Coatings for Centrifugal Compression

George Fenske, Robert Erck (presenter), and Osman Eryilmaz
Argonne National Laboratory
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PD050

Overview

Timeline

- Start: Oct 2006
- Completion: Sept 2012
- Percent Completed: 40 %

Budget

- Total project funding
  - DOE share ($725K)
- Funding for FY09 ($100K)
- Funding for FY10 ($100K)

Barriers

- Delivery Barrier B – Reliability and costs of hydrogen compression
- Hydrogen delivery targets related to hydrogen Delivery of large compressors for FY2012:
  - Reliability – > improved
  - Efficiency - 98%
  - Capital investment - $12M/compressor
  - Maintenance – 7% of TCI

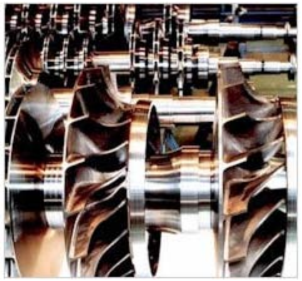
Partners

- MITI (Mohawk Innovative Technologies Inc.) - Oil-free, high-speed centrifugal compressor (bearings)
- CSM – test machine development
- John Crane - seals

Relevance

- Overall objective:
  - Develop the technology to attain *the cost and reliability* targets for oil-free centrifugal and forecourt compressors by reducing/eliminating downtime or repair costs
- Means to objective:
  - Identify, and develop as required, advanced materials and coatings that can achieve the *tribological performance* necessary for durable operation of dry-sliding seals and bearings
- Two-prong technical approach:
  - Using commercial or lab materials and coatings (compound, composite, intermetallic, carbon based.) test and identify those materials that produce the lowest friction and wear in a hydrogen environment
  - *Focus on understanding* the tribological mechanisms by which the best materials produce low friction and wear and optimize the properties
- Objectives FY10:
  - Install and bring to operation new elevated-temperature hydrogen test machine (tribometer)
  - Focus on *understanding the mechanisms* by starting nanoindentation and FIBS (focused ion beam spectroscopy) work
  - Conduct longer-term sliding tests on materials used in forecourt compressors

Compressor



Compressor rotor

Mechanical Seal

Technical Approach

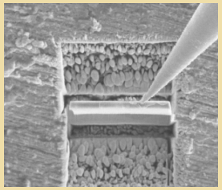
- Identify critical dynamically loaded compressor components, materials/alloys/surfaces, and operating environments
- Evaluate tribological performance of commercial or lab materials under well-defined tribological conditions:
  - Temperature, H_2 pressure
  - Speed, load/stress
  - Air/H_2/impurities
- Characterize/identify critical phenomena/mechanisms that control tribological performance
- Target: durable friction coefficient <0.1 and extremely high durability
- Engineer and validate solution(s) into compressor design

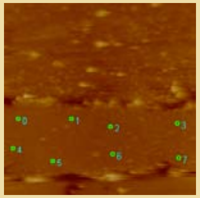
Testing

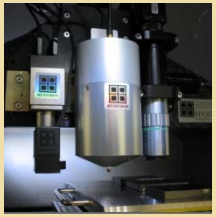
Laboratory testing of friction and wear under simulated service conditions

Understanding mechanisms

Post-test characterization







Milestones

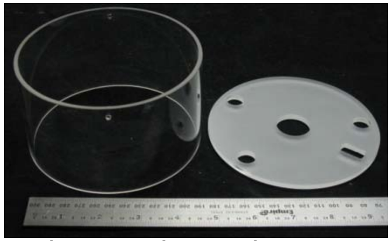
Milestones	Progress Notes	Comments	% Comp
Continue room temperature tests of commercial and lab materials/coatings. Perform characterization.	Performed tests of following new materials: amorphous carbon Diamonex and Argonne NFC7 amorphous hydrogenated carbon. First tests of nanoindenter/ nanoprobe with hydrogen worn specimens.	The new Argonne NFC7 carbon performs better than current leader NFC6. Later tests are harsher: 2-hr duration at 6,000 rpm, 50% duty cycle, up to 15 N.	60%
Acceptance test demonstrating 2000 rpm operation for 1 hour in 0.9 bar H_2 gas at 800°C nominal temperature with continuous measurement of friction, wear, temperature, and sliding distance.	Attained 2000 rpm operation for 1 hr in 0.9 bar N_2 gas at 800°C with continuous measurement of friction, wear, and temperature, but not in tests scheduled with H_2 gas.	Hydrogen environment test awaiting installation of thermal insulation.	80%
Complete ball-on-disk tests on the test materials from inventory (N3FC, NFC6, MoS_2/graphite, X-750, boride, carbon composite) at temperatures up to 400°C for durations up to 12 hours or until materials fail.	Tests done on inventory specimens at room temperature but not 400°C using new machine due to shakedown problems.	Damaging effects of hydrogen on uncoated nickel alloys were dramatized when new test machine jammed and galled during maintenance.	0%

Technical Accomplishments 2010

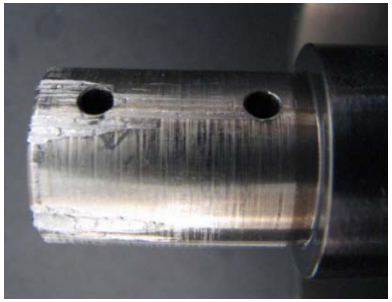
- Successful receipt and installation of elevated-temperature hydrogen tribometer
- Shakedown tests (2000 rpm at 800°C) were performed in N_2 but not in H_2
- Reducing nature of H_2 on uncoated nickel alloys was dramatized when new machine jammed and galled during maintenance – necessitating factory repair
- Special high-performance thermal insulation has been designed

Installed test machine

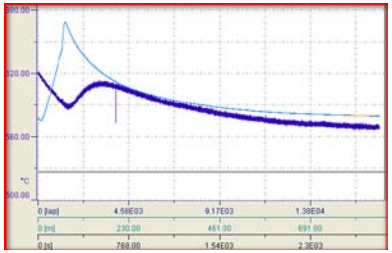
Open for service



Thermal Insulation



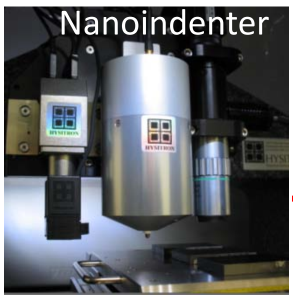
Galling

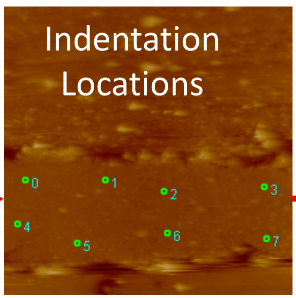


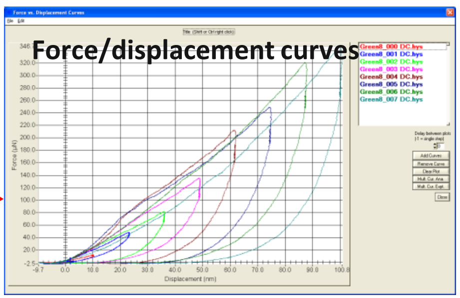
Thermal behavior

Technical Accomplishments 2010

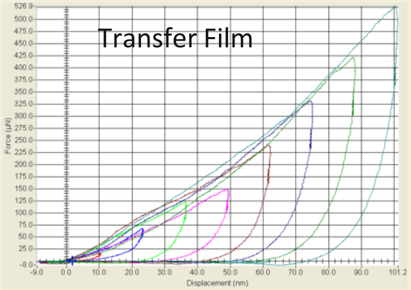
- First tests of mechanical properties of specimens were performed with nanoindenter/nanoprobe using Berkovich indenter that had been tested in hydrogen.
- Force/displacement curves of N3FC (either new or worn) are not typical and are extremely elastic (lower graphs) in comparison to transfer film or metal substrate. Tests are ongoing to understand this unusual behavior.

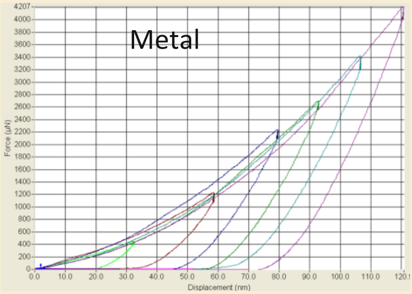


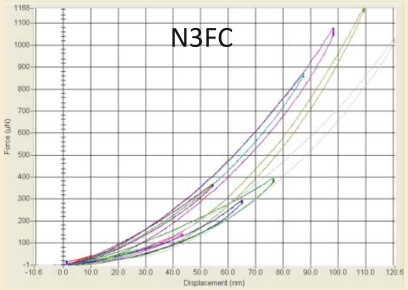


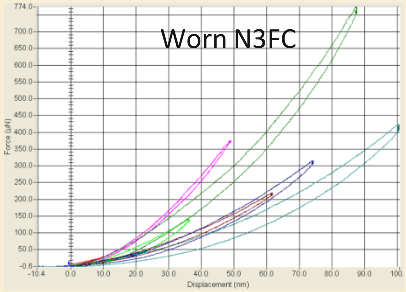


Sample and region of probing	Hardness (GPa)	Elastic Modulus (GPa)
4118 steel with no coating or transfer film	13.8±1.3	234±20
Transfer film of H_2 tested N3FC DLC	1.7±0.42	60±14
Transfer film of H_2 tested N3FC DLC	1.7±0.5	30±5
N3FC tested in H_2	5.3±2.5	35±15
As-deposited N3FC DLC	6.4±2.6	44±22



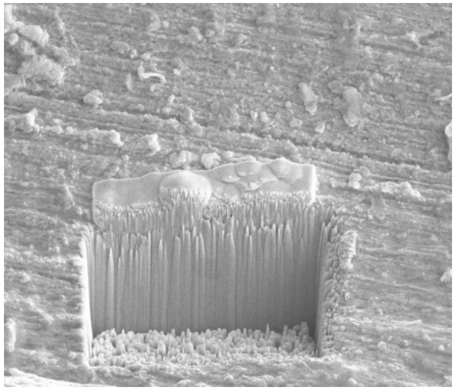




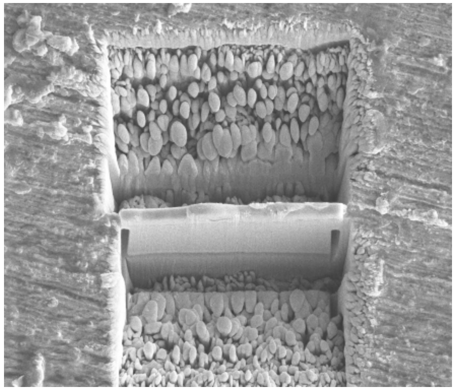


Technical Accomplishments 2010

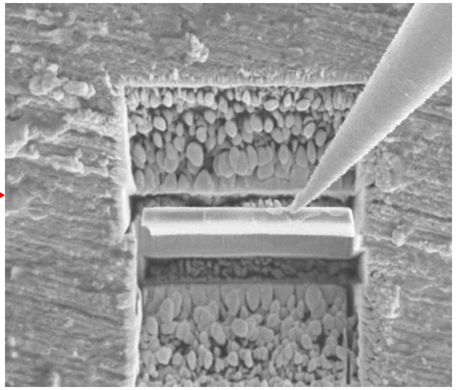
- Started focused ion beam examination of near-surface region (O. Ajayi and C. Lorenzo-Martin)
  - FIB is means to perform detailed probing into the near-surface region
    - Large specimens – University of Illinois – Champaign-Urbana
    - Small specimens – Argonne



Mill first trench



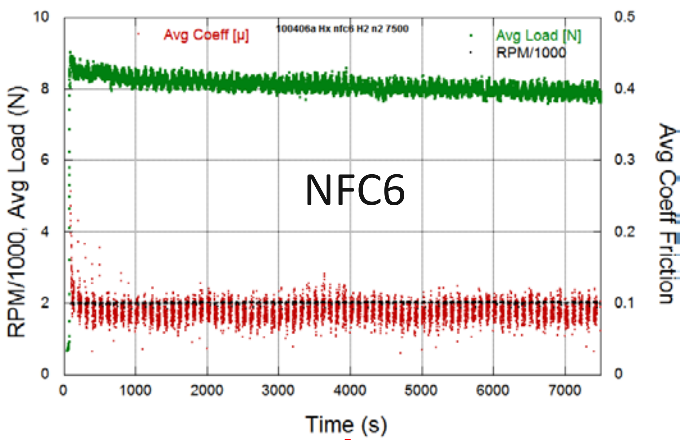
Mill second trench
to make wall

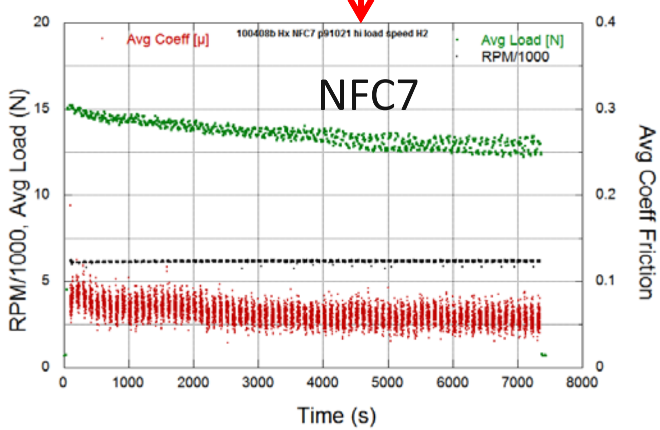


Remove thin sample
for examination

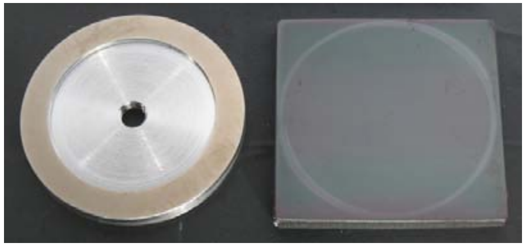
Technical Accomplishments 2010

- New Argonne NFC7 carbon performs better than former leader NFC6. Tests are harsher with 2-hr duration at 6,000 rpm, 50% duty cycle, up to 15 N load.



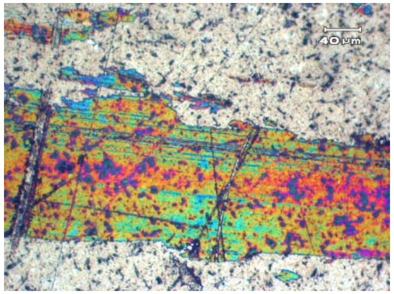


NFC6

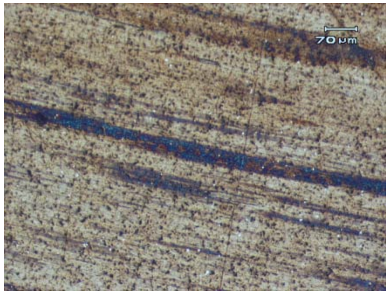


NFC7

NFC6



NFC7



Technical Accomplishments 2010

Materials Tests					
Rotating face	**Stationary counterface**	**Environment**	**Friction**	**Wear face**	**Wear counterface**
Molykote MoS_2	X750	Hydrogen	Medium 0.4	High abrasion	Low
Fe/Mo/Boride	316ss	Hydrogen	Med high 0.6	Low abrasion	Low
CF composite	X750	Hydrogen	Medium 0.4	Low	Low
N3FC	4118 steel	Hydrogen	Low 0.15	Low	Immeasurable
Hastelloy X	Hastelloy X	Hydrogen	Very high >1	High galling	High galling
X-750	X-750	Hydrogen	High 0.6-0.9	High	High
NFC6	Hastelloy X	Hydrogen	Low 0.1	None	Very low
316ss	316ss	Hydrogen	High 0.6-0.9	High	High
Hastelloy X	Diamonex	Hydrogen	Medium 0.4	Low	Medium
NFC7	Hastelloy X	Hydrogen	Low 0.06	None	Immeasurable

Collaborations

- **MITI – Mohawk Innovative Technologies Incorporated**
  - Oil-free, high-speed centrifugal compressor (bearings)
- **CSM**
  - Advanced instruments for tribological testing in pure hydrogen gas
- **John Crane**
  - Oil-free, high-speed gas lubricated seals

- **Discussions underway with manufacturers of positive displacement compressors (forecourt compressors 10-12 kpsi)**

Summary

- Project initiated to address concern over potential impact of hydrogen on friction, wear, and embrittlement of dynamically loaded components (bearings and seals)
  - Despite limited funding, longer-duration room-temperature testing was performed on existing (NFC6) and new (Diamonex amorphous carbon and Argonne NFC7) materials
  - Installation of new elevated temperature tribometer is 80% complete, with shakedown tests performed in N_2 but not in H_2. The reducing nature of H_2 on uncoated nickel alloys was dramatized when the new machine jammed and galled during maintenance – necessitating factory repair
  - Preliminary studies (room temperature) identified several promising candidate materials (e.g., non-metallic solid-lubricant composites and amorphous carbon films)
  - First tests of mechanical properties of tested specimens obtained using nanoindenter/nanoprobe show very soft carbon films and transfer films
  - Development and testing of amorphous carbon coatings containing hydrogen (the Argonne NFCX series) showed excellent friction and wear behavior

Proposed Future Work

- Complete installation of elevated temperature tribometer and finish up testing of promising materials at typical in-service temperatures
- Conduct longer-term sliding tests on materials used in forecourt compressors for “bone dry” use (e.g., PEEK and carbon-TFE instead of nickel alloys as has been done so far)
- Continue nanoprobe/nanoindentation studies to elucidate possible relationship of surface mechanical properties to tribology friction and wear
- Perform electron microscopy for wear mechanism studies (maybe)
- Apply focused-ion-beam method to understand how H_2 can impact near-surface and subsurface failure
- Study embrittlement and crack behavior