6]







Ouellette (2016).



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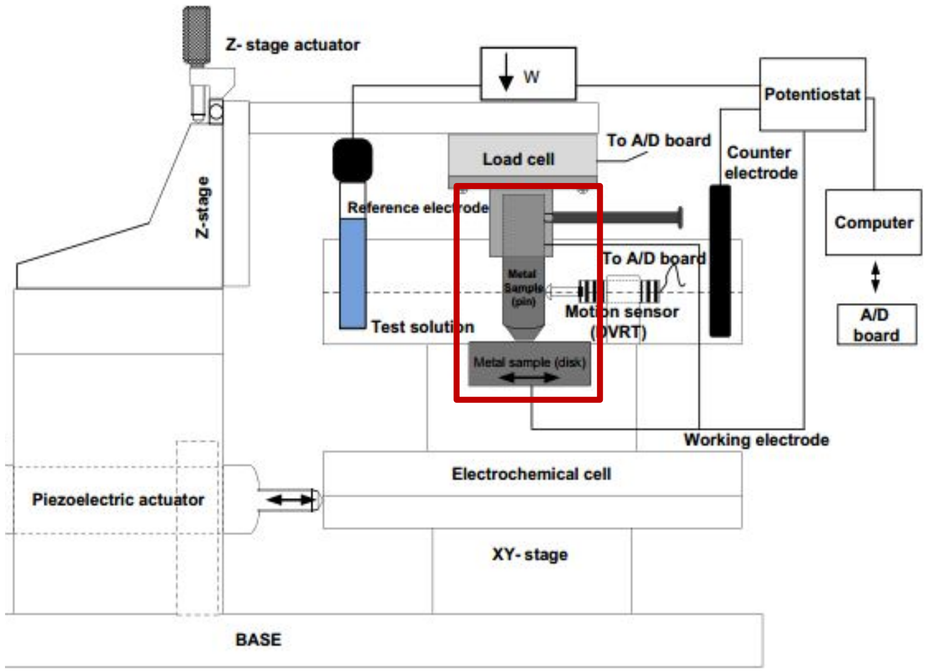
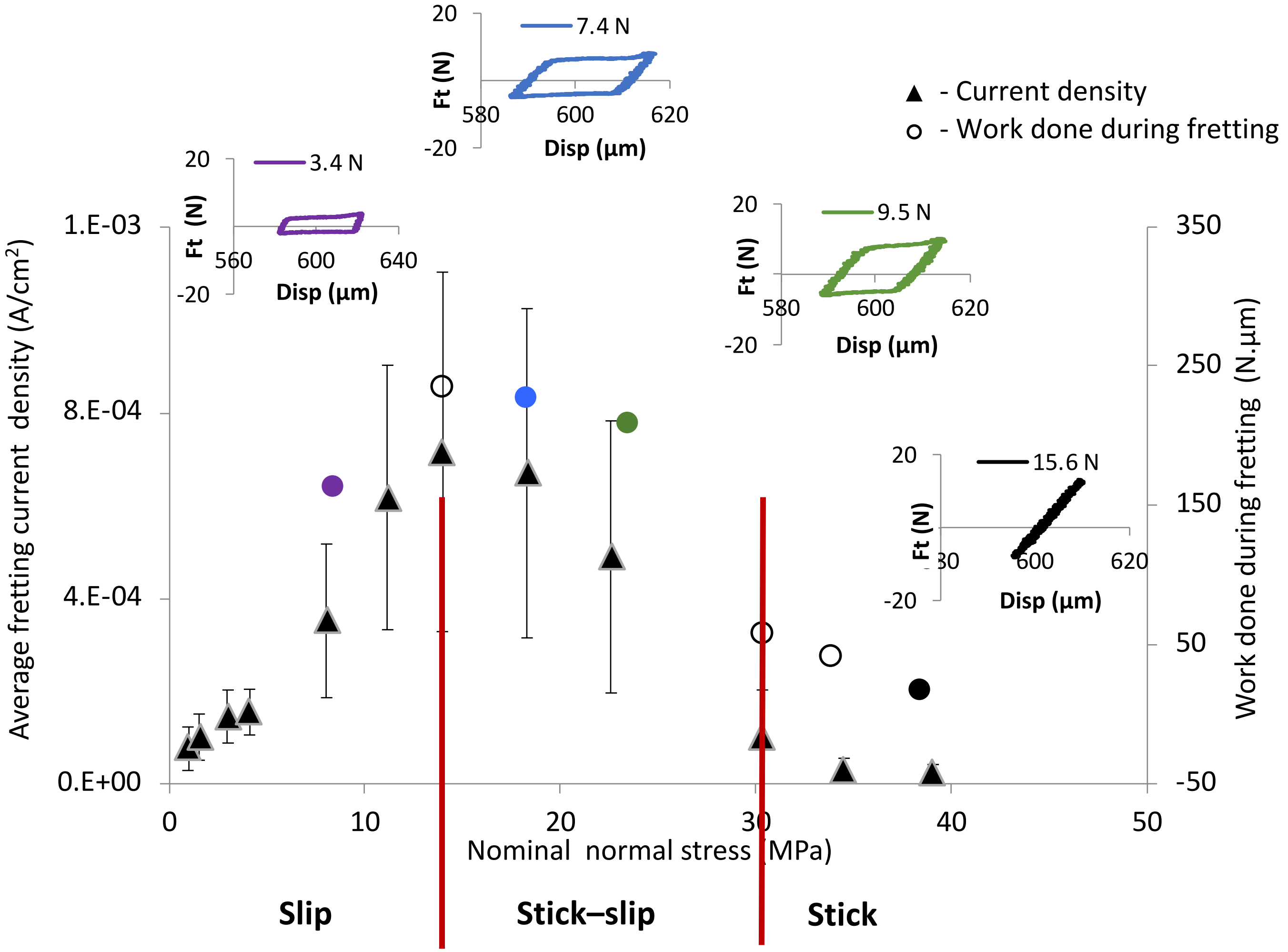
Approach: Pin on disk





Swaminathan, V., & Gilbert, J. L. (2012).

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Approach: Pin on Disk

Sample set:

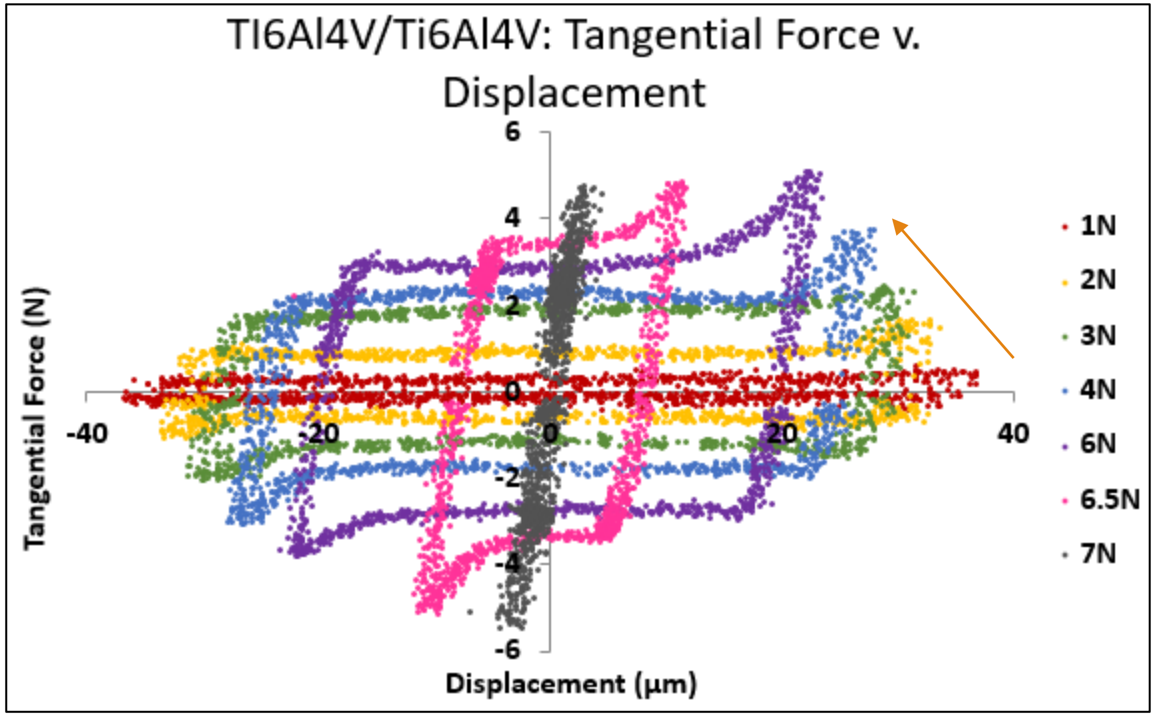
4 alloy pin/disk combinations (n = 3)

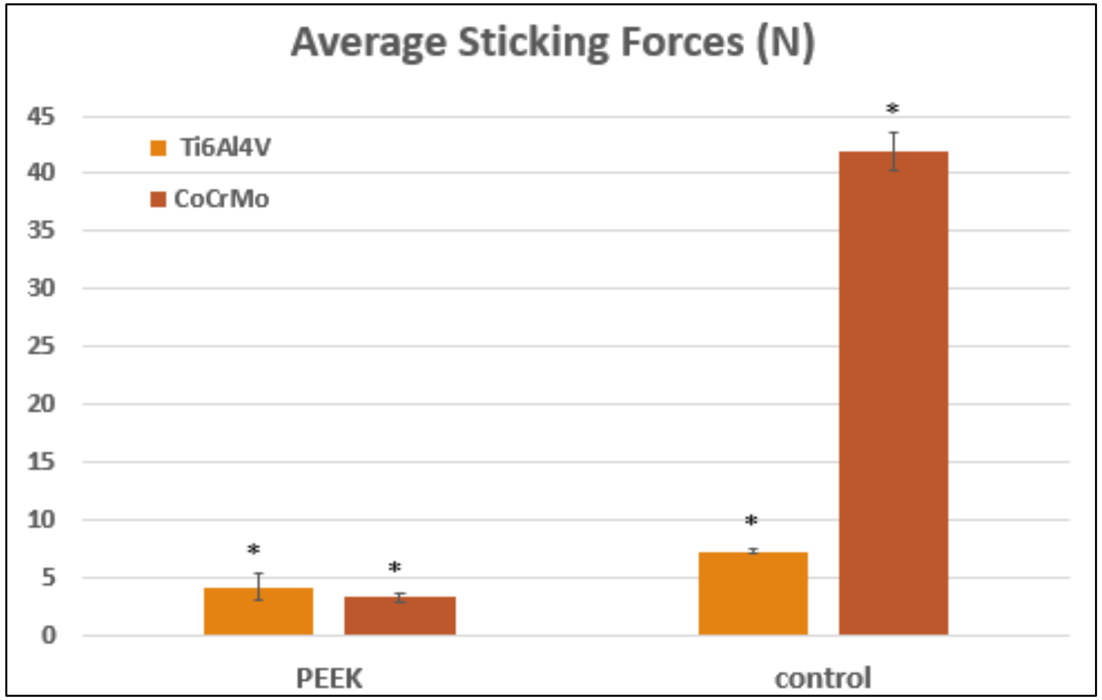
a. PEEK (Victrex 381G)/ Ti6Al4V
b. PEEK (Victrex 381G) / CoCrMo
c. Ti6Al4V / Ti6Al4V (control)
d. CoCrMo / CoCrMo (control)

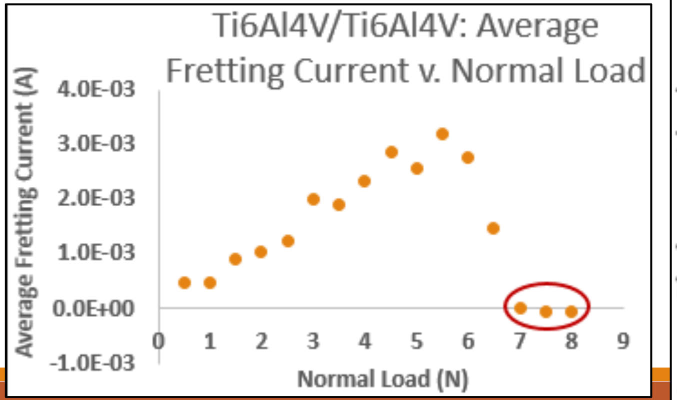
Procedure:

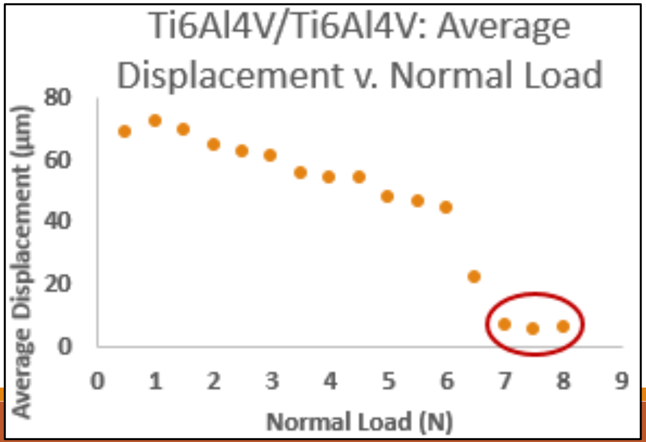
1. Load-variable, potentiostatic pin-on-disk test
   - 0-50 N, 100 sec fretting per load, 100 sec recovery
   - 100 µm displacement, 1 Hz
2. Data collection:
   - mechanical (force, displacement, COF)
   - electrochemical (current)
3. Results (averages):
   - fretted contact area
   - current/current density
   - sticking force
   - fretting loops
   - pin, system k
   - contact stresses
   - work done per fretting cycle

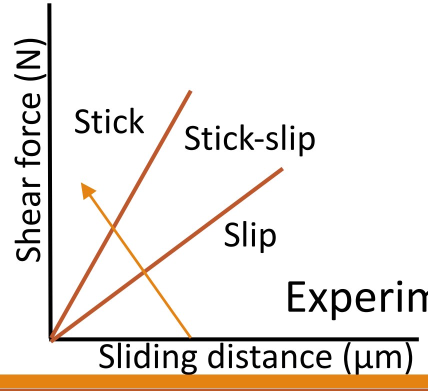
Results: Sticking Conditions





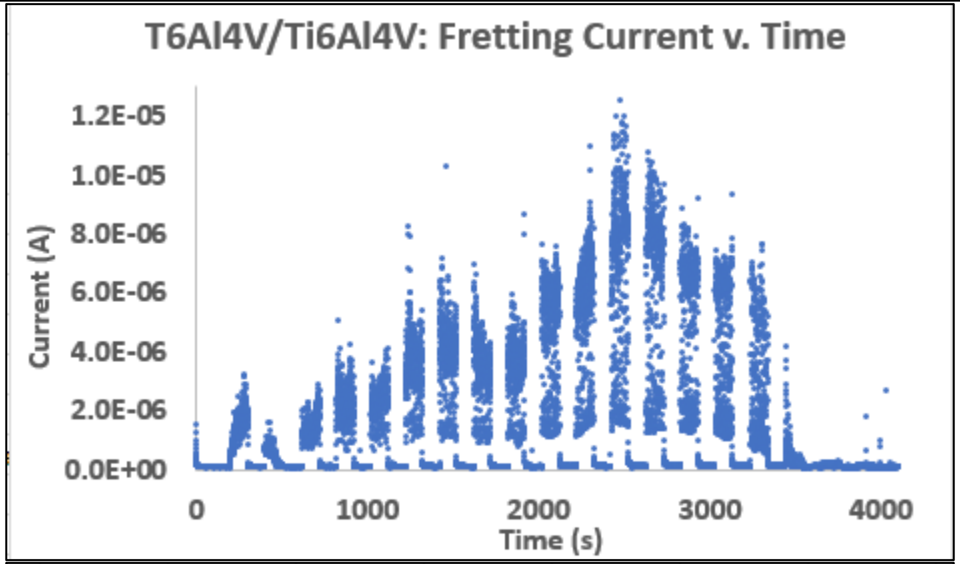


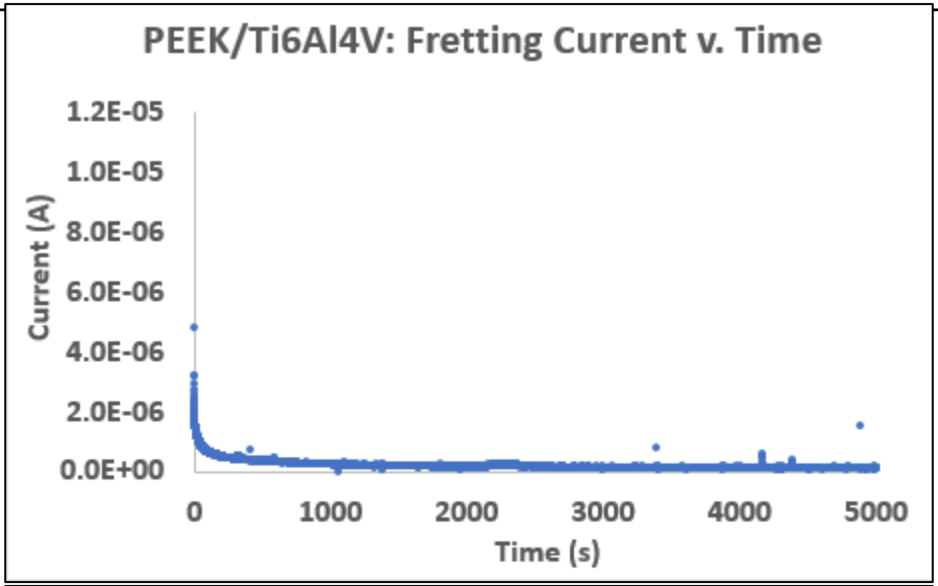


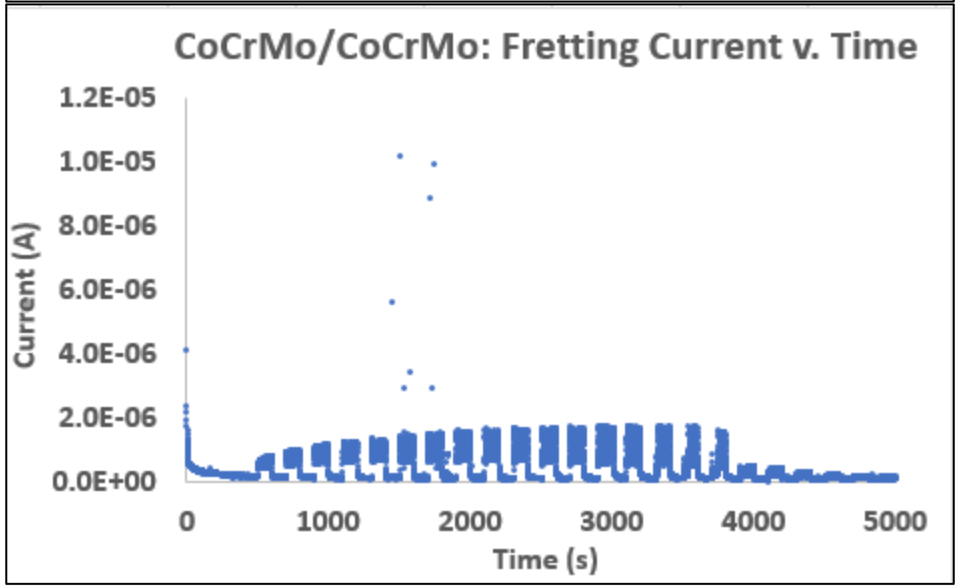


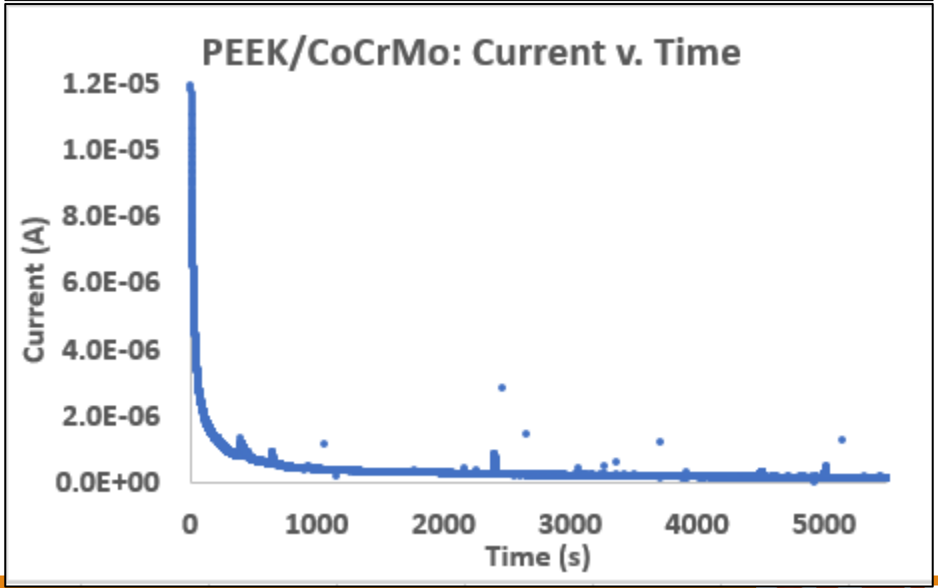
Experimental load-displacement path

Results: Surface Damage

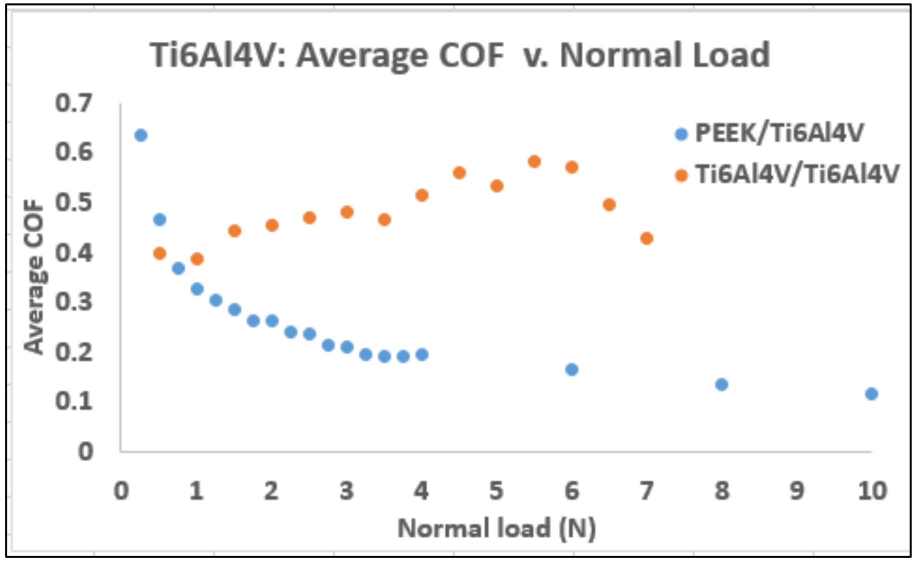


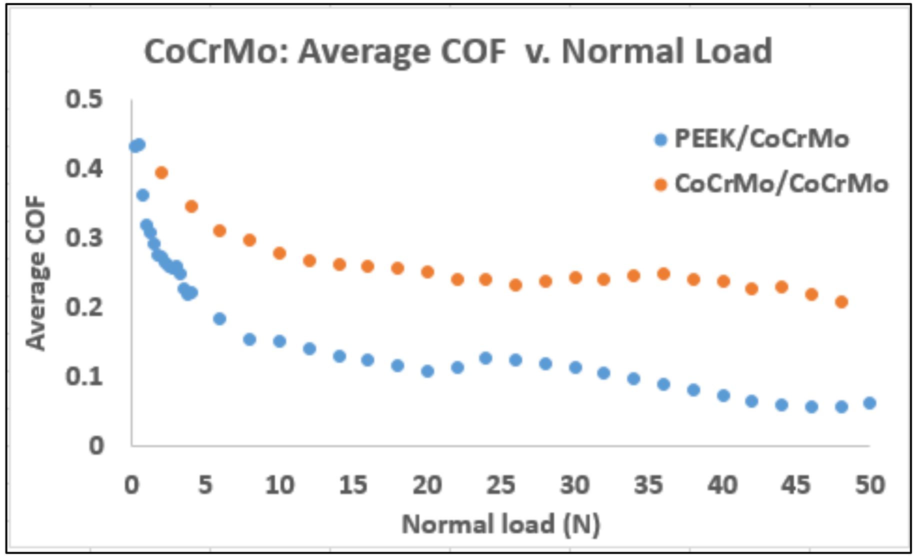




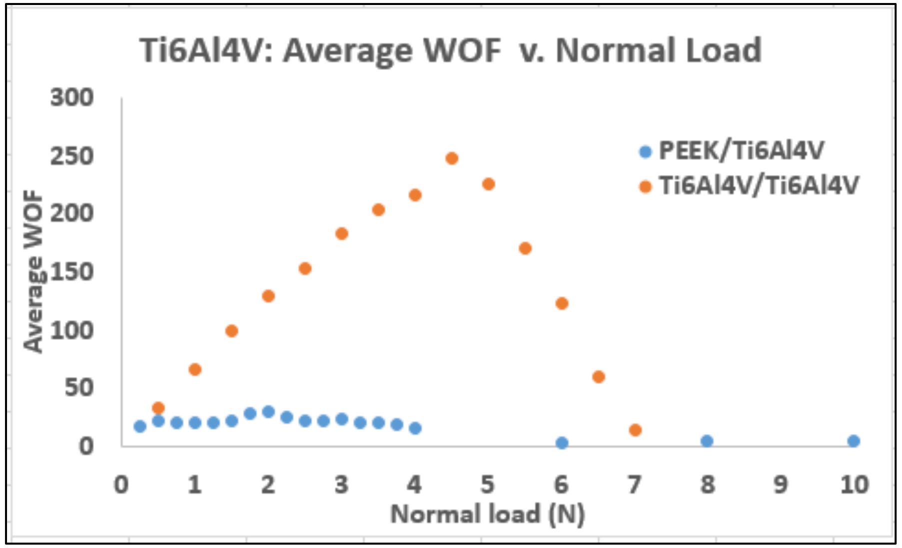


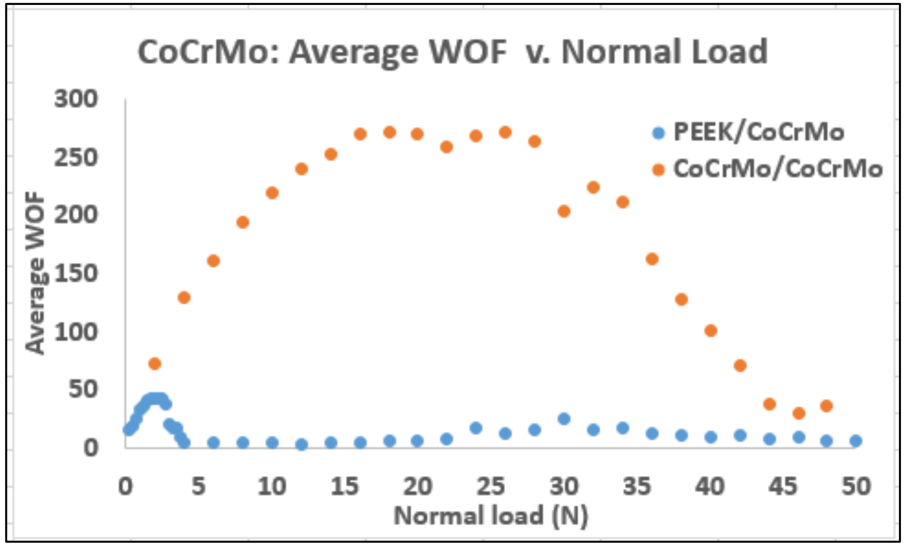
Results: Coefficient of Friction

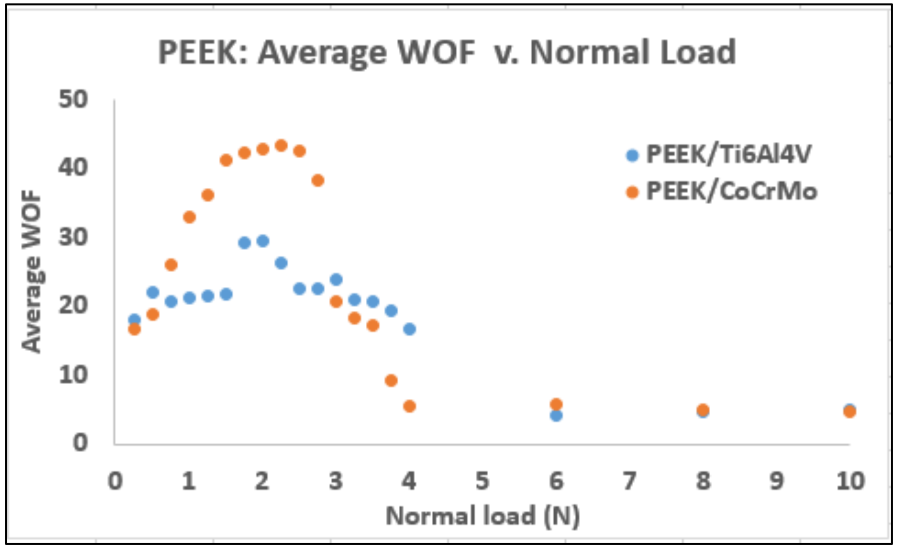




Results: Work of Fretting







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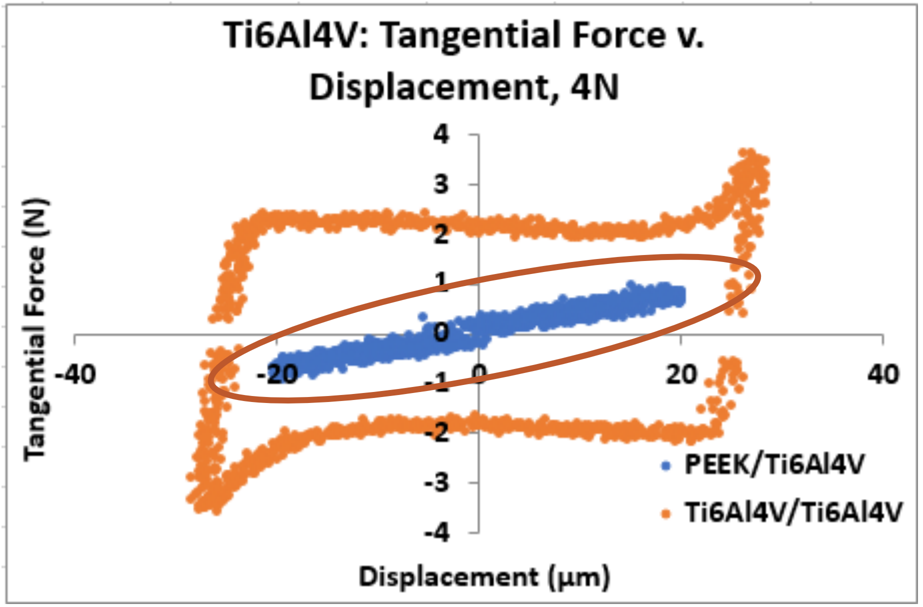
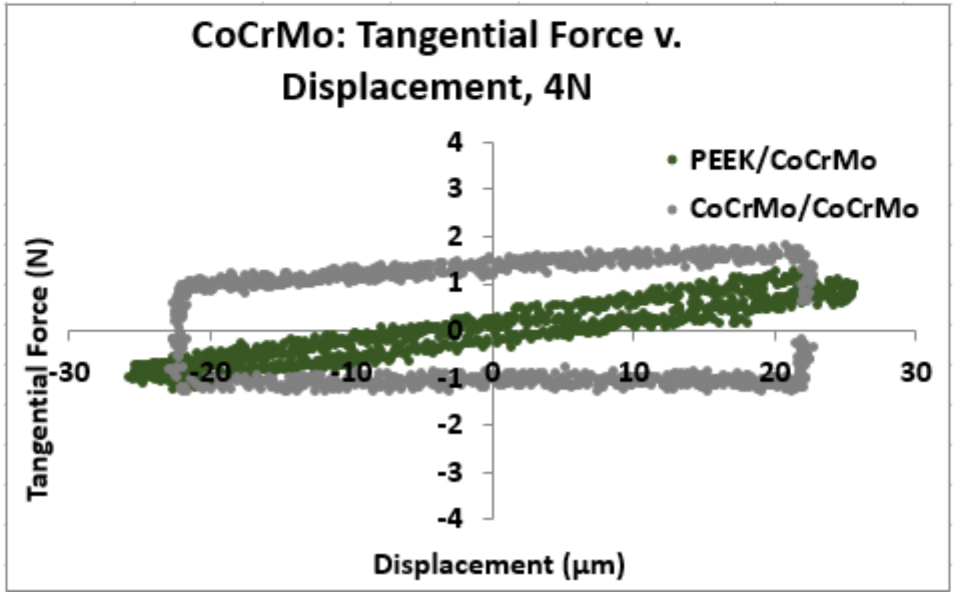
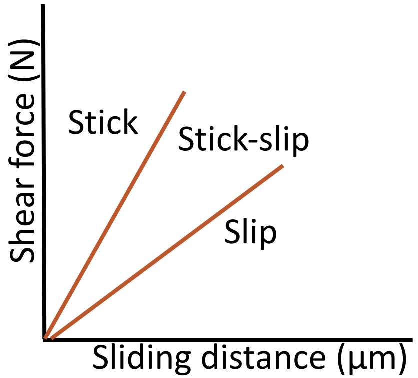
Results: System Compliance







Conclusions

1. PEEK couples cause significantly lower sticking forces under typical fretting corrosion conditions
   - → PEEK dominates behavior regardless of alloy
2. Decreased sticking forces do cause less surface damage via lower fretting currents
3. PEEK caused minimal alloy surface damage even under full slip conditions
   - → Likely due to its compliance, hardness, COF, high-performance properties

Acknowledgements

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Hansjörg Wyss

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Hannah Spece

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