Diamond Coated Silicon Carbide
by Flowserve
To date, Flowserve has sold more than 40,000 diamond coated seal faces... more than any other seal company

Flowserve tests the first crystalline diamond coated seal face made by Argonne National Labs

Burgmann commercializes crystalline diamond

Flowserve begins new evaluation of ADT UNCD

John Crane purchases ADT for $8MM

ADT Spins off from Argonne National Labs

John Crane forms 5 year exclusive agreement with ADT

Flowserve forms 5 year exclusive agreement with ADT
John Crane Purchases ADT

John Crane bought the assets of ADT on April 26, 2019 and operates the business as John Crane Diamond (JCD)

- Flowserve remains their number one diamond coating customer and they aim to keep our business
- Flowserve has an uninterrupted relationship with JCD as supplier of diamond coating services
  - Supplier performance metrics (OTD, quality, responsiveness…) and technical support are unchanged
  - Confidentiality agreements binding the sharing of proprietary information are unchanged
  - Standalone facility, production staff and support relationships are unchanged
- Flowserve retains our proprietary surface treatment essential for diamond adhesion: performance unchanged
- How is Flowserve responding? Delighting our customers with the best diamond coated silicon carbide on the market
  - Business as usual: Flowserve has a secure supply of diamond coatings for silicon carbide seal faces
  - Just as John Crane remains a supplier to Flowserve Pumps, JCD remains a supplier to Flowserve Seals – both with firewalls in place
  - Flowserve is committed to staying in the business of solving sealing problems – and we’ve been doing it longer with measurable success
Our Commercial Success

- Diamond Coated SiC seal faces contribute $4 MM USD per year in additional revenue
- More than 2,500 diamond coated seal faces sold per year for *engineered* seals
- Diamond Coated SiC sales continue to grow year-over-year
- Diamond Coated SiC is now available in PSS 4 split seals
Agenda

Diamond coatings, still differentiating technology

- Selecting Applications
  - Exploit our experience, our success compared to John Crane
- Setting Expectations
- Choosing the Mating Face Material
- Success Stories
- Seal Failure Analysis
The Truth About K10 Diamond Coating

K10 diamond was created to run against carbon mating faces

• Flashing hydrocarbon
• <50 designs
• 6% of diamond applications
Seals Available with Diamond Coated Faces

- **Pusher Seals**
  - ISC2 / ISC2-682
  - QB / QBQ / QBS
  - UC / D
  - PSS 4

- **Bellows Seals**
  - BX Series

- **High Temperature Bellows**
  - BXRH
  - BXHHS
  - BRCSH

- **High Duty**
  - UHTW / DHTW
  - HSH

- **Slurry Seals**
  - SLC
  - SLM
  - RIS

- **Specialty Seals**
  - GLS

Most wet running Flowserve seals with face diameters less than 300 mm (11.800 inches)
Target Applications

- **Upstream Oil & Gas**
  - Produced water
  - Crude oil pipeline
  - Multiphase pumps

- **Power**
  - FGD slurries
  - Boiler feed water
  - River water (dirty water)

- **Refineries & Petrochemical**
  - Dirty hydrocarbons
  - Light hydrocarbons

- **Mining & General Slurries**
  - Fibrous slurries
  - Abrasive slurries
  - Batch processes

- **Chemical**
  - Loading & unloading pumps
  - Fluids with entrained gases
  - Solutions with abrasives
  - Caustics
  - Strong acids
  - Solvents

**Common Denominator:** Low lubricity fluids or fluids containing solids
General Application Range

- **Operating Parameters**
- **Pressure:** 0 to 140 BarG (0 to 2000 PSI)
- **Temperature:** -40° to 370°C (0 to 700°F)
- **Speed:** up to 46 m/s (150 ft/sec)
- **Viscosity:** 0.2 to 500 cP
- **Specific Gravity:** 0.4 to 2.0
- **Sizes:** 25.4 to 280 mm (1.000 to 11.000 inches)

- These are not firm limits, the range of diamond coating experience continues to increase
Selecting Applications

Most Common

- Chemical 17%
- Hydrocarbon 16%
- Light Hydrocarbon 12%
- Contaminated Water 12%
- Water 10%
- Boiler Feed Water 8%
- Slurry 8%
- Heavy Hydrocarbon 8%
- Heat Transfer Fluid 3%
- Hot Hydrocarbon 3%
- Amine 2%
- Refrigerant 1%
Guidance on Using Diamond Coating in Hot Water

Approved range without cooling

- Up to 355°F (180°C)
- Up to 3,600 rpm
- UNCD vs UNCD or UNCD vs SiC or UNCD vs WC
- D seal, QB Series or ISC2 Series

Notes

- Either grade of SiC may be run against UNCD
- UNCD may be used in hot water service with Plan 23 beyond the stated ranges or seal types

Enhanced images of seal face surfaces from UNCD vs UNCD test – no wear
Success Using Diamond in Hot Water with Plan 11

- P-M Industrial
- Furey Filter & Pump
- Davidson Sales & Eng Inc
- Corrosion Fluid Products
- Geiger Pump and Equipment
- EPUMPS Inc
- JCI Industries
- Montana Seals and Packing

With Plan 23

- Colorado Seals Inc
- Cummins-Wagner
- Disney
Why UNCD Coated Seal Faces?

Because low lubricity services can damage traditional seal face materials.
What Diamond Combination is Best?

- **Diamond vs Diamond**
  - Best for:
    - Very abrasive slurries
    - Hot water without cooling
    - High value applications

- **Diamond vs Tungsten Carbide**
  - Best for:
    - Partial dry running
      - Loading/unloading
      - Entrained gas
    - Industrial seals
      - ASME B73.1 pumps
    - Slurries

- **Diamond vs Silicon Carbide**
  - Best for:
    - Light hydrocarbons
    - Acids
    - Caustics
    - Bellows seals
    - API 682 seals
    - When Tungsten Carbide is not available
Selecting Mating Face Materials

• General Rule
  - Diamond vs Diamond will perform the best
• Diamond vs Tungsten Carbide (WC) may be under utilized
  - Tested well
  - No issues reported from the field
Diamond Failures

• Who has seen a failed diamond coated SiC face?
• Who reported that failure to Flowserve?
• Who has seen a failed uncoated SiC?
• Who reports every uncoated SiC failure to Flowserve?

The main criteria to consider is, “Did diamond last longer than the material it replaced?”
Diamond Failures

Failures are uncommon, but attract a lot of attention

- <1% of diamond coated faces have been reported as not meeting the traditional seal face material’s reliability
- Diamond is typically applied as a solution to bad actor applications

Diamond will not solve all problems

- Extreme torque loads
- High vibration
- Long duration dry running
- Impact/fracture damage
Success Stories

• Waste water treatment plant ran UNCD dry for 2 hours with no detriment in sealing performance
  - The seal continues to operate, extending the pump’s reliability by over 5x the competitor seal

• Alumina plant retrofitted SLC seals with UNCD for tough slurry service
  - Reliability increased from a few weeks with traditional face materials to exceeding the life of the pump’s wear components
  - The customer was thrilled and has install UNCD on numerous additional applications, all very successful
Success Stories

• PSI Engineering, **Jeff Schmidt**
  - Ethanol

• 50 cSt Oil

POLL THE AUDIENCE
Seal Failure Analysis, Shiny Spots & Cross Hatching
Seal Failure Analysis

Discoloring on sides or back of diamond coated seal face
Material Missing, Flaking Appearance
Missing Material, Thin Spots
Intermittent Film Failure
Seal Failure Analysis, Wear
Seal Failure Analysis, Stacco Chipping
Seal Failure Analysis, Complete Film Failure
High Initial Leakage

Causes

• Diamond vs Diamond
  - Matte vs matte
• High radial taper
• Large size
Flowserve offers a wide range of seal face surface preparations to address challenging applications

- Ultrananocrystalline diamond (UNCD) coatings
- Diamond-like carbon (DLC) coatings
  - Used for hard vs hard non-contacting Gaspac and Mixerpac seals
- Laser-applied precision face topography
  - Wavy faces
  - Advance pattern grooves
- Machined-applied face topography
  - Lube grooves
  - Hydropads
DuraClear HT Value Statement

An exclusive Flowserve product

• Formulated specifically for extreme temperature duty
  - High temperature hydrocarbon applications
    • Chemically compatible with all hydrocarbons
    • Soluble in hydrocarbons
  - Cryogenic (DuraClear LT)

• Will not coke, breakdown, oxidize, react, or ignite at barrier fluid temperatures up to 204°C (400°F)

• No cooling water required for many applications with process temperatures up to 204°C (400°F)
  - Reduces operating cost
  - Can be used where cooling water is not available
  - No risk of water fouling

• Reduced cooling water dependence for applications with process temperatures up to 400°C (750°F)
Viscosity

Goal for mechanical seal faces is 1-10 cP at operating temperature

- This corresponds to a usable temperature range for DuraClear HT of 40 to 204°C (104 to 400°F)
Coking is the deposition of carbon-rich solids resulting from oil undergoing severe oxidative and thermal breakdown

- Can occur in any hydrocarbon-based buffer or barrier fluid
  - Even without air or oxygen present
- Most serious risk when temperatures exceed 175°C (350°F)
  - Can occur at temperatures as low as 135°C (250°F)
- Concern is further raised in stagnant areas where temperatures can elevate above the bulk fluid temperature and heat load on the buffer/barrier fluid is higher

- With hydrocarbon-based barrier fluids, cooler barrier fluid increases life
  - For every 18°F (10°C) over 212°F (100°C), the oxidation rate doubles
  - Cooling coils are almost always recommended for process fluids greater than 120°F (50°C)
With DuraClear HT, the hydrocarbon risks from exposure to high temperatures are greatly mitigated

- DuraClear HT contains no Hydrogen and is non-flammable
- DuraClear HT does not breakdown and form coke at any pump temperature

**Pictured:**

- Laboratory testing with pressurized hydrocarbon-based barrier fluid
- Full synthetic barrier fluid coking at seal face temperatures of less than 143°C (290°F)
  - (Outer seal shown)
- Barrier fluid temperature was under 100°C (212°F)
- Duration of less than a week
General DuraClear HT Selection Guidance

- Select DuraClear HT for high temperature applications where coking barrier fluid has been seen before or is likely
- Select DuraClear HT when traditional barrier fluid temperature cannot be maintained below 100°C (212°F)
- Select DuraClear HT when a suitable viscosity to support seal faces cannot be achieved with another DuraClear grade
DuraClear HT Field Trials

- Currently soliciting applications for free trials of DuraClear HT
  - Looking for hot services over 400°F
  - A 6-9 month supply of DuraClear HT will be provided
  - Looking for a customer who will stay with DuraClear HT after the trial term
  - DuraClear HT falls between DuraClear 5-F and DuraClear Crystal 7

End User Price Per Gallon

<table>
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<tr>
<th>Price Per Gallon</th>
<th>DuraClear 5F and 32F</th>
<th>DuraClear HT</th>
<th>DuraClear Crystal 7</th>
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<tr>
<td>$0.00</td>
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<td>$2,000.00</td>
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New Elastomer Grades

- New Fluoroelastomer (FKM) focus
  - Best performance
  - Good chemical compatibility
  - Great cost
  - Added granularity

- New perfluoroelastomer focus
  - Added Parker Ultra FFKM
    - Lowest compression set rate amongst our elastomers
    - 2nd lowest priced FFKM option
    - Inventory and pricing now in place
  - [GG] General FFKM now lowest priced and fastest lead-time option

<table>
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<tr>
<th>PHASE</th>
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<td>Fluoroelastomer, FKM (GU)</td>
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<td>TFE-P Elastomer, Atlas® (AF)</td>
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<td>General Perfluoroelastomer (GG)</td>
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<td>PTFE, Duraflon, Glydon 351 (GT)</td>
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| Max Temp °F (°C) | 0 (-17) | 40 (-40) | 36 (-33) | 32 (-34) | 20 (-40) | 19 (-45) | 19 (-47) | 19 (-47) | 19 (-47) | 19 (-47) | 19 (-47) | 19 (-47) | 19 (-47) | 19 (-47) | 19 (-47) | 19 (-47) | 19 (-47) | 19 (-47) | 19 (-47) | 19 (-47) | 19 (-47) | 19 (-47) | 19 (-47) | 19 (-47) | 19 (-47) | 19 (-47) | 19 (-47) | 19 (-47) | 19 (-47) | 19 (-47) | 19 (-47) | 19 (-47) | 19 (-47) | 19 (-47) | 19 (-47) | 19 (-47) | 19 (-47) | 19 (-47) | 19 (-47) |}

| Min Temp °F (°C) | 0 (-17) | 36 (-40) | 32 (-40) | 30 (-40) | 28 (-40) | 19 (-47) | 19 (-47) | 19 (-47) | 19 (-47) | 19 (-47) | 19 (-47) | 19 (-47) | 19 (-47) | 19 (-47) | 19 (-47) | 19 (-47) | 19 (-47) | 19 (-47) | 19 (-47) | 19 (-47) | 19 (-47) | 19 (-47) | 19 (-47) | 19 (-47) | 19 (-47) | 19 (-47) | 19 (-47) | 19 (-47) | 19 (-47) | 19 (-47) | 19 (-47) | 19 (-47) | 19 (-47) | 19 (-47) | 19 (-47) | 19 (-47) | 19 (-47) | 19 (-47) | 19 (-47) | 19 (-47) | 19 (-47) | 19 (-47) | 19 (-47) | 19 (-47) | 19 (-47) | 19 (-47) | 19 (-47) | 19 (-47) |