Tribology Research at Texas A&M University

Surface and Interface Science Laboratory
Director: Hong Liang, PhD
Tribological Evaluation Under Extreme Conditions

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PhD Student
Graduate May 2014
Topic: Tribo-surface characterization and electrical engineering

BS (2009) and MS (2011) from Texas A&M
Outline

• Introduction
• Testing Equipment
• Testing Methods
• High Temperature/Pressure Testing
• Cryogenic Temperature Testing
• API Friction and Galling Testing
• Conclusions
• Acknowledgements
• Q&A
Introduction

- Traditional tribotesting
  - Room temperature
  - Atmospheric conditions
- Lubricants and coatings are often used under very different conditions
- Testing under extreme environment conditions is necessary
Testing Equipment

• **Pin on Disc Tribometer**
  - High Temperature (up to 1000{o}C)
  - Cryogenic Temperatures (>\(-130\)°C)
  - High Vacuum pressure (>\(-100\)kPa)
  - Controlled humidity (~0% RH)

• **API Galling Tester**
  - High loads (up to 100klbs)
  - High Torques (up to 800ft-lbs)
Test Apparatus

- API RP 7A1 Test
  - Recommended Practice for Testing of Thread Compounds for Rotary Shouldered Connections
  - This method is still being revised and newer methods are being developed.
Test Apparatus
Test Configuration

TEST SPECIMENS

SPRINGS

LOAD CELL

[Image: Diagram of test specimens with labels for SPRINGS and LOAD CELL, and a photograph of a test setup.]
Galling

- Severe form of wear
  - localized material transfer, removal, or formation of surface protrusions when two solid surfaces experience relative sliding under load
- There is currently no standard for testing galling under lubricated conditions.
  - “galling will not usually occur under lubricated sliding conditions”
    - API RP 7A1
    - API C1/SC5 test program
Thread Compounds

- Composition
  - Materials that mould into threads, seal, and reduce thread contact
- Spherical-shaped additives
  - Additives are flattened and elongated during torque, bonding together and reducing metal to metal contact
- Particles compact during makeup, separate during breakout
Types of Thread Compounds

- Metallic
  - Use metallic particles to seal and protect the threads against galling
  - Lead, Zinc, and Copper based
- Non-Metallic
  - Use solids such as graphite, and talc to seal and prevent galling
  - More environment and worker safe
  - Non-hazardous
API Galling & Friction Testing

- Thread compounds are used when pipelines are formed
- Compounds must:
  - protect, seal, and lubricate
- Traditional compounds contained lead as the primary additive
- Legislation was passed to prevent further use of lead based compounds
- A method of comparing new compounds to the standard must be established
Results: Torque vs. Turns
Results: Torque vs. Turns
Friction Analysis

• Friction Factor
  • the ratio of the performance of a compound relative to a specific reference

• CaFl Reference Compound
  • a laboratory test compound formulated to produce consistent results from batch to batch that is used as a calibration standard.

<table>
<thead>
<tr>
<th>Thread Compound</th>
<th>Friction Factor</th>
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<tbody>
<tr>
<td>TiO2 based</td>
<td>0.98</td>
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<tr>
<td>Minearal based, no VOCs</td>
<td>0.84</td>
</tr>
<tr>
<td>Non-metallic, no VOCs</td>
<td>0.84</td>
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<tr>
<td>Biodegradable ester</td>
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Testing Equipment

- Pin on Disc Tribometer
  - High Temperature (up to 1000°C)
  - Cryogenic Temperatures (> -130°C)
  - High Vacuum pressure (> -100kPa)
  - Controlled humidity (~0% RH)

- API Galling Tester
  - High loads (up to 100klbs)
  - High Torques (up to 800ft-lbs)
Example I - Cryogenic Temperature Tribotesting

- Determine the influence of cryogenic temperatures (less than -130°C) on the friction and wear characteristics of three proposed bearing coatings on Ti6Al4V substrates.
- Improve wear resistance of bearings under cryogenic conditions.
- Help select best coating for cryogenic applications.

Liquid Hydrogen/Liquid Oxygen Rocket Engines

http://www.allstar.fiu.edu/aero/rocket2.htm
Motivation
Turbopump Wear Examples

Adhesive wear of bearing silver contact surface.
Experimental Setup

- **Pin**
  - Forged Sterling Silver
  - 1.47” radius tip
  - 0.434” dia

- **Disks**
  - Substrate
    - Ti6Al4V
  - Three Coatings
    1. TiSiCN-PEMS
    2. TiN
    3. WC

- Emphasize coating performance, not pin performance
  - Use nitrogen gas environment for room temp tests
  - Lower loads
  - Reduced sliding distance

Unexpected Laminar Pin Debris in Cryo Tests
Experimental Setup

• Variables
  • Temperatures (27°C, <-130°C)
  • Coating
    • TiSiCN-PEMS

• Constants
  • Linear Speed
    • 175 ft/min
  • Sliding Distance
    • 1750 ft
  • Normal Load
    • 1 lb

AMTI Pin-on-Disk Tribometer
Results: Wear Rate

TiSiCN coating
Results: Surface Analysis

TiSiCN coating

Cryo Temp

Room Temp

100x

1000x
Summary

• The test setup can evaluate tribological performance at cryogenic temperatures
• The effect of temperature on the coatings is significant
• TiSiCN appears to have a higher wear rate at lower temperatures
High Temperature/Pressure Tribotesting

- Evaluate the performance of coatings under the influence of temperature and environment
- New solid lubricants are needed for high-temperature and high vacuum applications.
- Applications in industries such as aviation where turbomachinery equipment operate in extreme environmental conditions
Solid Lubricants

• NASA
  • Solid lubricants are essential in space applications
  • Graphite performs poorly in brushed motors at high vacuum, low humidity environments
  • Graphite lubricants in high vacuum cause failure
• When used in high vacuum the high increase in friction always causes failure.


Carbon Based Solid Lubricants

- Lubricating properties are highly dependent on ambient water vapor
  - Absorbed water molecules on the graphite surface cause further weakening of the bonding between planes
- In a moist environment, CoF can be as low as 0.07
- Typical applications:
  - Sliding electrical contacts (high electrical conductivity)
  - Motor brushes
Experimental Setup

- Pin on disc tribometer
- Variables
  - Temperature
  - Vacuum Pressure
  - Relative humidity
- Samples tested under constant load of 12lb
  - Oscillatory
  - 3cm path length
  - 2.5 osc/sec
Test Materials

- **Disc Samples**
  - **Perma-Slik® RGE**
    - Lube Solid: MoS2
    - $\rho = 923 \pm 60$ g/L
    - Epoxy binder
    - 0.3mm
  - **Perma-Slik® RGAC**
    - Lube Solid: C
    - $\rho = 839 \pm 60$ g/L
    - Organo-metallic binder
    - 0.3mm
Test Materials

- Ball Bearings (6mm)
  - 440C Stainless Steel (SS)
  - Tungsten Carbide (WC)

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## Testing Matrix

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Results: CoF Plots

Graphite based coating
Results: CoF Comparison

Graphite based coating
Results: CoF Comparison

MoS2 based coating
Results: Wear Volume

![Wear Volume Graph](image_url)
Wear Track: RGAC against WC

- Abrasion is shown to be the dominant wear mechanism
- Under atmospheric conditions, wear debris remains to serve as a lubricant
Wear Track: RGAC against SS

Atmospheric Conditions Low P, RH & High T

• Under atmospheric conditions, wear debris remains to serve as a lubricant
• Abrasive wear can be seen at severe conditions
Summary

• Test setup is effective for evaluating the effects of high temperatures and low pressures
• Graphite based lubricant provides higher friction in extreme conditions
  • Not stable at high T, low P
• The durability of the coating is affected by low pressure due to absence of moisture
• Abrasive wear is the dominant wear mechanism
• Molybdenum disulfide coating performed similar at atmospheric and severe conditions
Conclusions

• Extreme environment testing is necessary for the proper evaluation of coatings and lubricants
• New testing conditions and setups have been developed to better evaluate test samples
• Our research has shown significant differences in performance for various coatings and lubricants at such conditions
• New testing parameters continue to be developed in our research lab
Acknowledgements

- Jet-Lube
- Stress Engineering
- GE Aviation
- Houston Chapter STLE
Thank You for Your Support!