IV.H.9 Low-Friction Coatings and Materials for Fuel Cell Air Compressors

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Objectives

- Develop and evaluate the friction and wear performance of low-friction coatings and materials for fuel cell air compressor/expander systems. Specific goals are:
  - 50 to 75% reduction in friction coefficient.
  - One-order-of-magnitude reduction in wear.
- Transfer technologies developed to DOE industrial partners.

Technical Barriers

This project addresses the following technical barrier from Fuel Cells section of the Hydrogen, Fuel Cells and Infrastructure Technologies Program Multi-Year Research, Development and Demonstration Plan:

- A. Compressors/Expanders

Approach

- Identify critical compressor components requiring low friction.
- Apply and evaluate Argonne's near-frictionless carbon (NFC) coatings to the components when appropriate.
- Develop and evaluate low-friction polymer composite materials.
- Develop tribological mechanism-based materials selection methodology for various compressor/expander components.

Accomplishments

- Developed and demonstrated NFC-coating for Meruit's turbo-compressor air bearings – the coating is now part of bearing design.
- Demonstrated NFC coatings increased the scuffing resistance of a steel surface about 10 times.
- Completed initial friction and wear testing of Nylon-12 polymer with B_2O_3 addition. Significant friction reduction and wear was observed with the addition of B_2O_3, especially under high relative humidity.
- Achieved 50% reduction in friction for application in Vairex-variable displacement compressor/expander using Hitco C/C composite and anodized Al contact pairs.
- Designed and constructed a new high speed friction and wear test rig for evaluation of materials using Mechanology's Toroidal Intersecting Vane Machine (TIVM).
- Evaluated high-speed frictional performance and identified candidate materials and coatings for TIVM vanes.

Future Directions

- Develop a tribology-based material selection methodology for compressor and blower components.
  - Continue compilation of a database of pertinent properties of candidate materials and coatings.
  - Generate T-maps for various materials sliding contact pairs.
- Continue work with compressor/expander developers to address their unique tribological challenges.
  - Conduct comprehensive tribological performance evaluation of select candidate materials for Mechanology.
  - Optimize NFC coating for TIVM vane application.
  - Coat TIVM components with optimized NFC for rig testing at Mechanology.
  - Develop and evaluate coatings and materials for Vairex vane compressor.
- Initiate efforts to develop and evaluate materials and coatings for compressors for direct hydrogen systems.

Introduction

A critical need in fuel cell systems for vehicles is an efficient, compact, and cost-effective air management system to pressurize the fuel cell systems to about 2.5 atmospheres. Pressurization of fuel cells will result in higher power density and lower cost. Because no off-the-shelf compressor technologies are available to meet the stringent requirements of fuel cell air management, several compressor and blower systems are currently being developed for DOE by different contractors. The efficiency, reliability and durability of compressors depend on effective lubrication or friction and wear reduction in critical components such as bearings and seals. Conventional oil or grease lubrication of compressor components is not desirable because such lubricants can contaminate and poison the fuel cell stack. The objective of this project is to develop and/or evaluate low-friction coatings and/or materials for critical components of air compressor/expanders being developed by various contractors for DOE vehicle fuel cell systems. The work this year focused on evaluation of materials and coatings for Mechanology's TIVM, as well as the development of generalized material selection methodology for compressor components.

Approach

For various air compressor/expanders being developed, we will identify the key critical components that require low friction coefficient and wear resistance. Over the years, the Tribology Group at Argonne has developed low-friction and low-wear coatings and materials. Most notable is the discovery of an amorphous carbon coating with extremely low friction coefficients (<0.001 in dry nitrogen) and very low wear. Where appropriate, the NFC coating will be applied to the critical component(s). Other commercially available low friction coatings will be evaluated for various applications. In other cases, alternative low friction polymeric materials and other low friction coatings will be evaluated. Also, because components in the various compressor/expanders being developed all operate under significantly different and varied sliding contact conditions of load and speed, a tribological mechanism-based material selection methodology will be developed.

Results

Mechanology TIVM Material Evaluation

Mechanology TIVM is one of compressor/expander concepts that is being developed to meet DOE requirements. In order to meet the efficiency target, it has been determined that a friction coefficient of less than 0.15 is required at the sliding vane interface. Of course, a lower friction coefficient is even better as it will translate to higher efficiency. The high sliding speed at the vane interface makes material selection for this component tribologically challenging. Furthermore, materials that can be injection-molded or easily machined are preferred so

Table 1. Disc Materials for Testing

Material	Description
PEEK FC30	Polyetheretherketone with 30% carbon fiber/powder
PEEK CPK 53	Weaved Carbon Fiber Reinforced PEEK
Ultem 1000	Polyetherimide base resin
Ultem 4000	Polyetherimide with glass reinforced and lubricant
Ultem 4001	Polyetherimide with lubricant additive
NFC Coated Steel	ANL's Amorphous Carbon Coating
Nylatron	Nylon & Molybdenum Disulphide (MoS2)
Ertalyte TX	Polyethylene Terepthalate (PET-P) w/solid lubricant
Fluorosint 500	Polytetrafluoroethylene (PTFE)

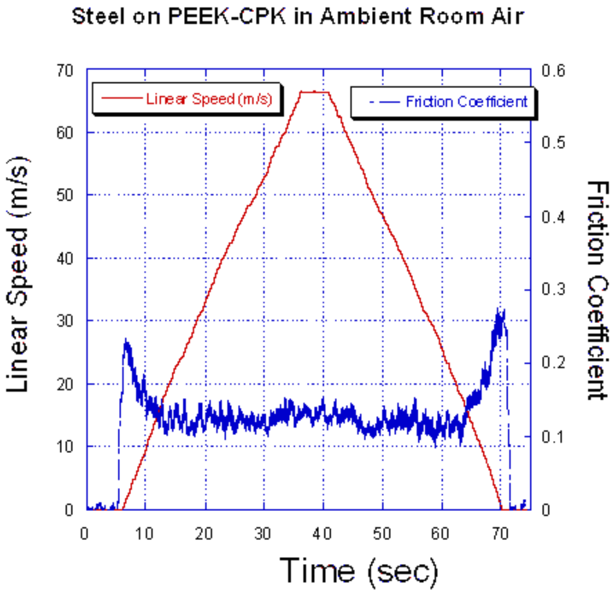

Figure 1. Variation of Friction with Sliding Speed During a Test With Steel Ball and Carbon Fiber Reinforced PEEK Material (CPK-53)

as to meet the cost target. Stable friction behavior and high wear resistance especially at high sliding velocities are required to meet the noise and durability targets, respectively.

As reported last year, a high-speed friction and wear test rig was designed and constructed for the evaluation of candidate materials. The test rig is based on three-ball-on-disc contact geometry with sliding speed range of 0-80 m/s. In consultation with Mechanology, several candidate materials were evaluated during this year. Three different ball materials, namely, 440 stainless steel, aluminum alloy (2017) and NFC-coated steel were used for testing. The balls were tested against several disc materials shown in Table 1 (materials in red are yet to be tested). Figure 1 shows the variation of friction coefficient with sliding speed during a typical test. The average friction coefficients between 30 and 60 m/s, which is the operating speed range for the TIVM vane sliding surfaces, were computed for various material combinations tested. Figure 2a shows the average friction coefficient under ambient room air, and Figure 2b shows the average friction coefficient under 100% relative humidity (RH). Several material pairs meet the <0.15 friction coefficient requirement under both dry and humid environments. Figures 3a and 3b show the specific wear rate in the various disc materials under dry and humid air, respectively.

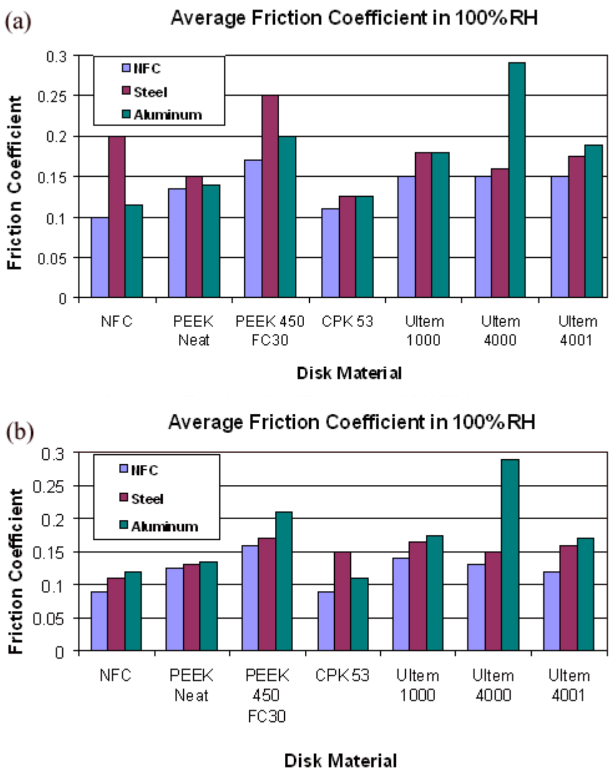

Figure 2. Average Friction Coefficient for Various Material Combinations Under (a) Ambient Room Air, and (b) 100% Relative Humidity

Material Selection Methodology

Under the high sliding speeds or high contact pressures that are typical of the sliding interfaces in many of the compressor/expander systems being developed, frictional heating is expected to govern the tribological performance. Consequently, analysis of frictional heating and estimation of temperature at both the bulk and asperity levels will be instructive in formulating a material selection

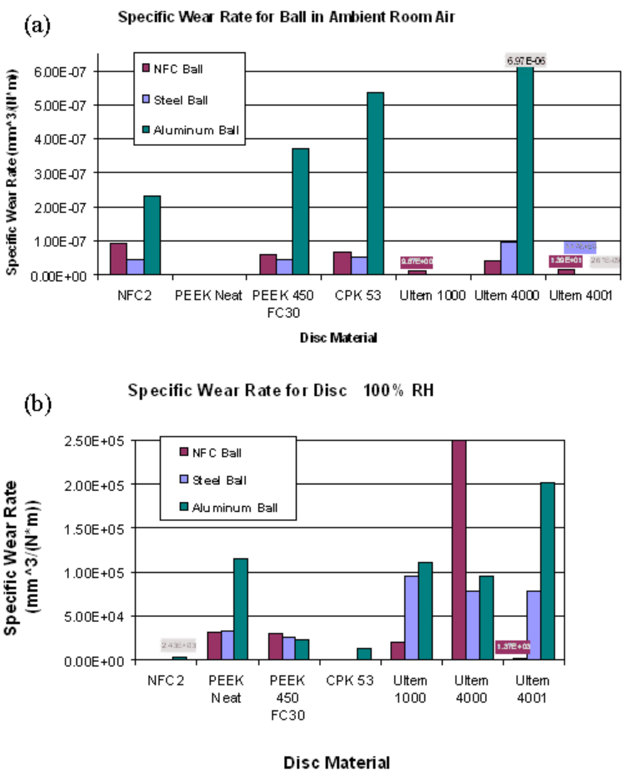

Figure 3. Specific Wear Rate (mm^3/Nm) for the Various Disc Materials in (a) Ambient Room Air and (b) in 100% Relative Humidity

methodology. Using the T-map approach by Ashby et al. [1], we have started the protocols of generating T-maps for some of the material combinations evaluated so far. Figures 4a and 4b show the T-map for steel-on-steel contact pair and for steel-on-Ultem™ 1000 polymer contact pair, under similar contact conditions.

Conclusions

Several new candidate materials were evaluated for the TIVM vanes. Results showed many candidate materials will meet the 0.15 friction coefficient requirement under both dry and humid environments. The lowest friction and wear were observed in contact involving NFC coating and closely followed by contact pairs involving carbon-fiber reinforced PEEK (CPK-PEEK). Highest friction and most wear were observed in contact pairs involving aluminum alloy balls. Preliminary T-map calculations show the impact of thermal conductivity on frictional heating.

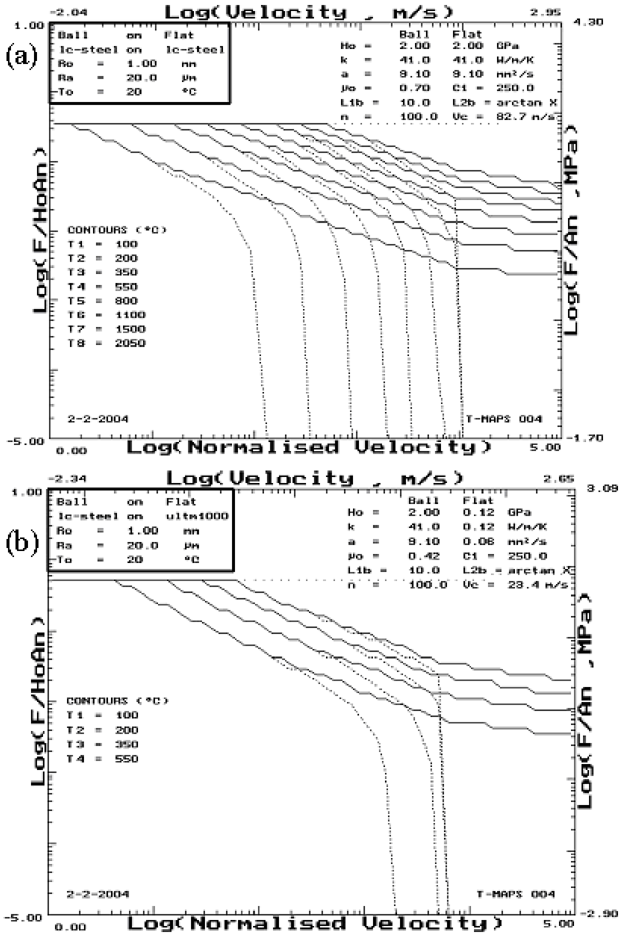

Figure 4. T-Map of Friction Heat Bulk and Flash Temperatures for (a) Steel-On-Steel Contact Pair, and (b) Steel-On Ultem™ 1000 Polymer Contact Pair (The x-axis is the sliding velocity (top) and velocity normalized with the contact size. The y-axis is the contact pressure (right) and the contact pressure normalized with the hardness.)

References

1. Ashby, M. F., Abulawi, J. and Hong, H. S., "Temperature Maps for Frictional Heating in Dry Sliding" Tribo. Trans., 34, (1991), 577-587.

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2. O. O. Ajayi, A. Erdemir , and G. R. Fenske, “Low Friction Coatings and Materials for Fuel Cell Compressor & Blowers,” 2004 DOE HFCIT Program Review Meeting, May 24-27, 2004, Philadelphia, PA.