World's first successful practical application of ceramic bearings

"Aren't there any bearings that can be used in seawater?"

...One of our customers asked this question, triggering our efforts to develop the ceramic bearing.

Initially, we attempted to use alumina as the raw material, but it split quickly and cracks developed...

Following this, research stalled and ended after approximately five years.

Research resumed again in 1978; this time with the development team consisting of five members.

Additionally, a material manufacturer known for leading ceramics research was invited to join the effort.

Starting with silicon nitride as the raw material, strength was reinforced using a sintering additive and a hot pressing process eliminated cracking.

As a result, the first ceramic bearings were commercialized in 1984.

Some of our customers had doubts about strength in the beginning, stating "if ceramic cracks, it will surely split in two!"

At that time, customers would hit the bearings with a hammer to test their strength.

Finding practical applications was initially difficult, but their strength and high-speed performance were gradually recognized, and ceramic bearings began to be utilized for the main spindles of machine tools.

Next, they began receiving attention from semiconductor manufacturers owing to the characteristics of not using oil and not producing waste.

Ceramic bearings were then utilized in a section of experimental equipment on the space shuttle Colombia, expanding their range of applications.

As productivity improved, ceramic bearings began being used in the mass production of computer HDDs and automobile engines.

Their excellent performance has been recognized and applications have received various awards, such as the Japan Fine Ceramics Award.

And now...

“For ceramic bearings, the answer is KOYO”
Introduction to Application Examples

1 Machine tools

1 Spindle (Angular Contact Ball Bearing)  Product: Hybrid Ceramic Bearings

- Machine tool spindle bearings are required to have superior rotational performance at extremely high speeds, quick acceleration/deceleration, high rigidity, and reduced temperature rise.
- Hybrid Ceramic Bearings, which satisfy these requirements, are widely used in this application.

- Use Conditions:
  - Rotational speed: 25,000 min⁻¹
  - Temperature: Room temp.
  - Spindle power: approx. 60 kW

2 Spindle (Cylindrical Roller Bearing)  Product: Hybrid Ceramic Bearings

- Seizure resistance performance under unbalanced load conditions due to misalignment improved at the Vertical Spindle Machining Center.

- Use Conditions:
  - Rotational speed: 12,000 min⁻¹
  - Lubrication: Grease

Film manufacturing equipment

1 Liquid Crystal Polarizing Film Manufacturing Equipment  Product: Corrosion Resistant Hybrid Ceramic Bearings

- Liquid crystal polarizing film manufacturing equipment use acid solution, alkaline solution, dying solution, distilled water, and other solutions.
- In such corrosive environments, Corrosion Resistant Hybrid Ceramic Bearings are widely used.

- Use Conditions:
  - Rotational speed: 80 min⁻¹
  - Temperature: Room temp. to 80°C
  - Lubrication: Chemical solution

2 Photographic Film Manufacturing Equipment  Product: Hybrid Ceramic Bearings (with special features)

- A photographic film production line treats film surfaces by applying a high voltage. Hybrid Ceramic Bearings are widely used in such environments, because the ceramic inner ring and balls serve as insulators.

- Use Conditions:
  - Rotational speed: 200 min⁻¹
  - Temperature: Room temp.
  - Lubrication: Grease

Power generation equipment

1 Wind Turbine Generator  Product: Hybrid Ceramic Bearings

- Wind Turbine Generators are strongly required to operate for extensive periods of time without the need of maintenance. Hybrid Ceramic Bearings, which have superior durability and reliability, are widely used in such environments.

- Use Conditions:
  - Rotational speed: 2700 min⁻¹
  - Temperature: Below freezing point to approx. 40°C
  - Lubrication: Grease

2 Micro Gas Turbine Generator  Product: Hybrid Ceramic Bearings

- The world’s smallest gas turbine generators emit clean exhaust emissions and hence are friendly to the environment. Hybrid Ceramic Bearings are used in these generators because they have low in vibration and noise generation, and have excellent high speed performance.

- Use Conditions:
  - Rotational speed: 10,000 min⁻¹
  - Temperature: 200°C
  - Lubrication: Oil
**Introduction to Application Examples**

1. **Liquid Crystal Panel Bonding and LC Sealing Furnace**
   - **Product**: Hybrid Ceramic Linear Motion Ball Bearings
   - Suitable for clean environments thanks to low particle emissions
   - **Use Conditions**:
     - Stroke speed: 5 mm/s
     - Temperature: 200°C
     - Ambient pressure: Normal pressure
     - Lubrication: Clean pro coating

2. **Furnaces Cars**
   - **Product**: High Temperature Hybrid Ceramic Bearings
   - Applicable to high temperature environments
   - **Use Conditions**:
     - Rotational speed: 10 to 500 min⁻¹
     - Temperature: 500°C
     - Lubrication: Graphite

3. **Baking Furnace Cars**
   - **Product**: High Temperature Hybrid Ceramic Bearings
   - Compatible with high temperature environments
   - **Use Conditions**:
     - Rotational speed: 2 to 10 min⁻¹
     - Temperature: 400 to 500°C
     - Lubrication: Graphite

4. **Tube Annealing Furnace Guide Rolls**
   - **Product**: Hybrid Ceramic Bearings
   - Compatible with high temperature environments
   - **Use Conditions**:
     - Rotational speed: 300 min⁻¹
     - Temperature: 300°C

5. **Diffusion Furnace Dolly**
   - **Product**: Full-complement Ceramic Ball Bearings
   - Compatible with high-temperature environments
   - **Use Conditions**:
     - Temperature: 800°C or higher
     - Ambient pressure: Corrosive gas atmosphere
     - Load: 10N

- **CERAMIC BEARINGS**
- **Industrial furnaces**

- **Liquid Crystal Panel Bonding**
  - Suitable for clean environments thanks to low particle emissions
- **LC Sealing Furnace**
  - The Clean Pro Hybrid Ceramic Linear Motion Ball Bearings are widely used for such jigs.
- **Furnaces Cars**
  - Applicable to high temperature environments
  - Because of their high heat resistance, High Temperature Hybrid Ceramic Bearings are used in such applications.
- **Baking Furnace Cars**
  - Compatible with high temperature environments
  - The guide roll bearings installed inside tube annealing furnaces are used under high temperatures without lubrication. Hybrid Ceramic Bearings are suitable for such applications.
- **Tube Annealing Furnace Guide Rolls**
  - Rotational speed: 300 min⁻¹
  - Temperature: 300°C
  - Lubrication: Graphite
  - The bogies, conveyers and other carrier systems used in furnaces are exposed to high temperatures. Because of their high heat resistance, High Temperature Hybrid Ceramic Bearings are used in such applications.
- **Diffusion Furnace Dolly**
  - Conditions in a diffusion furnace are harsh, including not only high temperature, but also corrosive gas. Incorporating a rolling mechanism for the conveyor dolly in the furnace enables smooth conveyance to be obtained, thereby leading to improvements in product quality and productivity.

- **Use Conditions**
  - **Liquid Crystal Panel Bonding**
    - Stroke speed: 5 mm/s
    - Temperature: 200°C
    - Ambient pressure: Normal pressure
    - Lubrication: Clean pro coating
  - **Furnaces Cars**
    - Rotational speed: 10 to 500 min⁻¹
    - Temperature: 500°C
    - Lubrication: Graphite
  - **Baking Furnace Cars**
    - Rotational speed: 2 to 10 min⁻¹
    - Temperature: 400 to 500°C
    - Lubrication: Graphite
  - **Tube Annealing Furnace Guide Rolls**
    - Rotational speed: 300 min⁻¹
    - Temperature: 300°C
  - **Diffusion Furnace Dolly**
    - Temperature: 800°C or higher
    - Ambient pressure: Corrosive gas atmosphere
    - Load: 10N
## Production equipment

### 1. Aluminum Electrolytic Capacitor Manufacturing Equipment

**Product:** High Corrosion Resistant Ceramic Bearings

- **Use Conditions:**
  - Corrosion resistance to strong acid solution
  - Rotational speed: 50 min⁻¹
  - Temperature: 90°C
  - Lubrication: Chemical solution (hydrochloric acid and sulfuric acid)

**Introduction to Application Examples**

In an aluminum foil electrolytic capacitor manufacturing equipment, a strong acid solution is used to treat the aluminum foils. High Corrosion Resistant Ceramic Bearings are widely used in such highly corrosive environments.

### 2. Synthetic Fiber Manufacturing Equipment

**Product:** Corrosion Resistant Hybrid Ceramic Bearings

- **Use Conditions:**
  - Corrosion resistance under acid solution, alkaline solution and water
  - Rotational speed: 20 to 100 min⁻¹
  - Temperature: Room temp. to 90°C
  - Lubrication: Chemical solution

**Introduction to Application Examples**

Acid solution, alkaline solution, water, and other liquids are used in synthetic fiber yarn reinforcing processes. Corrosion Resistant Hybrid Ceramic Bearings are applied in such corrosive environments.

### 3. DVD Sputtering Equipment

**Product:** Hybrid Ceramic Bearings

- **Use Conditions:**
  - Insulation
  - Rotational speed: 300 min⁻¹
  - Temperature: Room temp.
  - Lubrication: Grease

**Introduction to Application Examples**

To improve reliability further, Hybrid Ceramic Bearings are used.

### 4. Steel Wire Stranding Machine

**Product:** Hybrid Ceramic Bearings

- **Use Conditions:**
  - Reduced temperature rises
  - Reliable durability
  - Rotational speed: 6 000 min⁻¹ or higher
  - Lubrication: Grease

**Introduction to Application Examples**

Steel wires for radial tires are produced by stranding steel wires to attain the required strength. In steel wire stranding machines, which involve high speed rotation, Hybrid Ceramic Bearings are used for improved service life and stability.

### 5. Jet Electrostatic Coating Machine

**Product:** Hybrid Ceramic Bearings

- **Use Conditions:**
  - Prevention of grease scattering
  - Prevention of paint contamination
  - Rotational speed: 20 000 min⁻¹
  - Lubrication: Fluorine polymer

**Introduction to Application Examples**

In a jet electrostatic coating machine, grease may escape from the spray nozzle due to the air motor, affecting the quality of the paint to be coated. To resolve this problem, Hybrid Ceramic Bearings that do not use grease are used.

### 6. Blister Packaging Equipment

**Product:** High-temperature Hybrid Ceramic Bearings

- **Use Conditions:**
  - Applicable to high-temperature environments
  - Contributed to improved productivity
  - Temperature: 250°C
  - Load: 9600N
  - Lubrication: Grease

**Introduction to Application Examples**

As heater roll bearings used in processing reach high temperatures during operation, conventional bearings are quickly damaged. Incorporating high-temperature ceramic bearings extends the bearing replacement cycle and improves productivity.
**Introduction to Application Examples**

### 1. Transfer Robot for Semiconductor and LCD Manufacturing Equipment

**Product:** 6 Series Full Complement Hybrid Ceramic Ball Bearings

For application in transfer robots for semiconductor and liquid crystal manufacturing equipment, bearings are required to be low in particle emissions and have a long service life. Bearings may be delivered incorporated in arm units for improved assemblability and maintainability.

- **Use Conditions**
  - **Temperature:** Room temp. to 200°C
  - **Ambient pressure:** 10−6 Pa
  - **Lubrication:** Grease or clean pro coating

### 2. Electron Beam Lithography

**Product:** Non-magnetic Hybrid Ceramic Bearings

The bearings in semiconductor production electron beam lithography are exposed to strong magnetic fields. Because of their non-magnetic characteristics, Hybrid Ceramic Bearings are used in such machines.

- **Use Conditions**
  - **Rotational speed:** 100 min−1
  - **Temperature:** Room temp.
  - **Ambient pressure:** 10−4 Pa
  - **Lubrication:** Grease

### 3. Gates in Chemical Vapor Deposition Equipment

**Product:** Hybrid Ceramic Ball Bearing, Clean Pro Linear Motion Ball Bearings

Hybrid Ceramic Ball Bearings and Clean Pro Linear Motion Ball Bearings are widely used for the doors of the chemical vapor deposition (CVD) equipment.

- **Use Conditions**
  - **Rotational speed:** 10 to 200 min−1
  - **Temperature:** 200°C
  - **Ambient pressure:** Normal to 10−8 Pa
  - **Lubrication:** Grease

### 4. Etching Equipment

**Product:** Hybrid Ceramic Bearings (with special features)

Bearings used in etching machines must be resistant to halogen and hydrofluoric acid, as well as low in particle emissions. To meet these requirements, PTFE coated Hybrid Ceramic Bearings are used.

- **Use Conditions**
  - **Temperature:** Room temp. to 60°C
  - **Ambient pressure:** Normal to 10−4 Pa
  - **Load:** Radial load at 10 N
  - **Lubrication:** PTFE coating

### 5. Vacuum Evaporator

**Product:** High Temperature Hybrid Ceramic Bearings (with special features)

Bearings used in the planetary section of vacuum evaporator are required to be high in durability under high temperatures, high load (moment) conditions. To ensure a long bearing life under high temperature conditions, High Temperature Hybrid Ceramic Bearings with special features are used.

- **Use Conditions**
  - **Rotational speed:** 1 to 30 min−1
  - **Temperature:** 200 to 400°C
  - **Ambient pressure:** Normal to 10−5 Pa
  - **Lubrication:** Molybdenum disulfide or silver

### 6. Spin-dryer for Wafer Cleaning Equipment

**Product:** Corrosion Resistant Hybrid Ceramic Bearings

Because of their high corrosion resistance, Corrosion Resistant Hybrid Ceramic Bearings are widely used in wafer cleaners.

- **Use Conditions**
  - **Rotational speed:** 2,000 to 3,000 min−1
  - **Temperature:** Room temp.
  - **Lubrication:** Grease

---

**Use Conditions**

- Applicable to vacuum environments and clean environments
- Optimal for machine size reduction
- Improved reliability in vacuum and high temperature environments
- Corrosion resistance to solutions such as cleaning chemicals, rinsing liquids, and distilled water

**CERAMIC BEARINGS**
Introduction to Application Examples

### Semiconductor manufacturing equipment

#### Wafer Transfer Equipment

**Product:** Hybrid Ceramic Linear Way Bearing Units (with special features)

For application in wafer transfer equipment, low particle emissions performance is required. For such devices, Clean Pro Hybrid Ceramic Linear Way Bearing Units are widely used.

- Suitable for clean environments thanks to low particle emissions
- Corrosion resistant to cleaning agent splashes

**Use Conditions**

- Stroke speed: 350 mm/s
- Temperature: Room temp.
- Ambient pressure: Normal pressure
- Lubrication: Clean pro coating

![Linear way bearing](Image)

#### Wafer Cleaning Equipment for Chemical Mechanical Polishing System

**Product:** Corrosion Resistant Ceramic Bearings

In the semiconductor multi-layer production process, each wafer surface should be treated to maintain evenness. This process uses chemical mechanical polishing equipment, and the cleaner attached to the equipment uses Corrosion Resistant Ceramic Bearings.

- Corrosion resistance to corrosive solutions

**Use Conditions**

- Rotational speed: 100 min⁻¹
- Temperature: Room temp.
- Lubrication: Fluorine polymer

![Ceramic bearings](Image)

#### Turbo Molecular Pump

**Product:** Full-Complement Hybrid Ceramic Ball Bearings (with special features)

Magnetic bearings are used in turbo molecular pumps driven at extremely high speeds. To protect the blades from fracture in case of a power failure or magnetic failure, touchdown bearing units are used. As touchdown bearings, Full-Complement Hybrid Ceramic Ball Bearings are used to increase the service life of the touchdown bearings under severe hostile conditions.

- Improved reliability in vacuum environments

**Use Conditions**

- Rotational speed: 20 000 to 60 000 min⁻¹
- Ambient pressure: 1 Pa
- Lubrication: Molybdenum disulfide or silver

![Turbo molecular pump](Image)

### Motor, Industrial machinery

#### Polygon Scanner Motor

**Product:** Hybrid Ceramic Bearings

Hybrid Ceramic Bearings, which exhibit superior high speed performance, are widely used in high speed polygon scanner motors.

- Excellent reliability in high speed rotation

**Use Conditions**

- Rotational speed: 26 000 min⁻¹ or higher
- Lubrication: Grease

#### Ultrasonic Motor in Magnetic Resonance Imagers

**Product:** Ceramic Bearings

The motors installed in magnetic resonance imagers (MRI) use magnetism insensitive Ceramic Bearings.

- Compatible with strong magnetic field environments

**Use Conditions**

- Rotational speed: 500 min⁻¹
- Temperature: Room temp.
- Lubrication: Grease

#### Switched Reluctance Motor

**Product:** Hybrid Ceramic Bearings

For high-speed, high efficiency switched reluctance (SR) motors, which do not use coils or permanent magnets, Hybrid Ceramic Bearings are applied.

- Excellent reliability in high speed rotation

**Use Conditions**

- Rotational speed: 30 000 min⁻¹
- Lubrication: Grease

![Motor, Industrial machinery](Image)
**Blood Centrifuge**

Product: Hybrid Ceramic Bearings (with special coating)

- Corrosion resistance is required of bearings to be used in blood centrifuge especially to physiological saline.
- Hybrid Ceramic Bearings with bearing rings coated with a corrosion resistant film are suitable for such corrosive environments.

**Ultrasonic Motor in Magnetic Resonance Imagers**

Product: Ceramic Bearings

- The motors installed in magnetic resonance imagers (MRI) use magnetism insensitive Ceramic Bearings.

**Air-conditioner motors**

Product: Hybrid Ceramic Bearings

- Electric pitting prevent through insulation performance

**Fan Motor**

Product: Hybrid Ceramic Bearings

- Prevention of electrical pitting

**Outer Space Experimentation Equipment**

Product: Ceramic Bearings

- Long Service Life under Freshwater Lubricating Conditions

**Inline Skates**

Product: Hybrid Ceramic Bearings

- Low torque and improved durability
Automobiles, Motorcycles

1. Turbocharger
   - Product: Hybrid Ceramic Bearings
   - Bearings supporting the main shaft of the turbocharger are responsive during acceleration and durable when using low-viscosity, dirty oil.
   - Hybrid ceramic bearings with superior reliability are utilized.

   **Use Conditions**
   - Service life three times longer than that of ordinary bearings
   - Acceleration response improved 20%
   - Oil quantity reduced 80%

   **Use Conditions**
   - Rotational speed: 160,000 to 210,000 min⁻¹
   - Temperature: 350°C
   - Lubrication: Oil

2. Fuel Injection System Control Valve
   - Product: Ceramic Ball
   - The common rail system (fuel injection system), which enables diesel engines to feature high power, good fuel economy and low emissions, is equipped with Ceramic Balls in the control valves.

   **Use Conditions**
   - Compatible with high pressure fuel injection thanks to improved wear resistance and seizure resistance

   **Use Conditions**
   - Maximum pressure: 135 MPa

3. Wheel Bearings for Solar Cars
   - Product: Hybrid Ceramic Bearings
   - Stable operation of the motor section under severe open conditions of running 8 hours or more per day. Improvements in weight reduction, durability and reliability.
   - Suppressing spinning resistance and efficiently transferring the driving force to the wheels contributes to saving power.

   **Use Conditions**
   - Australia: Covered over 3,000km vertically
   - South Africa: Covered over 4,000km

   **Use Conditions**
   - Rotational speed: 1000 min⁻¹
   - Lubrication: Grease

4. Rally Car Hub Units
   - Product: Hybrid Ceramic Bearings
   - Excellent abrasion resistance even under severe environmental conditions has improved durability and reliability.

   **Use Conditions**
   - Utilized in the car entered in the Paris-Dakar Rally in 1997 and 1998
   - Rigidly improved
   - Unsprung weight reduced

5. Motorcycle Superchargers
   - Product: Hybrid Ceramic Bearings
   - The new superchargers for large motorcycles utilize lightweight, high-strength ceramic balls capable of high-speed rotation. The incorporation of ceramic balls has achieved bearings with excellent high-speed performance, heat resistance and abrasion resistance. Additionally, when using hybrid ceramic bearings, high-output is achieved even for race specification motors operating under harsh conditions.

   **Use Conditions**
   - High-speed performance, heat resistance and abrasion resistance improved
   - Contributes to achieving high output supporting race specifications
Properties of ceramic materials

1. Material characteristics

Table 1 below lists the mechanical and physical properties of major ceramic materials used as bearing materials. Table 2 compares silicon nitride and high carbon chromium bearing steel.

<table>
<thead>
<tr>
<th>Property</th>
<th>Unit</th>
<th>Ceramic Material</th>
<th>Silicon Nitride Si₃N₄</th>
<th>Zirconia ZrO₂</th>
<th>Silicon Carbide SiC</th>
</tr>
</thead>
<tbody>
<tr>
<td>Density</td>
<td>g/cm³</td>
<td>3.2</td>
<td>6.0</td>
<td>3.1</td>
<td></td>
</tr>
<tr>
<td>Linear expansion coefficient</td>
<td>K⁻¹</td>
<td>3.2×10⁻⁶</td>
<td>10.5×10⁻⁶</td>
<td>3.5×10⁻⁶</td>
<td></td>
</tr>
<tr>
<td>Vickers hardness</td>
<td>HV</td>
<td>1500</td>
<td>1200</td>
<td>2200</td>
<td></td>
</tr>
<tr>
<td>Module of longitudinal elasticity</td>
<td>GPa</td>
<td>320</td>
<td>220</td>
<td>380</td>
<td></td>
</tr>
<tr>
<td>Poisson’s ratio</td>
<td></td>
<td>0.29</td>
<td>0.31</td>
<td>0.16</td>
<td></td>
</tr>
<tr>
<td>Three point bending strength</td>
<td>MPa</td>
<td>1100</td>
<td>1400</td>
<td>500</td>
<td></td>
</tr>
<tr>
<td>Fracture toughness</td>
<td>MPa·m¹/²</td>
<td>6</td>
<td>5</td>
<td>4</td>
<td></td>
</tr>
<tr>
<td>Heat resistance (in atmospheric air)</td>
<td>°C</td>
<td>800</td>
<td>200</td>
<td>1000 or higher</td>
<td></td>
</tr>
<tr>
<td>Thermal shock resistance</td>
<td>°C</td>
<td>750 or higher</td>
<td>350</td>
<td>350</td>
<td></td>
</tr>
<tr>
<td>Coefficient of thermal conductivity</td>
<td>W/(m·K)</td>
<td>20</td>
<td>2</td>
<td>70</td>
<td></td>
</tr>
<tr>
<td>Specific heat</td>
<td>J/(kg·K)</td>
<td>680</td>
<td>460</td>
<td>670</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Property</th>
<th>Unit</th>
<th>Silicon Nitride Si₃N₄</th>
<th>High Carbon Chromium Bearing Steel SUJ2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Density</td>
<td>g/cm³</td>
<td>3.2</td>
<td>7.8</td>
</tr>
<tr>
<td>Linear expansion coefficient</td>
<td>K⁻¹</td>
<td>3.2×10⁻⁶</td>
<td>12.5×10⁻⁶</td>
</tr>
<tr>
<td>Vickers hardness</td>
<td>HV</td>
<td>1500</td>
<td>750</td>
</tr>
<tr>
<td>Module of longitudinal elasticity</td>
<td>GPa</td>
<td>320</td>
<td>200</td>
</tr>
<tr>
<td>Heat resistance</td>
<td>°C</td>
<td>800</td>
<td>180</td>
</tr>
<tr>
<td>Corrosion resistance</td>
<td></td>
<td>High</td>
<td>Low</td>
</tr>
<tr>
<td>Heat resistance</td>
<td>°C</td>
<td>800</td>
<td>100</td>
</tr>
<tr>
<td>Corrosion resistance</td>
<td></td>
<td>High</td>
<td>Low</td>
</tr>
<tr>
<td>Conductivity</td>
<td></td>
<td>Non-magnetic</td>
<td>Ferromagnetic</td>
</tr>
<tr>
<td>Bond</td>
<td></td>
<td>Covalent bond</td>
<td>Metallic bond</td>
</tr>
</tbody>
</table>

Advantages of Ceramic Bearings:
- Decrease in centrifugal force induced by rolling elements (balls or rollers)
- Lower service life and reduced bearing temperatures
- Decreased thermal expansion due to reduced bearing temperature rise
- Lowered vibration and reduced preload changes
- Lowered vibration and reduced preload changes
- Higher rigidity
- Useful in acid or alkaline solutions
- Non-magnetic
- Metallic bond
- Decrease in adhesive (or material transfer) due to oil film thinning in rolling contact areas.

The individual ceramic materials were tested for rolling fatigue under oil lubrication and under water lubrication, to evaluate their applicability as bearing material. Figs. 1 and 2 show the results of the tests. The figures indicate that each ceramic material has a certain level of rolling fatigue strength and that silicon nitride has the highest fatigue strength among the ceramic materials tested.

2. Rolling fatigue of ceramic materials

Fig. 1 Comparison in rolling fatigue life under oil lubrication

Fig. 2 Comparison in rolling fatigue life under water lubrication

Fig. 3 Rolling fatigue life test conditions and test equipment
CERAMIC BEARINGS

Table 3 shows the results of evaluating the ceramic materials in terms of their characteristics and the rolling fatigue strength. Among the ceramic materials tested, silicon nitride is the most suitable as a rolling bearing material. JTEKT uses the silicon nitride produced by the hot isostatic pressing (HIP) method as the standard ceramic material for bearings.

Table 3 Ratings of ceramic materials as rolling bearing materials

<table>
<thead>
<tr>
<th>Material</th>
<th>Application to rolling bearings</th>
<th>Characteristics</th>
</tr>
</thead>
<tbody>
<tr>
<td>Silicon nitride</td>
<td>Suitable for high performance applications</td>
<td>- Comparable to bearing steel in load carrying capability and service life</td>
</tr>
<tr>
<td>Si₃N₄</td>
<td>- Suitable for high performance applications</td>
<td>- High speed</td>
</tr>
<tr>
<td>Zirconia</td>
<td>- Useful under a limited load</td>
<td>- Heat resistant</td>
</tr>
<tr>
<td>ZrO₂</td>
<td>- Applicable in highly corrosive conditions</td>
<td>- Non-magnetic</td>
</tr>
<tr>
<td>Silicon carbide</td>
<td>- Useful under a limited load</td>
<td>- Corrosion resistant</td>
</tr>
<tr>
<td>SiC</td>
<td>- Applicable in highly corrosive conditions</td>
<td>- High rigidity</td>
</tr>
</tbody>
</table>

With silicon nitride, characteristics such as density and strength can vary greatly depending on the manufacturing method and manufacturing conditions. Therefore, it is necessary to strictly control items such as shape, sintering, and other processes when manufacturing silicon nitride for ball and roller bearings. The general manufacturing process is shown in Fig. 5.

Composition of ceramic bearings

Koyo ceramic bearings are divided into Full Ceramic Bearings (with all components, namely, the outer ring, inner ring, and rolling elements, made of ceramic) and Hybrid Ceramic Bearings (with only the rolling elements made of ceramic). The outer ring and inner ring of the Hybrid Ceramic Bearings are made from special steel, including high carbon chromium bearing steel. The cage may be made of a metallic material, resin, or composite material, depending on the intended operating conditions of the bearing.

Fig. 4 Composition of ceramic bearings

Fig. 5 Ball and roller Bearing Silicon Nitride Manufacturing Process
1 Rolling fatigue life of ceramic bearings

A typical service life test for Ceramic Bearings and steel bearings was performed under the conditions specified in Fig. 7. The test results showed that the service life of Ceramic Bearings was equal to or longer than that of steel bearings, exceeding the calculated life. The Ceramic Bearings were found to exhibit flaking (Fig. 6) when their service life terminated. The same phenomenon was observed on the steel bearings whose service life terminated. Based on these findings, as the dynamic load rating of a Ceramic Bearing, that of a steel bearing of the same dimensions can be used.

2 Static load rating of ceramic bearings

The basic static load rating of a steel bearing represents a load that produces a localized permanent deformation in the rolling element/raceway contact area, impeding smooth rotation. However, ceramic materials, which are highly rigid, produce little permanent deformation. Therefore, the theory of the basic static load rating for steel bearings is not applicable to ceramic bearings.

### Static load rating of Full Ceramic Bearings

When exposed to continuous excessive loads, ceramic materials may break down; however, before breakdown occurs, the materials develop cracking. Fig. 8 compares the load measurements at which ceramic balls developed cracking with the basic static load ratings of steel bearings. Fig. 9 shows the measurement system. As these results show, the loads at which cracks develop on the Full Ceramic Bearing are far higher than that of the basic static load rating of steel bearings. This means that the basic load ratings specified in the ISO standard can be used as the allowable static loads of the Full Ceramic Bearing.

### Load ratings of ceramic bearings

<table>
<thead>
<tr>
<th>Material (outer/inner rings and balls)</th>
<th>Steel ball (SUJ2)</th>
<th>Ceramic ball</th>
<th>Ceramic inner ring</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bearing number</td>
<td>NC6206</td>
<td>6206</td>
<td>NC6206</td>
</tr>
<tr>
<td>Diameter (mm)</td>
<td>30 × 62 × 16</td>
<td>(30 + 0/008)</td>
<td>(30 + 0/008)</td>
</tr>
<tr>
<td>Condition</td>
<td>Steel bearing (SUJ2)</td>
<td>Full Ceramic Bearing</td>
<td>85% that of steel bearings</td>
</tr>
</tbody>
</table>

Note: The steel bearings here refer to bearings consisting of rings and rolling elements both made of high carbon chromium bearing steel.

### Table 4 Load ratings of ceramic bearings

<table>
<thead>
<tr>
<th>Bearing</th>
<th>Full Ceramic Bearing</th>
<th>Hybrid Ceramic Bearing</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dynamic load rating</td>
<td>C/r</td>
<td>C/r</td>
</tr>
<tr>
<td>Static load rating</td>
<td>C/r</td>
<td>C/r</td>
</tr>
<tr>
<td>Comparable to steel bearings</td>
<td>Comparable to steel bearings</td>
<td>85% that of steel bearings</td>
</tr>
</tbody>
</table>

### Table 5 Measurements of permanent deformation produced on flat steel plates and balls

<table>
<thead>
<tr>
<th>Load (kN)</th>
<th>Permanent deformation (μm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Steel ball</td>
<td>Ball</td>
</tr>
<tr>
<td>0.65</td>
<td>0.5</td>
</tr>
<tr>
<td>1.3</td>
<td>1.9</td>
</tr>
<tr>
<td>2.6</td>
<td>5.2</td>
</tr>
<tr>
<td>3.9</td>
<td>9.3</td>
</tr>
<tr>
<td>0.65</td>
<td>0.4</td>
</tr>
<tr>
<td>1.3</td>
<td>1.11</td>
</tr>
<tr>
<td>2.6</td>
<td>4.0</td>
</tr>
<tr>
<td>3.9</td>
<td>6.8</td>
</tr>
</tbody>
</table>

These results indicate that ceramic balls do not suffer permanent deformation and that the permanent deformation produced on the flat steel plate by the ceramic balls is approximately 1.2 times the sum of the deformation produced on the flat plate by steel ball and the deformation that the steel ball underwent. Accordingly, the static load rating of Hybrid Ceramic Bearings can be determined based on the permanent deformation of their bearing steel rings. JTEKT uses the load equal to 85% of the static load rating of steel bearings as the static load rating of the Hybrid Ceramic Bearings.

### Table 5 Load cell measurement system

- **Load cell**
- **Load meter**
- **Filter and amplifier**
- **Counter**
- **Recorder**
- **Amplifier**
- **Amplifier**
- **Load cell**
- **Filter and amplifier**
- **Counter**
- **Recorder**

### Fig. 8 Crack developing loads for Full Ceramic Bearings

![Crack developing loads for Full Ceramic Bearings](image)

### Fig. 9 Crack generating load measurement system

![Crack generating load measurement system](image)
### Impact strength of ceramic bearings

To evaluate the impact strength of ceramic bearings, ceramic balls were crushed by two methods: a static load and an impact load. The test results are shown in Fig. 10. Fig. 11 shows the testing methods.

This figure shows that the impact strength of the ceramic bearings is almost equal to the static load strength, which means the bearings possess sufficient impact strength.

---

### Fitting of ceramic bearings

When using ceramic bearings, it should be noted that ceramic materials are largely different from steel materials in the coefficient of linear expansion. Attention should therefore be paid to fitting stresses and temperature rises.

The following are the results of evaluating the fitting of a Ceramic Bearing on a stainless steel shaft.

---

#### Maximum stress produced by fitting

Table 6 shows the results of a static strength test conducted on a ceramic ring fitted on a stainless steel shaft. Table 7 shows the results of a dynamic strength test (running test) conducted on a ceramic ring fitted on a stainless steel shaft.

Based on the results of these tests, JTEKT makes it a rule for the maximum stress produced by interference to be no greater than 150 MPa when a ceramic inner ring is fitted on a stainless steel shaft.

Consult JTEKT for applications requiring tighter fitting.

---

#### Influence of temperature

During operation, bearing temperature exceeds the ambient temperature. When a ceramic bearing is operated on a stainless steel shaft or in a stainless steel housing, the interference with the shaft increases due to the difference in linear expansion coefficient while the interference with the housing decreases. (When the outer ring is loose-fitted, the clearance increases.)

To determine the class of fit for a ceramic bearing, the maximum temperature during operation should be assessed carefully.

---

The maximum stress generated on the inner ring due to the interference with the shaft can be determined from the following equation:

\[
\sigma = \frac{P_m}{d_i} \left( \frac{D_i^2 + d_i^2}{D_i^2 - d_i^2} \right) + \frac{d_i}{d_0} \left( \frac{d_i^2 + d_i^2}{d_i^2 - d_0^2} \right)
\]

- \(\sigma\): Maximum circumferential stress to interference (MPa)
- \(P_m\): Pressure of contact on fitting surface (MPa)
- \(d_i, D_i\): Inner ring bore diameter and outside diameter (mm)
- \(d_0\): Bore diameter of hollow shaft (mm)
- \(E_s, \nu_s\): Bearing’s modulus of longitudinal elasticity and Poisson’s ratio (MPa)
- \(E_s, \nu_s\): Shaft’s modulus of longitudinal elasticity and Poisson’s ratio (MPa)
There are two types of ceramic corrosion: One is the corrosion of the alumina-yttria system sintering aid (Al₂O₃-Y₂O₃), which is used to bake ceramic materials. To avoid this type of corrosion, silicon nitride ceramic rings treated with a spinel sintering aid (MgAl₂O₄) should be used. Fig. 14 shows the mass reduction and bending strength deterioration of corrosion resistant silicon nitride dipped in an acid or alkali solution for a given period of time. The other type of corrosion is the corrosion of the silicon nitride itself. For use in a highly corrosive solution, bearings made of zirconia (ZrO₂) or silicon carbide (SiC) may be effective. To select a ceramic bearing for use in a highly corrosive environment, its corrosion resistance to the specific condition should be carefully examined.

Service life of corrosion resistant bearings

Table 9 lists the bearings suitable for applications requiring corrosion resistance, along with their major applications.

Table 9 Typical corrosion resistant Ceramic Bearings

<table>
<thead>
<tr>
<th>Applications</th>
<th>Bearing Rings</th>
<th>Balls</th>
</tr>
</thead>
<tbody>
<tr>
<td>Corrosion Resistant Hybrid Ceramic Bearing</td>
<td>SUS430</td>
<td>Silicon nitride</td>
</tr>
<tr>
<td>Ceramic Bearing</td>
<td>Silicon nitride</td>
<td>Silicon nitride</td>
</tr>
<tr>
<td>Corrosion Resistant Ceramic Bearing</td>
<td>Corrosion resistant silicon nitride</td>
<td>Corrosion resistant silicon nitride</td>
</tr>
<tr>
<td>High Corrosion Resistant Ceramic Bearing</td>
<td>Silicon carbide</td>
<td>Silicon carbide</td>
</tr>
</tbody>
</table>

When Ceramic Bearings are operated in a solution, the solution serves as a lubricant. This means the solution is closely associated with the service life of the bearings. Fig. 15 shows the service life evaluation results for three types of Ceramic Bearings under water. The Ceramic Bearings terminate their service life due to the pitting of the rolling element or fatiguing of the bearing ring or ball surfaces. In case of the Hybrid Ceramic Bearings, ceramic balls do not develop pitting or wear. Their service life ends due to wear attributed to the minute corrosion of stainless steel bearing rings. When bearings are used in a solution whose lubrication performance is not enough, such as in water, it is important to evaluate in advance the susceptibility of the bearings to corrosion and the relationship between the bearing load and wear in the solution.

SUS400C has a longer service life than SUS300; however, the former steel is not suitable for use in water because it may rust and cause contamination. Ceramic Bearings may develop wear at an early stage of use depending on the characteristics of the solution, temperature, and load. Please contact JTEKT before using Ceramic Bearings in solutions.
A cause of bearing failure in motors or generators is electric pitting. Electric pitting occurs when a surface in rolling contact is locally molten due to sparks produced over the very thin lubricating oil film on the surface when electricity passes through the bearing in operation.

To avoid such pitting, a bypass is provided to ensure that no electric current passes through the bearing. Another method is to use an insulating bearing that can block electric current. Since ceramic materials exhibit an excellent insulation performance, Hybrid Ceramic Bearings consisting of ceramic rolling elements can be used as insulating bearings.

Hybrid Ceramic Bearings prevent electric pitting, also reduce bearing temperature rise, and lengthen grease service life. For these reasons, Hybrid Ceramic Bearings assure long term maintenance free operation and high speed equipment operation.

**Continuous sparks of weak current**

Example of electric pitting on inner ring raceway surface

**Wave-like wear**

Wave-like wear marks along entire inner ring raceway surface

**Power losses at high speed**

Fig. 20 compares power losses between the Hybrid Ceramic Bearings and steel bearings. When compared to steel bearings, the Hybrid Ceramic Bearings lose smaller power during high speed operation. The power loss decreases with increasing rotational speed. The Hybrid Ceramic Bearings also have superior anti-seizure characteristics, which means that they consume smaller amount of lubrication oil and thereby reduce rolling resistance (power loss).

**Seizure limit at high speed**

Fig. 21 shows the seizure limits of Hybrid Ceramic Bearings and steel bearings. The limits were measured by gradually reducing lubricating oil feed rate. Compared with general purpose steel bearings, Hybrid Ceramic Bearings consume smaller amount of lubricating oil under the same speed condition, while they can run at a higher speed under the same lubricating oil feed rate condition.
CERAMIC BEARINGS

Ceramic balls

JT-EKT also supplies Ceramic Balls (silicon nitride), which have excellent resistance to wear and seizure, and are usable in corrosive environments and ultrahigh vacuums. Other major features of these balls are excellent heat resistance (up to 800°C), high rigidity, lightweight (40% compared to bearing steel), non-magnetic, and have insulating characteristics.

The Ceramic Balls are useful in many applications such as jigs, tools, gauges, solenoid valves, check valves, other valve varieties, high grade bicycle parts, automotive parts, and machine components.

### Table of Dimensions and Masses

<table>
<thead>
<tr>
<th>Nominal dimension (mm)</th>
<th>Nominal outside diameter (mm)</th>
<th>Precision grade (5)</th>
<th>Mass (g) (per piece)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.8</td>
<td>0.8000</td>
<td>1</td>
<td>3.230 g</td>
</tr>
<tr>
<td>1.0</td>
<td>1.0000</td>
<td>2</td>
<td>3.854 g</td>
</tr>
<tr>
<td>1.2</td>
<td>1.2000</td>
<td>3</td>
<td>4.364 g</td>
</tr>
<tr>
<td>1/16</td>
<td>1.5875</td>
<td>4</td>
<td>4.885 g</td>
</tr>
<tr>
<td>2.0</td>
<td>2.0000</td>
<td>5</td>
<td>5.406 g</td>
</tr>
<tr>
<td>3/32</td>
<td>2.3812</td>
<td>5 and 6</td>
<td>5.927 g</td>
</tr>
<tr>
<td>7/64</td>
<td>3.175</td>
<td>3 and 5</td>
<td>6.448 g</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Nominal dimension (mm)</th>
<th>Nominal outside diameter (mm)</th>
<th>Precision grade (5)</th>
<th>Mass (g) (per piece)</th>
</tr>
</thead>
<tbody>
<tr>
<td>3.5</td>
<td>3.5000</td>
<td>6</td>
<td>11.797 g</td>
</tr>
<tr>
<td>5/32</td>
<td>3.9698</td>
<td>7</td>
<td>12.317 g</td>
</tr>
<tr>
<td>3/16</td>
<td>4.7625</td>
<td>8</td>
<td>12.837 g</td>
</tr>
<tr>
<td>7/32</td>
<td>5.5525</td>
<td>9</td>
<td>13.357 g</td>
</tr>
<tr>
<td>15/64</td>
<td>5.9312</td>
<td>10</td>
<td>13.877 g</td>
</tr>
<tr>
<td>1/4</td>
<td>6.3500</td>
<td>11</td>
<td>14.397 g</td>
</tr>
</tbody>
</table>

**Notes:**
1) For the grades, those specified in JS B 1051 shall apply.
2) The masses are calculated on the basis of 3.23 g/mm³ in density.

### Material and Dimension Codes

- **Material code:** silicon nitride ceramic
- **Dimension code:** 5/32 5 NC

### Additional Information

- **JT-EKT**

**Product Introduction**

**OFFICES**

- **KOYO CANADA INC.**
  3934 South Service Road, Burlington, Ontario L7L 5H8, CANADA
  TEL: 1-905-661-1321
  FAX: 1-905-661-1392

- **JT-EKT NORTH AMERICA CORPORATION**
  Main Office:
  47771 Hayward Drive, Plymouth, MI 48170, U.S.A.
  TEL: 1-734-454-1500
  FAX: 1-734-454-1509

- **Cleveland Office**:
  13725 Euclid Avenue, P.O.Box 45028, Westlake, OH 44145, U.S.A.
  TEL: 1-440-835-1100
  FAX: 1-440-835-9347

- **KOYO MEXICANA, S.A. DE C.V.**
  Av. Ejército de la República 2715-305, Col. Chimalistac, Del. Álvaro Obregón, C.P. 01270, México, D.F.
  TEL: 52-55-5207-3860
  FAX: 52-55-5207-3875

- **KOYO LATIN AMERICA, S.A.**
  Edificio Banco del Pacifico Paseo Baja, Calle Aquilino de la Guerra y Calle 52, República de PANAMA
  TEL: 507-208-5920
  FAX: 507-287-297-2679

- **KOYO ROLAMENTOS DO BRASIL LTDA.**
  Rua samambaia no. 36/103, 1º Piso – Cj. 12
  São Paulo – SP, Brasil CEP 04575-001
  TEL: 55-11-3273-7850
  FAX: 55-11-3867-3309

- **KOYO MIDDLE EAST FZE**
  Building 501, Dubai Airport Free Zone, P.O. Box 54816, Dubai, U.A.E.
  TEL: 971-4-4298-3800
  FAX: 971-4-4298-3700

- **KOYO BEARINGS INDIA PVT. LTD.**
  1st Floor Commercial Services Pvt. Ltd., Ground floor, The Beach E-1, Marathahalli, Bangalore 560099, INDIA
  TEL: 91-80-4276-4887 (Reception Desk of Service Office)
  FAX: 91-80-4276-4868

- **KOYO BEARINGS INDIA PVT. LTD.**
  127, Near 12, Gurung Commercial Complex, Amruth Bangasogalu, Chinnagoraipura 241614, THAILAND
  TEL: 66-2-532-327
  FAX: 66-2-532-327

- **PT. JT-EKT INDONESIA**
  Jl. Surabaya-Merak 127, Kawasan Industri Surabaya Ciputra, Karawang, Cimahi, Karawang, 11363 INDONESIA
  TEL: 62-287-8180-170
  FAX: 62-287-8180-171

- **PJ. JT-EKT INDONESIA**
  57, Perpuri Lane, Level 3, Phase One Warehouse #05-01, SINGAPORE 098725,
  TEL: 65-6274-2300
  FAX: 65-6282-1833

- **PHILIPPINE JT-EKT BEARINGS CORPORATION**
  4th Floor, One World Square Building, P10 Upper McKinley Road, McKinley Town Center Bonifacio, 1634 Taguig City, PHILIPPINES
  TEL: 63-2-856-5066
  FAX: 63-2-856-5046

**PUBLISHER**

- **JT-EKT CORPORATION NAGOYA HEAD OFFICE**
  No.7-1, Nisai 4-chome, Nakamura-ku, Nagoya, Aichi 450-8515, JAPAN
  TEL: 81-52-527-1000
  FAX: 81-52-527-1911

- **JT-EKT CORPORATION OSAKA HEAD OFFICE**
  No.5-8, Minamiasa 3-chome, Chuo-ku, Osaka 542-8502, JAPAN
  TEL: 81-6-6271-8451
  FAX: 81-6-6246-3712

- **Sales & Marketing Headquarters**
  No.5-8, Minamiasa 3-chome, Chuo-ku, Osaka 542-8502, JAPAN
  TEL: 81-6-6245-6087
  FAX: 81-6-6244-0007
Koyo® EXSEV FOR EXTREME SPECIAL ENVIRONMENTS
CERAMIC BEARINGS

— Value & Technology

JTEKT
JTEKT CORPORATION