Low Friction Coatings for Fuel Cells Compressors

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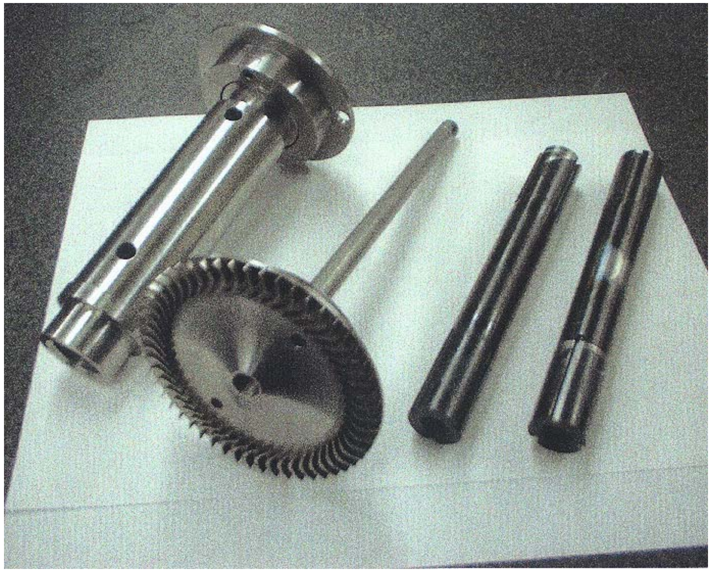
Low Friction Coatings for Fuel Cell Compressors/Expander



Technology Issue: Fuel cell stacks requires a compact lightweight highly efficient compressor/expander. Efficiency, reliability and durability is dependent on effective lubrication of critical components such as bearings and seals.

Objective: Develop and evaluate low-friction coatings and/or materials for critical components of air compressor/expanders being developed for fuel cells.

Approach:

•Identify critical compressor components requiring low friction

•Apply and evaluate Argonne's near-frictionless carbon coatings to the components when appropriate

• Develop and evaluate polymer composite materials with boric acid solid lubricant.

Past Year Accomplishments:

• Durability testing of NFC-coated Meruit's air bearing with good results

• Evaluated several materials and coatings with potential to meet the 0.3 friction coefficient requirement of Mechanology TIVM device.

• Initial contact with A.D. Little and UTC fuel cells to identify tribological issues in the compressor/expander programs

Fuel Cell Compressor/Expanders

Meruit: Turbo-compressor air bearing

Mechanology: Toroidal Intersecting Vane Machine (TIVM)

AD Little: Hybrid compressor/Expander Module

UTC Fuel Cells: Motor Blower/compressor Technology

Honeywell: Turbo-compressor/Expander

Meruit Air Bearing - Tribological Issues

• Prototype test showed that high friction in radial journal bearing at start-up resulted in thermal instability and seizure.

- unbalanced shaft.
- lubrication required

• Desirable larger clearance in journal bearing makes the shaft more susceptible to imbalance in in the event of any shock loading.

- Shaft unbalance caused excessive wear during test
- Wear resistant surfaces needed to meet DOE durability target

• Debris contamination was another observed failure mode.

- Hard, debris resistant surfaces required

• Laboratory friction and wear tests showed NFC coatings will reduce friction, substantially increase wear and scuffing resistance.

•Air bearing test showed NFC coating aided lift-off speed and time.

NFC Durability Testing

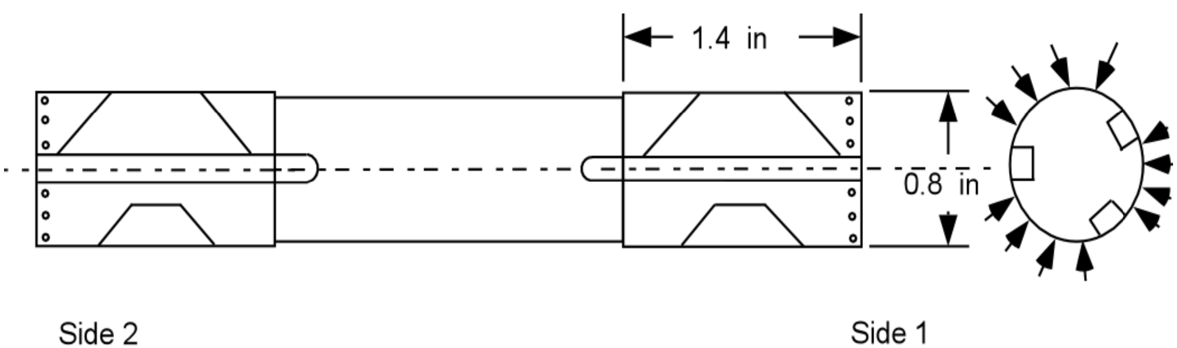
• Both Laboratory and initial air bearing rig tests showed NFC coating is needed for successful running of air bearing

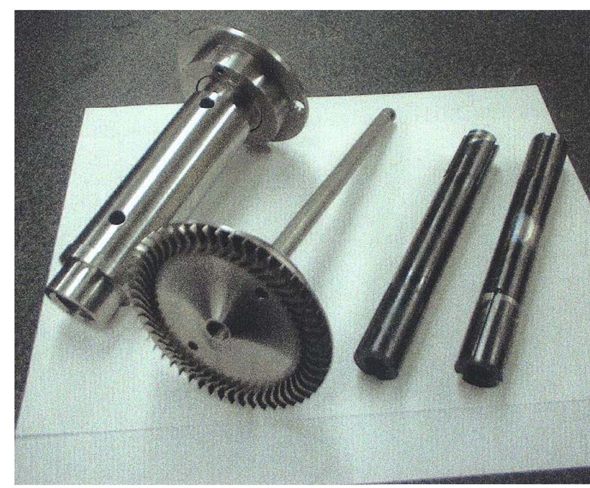
– Uncoated air bearing did not run - due to excessive wall climbing

• Durability of NFC coated rotor was evaluated by a start-stop cycles test protocol.

•Dimples were created coated bearing shaft surface to measure wear

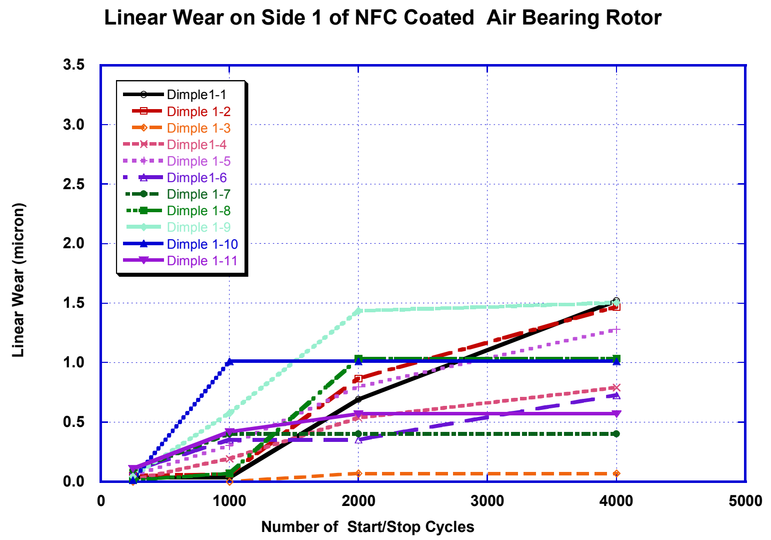
– Tests were interrupted at predetermine intervals and dimple dimensions measured. From change in dimple diameter linear wear on the coated surface can be calculated

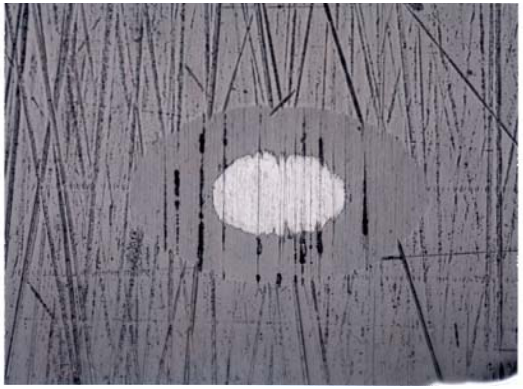




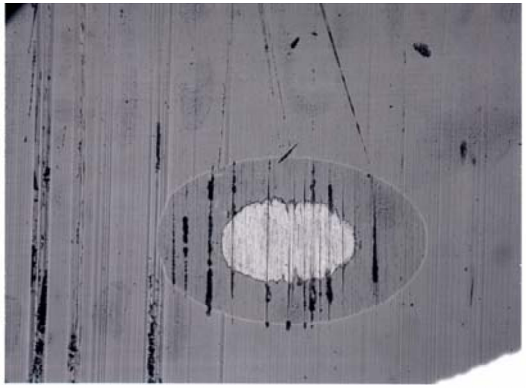
NFC durability test Results

- Maximum linear wear was about 1.6 µm of the original 2.5 µm coating thickness
  - Wear in most dimples less than 1 µm
- More wear occurred on side 1 than side 2
  - perhaps due to bearing imbalance
- Wear in all the dimples occurred by a mild abrasive or polishing wear modes.
- Bearing failed after 4000 cycles due to debris contamination

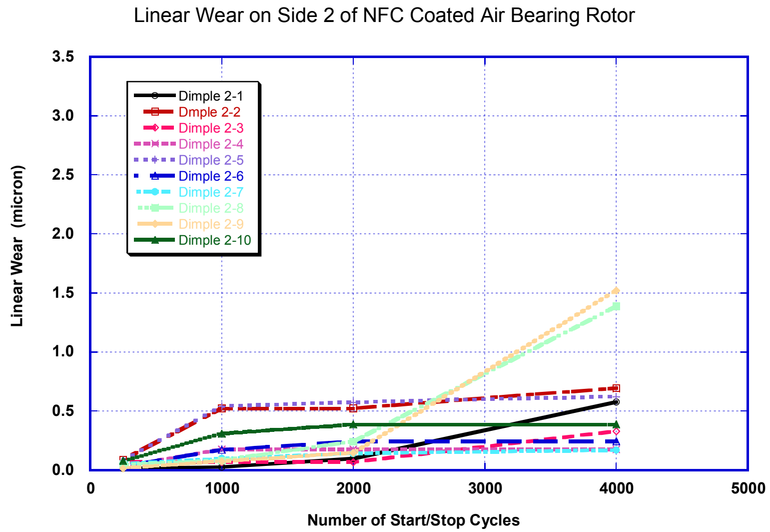




Dimple 1-9 after 250 cycles



Dimple 1-9 after 4000 cycles



Air Bearing Durability Results

- Initial results show that NFC coating is durable in terms of wear resistance. At point of test failure due to debris contamination, wear on most dimples was leveling off.

- A second coated bearing ran for 10,250 cycles before failing by debris contamination. Wear rates and mechanisms on the dimples were almost identical to the ones in the first test.
  - Contamination of the tested bearings by debris and the resulting failures may be the result of periodic test interruption for wear measurement.

- Plan is in progress to evaluate the effect of humidity on coated air bearing performance.
  - Assess impact of moisture on NFC coating wear rate and wear mechanism

Mechanology TIVM: - Tribological Issues

This compressor concept offer a great potential for meeting the size, weight, and efficiency targets.

•Initial design and prototype fabrication of TIVM completed by Mechanology

•Analysis showed that friction will significantly impact the efficiency of compressor.

•ANL working with Mecahnology to develop and evaluate low friction and wear resistant surfaces for critical components.

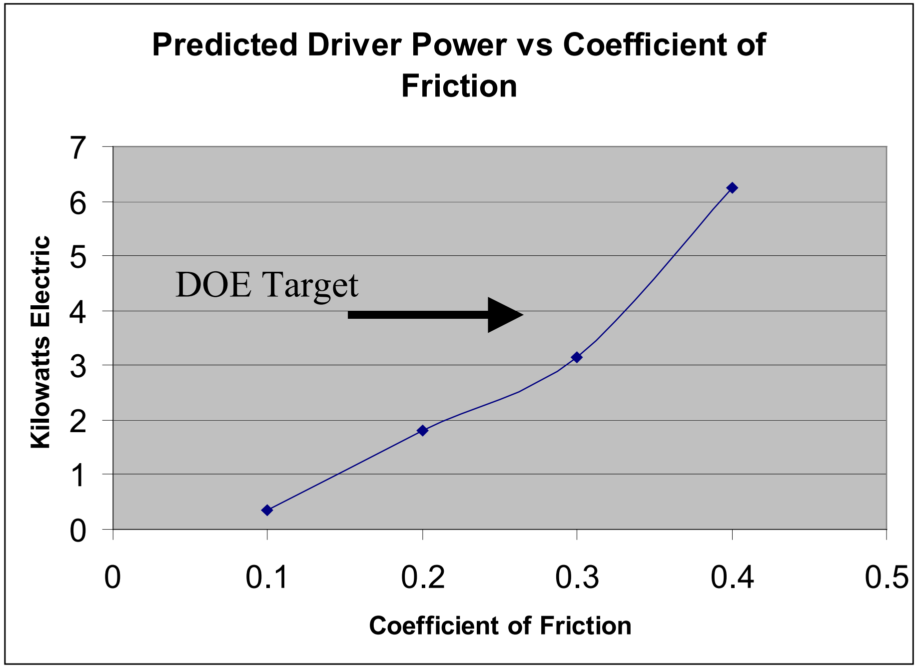


Figure from Mechanology phase I final report

TIVM Frictional Sources

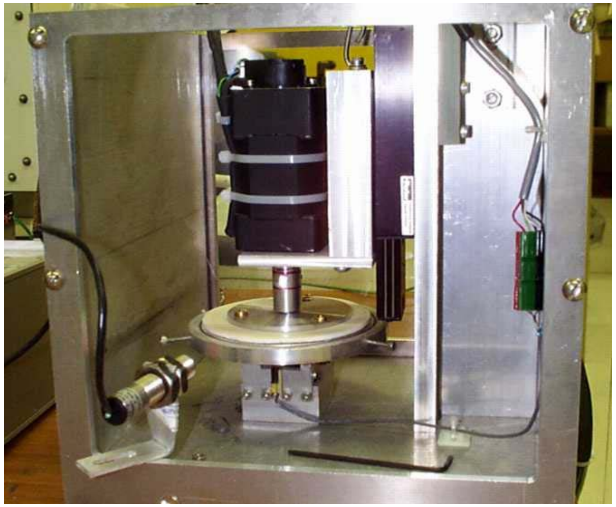
- To meet DOE compressor driver power target, overall friction coefficient in the TIVM must be less than 0.3

- The largest source of frictional loss is vane sliding interface; followed by compressor and expander bearings and the housing seal.

- In addition to low friction, the vane and seal surfaces must be wear resistant to meet the durability targets. They must also slide quietly to meet the noise target.

Friction Test for Vane Materials

- Design sliding velocity for the TIVM vanes ranges from 60 - 75 m/s
  - Need to identify materials capable of such sliding speeds.
  - Other constraints include relatively low cost, light weight, easy to fabricate,



- A screening test protocol was developed to evaluate the effect of sliding speed on friction coefficient
  - Uses three balls-on-disc contact configuration
  - gradual continuos increase in speed from 0 to a maximum speed, some dwell time at maximum speed, and gradual decrease of speed to 0

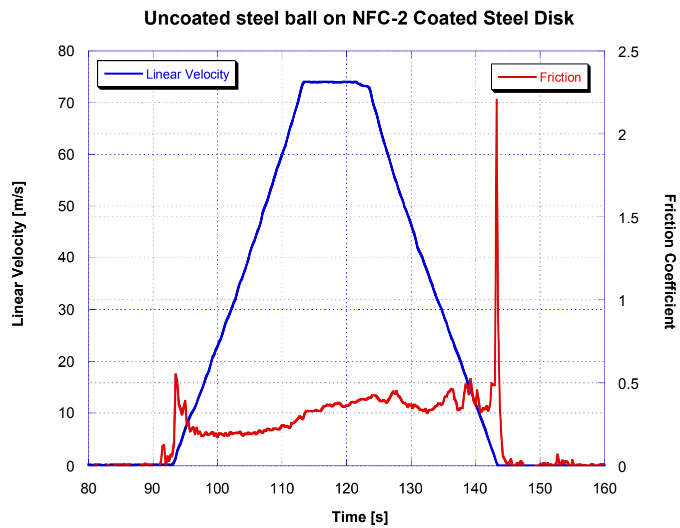
- Several materials screened: 440 C S.S., Bronze, Teflon, Delrin, PEEK, Torlon, Vespel, Armaloy coated bronze, NFC coated steel

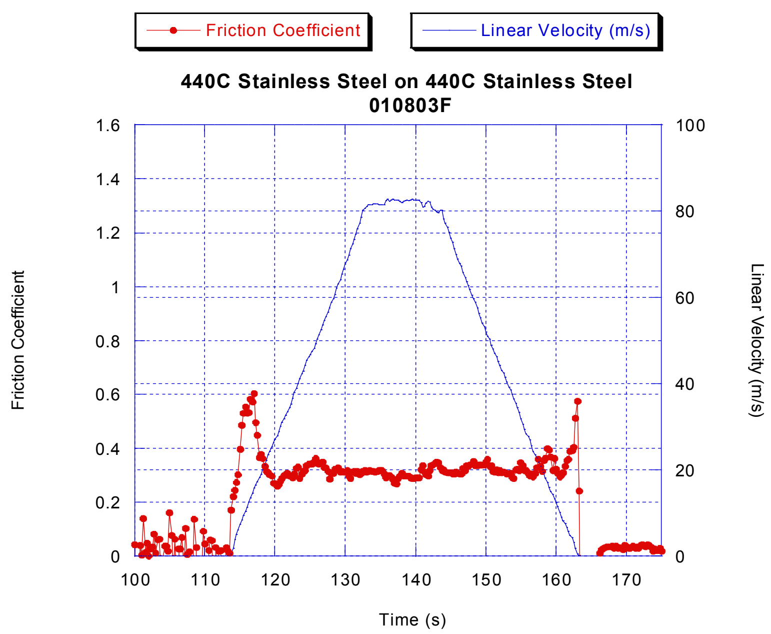
NFC coated steel results

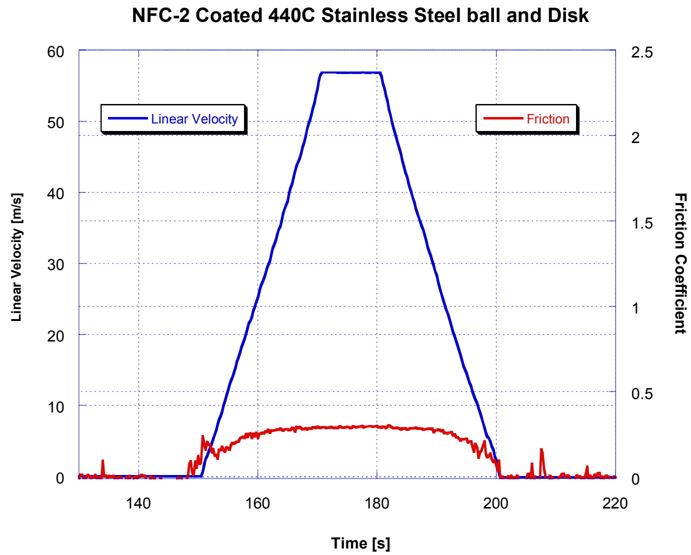
- Presence of NFC on one or both surfaces reduced friction, and more importantly wear.

•Wear in uncoated surfaces involves oxidation and a lot of debris generation

- Wear in NFC coated surfaces involve polishing

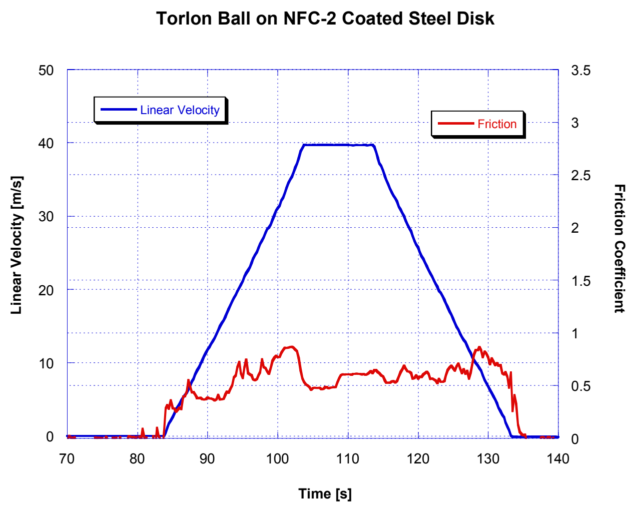


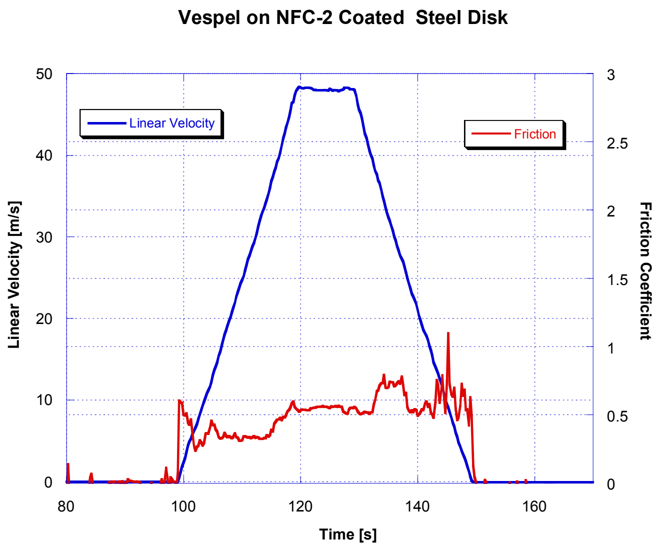


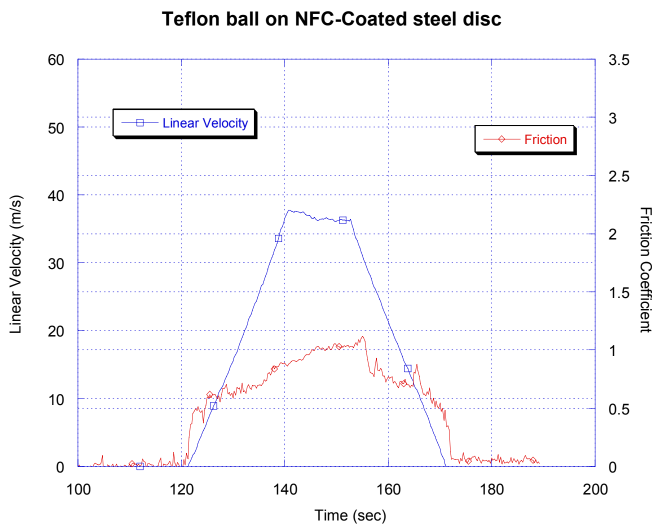


Polymer and NFC coated steel

- Combination of low friction polymers and NFC coating did not result in low and stable friction.
  - Local melting and excessive wear was observed in all the polymeric materials.

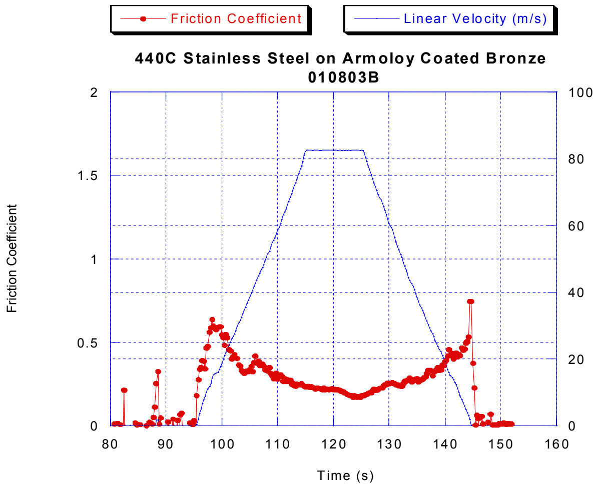


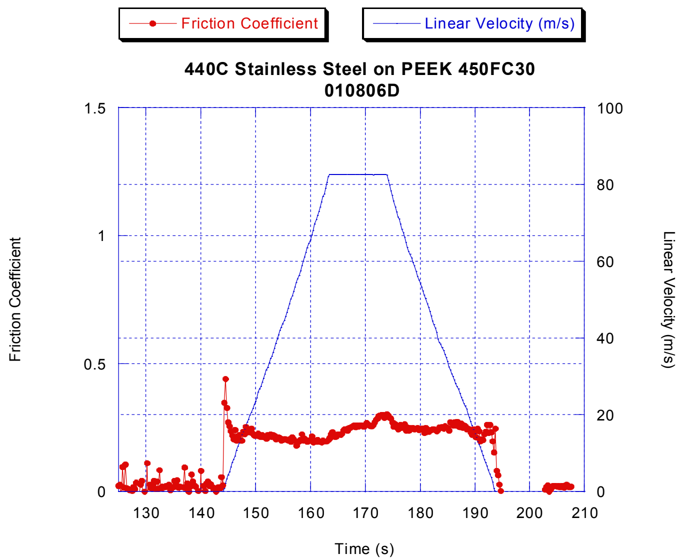


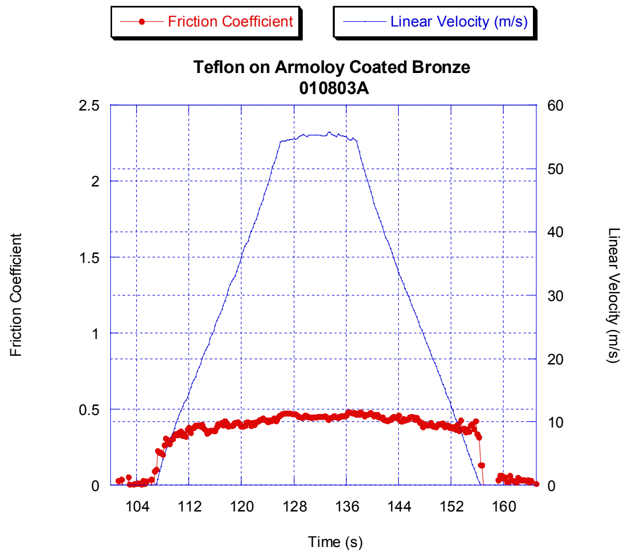


Other promising combinations

- There are other combinations of material with relatively low and stable friction at high speed
  - S.S. Steel and PEEK combination
  - S.S. steel and armaloy coated bronze
  - Teflon on armaloy coated bronze for friction; but excessive wear on teflon







Future Plans

- Meruit Air Bearing
- Evaluate the effect of humidity on performance of NFC coating in air bearing test
- Transfer NFC coating technology to Meruit for air bearing

Mechanology TIVM

- Detailed tribological performance evaluation of promising material combinations from screening - including effect of humidity
- Optimize NFC coating for Mechanology TIVM vanes operating conditions
- Evaluate the performance of candidate materials/coatings in TIVM test rig at Mechanology.

AD Little and UTC Fuel Cell

- Initiate project(s) to address the tribological needs and issues in the compressor/expander program

LOW-FRICTION COATINGS AND MATERIALS FOR FUEL CELL AIR COMPRESSORS

Opportunity

Fuel cells require a clean flow of air to the fuel cell stack, typically supplied by a small and lightweight air compressor. Effective lubrication of critical components, such as bearings and seals, is necessary for maximum compressor efficiency, reliability and durability. Grease and oil-based lubricants cannot be used, because they can contaminate the fuel cell stack.

Approaches

- Apply Argonne-developed near-frictionless carbon (NFC) coatings to critical components
- Develop and evaluate coated and uncoated low-friction materials for appropriate applications

Argonne Solution

Argonne researchers and partners are developing and evaluating low-friction coatings and materials for key compressor components to protect against sudden failures and excessive wear.

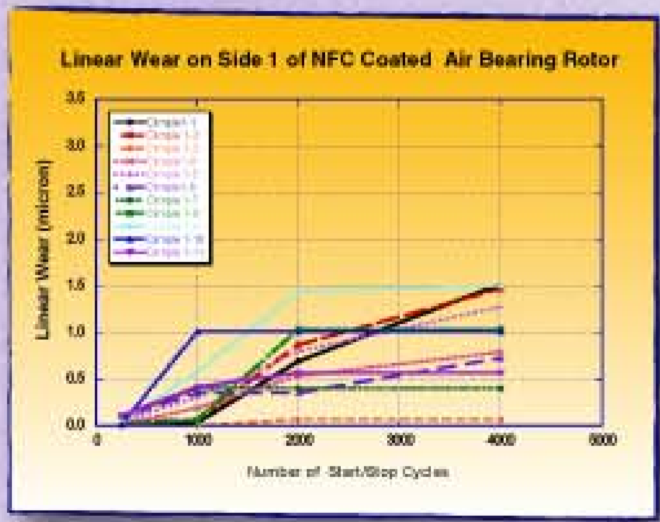
RESEARCH PARTNERS

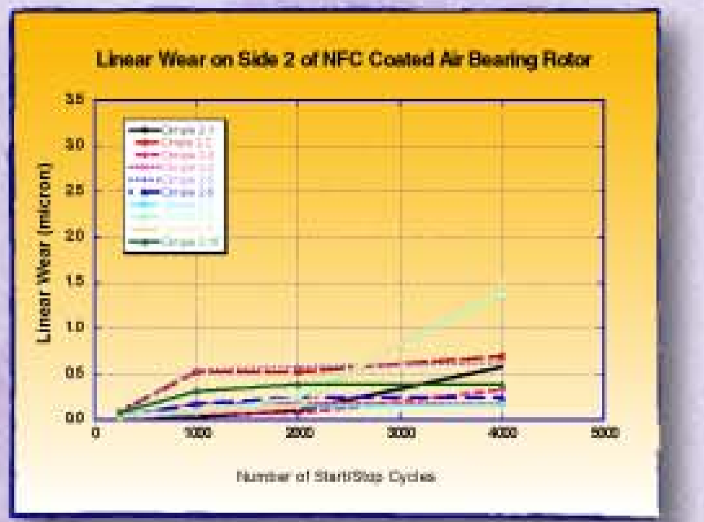
Arthur D. Little, Inc.
Honeywell
Meruit Inc.
Mechanology, LLC
UTC Fuel Cells

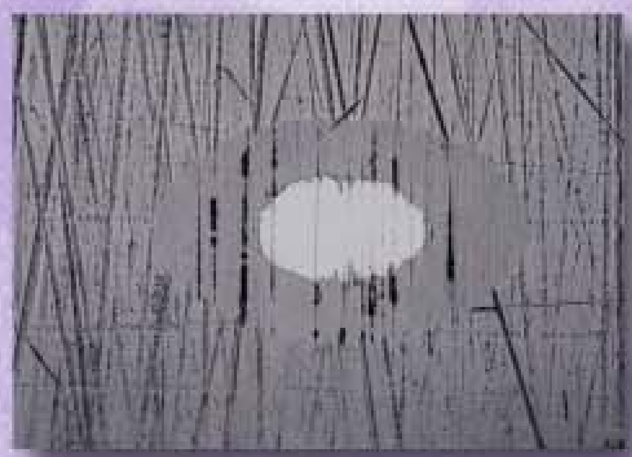
Project funded by the U.S. Department of Energy, Office of Transportation Technologies

Turbo-Compressor Air Bearing Testing

Durability tests on NFC-coated air bearing rotor show linear wear typically stabilizes at < 1.0 μm. Greater wear on side 1 may be due to bearing imbalance. Bearing failed after 4,000 cycles (and later after 10,250 cycles) due to debris contamination.







Dimple 1-9 after 250 cycles

Dimple 1-9 after 4,000 cycles

Approaching Commercialization

Argonne has shown that the cost of applying NFC coatings to critical compressor components is comparable to or less than applying other carbon-based coatings.

A commercial-scale, plasma-based NFC coating system is now fully operational.

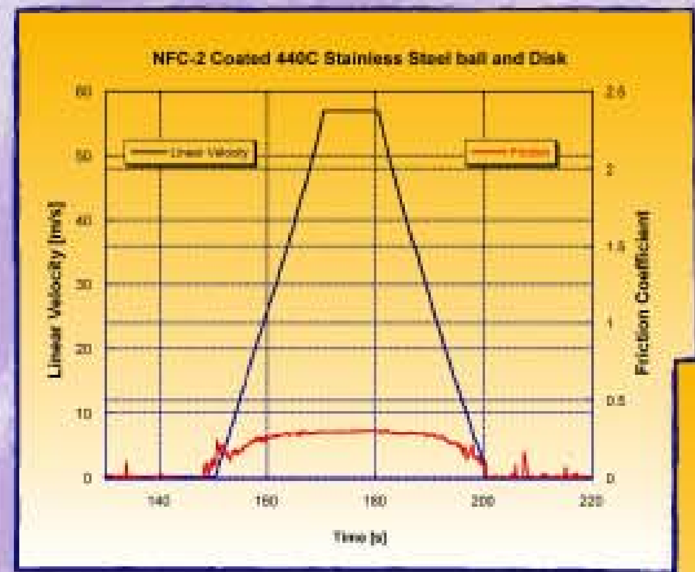
Meruit Inc. has determined that the NFC coating is necessary for further development of its air bearing. Argonne is now optimizing a commercial-scale coating process for future transfer to Meruit.

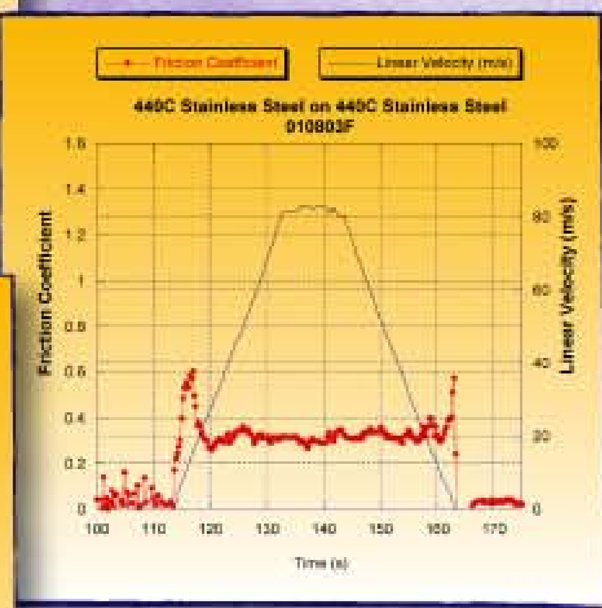
Material Selection for TIVM

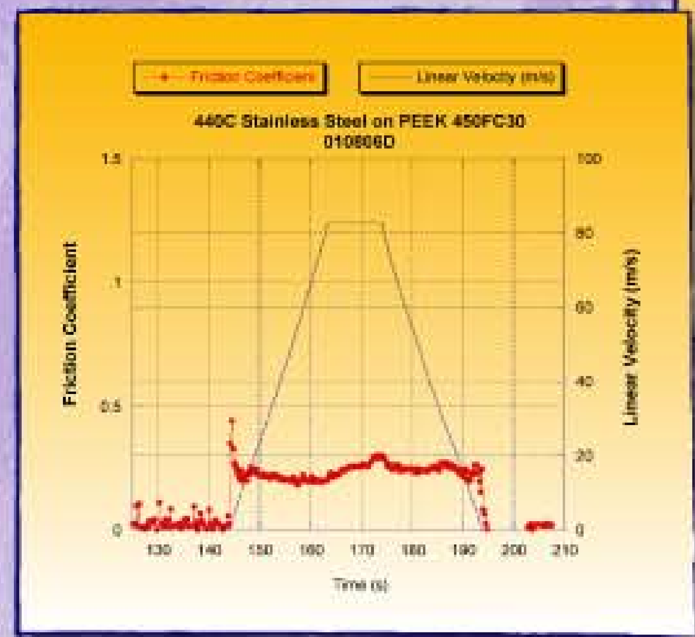
Toroidal intersecting vane machine (TIVM) components.

Material Evaluation

NFC coating on one or both surfaces reduced friction and wear. Friction was stable with low noise levels across a wide range of speed.







Future Efforts

Meruit Air Bearing: Evaluate effect of humidity on NFC coating performance in air bearing tests; transfer coating technology.

Mechanology TIVM: Evaluate tribological performance of promising materials; optimize NFC coating process for TIVM vane operation; evaluate candidate materials/coatings.

ADL and UTC: Initiate project(s) to address tribological needs in a compressor program.