# Tribological Studies of Dynamic Thermal Seal Materials

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**Materials Science & Technology**
**Thermal Protection Materials and Systems**
**Salt Lake City, UT**
**October 24-27, 2016**

This research was funded by the U.S. Government under NASA Contract NNC13BA10B. The views and conclusions contained in this document are those of the authors and should not be interpreted as representing the official policies, either expressed or implied, of the U.S. Government.

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  - Types/Construction of Dynamic Thermal Barriers
- Objectives and Approach
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  - Tribometer upgrades and checkout
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- Triobological Results
  - Previous results from NASP
  - Tribopairs (base materials and coatings)
  - Temperature
  - Load
- Summary, Conclusions, and Challenges

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# An Integral Part of the TPS


**Fin Control Surfaces**

- Referred to as “dynamic thermal seals” or “dynamic seals”
- High-temp. ceramic-based materials
- Installed in TPS interface gaps between moving structures
- Roles
  - Thermal – limit inboard temperatures
  - Structural/physical – survive temps. and wear, not impede actuation/operation of control surface, accommodate deflections

**Body Flap**


**X38 CRV**

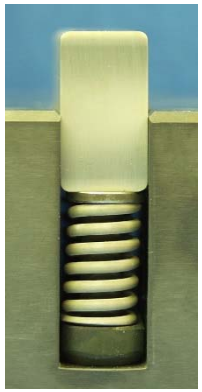
**Compliant Thermal Barriers (CTB’s)**

# DYNAMIC THERMAL SEALS

**Compliant Thermal Barrier**

**Rope Thermal Barrier**

**Hybrid Sheath Thermal Barrier**

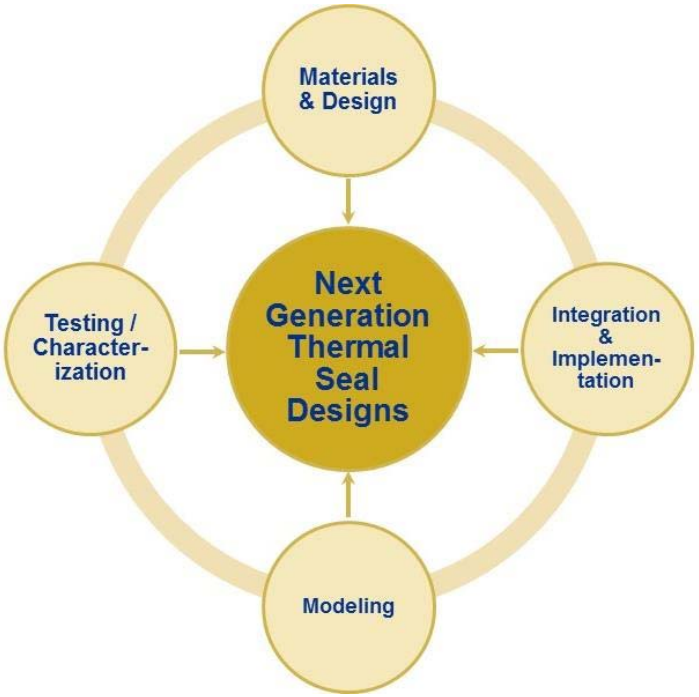


**Wafer Seals**

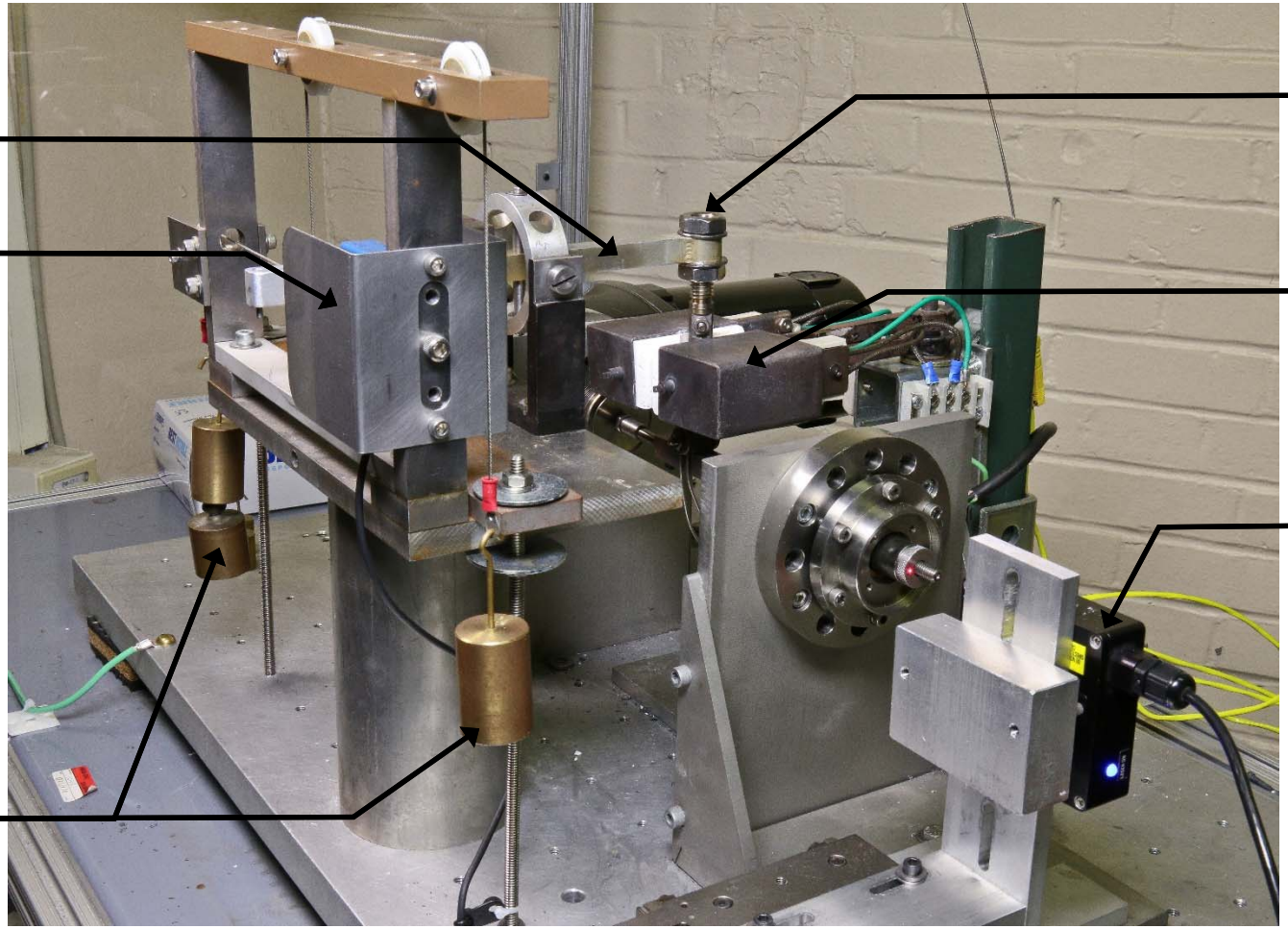
- Compliant Thermal Barriers (CTB)
  - Nextel™ sheath
  - Saffil® core, spring tube
  - Higher temps, lower stiffness, higher leakage
- Rope Thermal Barriers (RTB)
  - Nextel™ sheath
  - Fiber/fabric/rope core
  - Higher temps, higher stiffness, lower leakage
- Hybrid Sheath Thermal Barriers (HSTB)
  - Metalllic wire braid/Nextel™ sheath
  - Saffil®, fiber/fabric/rope core
  - Better wear resistance, lower temps
- Wafer Seals
  - Monolithic materials (metals, ceramics, etc.)
  - Low leakage (tight tolerences)
  - Require preloader

# OBJECTIVES

- Overall Objectives
  - Develop a repeatable screening tool to assess tribological performance of dynamic thermal barrier materials
  - Create a database of thermal barrier tribological performance (against TPS or propulsion materials)
  - Improve tribological performance of dynamic thermal barriers
- Dynamic thermal barrier triobological performance
  - Baseline performance against several materials
    - Metal
    - Non-ablative TPS
    - Ablative TPS
  - Effects of various parameters
    - Load
    - Temperature
    - Coatings



# High Temperature Tribometer Upgrades



# High Temperature Tribometer Checkouts

| Test ID | Date | Pin | Plate | Normal Load | | Est. CoF, sliding | Published Data | Source |
|---|---|---|---|---|---|---|---|---|
| | | | | g | lbf | | | |
| 0.1 | 19-Aug | 304 SS | 304 SS | 200 | 0.39 | 0.18 | --- | --- |
| 0.2 | 20-Aug | 304 SS | 304 SS | 200 | 0.39 | 0.57 | 0.53 | ASM Handbook[1] |
| 0.3 | 20-Aug | 304 SS | 304 SS | 400 | 0.79 | 0.46 | 0.53 | ASM Handbook[1] |
| | | | | | | | | |
| 0.4 | 27-Aug | 4130 Steel | 4130 Steel | 200 | 0.39 | 0.42 | 0.40-0.60 | ASM Handbook[2], www.engineersedge.com |
| 0.5 | 28-Aug | 4130 Steel | 4130 Steel | 400 | 0.79 | 0.54 | 0.40-0.60 | ASM Handbook[2], www.engineersedge.com |
| 0.6 | 28-Aug | 4130 Steel | 4130 Steel | 400 | 0.79 | 0.46 | 0.40-0.60 | ASM Handbook[2], www.engineersedge.com |
| | | | | | | | | |
| 0.7 | 28-Aug | Teflon | 4130 Steel | 200 | 0.39 | 0.18 | 0.16 | ASM Handbook[3] |
| 0.8 | 28-Aug | Teflon | 4130 Steel | 400 | 0.79 | 0.17 | 0.16 | ASM Handbook[3] |
| | | | | | | | | |
| 0.9 | 28-Aug | Teflon | Teflon | 200 | 0.39 | 0.13 | 0.04-0.07 | ASM Handbook |
| 0.10 | 28-Aug | Teflon | Teflon | 200 | 0.39 | 0.13 | 0.04-0.07 | ASM Handbook |
| | | | | | | | | |
| N0.1 | 28-Aug | 4130 Steel | Nextel 312 | 100 | 0.19 | 0.65 | 0.50-0.60 | NASA TM 105199 |
| N0.2 | 28-Aug | 4130 Steel | Nextel 312 | 200 | 0.39 | 0.60 | 0.50-0.60 | NASA TM 105199 |

# High Temperature Wear-Resistant Coating Candidates

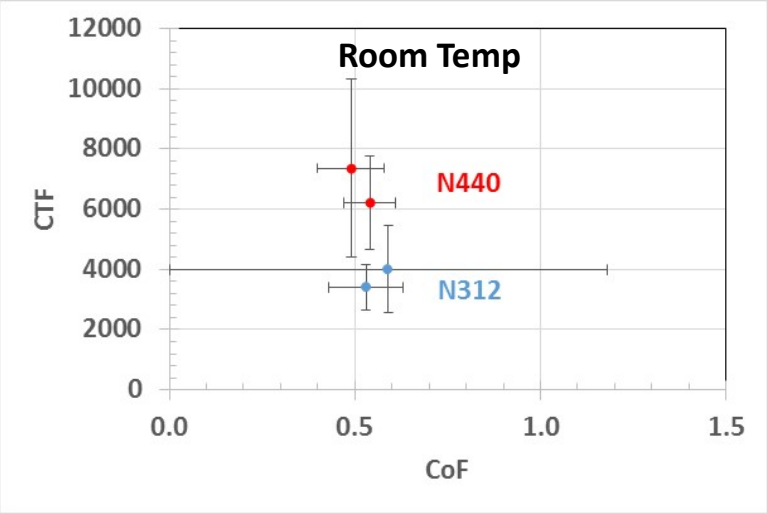
| Coating | Room Temp CoF | High Temp CoF | Max Tested Temp (°C/°F) | Predicted Max Thermal Stability (°C/°F) | Trade Study Weight |
|---|---|---|---|---|---|
| **NbN/Ag** | 0.35 | 0.27 | 1000/1832 | 1123/2053 | 297 |
| **Silver Tantalate ($AgTaO_3$)** | 0.60 | 0.06 | 750/1382 | 1172/2142 | 277 |
| **73 $TiO_2$– 27 $Cr_2O_3$** | 0.80 | 0.35 | 800/1472 | 1780/3236 | 272 |
| **100 $Cr_2O_3$** | 0.25 | 0.55 | 800/1472 | 1650/3002 | 283 |
| **Au/Cr** | 0.54 | 0.34 | 1000/1832 | 1000/1832 | 284 |
| **MAX phase $Ti_2AlC$** | 0.70 | 0.36 | 550/1022 | 1400/2552 | 261 |
| **MAX phase $Ti_3SiC_2$** | 0.60 | 0.62 | 550/1022 | 1400/2552 | 249 |
| **xo** | **0.5** | **0.5** | **1100** | **1200** | |
| **w** | **5** | **9** | **7** | **10** | |

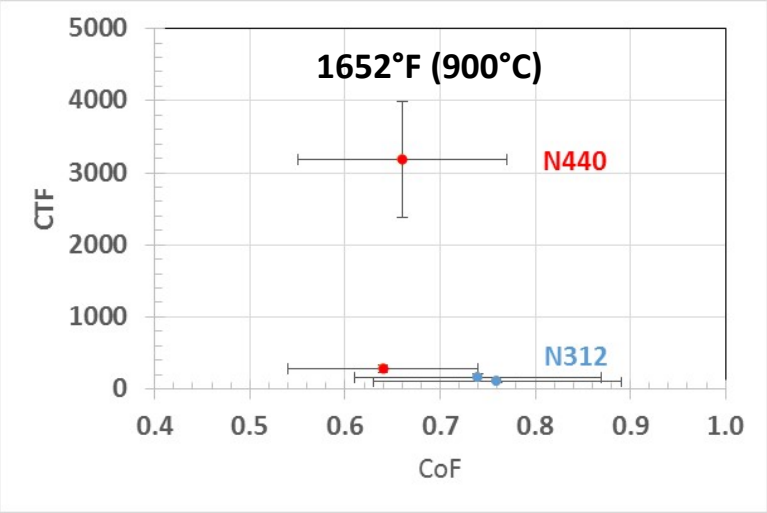
- Challenges with coatings – chemical compatibility/reactions, coating thickness, adherence
- Investigated a nanocomposite MAX phase type coating (SwRI Surface Engineering)

# TEST APPROACH

- Test Samples
  - Seal material: Nextel 312 (AF-20) and Nextel 440 (BF-20)
    - 5 harness satin weave
    - Warp: 30 threads per in.; Fill: 26 threads per inch
  - Fabric Coatings: None, TaSiN, TaSiCN (nano-composite coatings)
  - Wear surface: 4130 steel, AETB-8 tile, IN-625
- Test Parameters
  - Load: 2, 8 psi (14, 55 kPa)
  - Temperature: Ambient, 1500°F (Ambient, 815°C)
  - At least 3 tests were conducted for each tribopair at a given test condition

# WEAR RESULTS: PREVIOUS TESTING




Dellacorte, C., *et al.* – Studies from 1988-1995

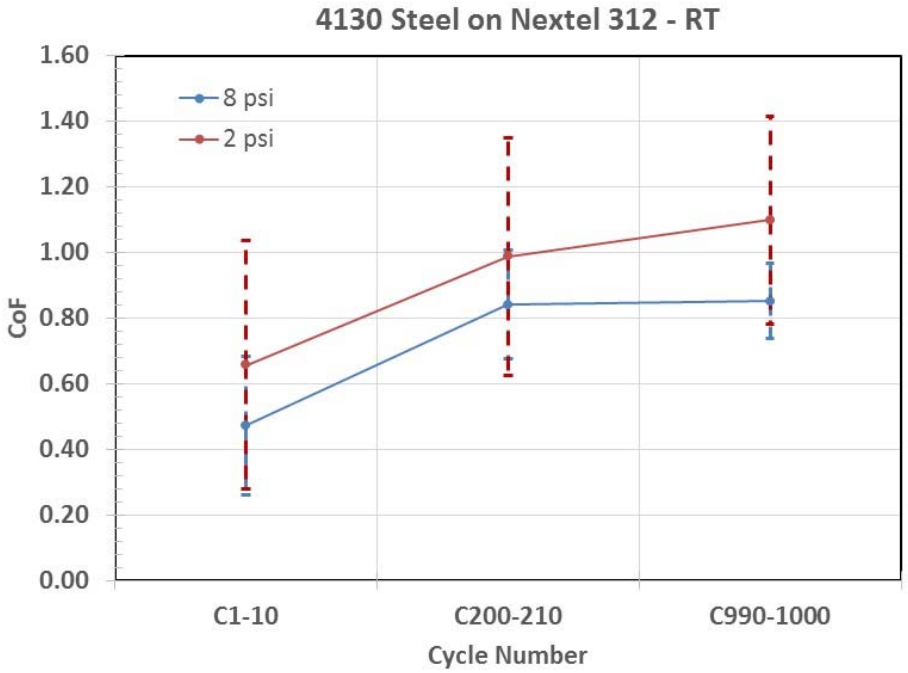
Approach

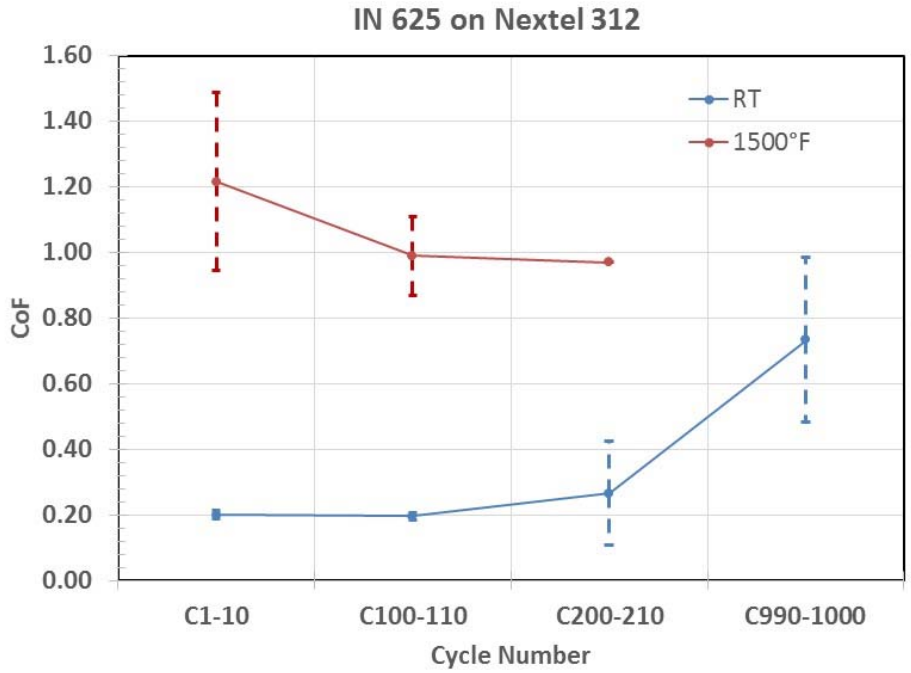
- Conducted numerous studies
- Pin-on-disk geometry (non-reciprocating)
- "Pin" materials: Nextel 312, Nextel 440, Nextel 550, Nextel 610
- Disk materials: IN 718, IN X-750, $Ti_3AlNb$
- Temperatures: Ambient - 1832°F (Ambient – 1000°C)
- Loads: 23 - 382 psi (160 - 2633 kPa)
- Coatings: Ag, $CaF_2$, BN, Au

Results

- CTF generally decreased with increasing temperature (oxide-based fibers)
- CoF's: ~0.6 - 1.0

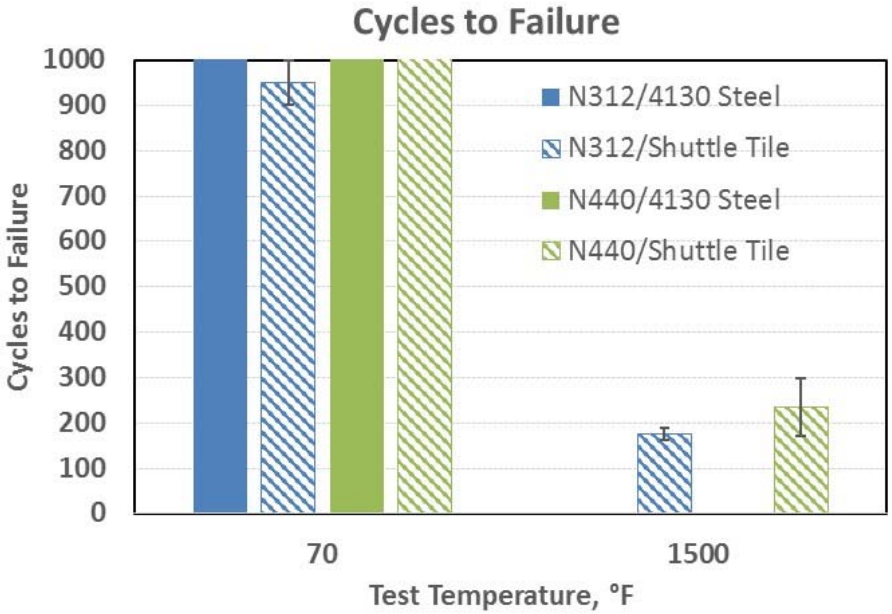
# Wear Results: Effect of Preload and Cycle Number

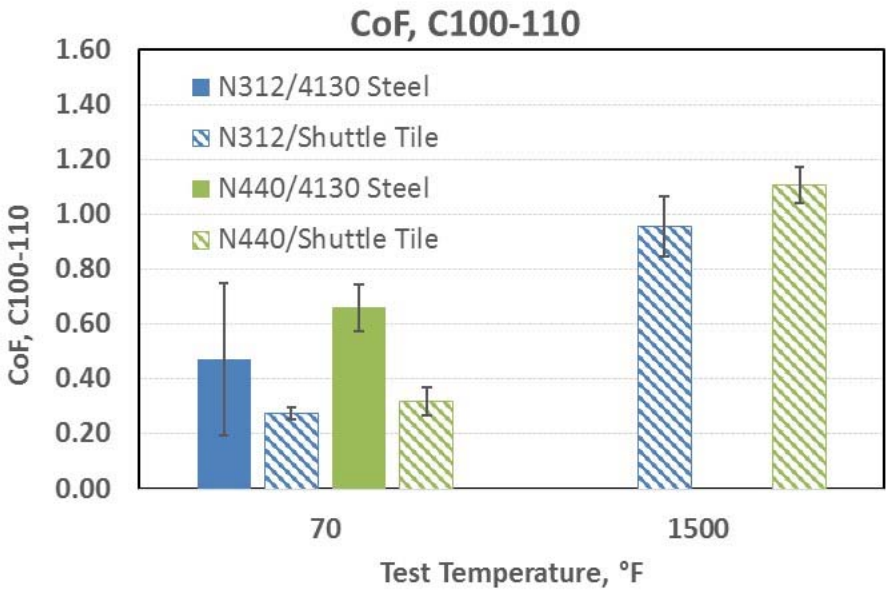



- CoF lower at higher preload, though likely not statistically significant
- At RT against 4130 steel, low initial CoF, than it increases
- At RT against IN-625, low initial CoF, than it increases
- At 1500°F, CoF was significantly higher starting off and then decreased to fairly high value

# Wear Results: Type of Nextel




- Nextel 440 showed slight improvement over Nextel 312
  - Most evident against Shuttle tile
  - Higher CTF likely due to higher breaking strength of N440 (250 lb/in. vs. 150 lbf/in.)
- Shuttle tile exhibited lower CoF than 4130 steel
- CoF appeared to significantly increase for higher temperatures with these tribomaterials

# Wear Results: Type of Nextel

**Nextel 312**

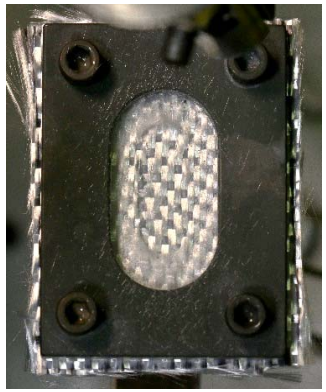
**Nextel 440**

**RT**

**4130 Steel**

**Shuttle Tile**

**4130 Steel**



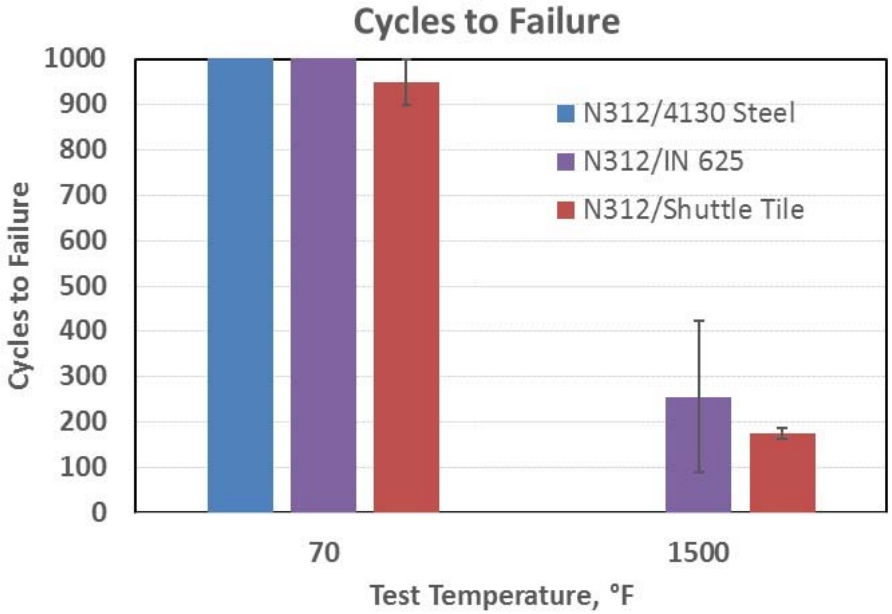
**Shuttle Tile**

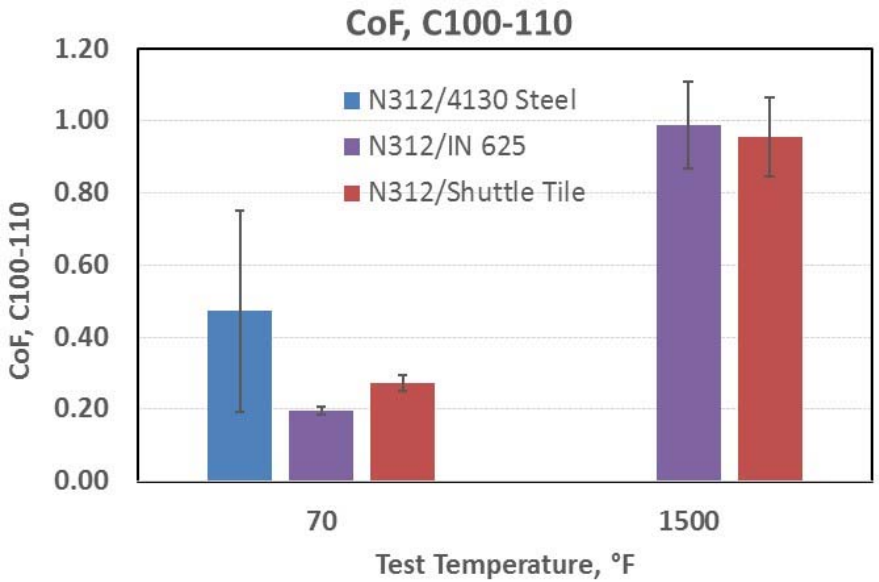
**1500°F**

**Shuttle Tile**

**Shuttle Tile**

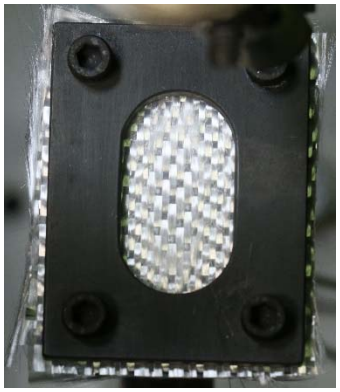
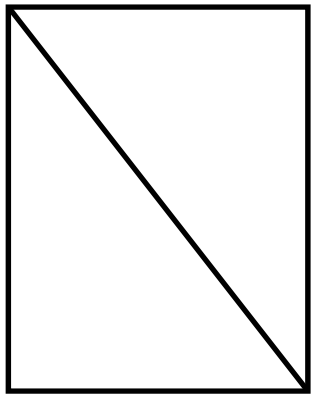
# Wear Results: Pin Material



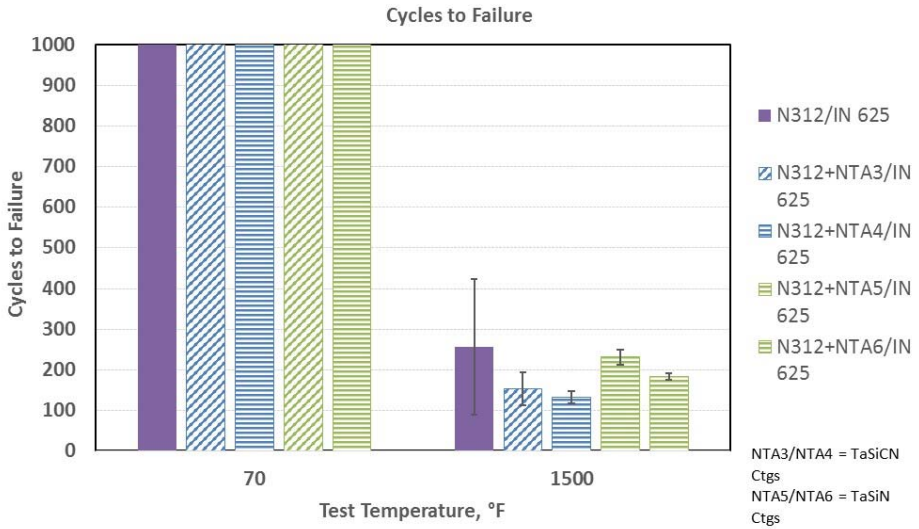



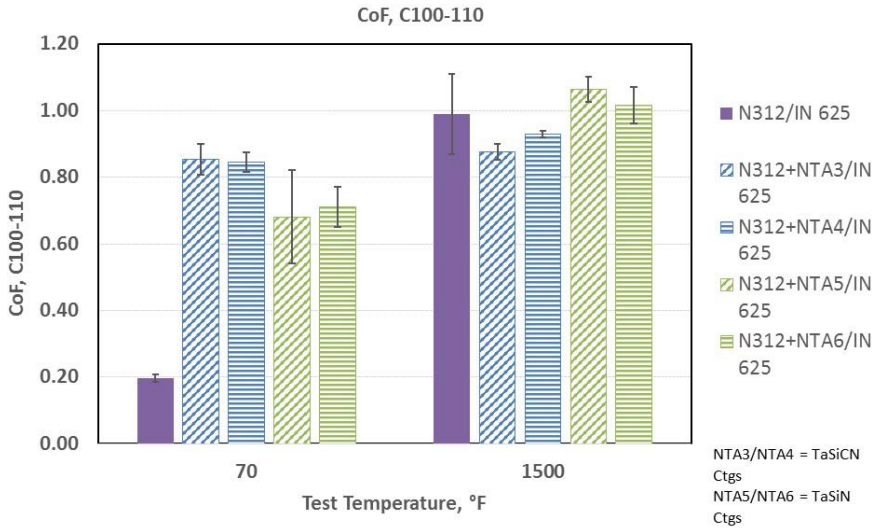

- Shuttle tile showed some difference when compared to metals
  - Slightly lower CTF
  - Most evident against Shuttle tile
- Shuttle tile exhibited lower CoF than 4130 steel
- CoF appeared to increase significantly with higher temperatures with these tribomaterials

# Wear Results: Pin Material

| | 4130 Steel | IN 625 | Shuttle Tile |
|---|---|---|---|
| RT |  |  |  |
| 1500°F |  |  |  |

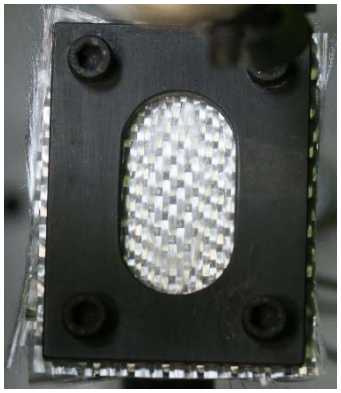
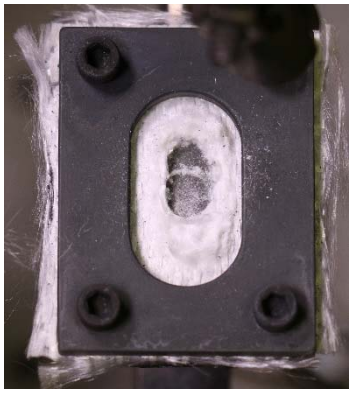
# WEAR RESULTS: EFFECT OF COATINGS



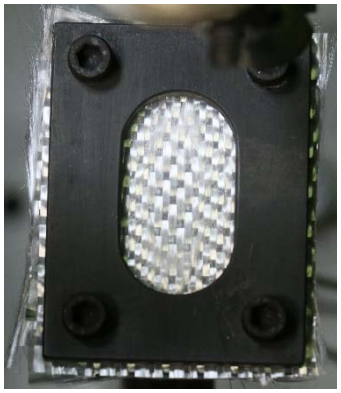
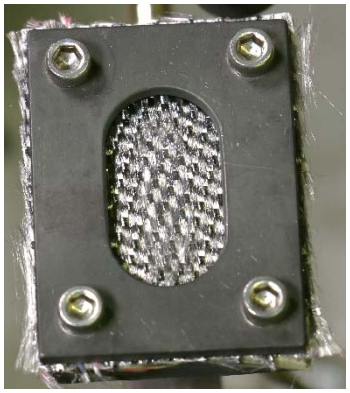
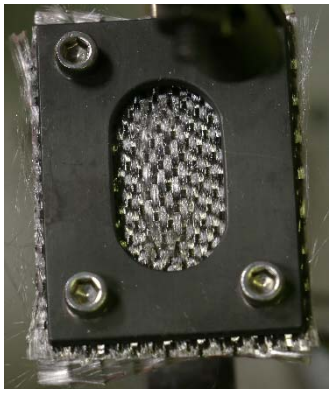
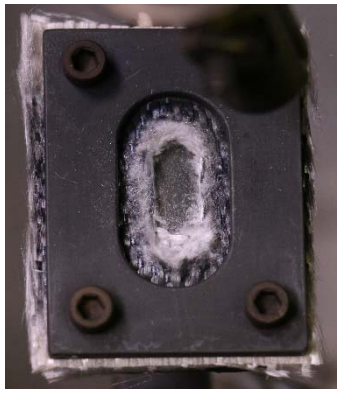
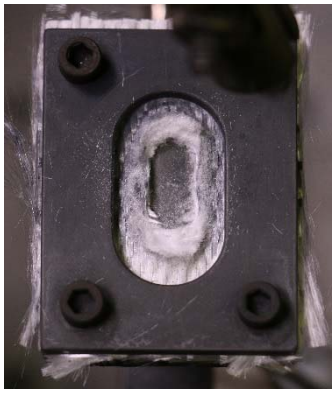




- No significant improvement in CTF with coatings
- Performance comparable (possibly slightly worse) than uncoated Nextel 312
- Possible coating adhesion issues and reactions with Nextel

# Wear Results: Effect of Coatings

| | N312 | N312 + NTA-3 | N312 + NTA-4 |
|---|---|---|---|
| RT |  |  |  |
| 1500°F |  |  |  |

# Wear Results: Effect of Coatings

| | N312 | N312 + NTA-5 | N312 + NTA-6 |
|---|---|---|---|
| RT |  |  |  |
| 1500°F |  |  |  |

# SUMMARY, CONCLUSIONS, & CHALLENGES

- Rig Upgrade
  - Improved instrumentation, modernized DAQ, augmented stroke length
  - Produced believable, reliable, repeatable results
  - Learned significant lessons to help in design of a newer higher-temperature rig
- Wear Performance of Nextel
  - Nextel durability insufficient for high temperature thermal barrier dynamic operation
    - Significant degradation in wear performance at high temperatures 1500°F
    - Require wear-resistant coatings
  - Initial tests of Nextel against TPS materials demonstrated poor wear resistance, even at room temperature
  - Preliminary tests with Ta-based nano-composite coatings showed no improvement
- Challenges
  - Coatings that are adherent, “non- reactive,” protective, low CoF
  - Coatings appear to work “better” when deposited on opposing wear surface
    - Most studies have deposited on metallic or ceramic substrates
    - Minimal evidence for success depositing on thermal barrier fabric materials

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