

# Diamond Bearing Technology for Deep and Geothermal Drilling

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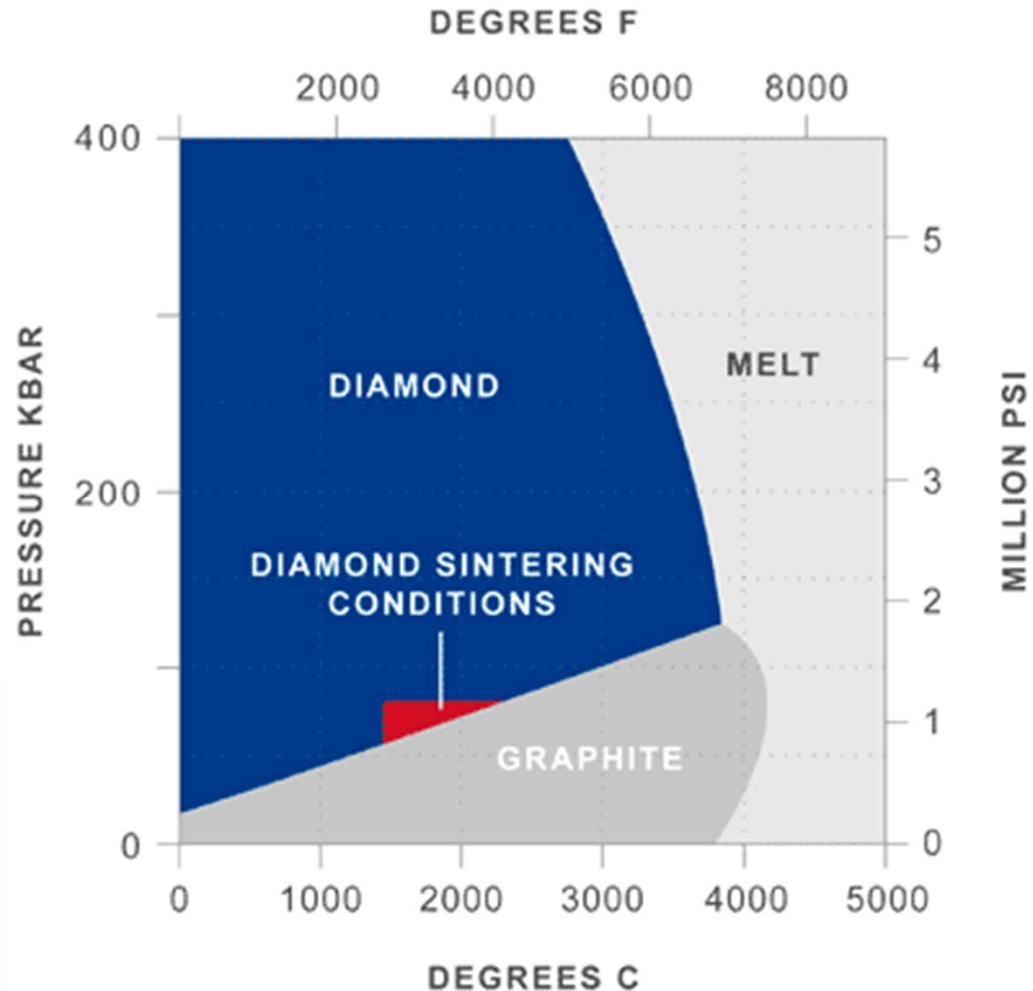
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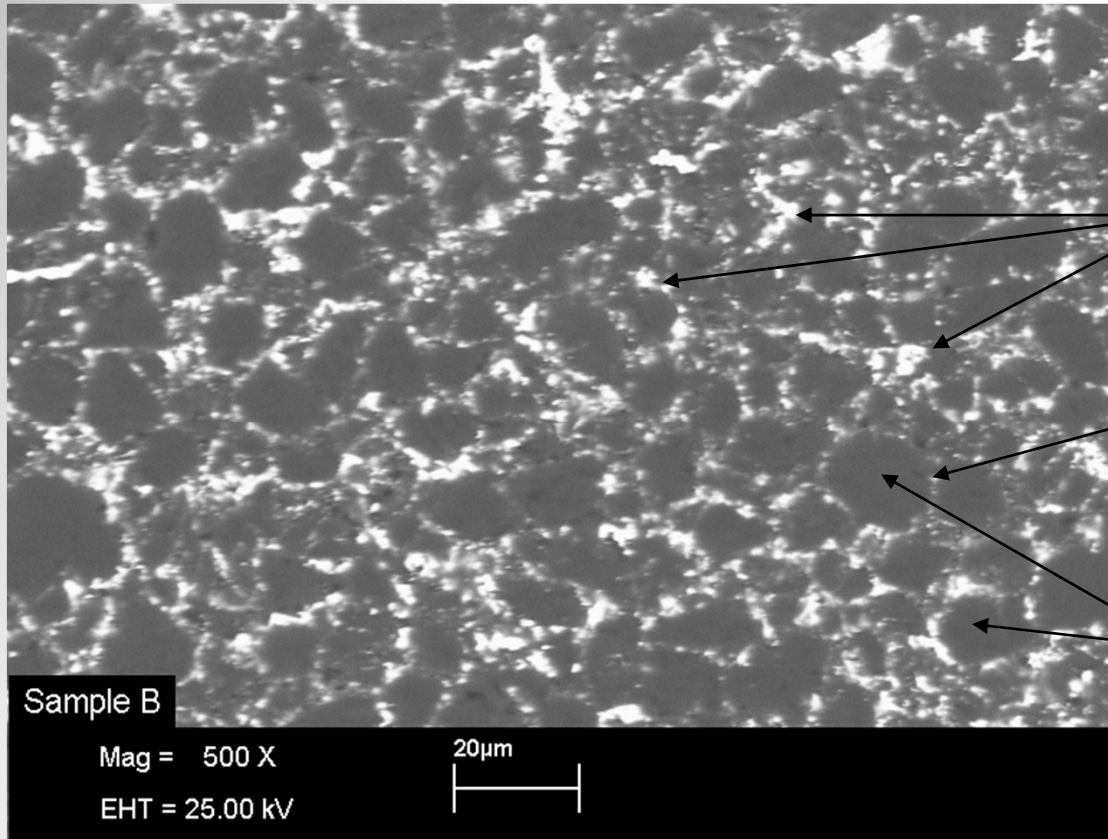
# Polycrystalline Diamond (PCD)

PCD is comprised of sintered diamond, with cobalt interspersed in the pore space

- Created in high-temperature, high-pressure presses
- Sintering is facilitated by a cobalt catalyst, supplied from a cobalt-cemented tungsten carbide substrate



# PCD – SEM Micrograph



Cobalt catalyst

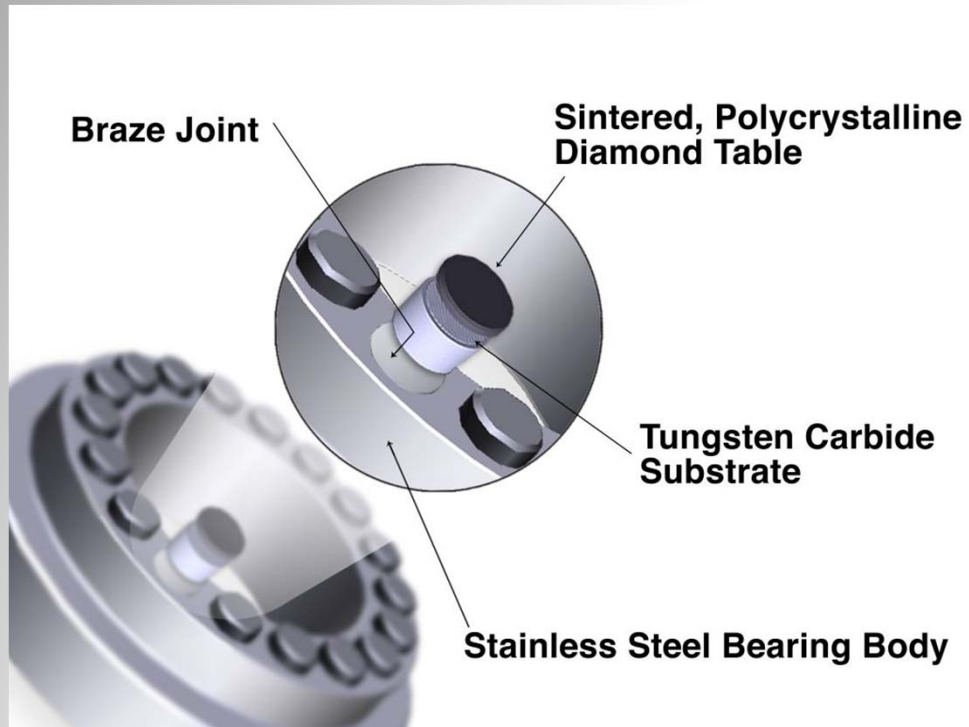
Diamond-to-diamond  
grain growth

Diamond grains

# PCD – Bearing Related Properties

Properties	PCD Diamond	Tungsten Carbide	Silicon Nitride	Silicon Carbide
Coefficient of friction (in water)	0.07	0.23	---	---
Thermal conductivity, W/mK	543	70	30	85
Fracture toughness MPa√m	14	17	4	3.7
Hardness, GPa Knoop	49.8	1.8	1.8	2.4
Compressive strength, GPa	7.3	2.7	--	2.5
Young's Modulus, GPa	841	680	296	434
Tensile strength, MPa	1450	334	520	500

# PCD Bearings

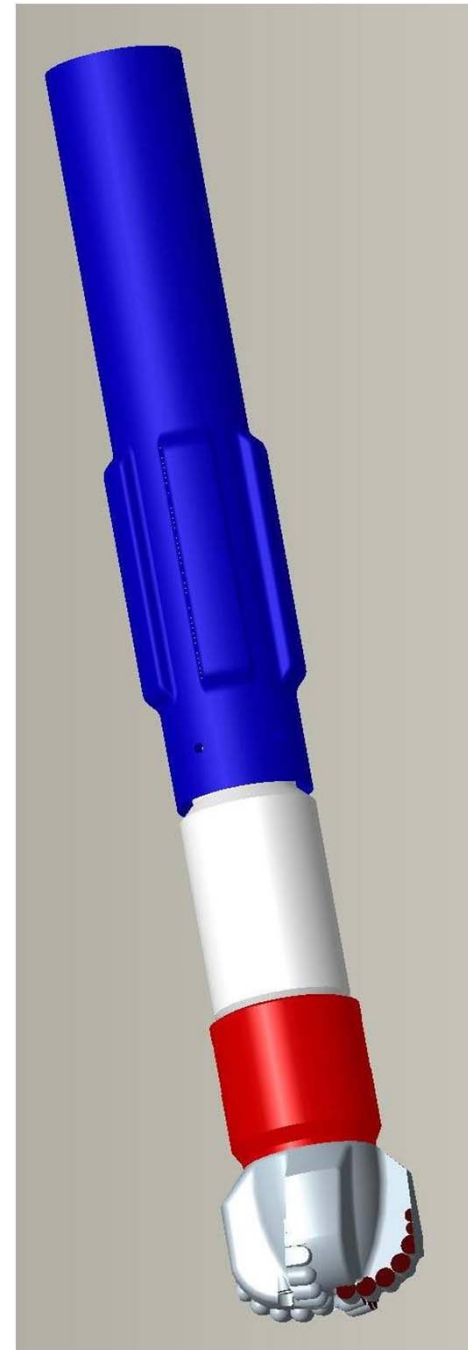


# PCD Bearings

- Benefits:
  - Resistance to wear in harsh environments results in long bearing life (and increased mean time between failure)
    - Abrasive (process lubricated)
    - High-temperature
  - Operate effectively in boundary, mixed, and hydrodynamic regimes
  - Withstand high loads and speeds
- Limitations
  - Some friction ( $0.005 < \text{COF} < 0.09$  depending on regime)
  - Coolant/lubricant requirement (ineffective dry-running)
  - Temperature at PCD wear surface  $< 700^{\circ}\text{C}$
  - High initial cost

# PCD Bearings – Current Applications

Drilling motor with PDC drill bit



# PCD Bearings – Current Applications

- Drilling motors (oil and gas)
  - Approximately 20 years in this application with resurgence in the past 3 years
  - High-load and high-speed applications
  - Drilling mud-lubricated
  - Replace conventional drilling mud-lubricated ball bearings
- Drilling turbines (oil and gas)
  - Approximately 30 years in this application
  - Often high well temperatures
  - Drilling mud-lubricated
- Other oil and gas drilling tools
  - Drilling mud-lubricated

# Requirements for Bearings in Geothermal and Deep Drilling Applications

- High temperature – up to 300 C
- Harsh environments
- Long mean-time between failure (costly to replace tools and/or components)
- Some friction is allowable? – depending on application

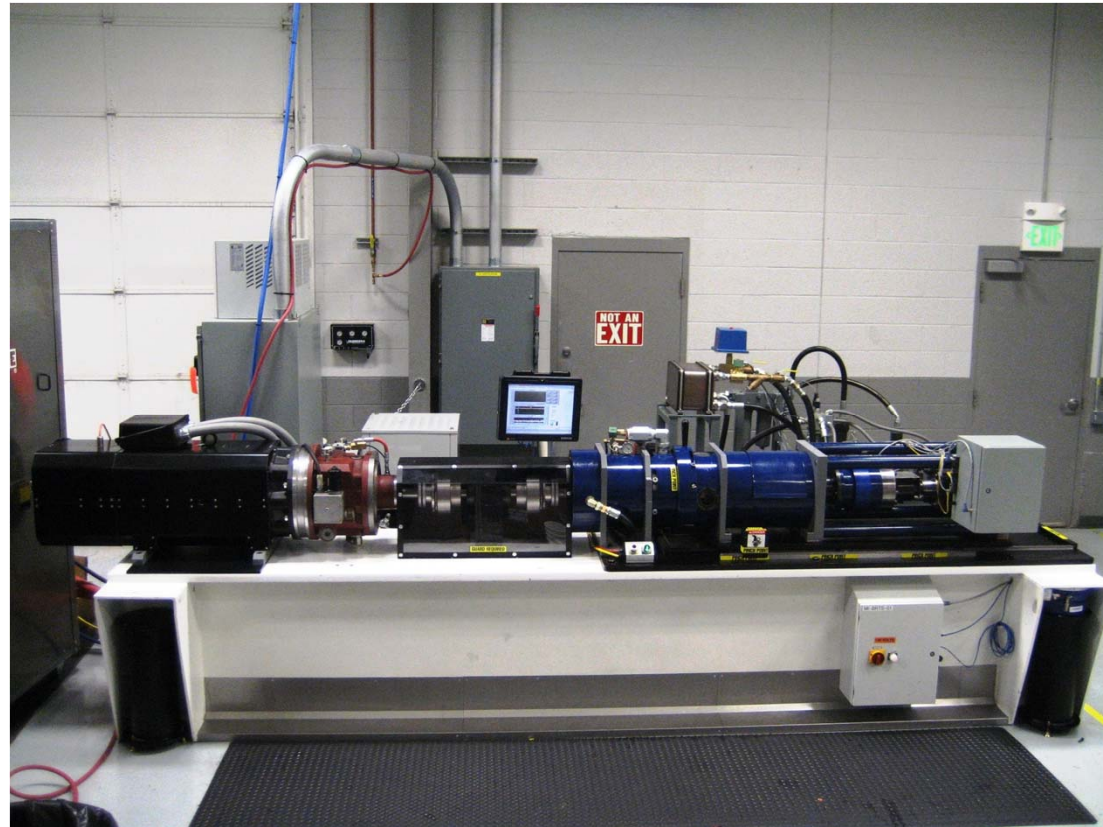
# Potential Geothermal and Deep Drilling Applications for PCD bearings

- Drilling turbines and motors for geothermal drilling
- Other drilling tools in deep or geothermal bottom-hole assemblies
- Roller-cone drill bits with open diamond bearings
- High temperature production pumps with process-lubricated bearings

# PCD Thrust Bearing Testing

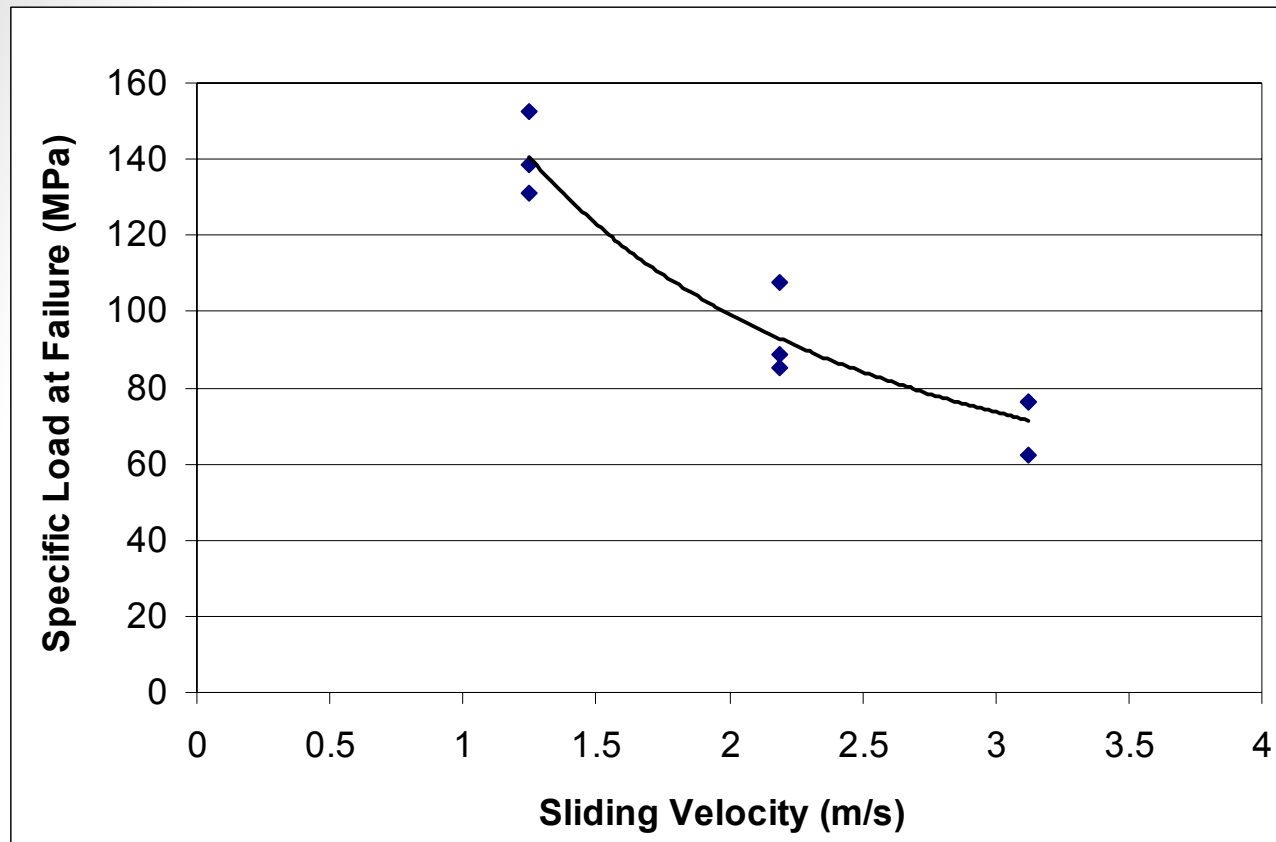
## Monitors and records:

- Bearing torque (friction)
- Bearing temperature
- PCD wear rate
- Results are used to predict:
  - Load capacity
  - Bearing life
  - Friction characteristics
- Axial load: 0 – 267 kN
- Speed: 0 – 3000 rpm



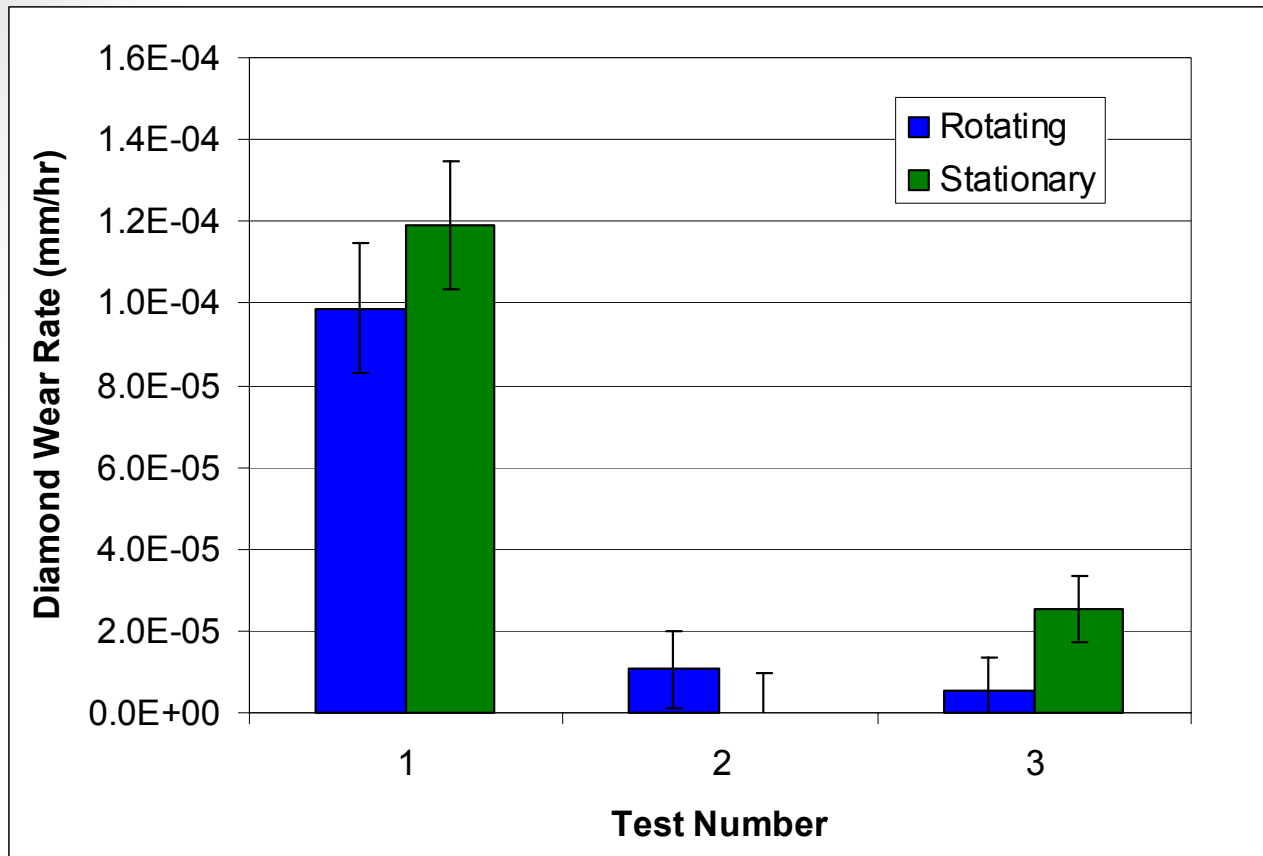
# PCD Bearing Performance in Boundary Lubrication

1. Capacity tests - show bearing failure load is a function of rotational velocity



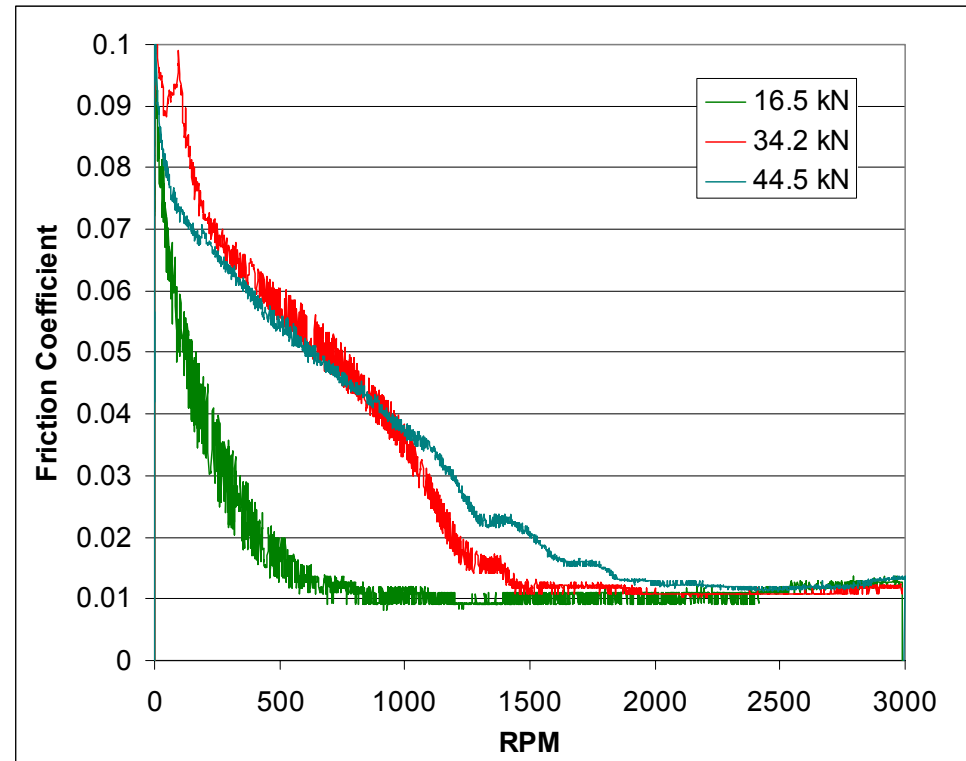
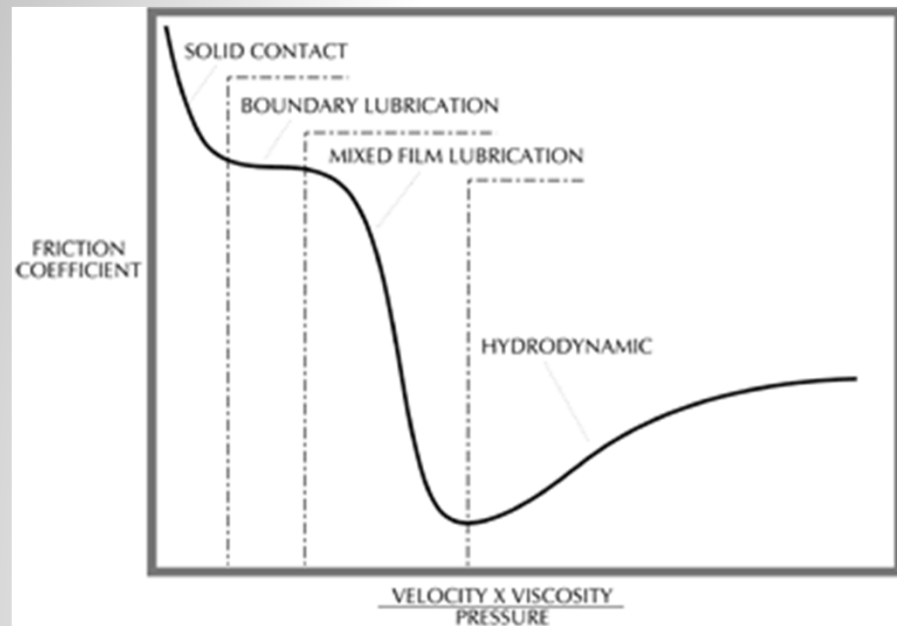
# PCD Bearing Performance in Boundary Lubrication

- Wear tests – PCD bearings can last well over 1000 hours, even when operating in the boundary regime

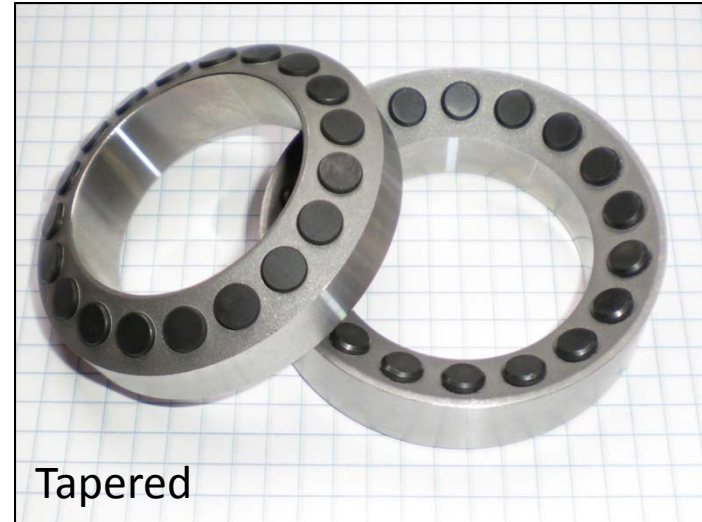


# PCD Bearing Performance in Mixed and Hydrodynamic Lubrication

- Tests at a constant axial load and increasing speed exhibit friction curves similar to standard Stribeck Curve
- Transition from boundary to mixed-mode to hydrodynamic regimes can be observed



# PCD Bearing Configurations



# Summary

- PCD bearings are currently used extensively in oil and gas drilling applications including those in deep and high-temperature wells
- PCD bearings are very likely suitable for many process-lubricated geothermal drilling and production applications
  - Each application must be judged on its own merits (including axial loads, speeds, and cooling conditions)
- PCD bearings perform well in a wide range of operating conditions including boundary, mixed-mode, and hydrodynamic lubrication regimes
- New PCD bearing configurations give tool manufacturers design flexibility