Elevated Temperature Tribology of Cobalt and Tantalum-Based Alloys

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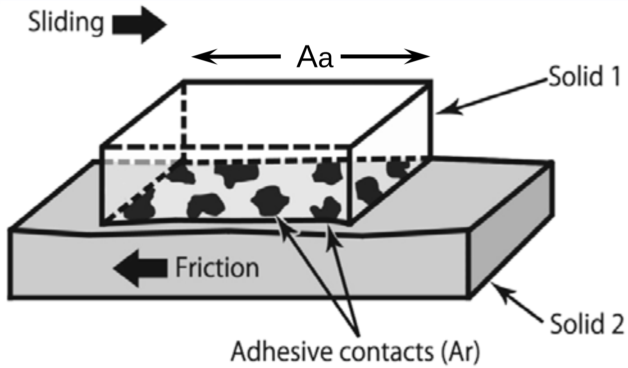
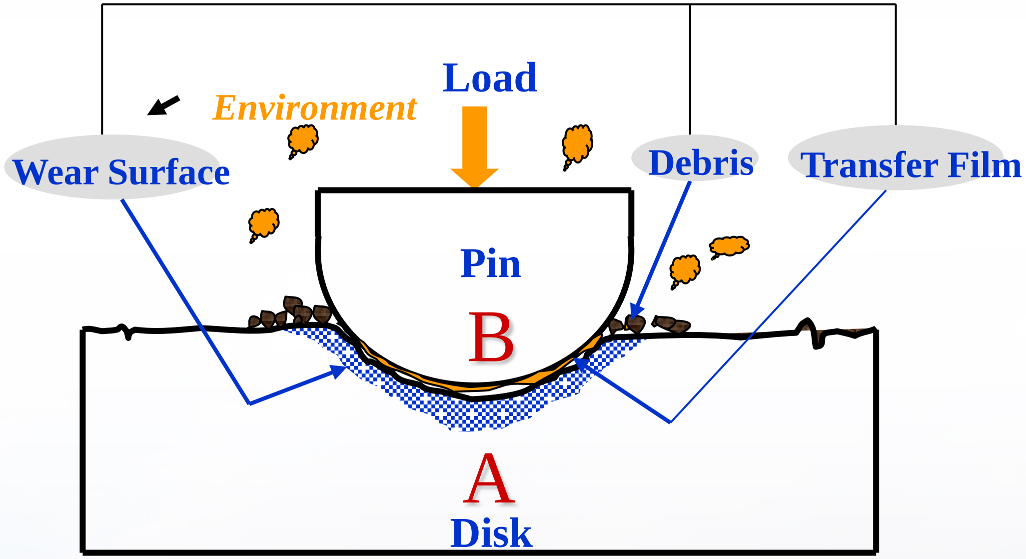
Friction and wear are systems properties



The real area of contact is a small fraction of the apparent area of contact



- Engineering surfaces are not atomically flat
- Sliding contact results:
  - Plastic deformation
  - Diffusion (Diffusion Barriers)
  - Tribochemistry and Environmental Reactions

Wear analysis must include:

✓ Surface chemistry

✓ Subsurface damage

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Wear mechanisms at elevated temperature are highly complex (Brief Overview)

- *Friction and wear could be significantly reduced whenever soft, low interfacial shear strength oxide films form (M. B. Petersen, 1960)*
- *High temp (850C) sliding tests on Nimonic 80 revealed the formation of oxide glaze and reduction in wear (F. H. Stott, 2002)*
- *Recent review (P. J. Blau, 2010) discussed the effects of oxidation, its role in debris formation,* its role in debris formation, and microstructural evolution during high temperature metallic wear
- The ability to form, maintain, and if necessary, self-replenish oxide films is the key, if long-lasting, low-friction, wear contacts at high temperatures are to be realized

Motivation

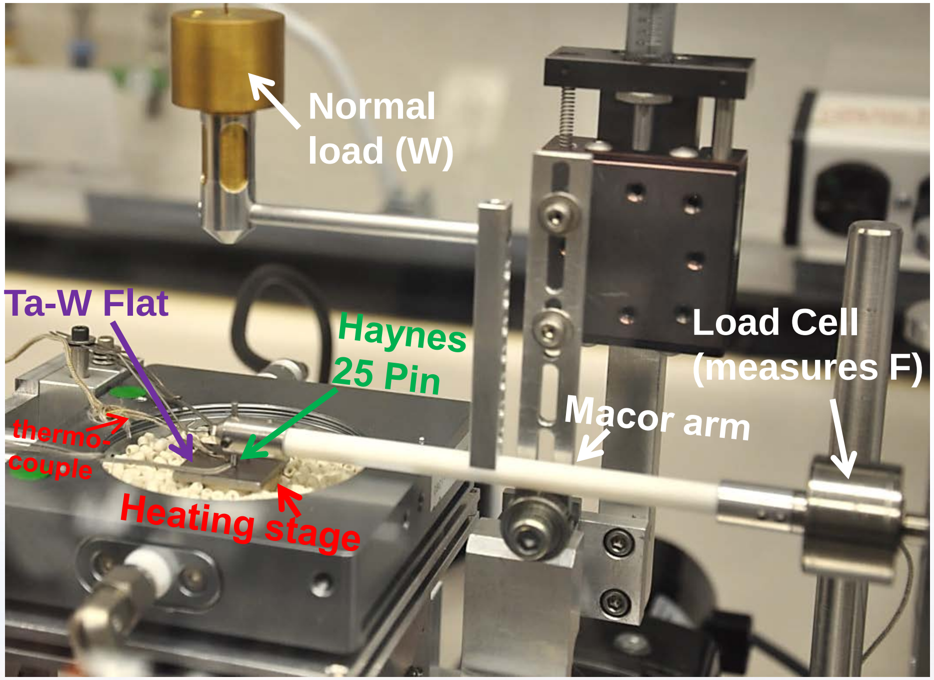
- ***Tantalum-tungsten refractory metal alloys are well known for their high temperature strength***
- ***Cobalt-chromium alloys, such as Haynes 25, exhibit superior resistance to oxidation at elevated temperatures***
- ***This pair forms an ideal combination for high temperature cladded structures***
- ***The major focus of this study was to evaluate the friction and wear behavior of Haynes 25/Ta-W contacts at elevated temperatures***
  - *Tribochemistry (formation of protective oxide glazes)*
  - *Friction and wear-induced metallurgical phase transformations in the subsurface regions*

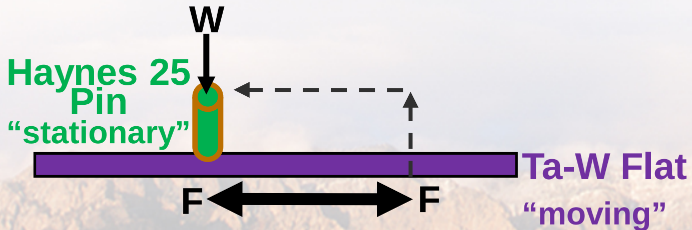
Compositions of Haynes 25 (Disk) and Ta-W (Pin)

Alloy	Compositions (wt%)	Hardness HV10 (GPa)	Elastic modulus (GPa)	Poisson's ratio	Tensile strength UTS (MPa)
Haynes 25*	51 Co, 20 Cr, 15 W, 10 Ni, 1.5 Mn, <3 Fe, <0.4 Si, 0.1 C	2.55	225	0.31	1015
Ta-W**	90 Ta, 10 W	1.88	207	0.30	620

* Analyses supplied by Haynes International, Inc.
** Analyses supplied by Cabot Supermetals

High Temperature Tribometer



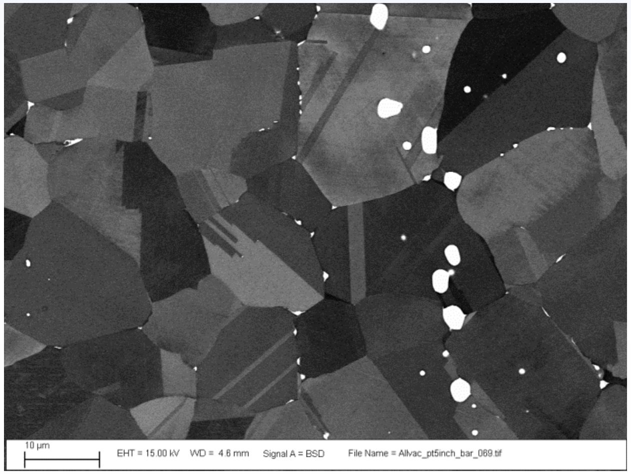


Normal Load: 1N

Contact Stress: 1.5 GPa
(Initial Hertzian Max)

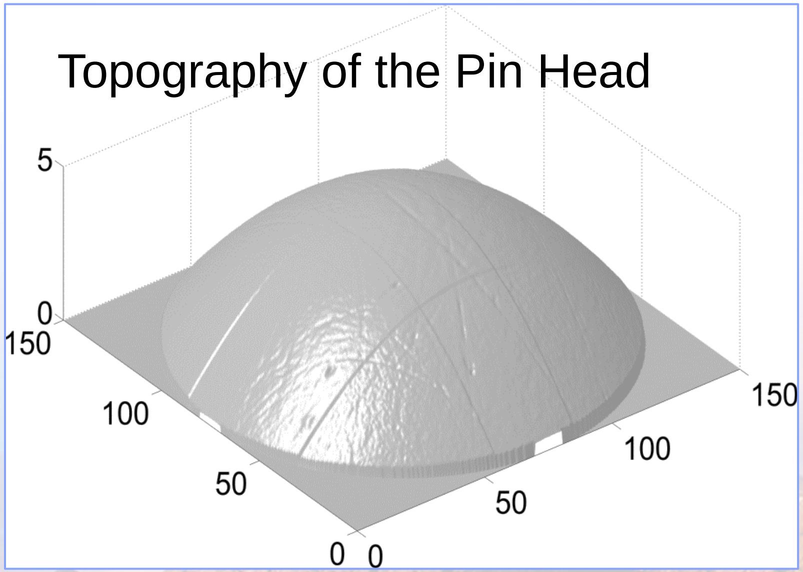
Atmosphere: Argon/RH ~ 0.3%
~10 ppm O2
~100 ppm H2O

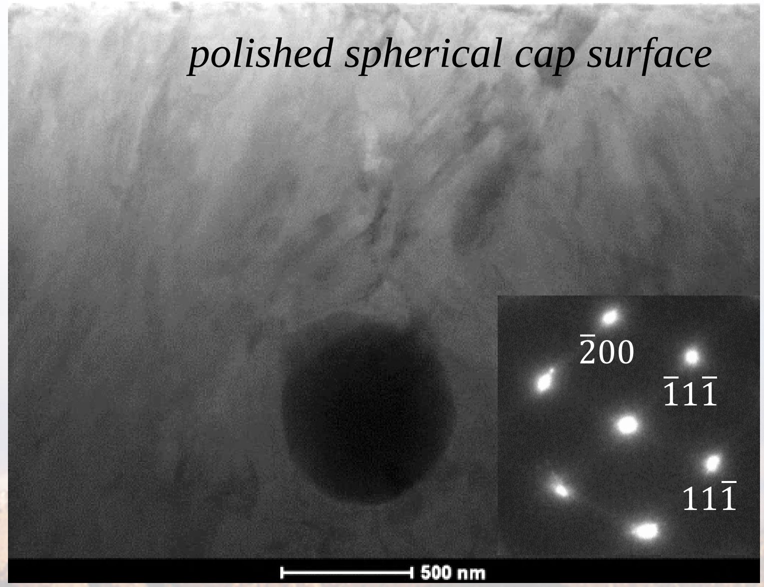
Haynes Pin



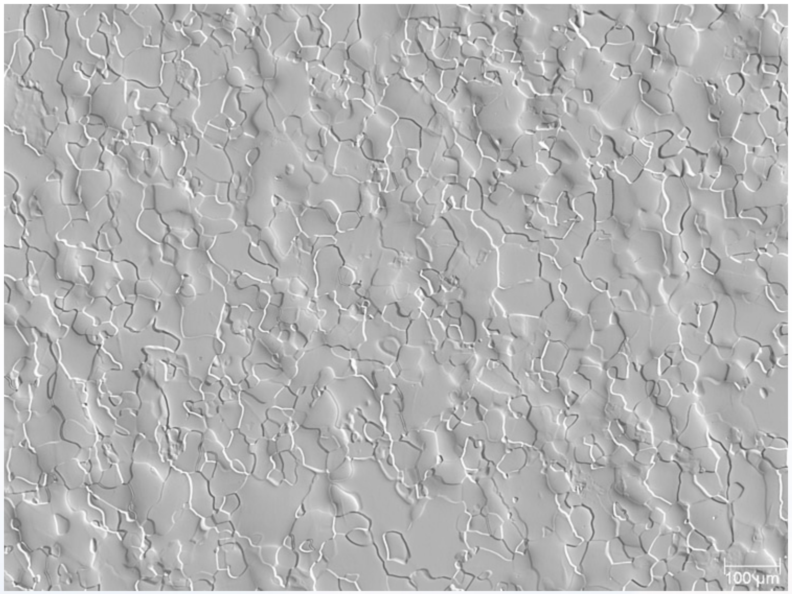
Metallography

- FCC structure (stabilized with Ni)
- Stacking Faults

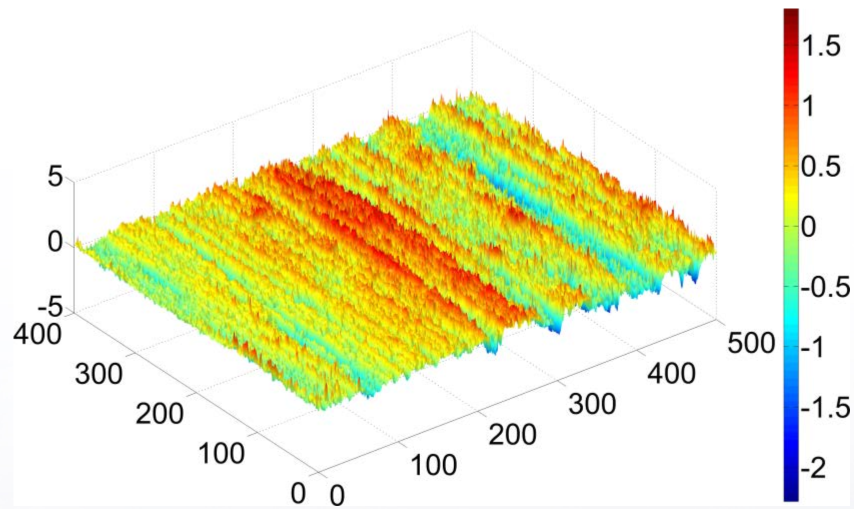




Ta-W Disk

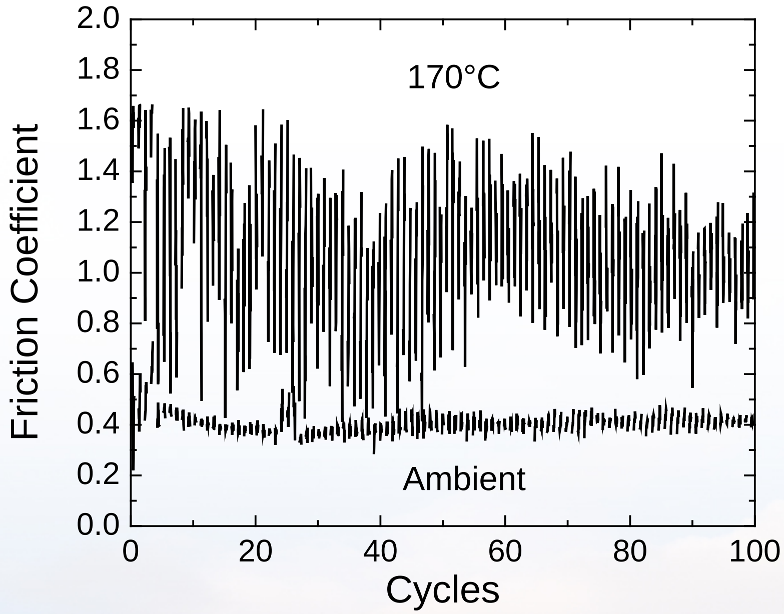


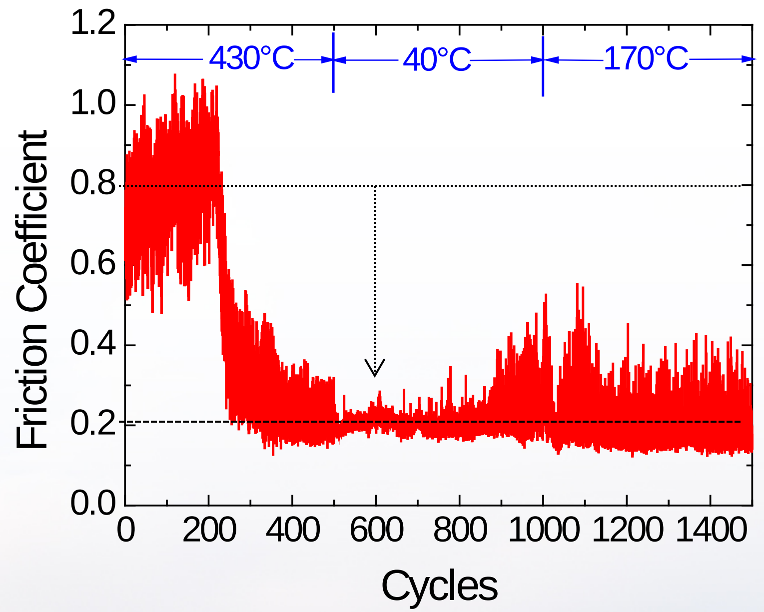
Microstructure of the Alloy



Topography of the Disk (SWLI)

Friction Behavior in various Temperature Regimes



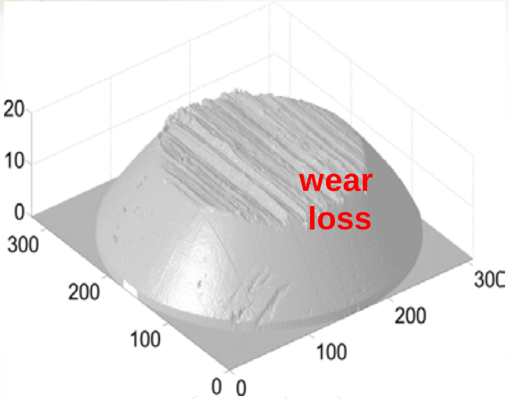


Thermally Cycled

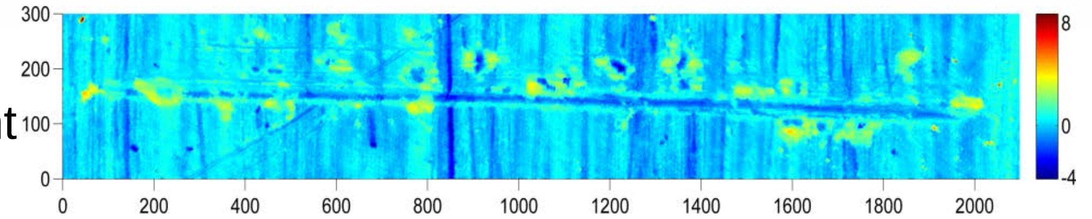
Wear Surface Analysis

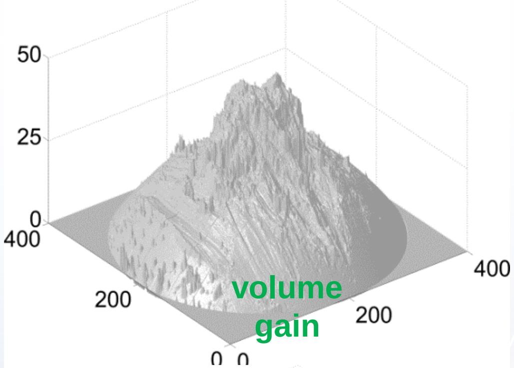
- **Topography (wear rates) by scanning white light interferometry**
- **SEM-EDS of wear surfaces on Ta-W disks and Haynes alloy pins**
- **Wear Subsurface analyses**
  - Sample preparation by FIB
  - Transmission electron microscopy
  - Selected area diffraction
  - AXSIA (Spectral Imaging)

Quantifying wear rates can be challenging

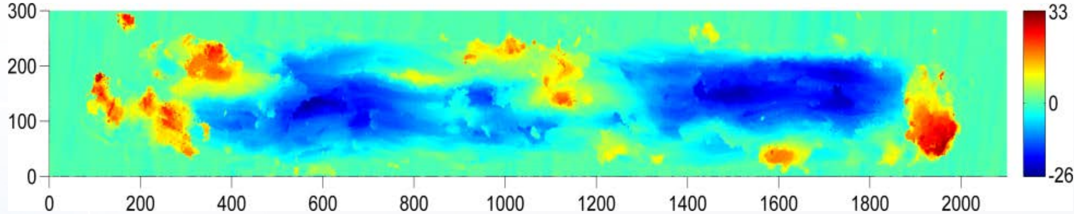


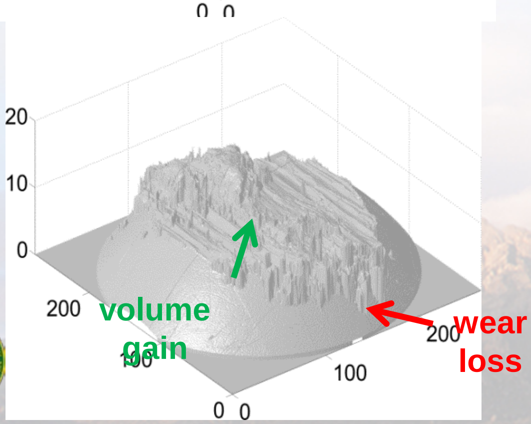
Ambient



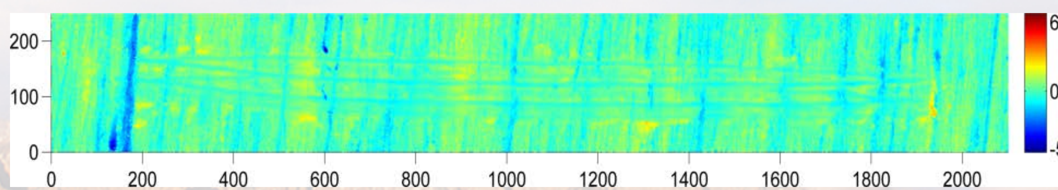


175°C



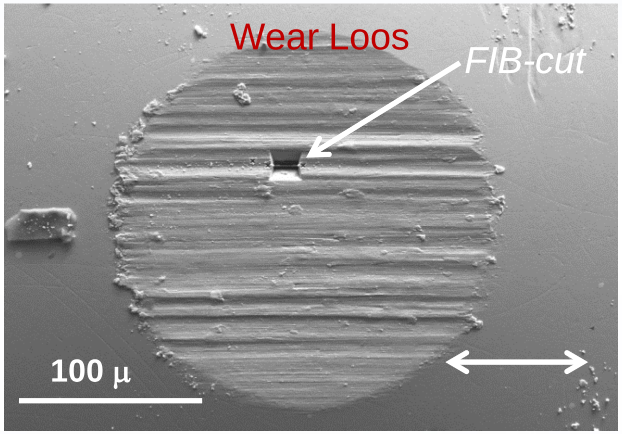


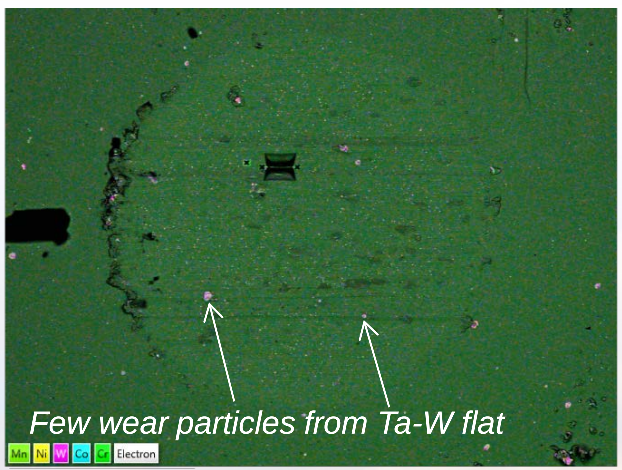
430°C



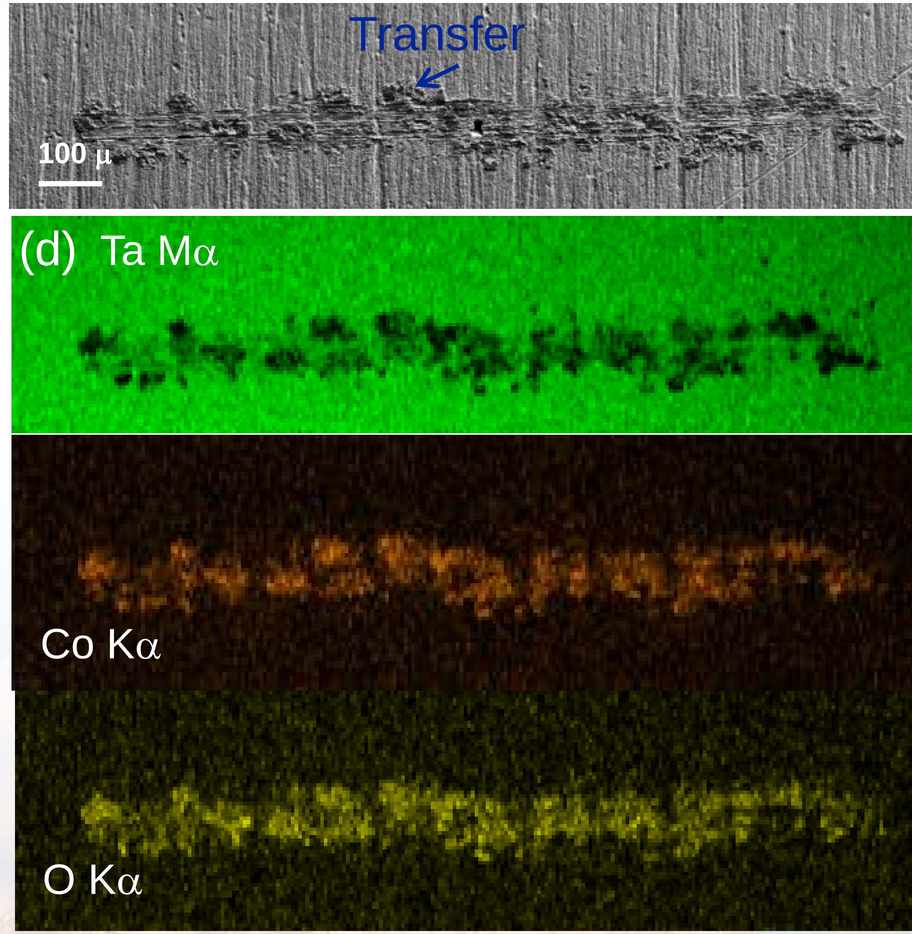
SEM-EDS on Wear Surfaces (Ambient)

Pin





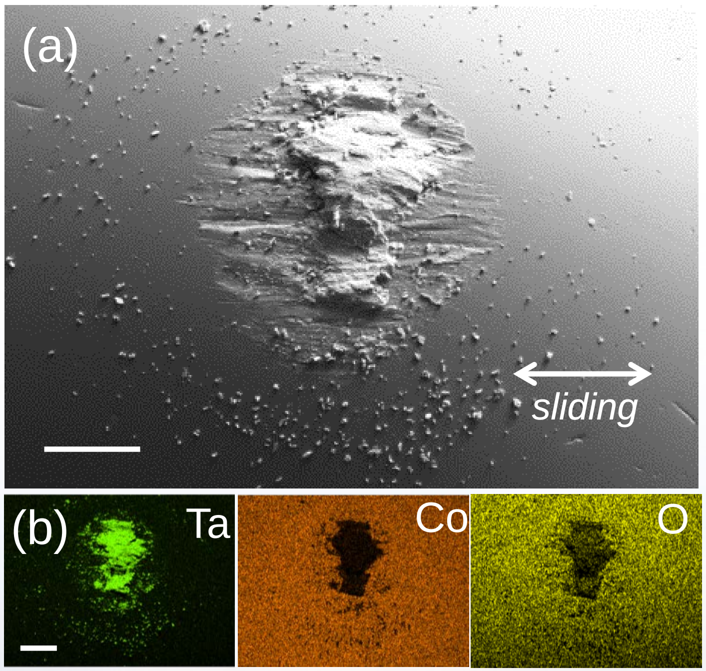
Disk



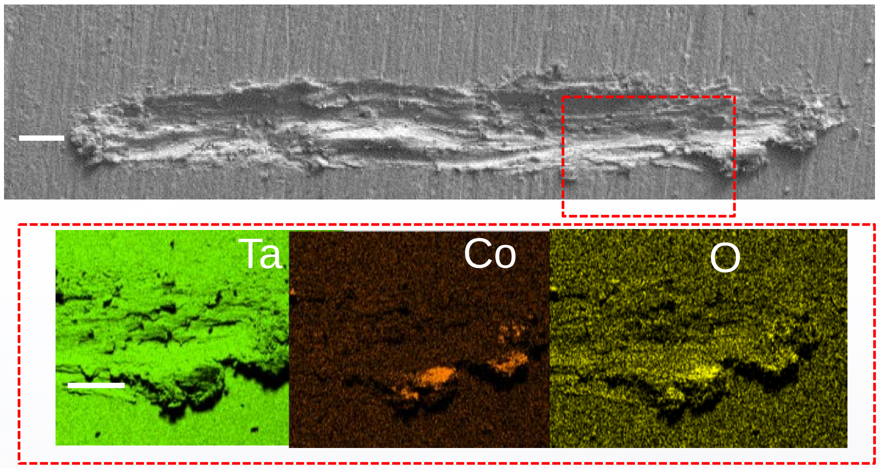
Non-continuous and thin Haynes metal oxide transferred to the disk

SEM-EDS on Wear Surfaces (170ºC)

Pin



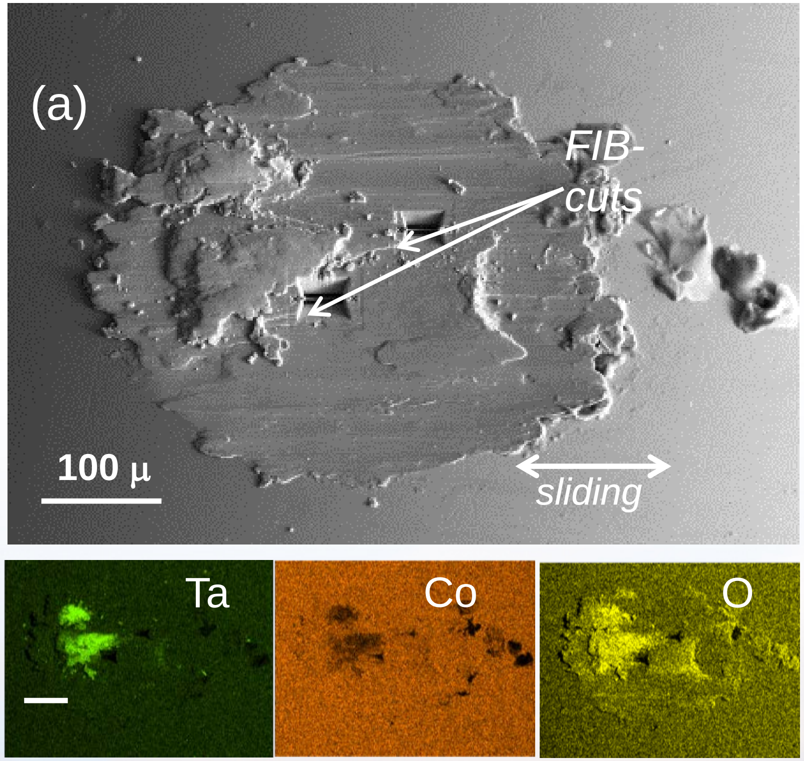
Disk

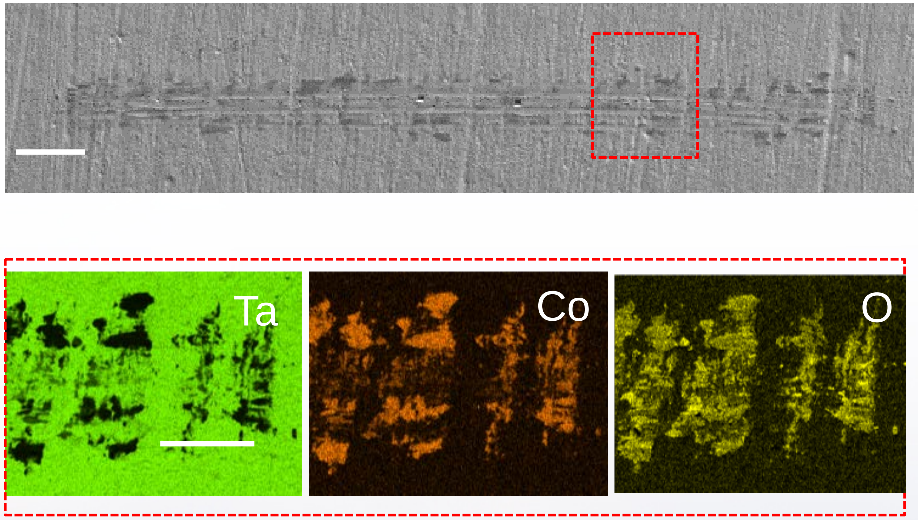


No significant formation of a protective oxide layers

Thermal Softening?

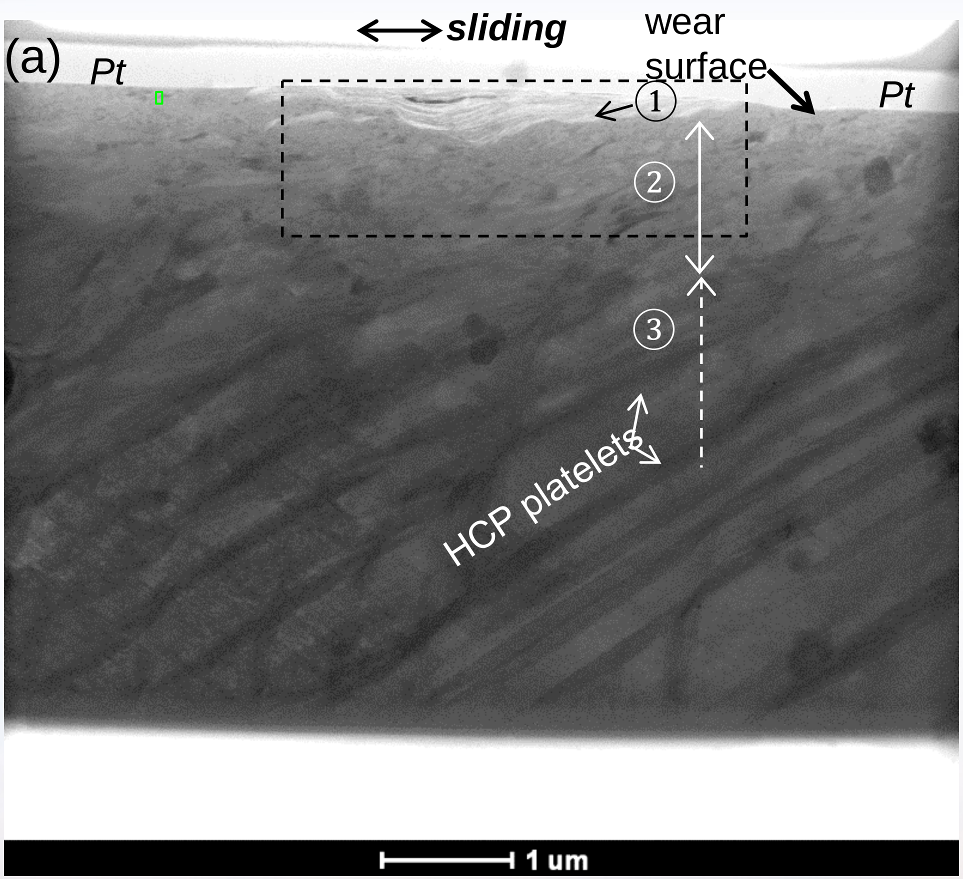
SEM-EDS on Wear Surfaces (430ºC)

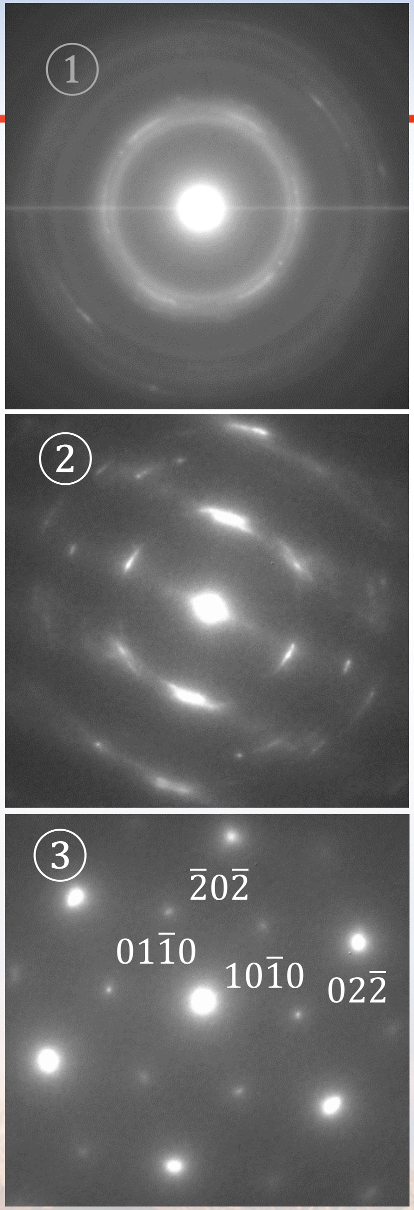




More continuous oxide layers on the Pin and the Disk surfaces

BFTEM and SADP of three wear zones in the subsurfaces of Haynes (Ambient)

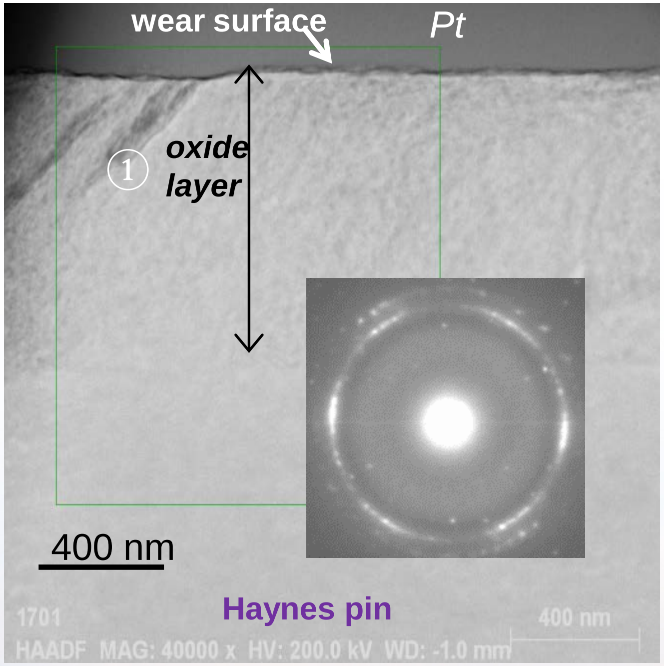




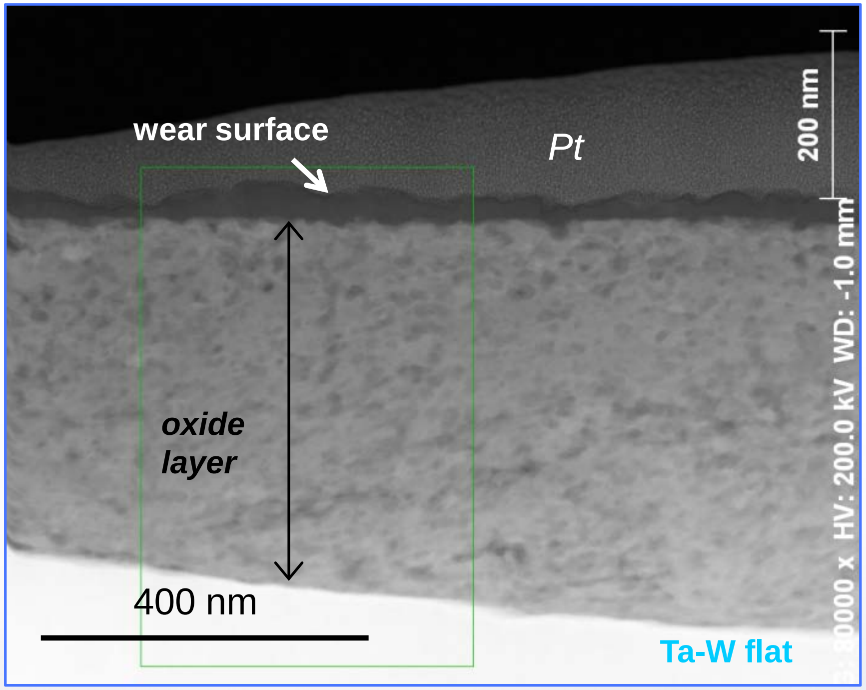
Wear-induced FCC to HCP transformation resulting in HCP platelets by stacking fault coalescence in the subsurface regions

Oxide glazes in the subsurfaces (430ºC)

Pin



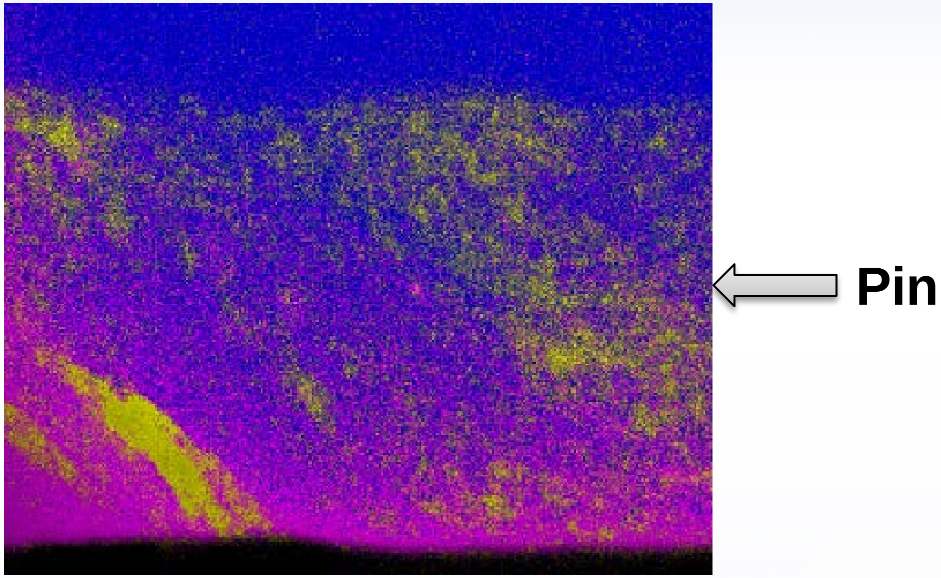
Disk



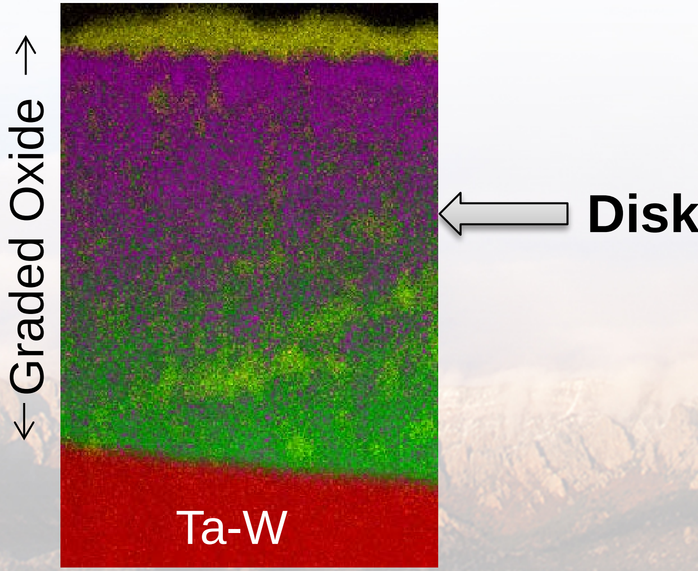
Identification of metal oxide layer (glaze), predominantly (Co,Cr)O with Rocksalt crystal structure by SAD

Co-based metal oxide (Co,Cr)O glazes in self-mated configuration (430ºC)

Blue = Haynes
Magenta = Oxidized Haynes
Yellow = Cr-O Rich



Yellow = Cr-O rich
Magenta = More oxidized Haynes
Magenta = More oxidized Haynes
Green = Less oxidized Haynes
Red = Ta-W



Wear Mechanism Maps

- **Ambient Temperature**
  - *Strain hardened the Haynes 25 alloy due to the wear-induced FCC to HCP transformation resulting in HCP platelets by stacking fault coalescence in the subsurface regions.*
  - *Non-continuous and thin Haynes metal oxide, predominantly Rocksalt (Co,Cr)O, on the pin that transferred to the Ta-W wear track*

- **Intermediate Temperature (175ºC)**
  - *The highest friction coefficients and formation of a protective (Co,Cr)O layer; Thermal softening on the Ta-W wear tracks*
  -

- **Higher Temperature (430ºC)**
  - *Friction transition due to thicker and more continuous protective (Co,Cr)O glaze layers on the pin sliding against self-mated oxide glaze*
  - *Heat transfer to the bulk from the sliding interface may be mitigated, thus reducing thermal softening*

- **Forming the oxide glaze layers on the surfaces of Haynes alloys prior to their deployment as claddings is desirable and could significantly reduce wear damage**

Acknowledgements

- ***Rand Garfield for friction measurements***
- ***Bonnie McKenzie for SEM***
- ***Lisa Lowery for FIB sample preparation***

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