Christopher DellaCorte
National Aeronautics and Space Administration
Glenn Research Center
Cleveland, Ohio

Oil-Free Turbomachinery Program

High Temperature Solid Lubricant Developments for Seal Applications

By
Dr. Christopher DellaCorte
NASA Glenn Research Center
Cleveland, Ohio

Oil-Free

Turbomachinery

Program

Lewis Research Center

Oil-Free Turbomachinery

. . . "High-speed rotating equipment operating without oil lubricated rotor supports . . . bearings, dampers, seals" . . .

Oil-Free Turbomachinery Program

Motivation/Goal

Realize revolutionary improvements in performance, efficiency and rotating of Aeropropulsion engines

CD-98-77844

Oil-Free Turbomachinery Program

Approach:

Incorporate recent advances in enabling technologies in...

- Foil Air Bearings
- High Temperature Solid Lubricants
- Computational Rotordynamics and Modeling

to successfully develop High Speed, High Temperature Oil-free Turbomachinery Systems

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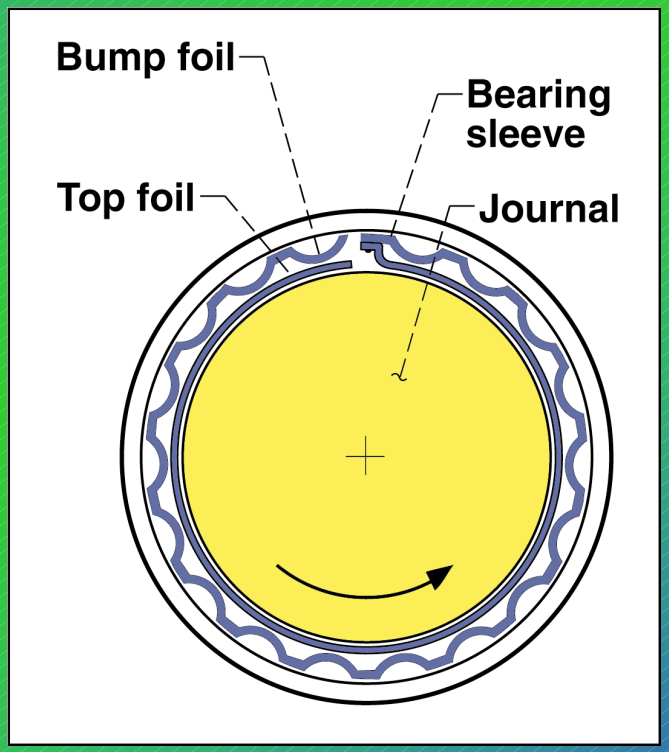
Foil Air Bearings...

- Self acting hydrodynamic
- Shaft "floats on air"
- No speed (DN) limit
- Operating temperatures to 1200°F+
- Compliant "spring" bump foil accommodates misalignment



...are ideal for high speed, high temperature applications

...require no maintenance or lubrication system

...exhibit reduced friction and virtually no wear

...eliminate possibility of oil related emissions

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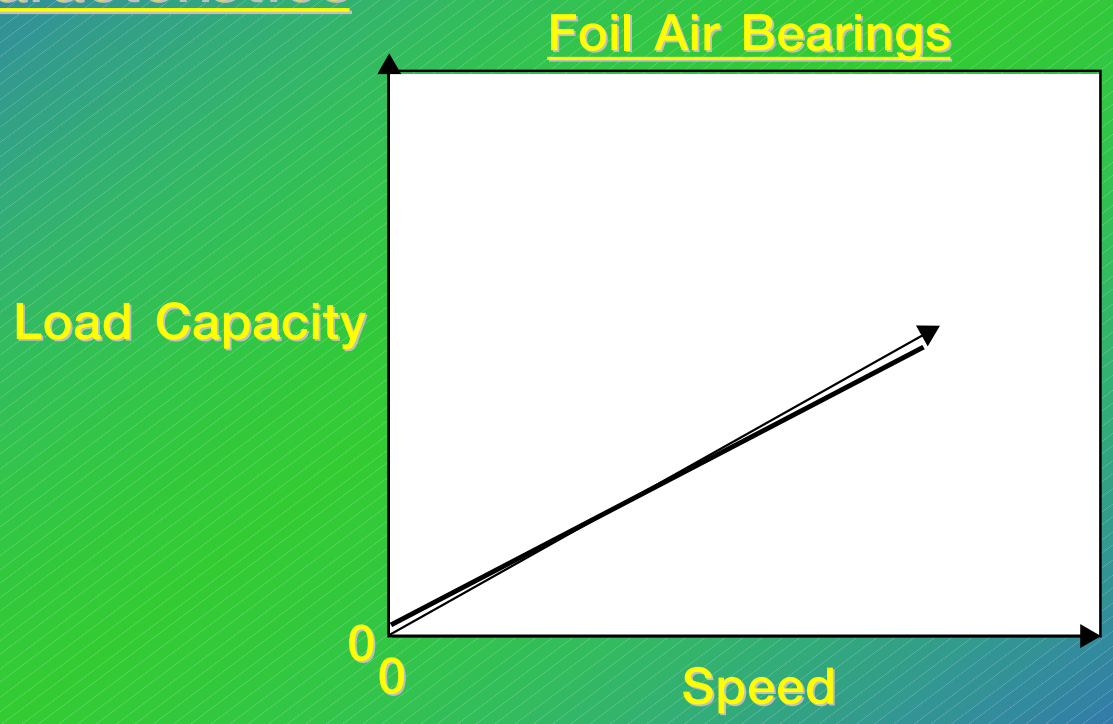
Bearing Characteristics



Foil Bearing Load Capacity...is very low at low speeds...

...increases linearly with speed...

...has no practical speed limitation

...requires solid lubricant for start/stop

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Current Practice

- Foil surface coated with PTFE or polymide coating
- Shaft coated with Ni or chrome plate
- Limited to 500°F operation
- Alternate "high temperature" solid lubricant (graphite, soft metals) to 800°F due to limited life
- Bearing fails when thin film lubricant worn through to underlying superalloy foil

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Relevance to Seals

- Sliding which occurs in foil bearings during start-up & shut-down is tribologically similar to certain types of seals (loads, speeds, temperatures)
- Test facilities for foil bearing evaluations are similar to seal conditions
- Environmental durability issues present in foil bearings are also present for seal applications

Recent Work

- Coat shaft with thick (250 μm) solid lubricant composite coating (e.g. PS300)
- Conduct start/stop durability tests using partial-arc foil air bearings
- Evaluate results

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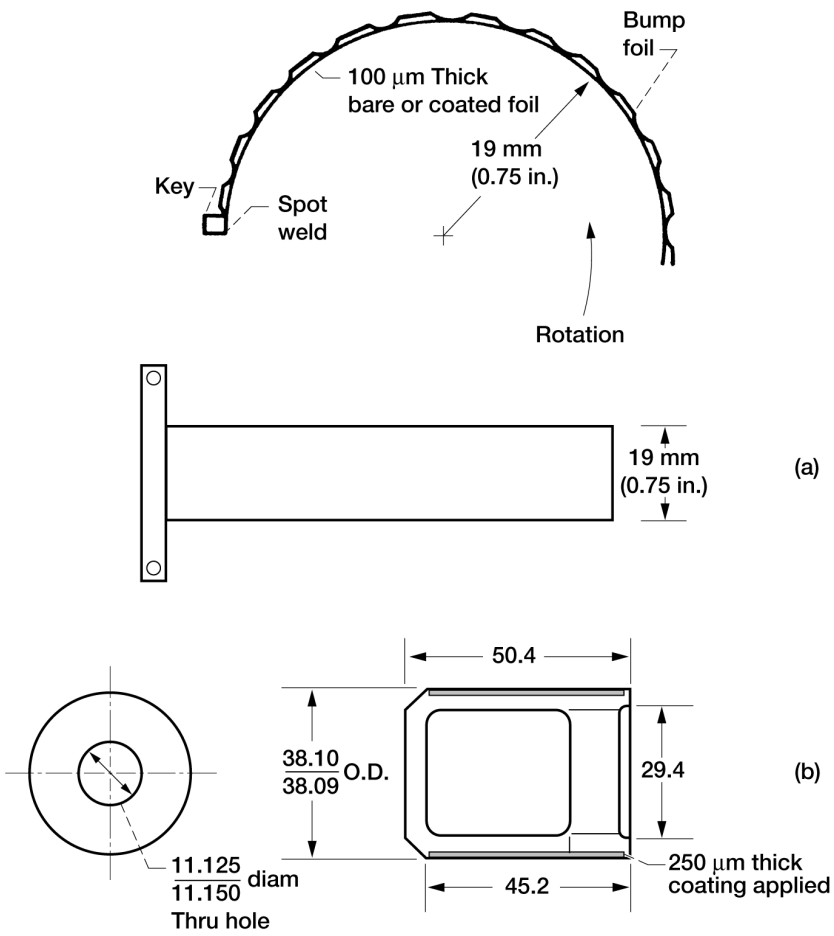
Test Specimens:



Specimen geometry. (a) Foil. (b) Journal. Units in mm.

Foil: Uncoated Ni Alloy

Journal: PS300

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PS300:	20 NiCr	Binder
	60 Cr_2O_3	Hardener
	10 BaF_2/CaF_2	High-Temp Lube
	10 Ag	Low-Temp Lube

Deposition: Plasma Spray, Carbide grind

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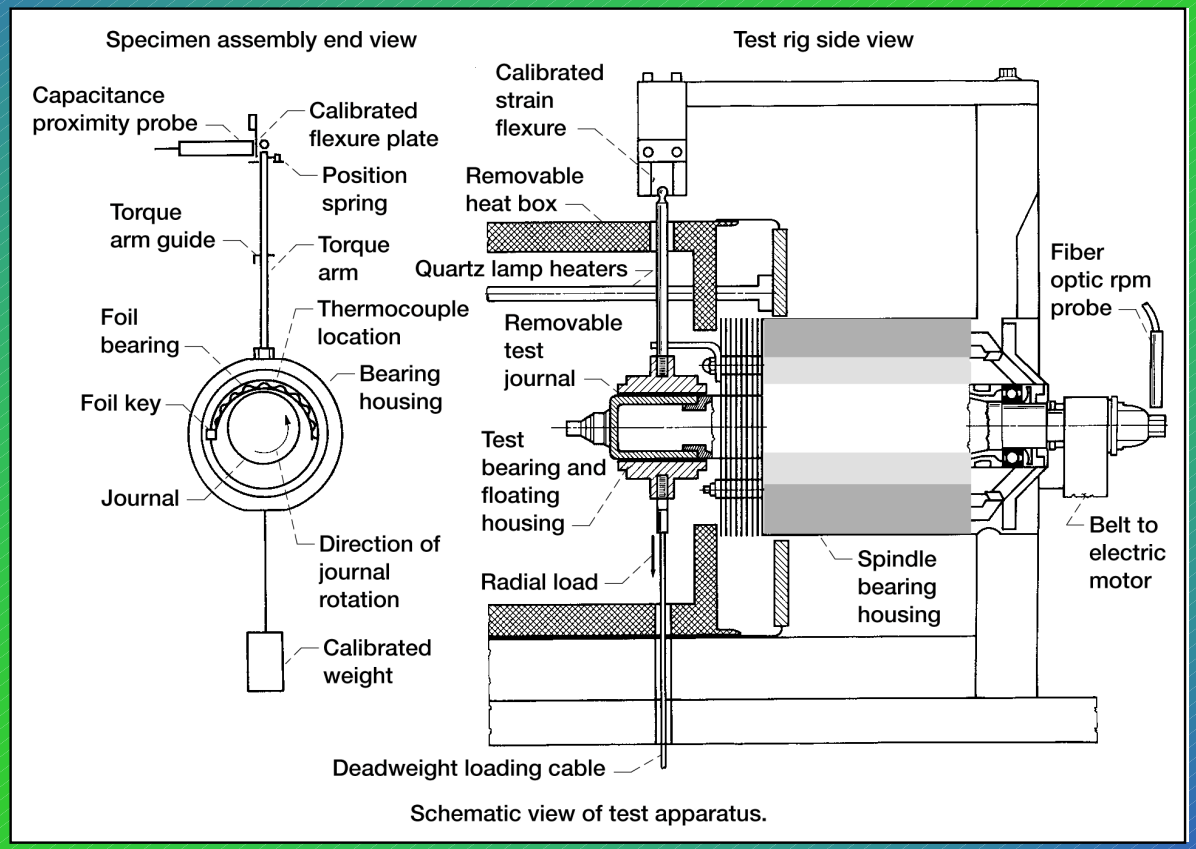
Testing: High Temperature Foil Bearing Test Rig



Schematic view of test apparatus.

Conditions: 10.1 KPa (1.5psi), 25 or 500°C, 20,000 start/stop cycles

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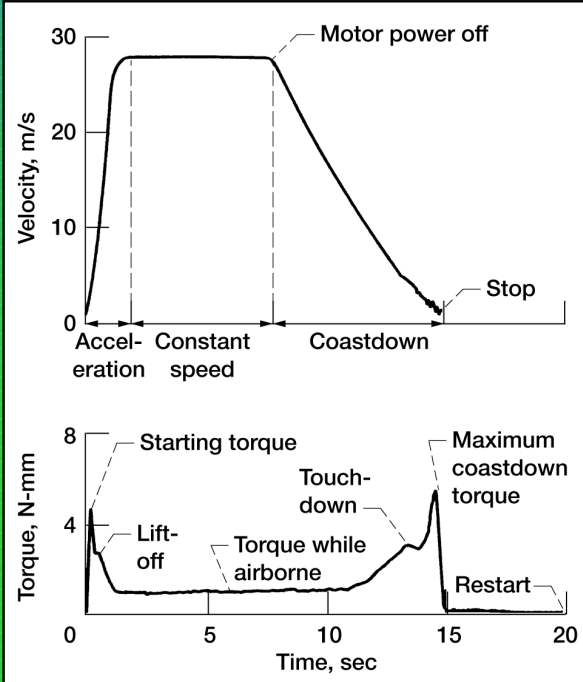
Test Results:

Sliding occurs at speeds less than 4,000 rpm



Typical test cycle speed/torque trace.

Data:

Torque (friction) measured every 100 cycles

Wear measure every ~ 5,000 cycles

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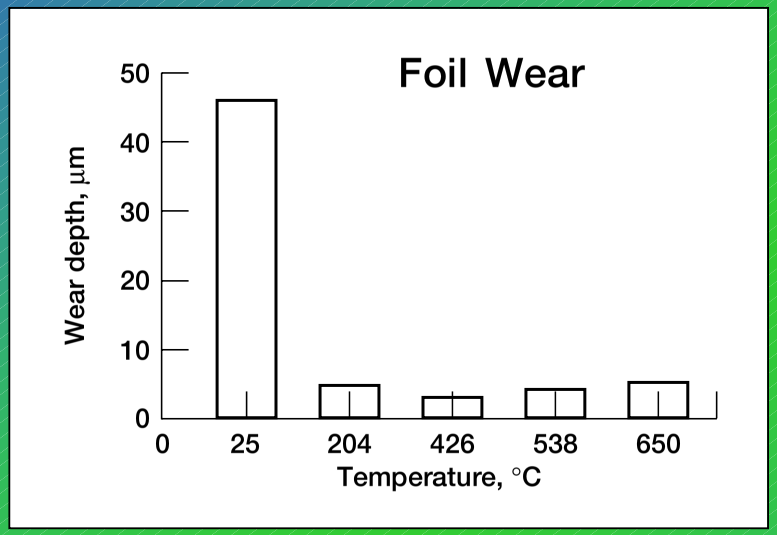
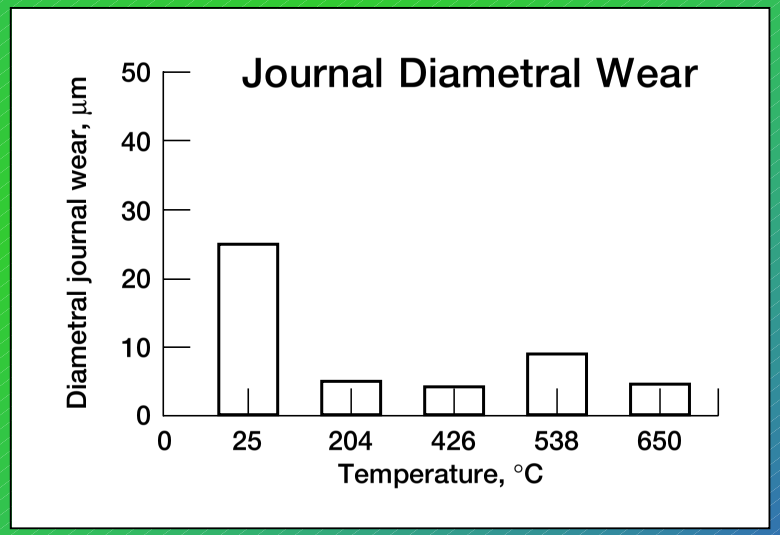
Test Results: Wear





- Wear is highest at 25°C but within order of magnitude.

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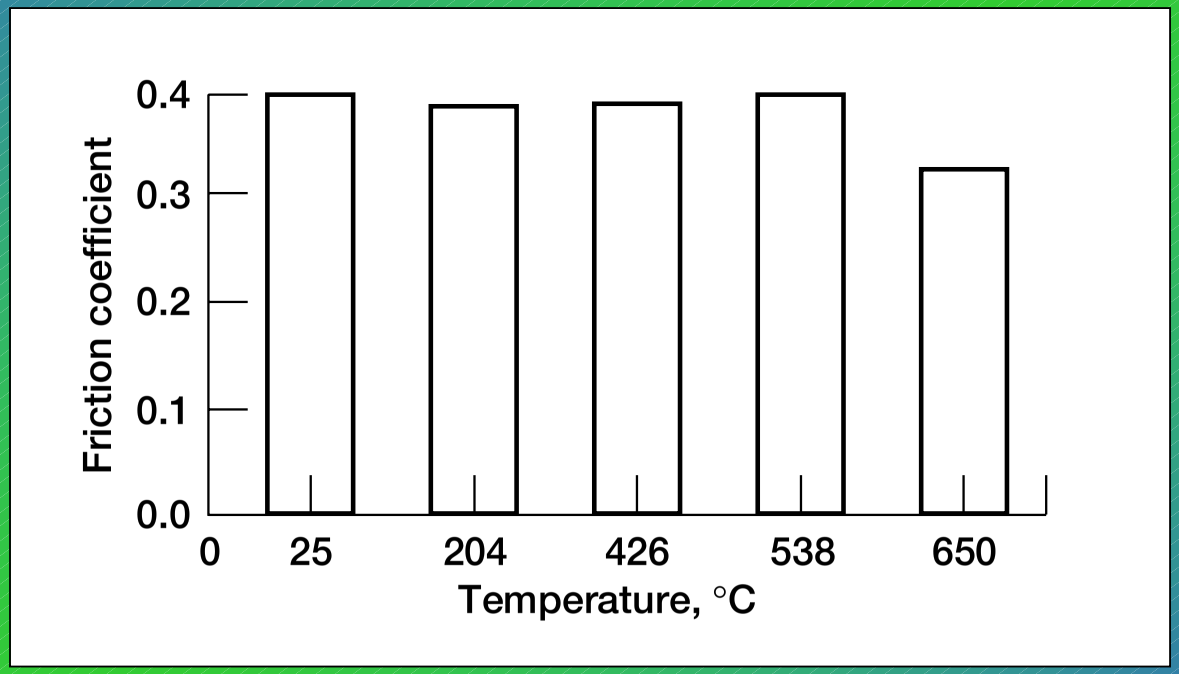
Test Results: Friction Calculated



- Friction coefficient is essentially constant with temperature.

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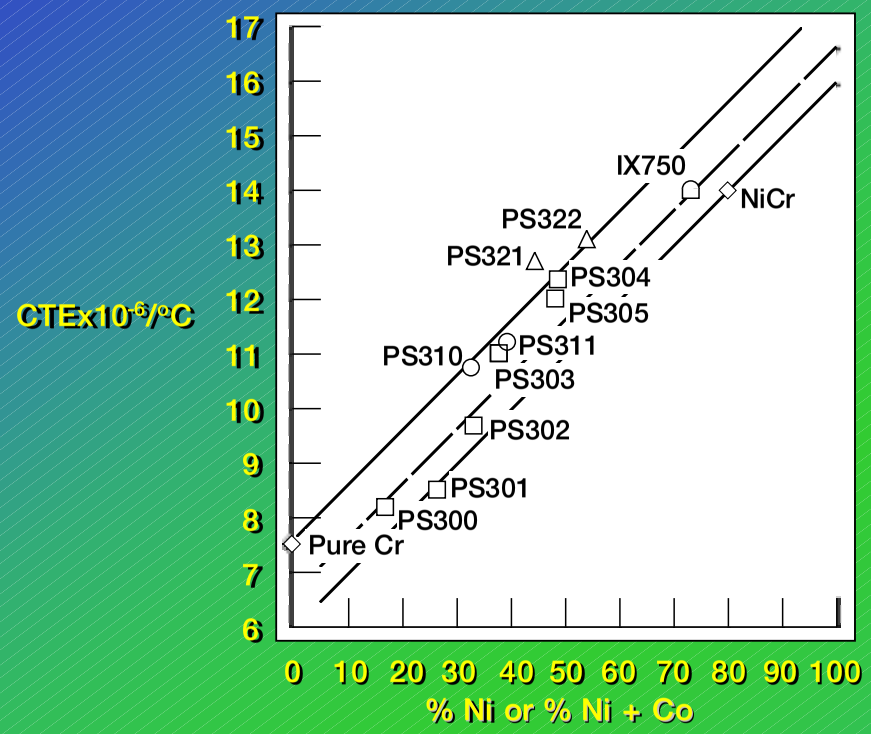
PS300 Compositional Tailoring



Constituent	Weight %	
	PS300	PS304
NiCr	60	20
Cr_2O_3	20	60
BaF_2/CaF_2	10	10
Ag	10	10

- PS304 has CTE "match" to superalloy substrates.
- Follow-up pin-on-disk testing of PS304 suggests potential for low friction and lower counterface (foils) wear.

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Enabling Technology: Coating process development

- Thermal spray technique evaluation
  - Plasma spray
  - HVOF
- Environmental durability
  - 1000's of hours of exposure
  - Microstructural changes
  - Environmental (air vs. inert) effects
- Coating adhesion enhancement
  - Surface treatment
  - Interfacial binder layers
  - Adhesion testing

Ongoing research efforts anticipate hurdles to overcome them before they are "showstoppers"

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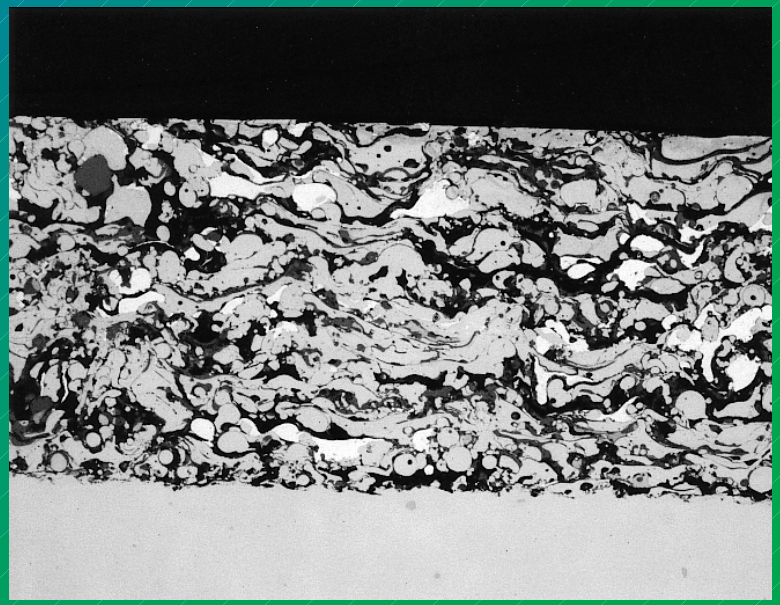
Enabling Technology: Long term coating environmental durability



PS304
As Deposited

PS304
700 hr at 1200 °F

- Microstructural and interfacial changes observed following long term use at elevated temperatures

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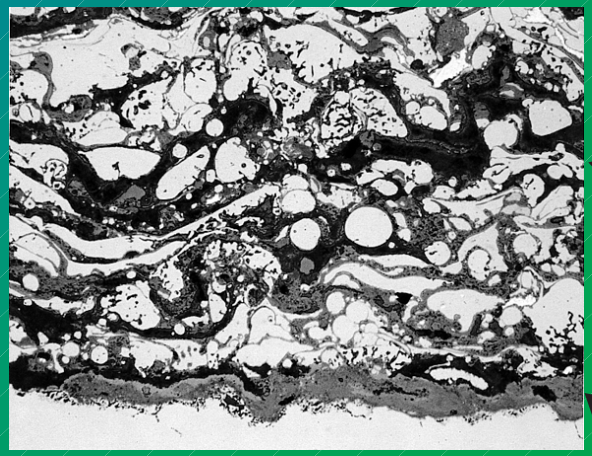
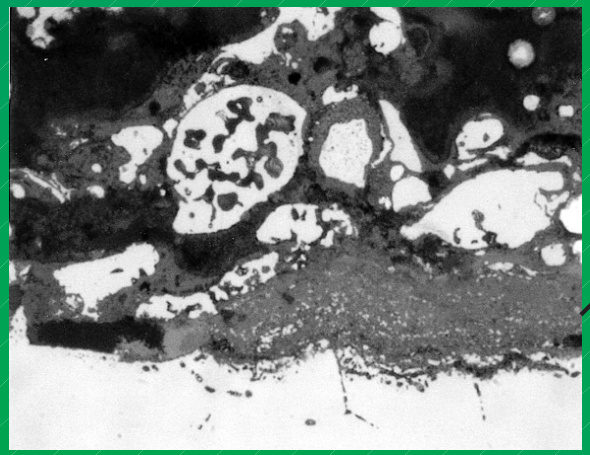
Enabling Technology: Long term, high temperature effects

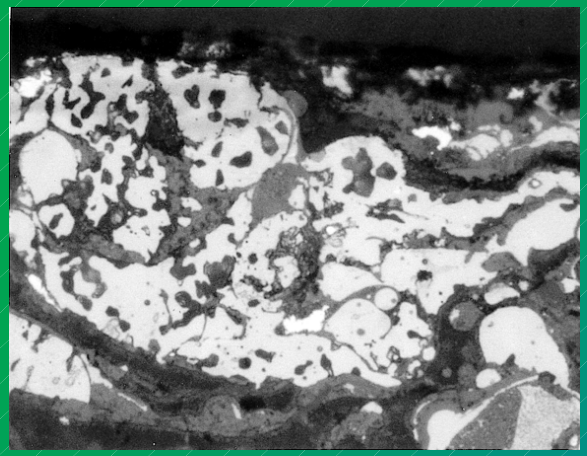


• Interface reaction layer



Major Changes

• NiCr binder phase altered



• Coating and interface changes do not effect performance but are under continued study and development

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Results Summary

- PS304 reduces friction and wear to manageable levels
- Tirbosurfaces develop smooth, polished characteristics
- PS304 exhibits excellent environmental durability
- PS304 can withstand centrifugal stresses associated with high speed shafts
- PS304 may be a good candidate for intermittent contact seals