Low-Friction Coatings and Materials for Fuel Cell Air Compressors

O. O. Ajayi, A. Erdemir, and G. R. Fenske

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Argonne National Laboratory

A U.S. Department of Energy Office of Science Laboratory Operated by The University of Chicago
Objectives

Technology Issue and Relevance:
Fuel cell stacks require a compact, lightweight, highly efficient, and low-cost compressor/expander. No off-the-shelf compressor technology that can meet DOE target exits. Several contractors are developing compressor/expander systems for DOE. Efficiency, reliability, and durability of such systems are dependent on effective lubrication of critical components such as bearings and seals. Such components cannot be oil lubricated - oil will contaminate fuel cell stacks.

Objectives: Develop and evaluate low-friction and wear-resistant coatings and/or materials for critical components of air compressor/expanders being developed for fuel cells by DOE contractors.

Budget & Effort: 200K FY04; 2 staff + visiting scientist & student
Technical Barriers and Targets

- Transportation Systems Barriers
  - A. Compressors/Expanders

- DOE Technical Targets for 50-kW System Compressor for 2010
  - Cost - $6/kW
  - Efficiency at Full Flow - 80%
  - Volume - 8-11 L
  - Weight - 8-11 Kg
  - Turndown Ratio – 10-15
  - Noise dB(A) at 2 meters – 70 dB(A)
Approach

• Work with various DOE contractors to
  – Identify tribologically challenging critical compressor components
  – 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.
  – Identify and evaluate other candidate materials for various specific compressor components
  – Transfer developed technology to DOE contractors

• Develop a tribology-based material selection methodology applicable to all the DOE compressor contractor’s operating conditions and requirements
Project Safety

• All the tasks in the project are on the laboratory bench top scale.

• It is the policy of Argonne National Laboratory that its activities be conducted in such a manner that worker safety, public safety, and protection of the environment are given highest priority.

• An environmental evaluation has been completed in accordance with the DOE-approved ANL-E process for implementation of the National Environmental Policy Act.
Project Timeline

**FY 2000**
- 50% Friction Reduction in Variex variable displacement low pressure low friction
- Developed Nylon-12 boron oxide polymer composite.

**FY 2001**
- Designed and constructed high speed turbo testing for mechanology TIVM vane
- Evaluated some materials and coatings for TIVM vane.

**FY 2002**
- Developed NFC coating for Meruit turbocompressor journal and thrust air bearings
- Meruit incorporated NFC technology into their air bearing design - tech. transfer.

**FY 2003**
- Continued evaluation of TIVM vane material.
- Material selection methodology-T map.
- Material evaluation and coating development for mesoscopic devices.

**FY 2004**
- Tribological evaluation of vane materials and coatings for TIVM
- Materials and coatings evaluation for Variex and DynEco
- Materials selection methodology
Mechanology TIVM Vane Materials Evaluation

- To meet DOE efficiency target, Mechanologys’ TIVM compressor vanes require sliding friction coefficient < 0.15 under high sliding contact.
  - Low-cost material – to meet cost target
  - Stable friction behavior – low noise
  - Wear resistant – for durability target

- Evaluated two classes of engineering polymers – PEEK and Ultem, and NFC coating
  - Three types of ball material – 440C stainless steel, Aluminum alloy (2017) and NFC coated steel ball.

- Test conducted under room and 100% relative humidity

High-speed three-ball-on disc test rig
# Disc Materials

<table>
<thead>
<tr>
<th>Material</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>PEEK FC30</td>
<td>Polyetheretherketone with 30% carbon fiber/powder</td>
</tr>
<tr>
<td>PEEK CPK 53</td>
<td>Weaved Carbon Fiber Reinforced PEEK</td>
</tr>
<tr>
<td>Ultem 1000</td>
<td>Polyetherimide base resin</td>
</tr>
<tr>
<td>Ultem 4000</td>
<td>Polyetherimide with glass reinforced and lubricant</td>
</tr>
<tr>
<td>Ultem 4001</td>
<td>Polyetherimide with lubricant additive</td>
</tr>
<tr>
<td>NFC Coated Steel</td>
<td>ANL’s Amorphous Carbon Coating</td>
</tr>
<tr>
<td>Nylatron</td>
<td>Nylon &amp; Molybdenum Disulphide (MoS2)</td>
</tr>
<tr>
<td>Ertalyte TX</td>
<td>Polyethylene Terephthalate (PET-P) w/solid lubricant</td>
</tr>
<tr>
<td>Fluorosint 500</td>
<td>Polytetrafluoroethylene (PTFE)</td>
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Friction Behavior

- Some candidate material and coatings will meet the < 0.15 friction coefficient requirement under both dry and humid environments.
## Wear Behavior

- Wear rate in some of the candidate materials and coating are acceptable in both dry and humid environments

### Specific Wear Rate for Disc Wear in Ambient RH

<table>
<thead>
<tr>
<th>Disc Material</th>
<th>NFC2</th>
<th>Neat PEEK</th>
<th>450</th>
<th>FC30</th>
<th>CPK 53</th>
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<tr>
<td>Specific Wear Rate (mm³/(N*m)) NFC Ball</td>
<td>1.27E-06</td>
<td>1.68E-06</td>
<td>6.08E-06</td>
<td>9.67E-07</td>
<td>0.00E+00</td>
<td>5.00E-05</td>
<td>1.00E-04</td>
<td>1.50E-04</td>
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### Specific Wear Rate for Disc Wear in 100% RH

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<tr>
<td>Specific Wear Rate (mm³/(N*m)) NFC Ball</td>
<td>1.37E+03</td>
<td>2.43E-06</td>
<td>0.00E+00</td>
<td>5.00E-05</td>
<td>1.00E-04</td>
<td>1.50E-04</td>
<td>2.00E-04</td>
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<td>9.87E+00</td>
<td>1.39E+01</td>
<td>1.17E+00</td>
<td>2.61E-09</td>
<td>6.97E-06</td>
<td>0.00E+00</td>
<td>1.00E-07</td>
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**Friction Heat Calculations**

- As expected, significant differences in frictional heating characteristics of steel-on-steel contact and steel-on-polymer contact pairs
  - Effect of differences in thermal conductivity

![T-map for Steel-on-steel contact](image1)

![T-map for Steel-on-Ultem 1000 polymer contact](image2)
Interactions and Collaborations

- Meruit Inc. and Texas AM: Coated several components for turbocompressor testing at Texas AM (Prof. San Andres).

- Mesoscopic Devices: Coated components for blowers for small fuel cells for testing.

- Mechanology LLC: Evaluation and characterization of tribological behavior of candidate materials for TIVM.

- Variex Corp: Material tribological evaluation for vane compressor.

- DynEco: Material/coating evaluation for vane compressor

Responses to Previous Year Reviewers’ comments

• Work on real devices
  - Components were coated for real turbocompressor device for testing by Meruit Inc.
  - Prototype components were coated for Mesoscopic Devices Inc. for real device testing

• Focus on specific friction problems for compressor/blower
  - Working with Mechanology LLC to address specific friction and wear needs in TIVM
Future Work

• Continue work with DOE compressor developers to address critical tribological and material issues
  - Mechanology TIVM
    - Comprehensive tribological performance characterization of candidate materials and coating
    - Coat prototype components for device testing by mechanology
  - Variex Vane compressors
    - Evaluate materials and coatings under prototypical operating conditions.
  - DynEco Vane compressors
    - Evaluate tribological and corrosion properties under …….

• Continue development of compressor/expander material selection methodology.

• Expand current effort to include compressor/expander units for direct hydrogen systems