# Ceramic Materials in Rolling Contact Bearings: Silicon Nitride for Increased Applications

The rolling contact fatigue of silicon nitride is considerably stronger than that of steel. This makes hybrid bearings a preferred bearing, especially for machine tool spindle bearings, and for a lot of applications, as they show significantly better performance: higher spindle speed, reduced vibration level of the spindle, cooler spindle operation, improved spindle run-out, simplified construction of spindle system, longer spindle life and lower spindle repair cost.

## Introduction

The first balls made of silicon nitride ($Si_3N_4$) were produced by means of hot pressing and tested back in the 1970s. The extremely complex and expensive technology was, however, not very suitable for application in rolling contact bearings. With the advent of sintering technology in the late 1970s, progress was made regarding effort and cost, but residual porosity in the material inhibited its acceptability at least as a rolling element material.

Only with the introduction of hot isostatic pressing technology at the end of the 1980s was it possible to produce nearly pore-free $Si_3N_4$ balls that had the potential to be used as bearing balls, especially if they were free of internal defects, and free particularly of surface defects. Although the advantages compared to steel balls were obvious, i.e. considerably lower weight, higher hardness and stiffness, smoother surface, lower thermal expansion, higher electrical resistance and higher corrosion resistance, the demand for these balls was low, and this drove up production costs, making prices unattractive for use in rolling contact bearing applications. Only in exceptional cases, when no other solution existed, were $Si_3N_4$ balls used. The positive experiences gained with these applications proved increasingly convincing, and other applications were opened up. The real breakthrough came at the end of the 1990s. More and more companies have become interested in $Si_3N_4$ balls, and a steady demand with ever higher need for balls has lowered the costs and therefore the prices, and with falling prices came other applications, which in turn have impacted demand and led to cost reduction.

Today, the use of $Si_3N_4$ balls in many, especially high-load applications has become indispensable. However, for low-load applications prices are still too high. For some years therefore, producers have tried to optimise the sintering technology so that hot isostatic pressing is no longer required. Improved starting powders and better equipment (gas pressure sintering equipment with extremely good temperature control) made it possible about a year ago that gas-pressure-sintered $Si_3N_4$ (GPSN) balls now qualify as bearing balls for many applications and so the cost could again be lowered.

Today, there are about 700 million $Si_3N_4$ balls as compared to 100 billion steel balls. With a clearly lower steel price (<1–5 % of the ceramic ball price), a maximum conversion potential of 2 % = 2 billion ceramic balls is envisaged. Today the high reliability and affordability are the main reasons for the growth in the demand for ceramic balls. The main growth markets are Europe, Japan, USA, and China with the following applications: automotive industry, machine tools, dental, electromotor, and wind energy.

*Keywords*
*silicon nitride, hybrid bearings*

## Production of $Si_3N_4$ balls

Three methods have become established based on the latest gas pressure sintering technology:

1. Direct hot isostatic pressing, i.e. sintering, densification at a pressure of 2000 bar of pressed, green glass-encapsulated ball blanks. The glass casing acts as a membrane and prevents the penetration of the gaseous pressure medium into the porous green blank. With this method, the best, near-pore-free quality is achieved.
2. Indirect hot isostatic pressing, i.e. the pressed, unsintered ball blanks are sintered first in conventional gas pressure sintering equipment, so that the balls exhibit closed porosity. This is followed by hot isostatic pressing at 2000 bar in order to further reduce the residual porosity. The quality of balls produced by this method is close to that of the first-mentioned method.

*Detlef Steinmann*
*hightech ceram Dr. Steinmann + Partner GmbH*

*E-mail: info@hightech-ceram.de*
*www.hightech-ceram.de*

Fig. 1a
Hybrid bearing with $Si_3N_4$ balls

Fig. 1b
Bearing balls in silicon nitride $Si_3N_4$ (HIPSN) and zirconia $ZrO_2$ (YPSZA)

Fig. 1c
$Si_3N_4$ rollers for roller bearings (HIPSN)

3. Optimised gas pressure sintering, i.e. sintering under lower gas pressure up to max 100 bar. However, a quality required for bearing technology can only be achieved if a very good starting powder is sintered together with an optimum combination of sintering aids under extremely well-controlled sintering conditions.

$Si_3N_4$ balls produced in such qualities are only as good as the used $Si_3N_4$ starting powder, the preparation along with the sintering aids and other additives will allow. Defects such as pores, inclusions of impurities, cracks and scratches, etc. have to be avoided or balls with these defects rejected. Even if inclusions inside the ball are less critical, they are critical on the surface or just below the surface. Critical is also everything that breaks through the ball surface. Therefore a 100-% inspection of all finished balls is necessary, in addition to all inspections carried out before after each process step, and defective balls have to be rejected in line with the given specifications.

## Hybrid bearings

Hybrid bearings (Fig. 1–2) are steel bearings containing $Si_3N_4$ balls instead of steel balls. These $Si_3N_4$ balls offer many improvements, compared to steel balls. The combination of characteristics like higher stiffness, higher hardness, lower weight, better surface finishing and ball geometry, as already mentioned in the introduction, lead to reduced heat generation, which in turn leads to a cooler bearing and lubrication temperature. The electrical resistance and the high corrosion resistance in combination with all other ball attributes helps to broaden the lubrication possibilities. All these advantages allow a higher bearing

Fig. 2a
Hybrid bearings cut open

Fig. 2b
Cages with silicon nitride ($Si_3N_4$) balls and bearing steel balls (100 Cr6)

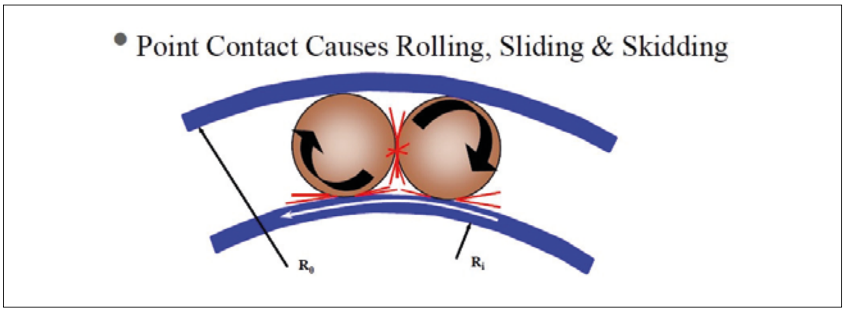


*Fig. 3*
*Study of ball rolling*

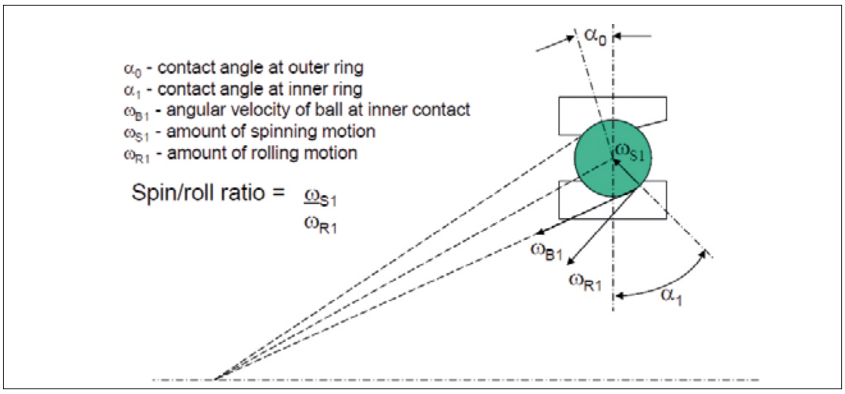


*Fig. 4*
*Spin/roll ratio study*

speed and lead to a longer service life. Hybrid bearings clearly set the standard for higher machining efficiency, lower downtimes and lower total cost.

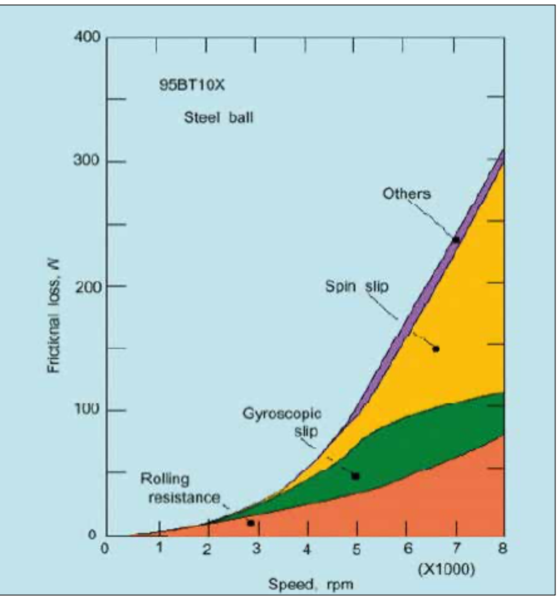


*Fig. 5*
*Friction losses from ball skidding*
*(Source: NSK Corporation)*

**Ball motion in a bearing**

The ball rolling (Fig. 3) in a bearing is in unobstructed motion in all three axes (X, Y, and Z planes). Owing to point contact in a bearing, the balls are in a constant state of rolling, skidding, and sliding.

Because of the different contact angles of the balls in relation to the outer ring $\alpha_0$ and inner ring $\alpha_1$, centrifugal forces are generated under higher velocities (speeds) which are superimposed by pretension and external forces acting on the bearing (Fig. 4). Consequently, the angular velocity of the ball at the inner ring contact, $\omega_{B1}$ comprises two components: a spinning component normal to the raceway, $\omega_{S1}$, and a rolling component, $\omega_{R1}$. The relationship between these two velocities is generally referred to as the spin/roll ratio. As speed increases the spin/roll ratio increases, producing more friction and heat, accompanied by increased surface distress at the rolling surfaces. Tests have shown the spin/roll ratio to be useful in indicating the likelihood of wear, and support an ideal maximum spin/roll ratio of 0,47, above which significant wear has to be expected.

Friction losses (Fig. 5) are a combination of rolling resistance, gyroscopic slip and spin slip, but there are other influences, too.

The effects of ball skidding and sliding in a bearing have a considerable impact on lifetime, speed, and performance. When steel balls slide on a steel raceway, micro-welding or "cold adhesion" will result from steel-on-steel contact. This contact causes damage to the surfaces of ball and raceway, thus accelerating the wear of the ball and the raceway. The damage leads to contamination of the lubricant and increased heat, which diminish the lubricating efficiency.

Because silicon nitride and steel are dissimilar in molecular structure, wear and adhesion are eliminated in the bearing, which greatly reduces wear and heat generation. If balls stay intact, damage is reduced. Cooler and smoother contact surfaces are the result and lubrication is extended. The hard silicon nitride ball tends to keep raceways clear of contamination longer than steel because dirt particles are pushed from the contact patch. Catalysis of lubricants based on hydrocarbon is significantly reduced and fretting is clearly reduced.

A better finish quality of the balls, better stability of geometry and higher stiffness as well as higher wear resistance result in a 70-%-lower coefficient of sliding friction, i.e. less friction, heat generation and ball/raceway wear, as well as higher precision, which all leads to a better bearing geometry, less vibration and therefore also less noise and longer service life. Hybrid bearings therefore need less lubrication thickness, i.e. lubrication is clearly less problematic.

$Si_3N_4$ balls are 50 % stiffer than steel. This leads to a smaller contact ellipsis of the balls on the raceway (Fig. 6). As a result, the contact patch between ball and raceway is much narrower and somewhat

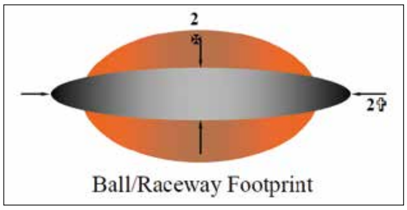


*Fig. 6*
*Ball/raceway footprint*

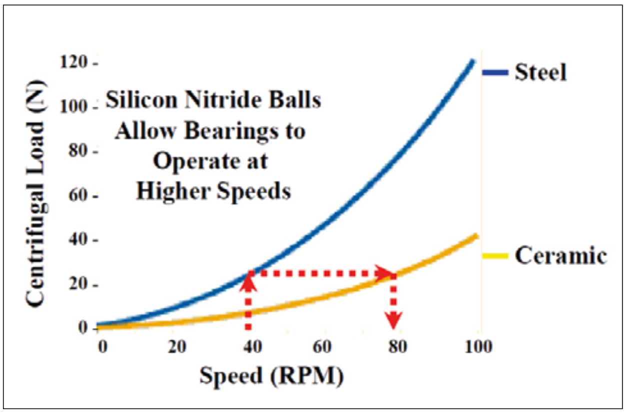


*Fig. 7*
*Velocity study using $Si_3N_4$ balls*

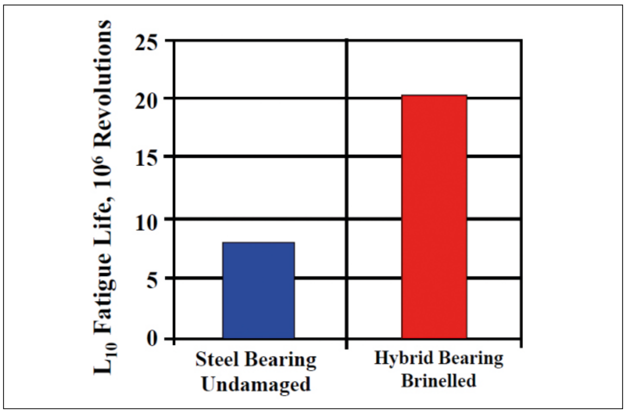


*Fig. 8*
*Fatigue life assessment of bearings*

longer than that given by a steel-on-steel system. The smaller contact patch (contact surface) means that there is reduced contact between the ball and the raceway, which leads to lower friction and less heat generation in the bearing even though skidding and sliding still occur.

$Si_3N_4$ balls are 60 % lighter than steel. Higher r.p.m. lead to more stress acting on the outer raceway because of the centrifugal forces, ultimately causing fatigue failure of the steel.

The lighter weight of $Si_3N_4$ balls reduces the stress on the raceway, enabling higher speed capabilities.

Similarly, the gyroscopic moment created by the X, Y, Z motion of the ball is significantly reduced at higher speed, which results in less ball skidding in the bearing. Skidding is a major source of internal heat generation and raceway wear. Ceramic balls with their lower density offer considerable advantages over steel in terms of spin/roll ratio. Over a range of constant preloads the theoretical maximum speeds achieved by bearings fitted with ceramic rolling elements, without exceeding a spin/roll ratio of 0,47, are approximately 40 % higher than for conventional bearings. Thanks to the lower density of the $Si_3N_4$ balls compared to steel balls, the velocity can be clearly increased, without increasing the centrifugal load. The result from SKF is shown in Fig. 7.

The higher hardness and better surface quality of the $Si_3N_4$ balls
- Typical raceway surface: ~0,025–0,05 µm RA
- Typical $Si_3N_4$ ball surface: <0,004 µm RA
- Typical steel ball surface: ~0,02–0,05 µm RA

lead to smoothening of the raceway surfaces and even of damaged surfaces, with the result that even hybrid bearings with damaged raceways have a three-times-longer lifetime than steel bearings with no damage. SKF ran a test with brinelled raceway surfaces. The result can be seen in Fig. 8.

The above-mentioned positive properties of the $Si_3N_4$ balls against steel balls in a bearing result in clearly reduced raceway wear, as SKF has proved in experiments (Fig. 9a).

Another experiment was conducted in contaminated oil. In this case, too, the hybrid bearings lasted three times longer than steel bearings regarding fatigue life (Fig. 9b).

At different frequencies the level of vibration is also clearly lower in hybrid bearings than in steel bearings (Fig. 9c).

## Effects of increasing speed on bearings with steel balls and $Si_3N_4$ balls

In the case of a steel bearing, this leads to an increased contact ellipse, increased friction, a system-temperature rise, reduction of speed and a shorter lifetime.

In hybrid bearings, the authors find a measurably lower system temperature rise, higher speed and longer bearing life (Fig. 10–11).

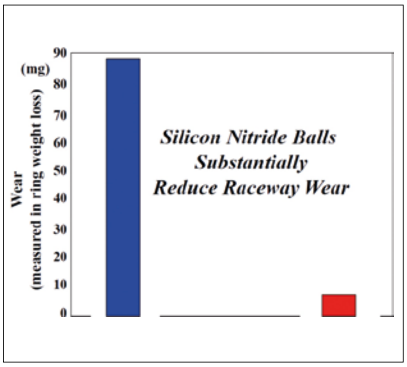


*Fig. 9a*
*Wear assessment of bearings*

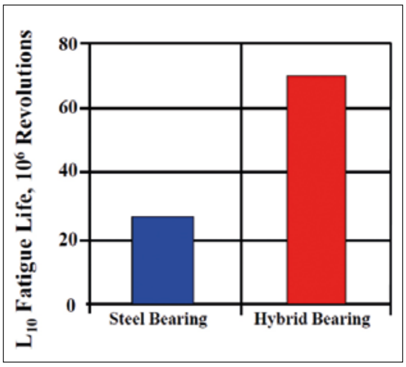


*Fig. 9b*
*Wear assessment of bearings*

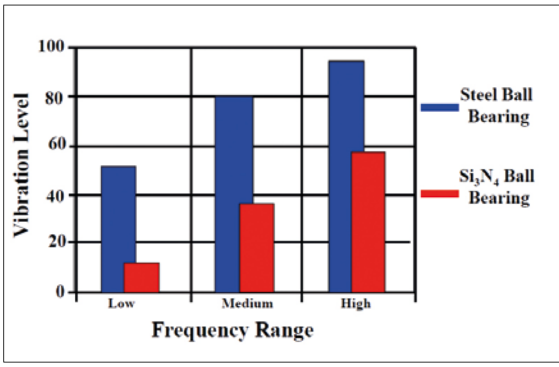


*Fig. 9c*
*Assessment of bearing on different frequency levels*

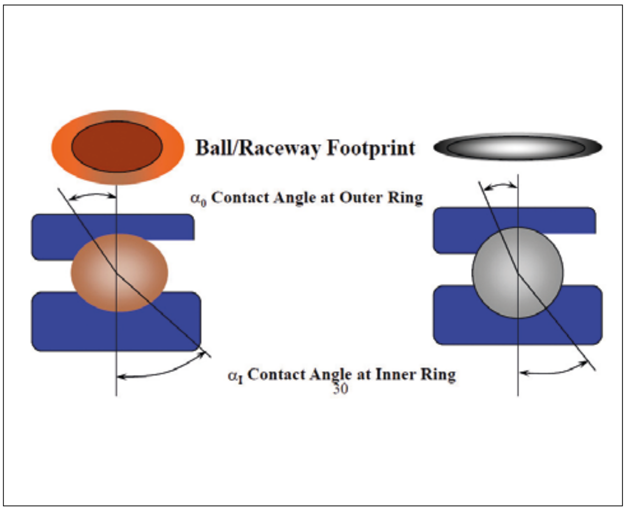


*Fig. 10*
*Comparison ball/raceway footprint (steel and hybrid)*

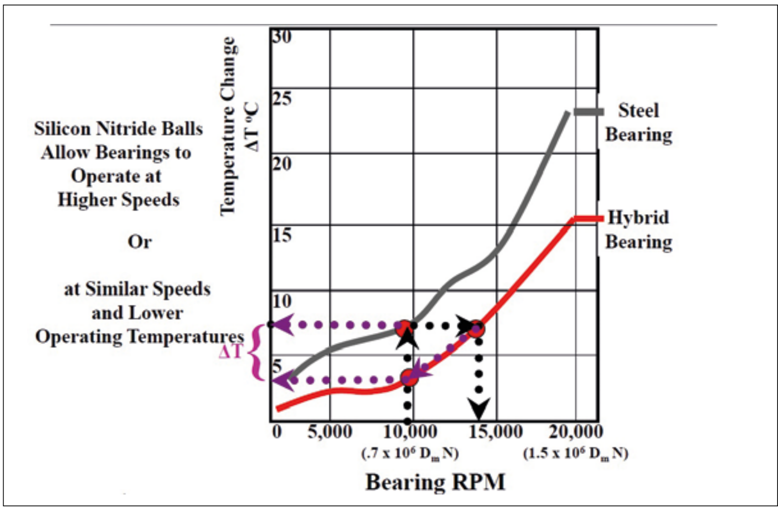
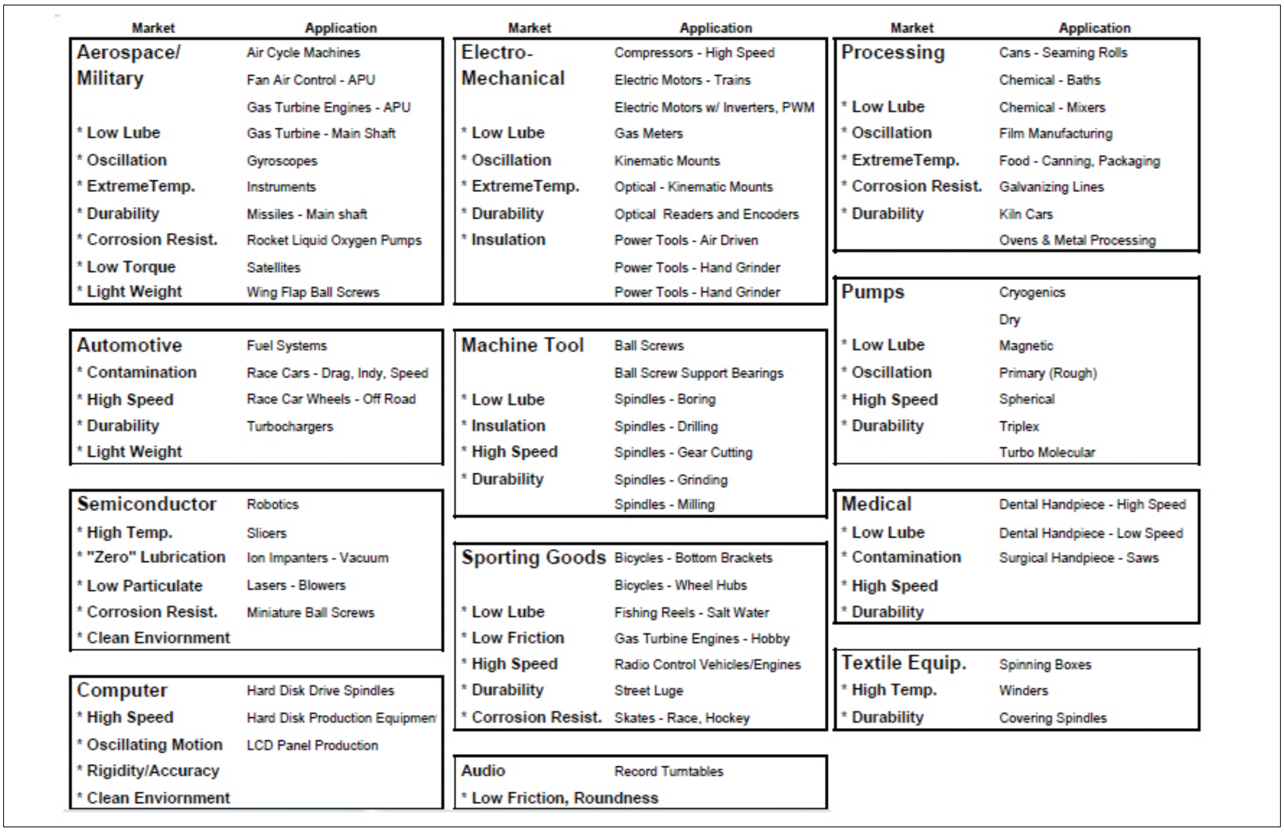


*Fig. 11*
*Comparison of bearing temperature dependant on bearing speed*

Silicon nitride is 50 % stiffer than steel and does not change with increasing temperature. These properties increase the rigidity of machine tool bearings at higher speeds because the balls do not deform under the higher temperatures. Additionally, the raceways are cooler, thus further lessening the effects of deformation on bearing stiffness. The result is a longer life and bearings are more precise.

**Typical applications of hybrid bearings**
Silicon nitride balls are used when design engineers are faced with difficult and often critical bearing applications. From liquid oxygen pumps in rockets and space shuttles, Boeing and Airbus wing flap ball bearings, satellites and dental bearings to in-line skates, engineers use silicon nitride balls to maximise bearing performance.



| Market | Application |
|---|---|
| **Aerospace/ Military** | Air Cycle Machines |
| | Fan Air Control - APU |
| | Gas Turbine Engines - APU |
| * Low Lube | Gas Turbine - Main Shaft |
| * Oscillation | Gyroscopes |
| * ExtremeTemp. | Instruments |
| * Durability | Missiles - Main shaft |
| * Corrosion Resist. | Rocket Liquid Oxygen Pumps |
| * Low Torque | Satellites |
| * Light Weight | Wing Flap Ball Screws |

| Market | Application |
|---|---|
| **Automotive** | Fuel Systems |
| * Contamination | Race Cars - Drag, Indy, Speed |
| * High Speed | Race Car Wheels - Off Road |
| * Durability | Turbochargers |
| * Light Weight | |

| Market | Application |
|---|---|
| **Semiconductor** | Robotics |
| * High Temp. | Slicers |
| * "Zero" Lubrication | Ion Impanters - Vacuum |
| * Low Particulate | Lasers - Blowers |
| * Corrosion Resist. | Miniature Ball Screws |
| * Clean Enviornment | |

| Market | Application |
|---|---|
| **Computer** | Hard Disk Drive Spindles |
| * High Speed | Hard Disk Production Equipmen |
| * Oscillating Motion | LCD Panel Production |
| * Rigidity/Accuracy | |
| * Clean Enviornment | |

| Market | Application |
|---|---|
| **Electro-Mechanical** | Compressors - High Speed |
| | Electric Motors - Trains |
| | Electric Motors w/ Inverters, PWM |
| * Low Lube | Gas Meters |
| * Oscillation | Kinematic Mounts |
| * ExtremeTemp. | Optical - Kinematic Mounts |
| * Durability | Optical Readers and Encoders |
| * Insulation | Power Tools - Air Driven |
| | Power Tools - Hand Grinder |
| | Power Tools - Hand Grinder |

| Market | Application |
|---|---|
| **Machine Tool** | Ball Screws |
| | Ball Screw Support Bearings |
| * Low Lube | Spindles - Boring |
| * Insulation | Spindles - Drilling |
| * High Speed | Spindles - Gear Cutting |
| * Durability | Spindles - Grinding |
| | Spindles - Milling |

| Market | Application |
|---|---|
| **Sporting Goods** | Bicycles - Bottom Brackets |
| | Bicycles - Wheel Hubs |
| * Low Lube | Fishing Reels - Salt Water |
| * Low Friction | Gas Turbine Engines - Hobby |
| * High Speed | Radio Control Vehicles/Engines |
| * Durability | Street Luge |
| * Corrosion Resist. | Skates - Race, Hockey |

| Market | Application |
|---|---|
| **Audio** | Record Turntables |
| * Low Friction, Roundness | |

| Market | Application |
|---|---|
| **Processing** | Cans - Seaming Rolls |
| | Chemical - Baths |
| * Low Lube | Chemical - Mixers |
| * Oscillation | Film Manufacturing |
| * ExtremeTemp. | Food - Canning, Packaging |
| * Corrosion Resist. | Galvanizing Lines |
| * Durability | Kiln Cars |
| | Ovens & Metal Processing |

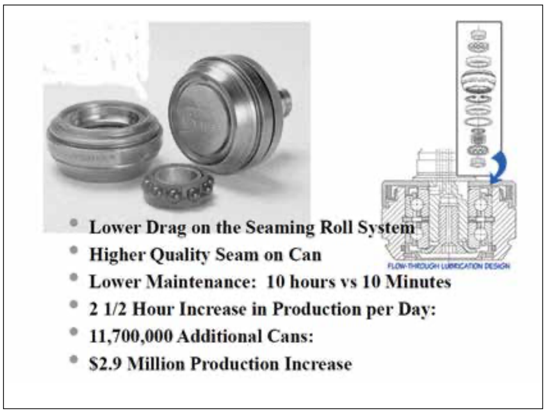
| Market | Application |
|---|---|
| **Pumps** | Cryogenics |
| | Dry |
| * Low Lube | Magnetic |
| * Oscillation | Primary (Rough) |
| * High Speed | Spherical |
| * Durability | Triplex |
| | Turbo Molecular |

| Market | Application |
|---|---|
| **Medical** | Dental Handpiece - High Speed |
| * Low Lube | Dental Handpiece - Low Speed |
| * Contamination | Surgical Handpiece - Saws |
| * High Speed | |
| * Durability | |

| Market | Application |
|---|---|
| **Textile Equip.** | Spinning Boxes |
| * High Temp. | Winders |
| * Durability | Covering Spindles |

*Fig. 12*
*Fields of applications for roller bearings*

Fig. 13
Aircraft generator bearing



- Lower Drag on the Seaming Roll System
- Higher Quality Seam on Can
- Lower Maintenance: 10 hours vs 10 Minutes
- 2 1/2 Hour Increase in Production per Day:
- 11,700,000 Additional Cans:
- $2.9 Million Production Increase

Fig. 14
Hybrid bearing in seaming rolls

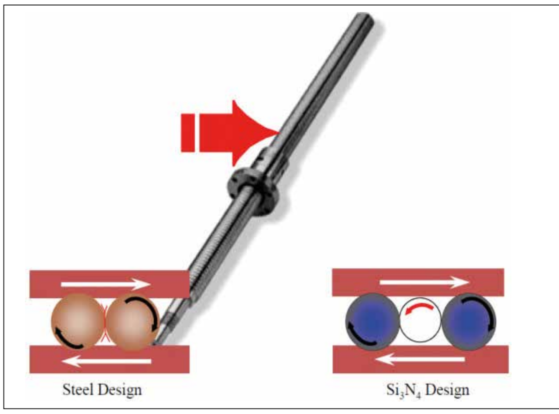


Fig. 15
Spacer for $Si_3N_4$ bearings

- Liquid Oxygen Pumps – Space Shuttle – Reason: Reliability;
- Dental Handpiece – 500 000 RPM – Reason: Durability;
- Long Range Satellites – Reason: Critical mission success;
- Machine Tool Spindles – Reason: Speed capability and safety;
- Machine Tool Ball Screws – Reason: Higher speeds, longer life;
- Ball Screws: Speed, Durability, Corrosion Resistance – Boeing 777, 737 and Airbus Wing Flaps – Reason: Longer life;
- In-Line Skates – Reason: Low start-up torque and less friction.

When reliability and long-time service are required in ball bearings, engineers use $Si_3N_4$ balls (Fig. 12).

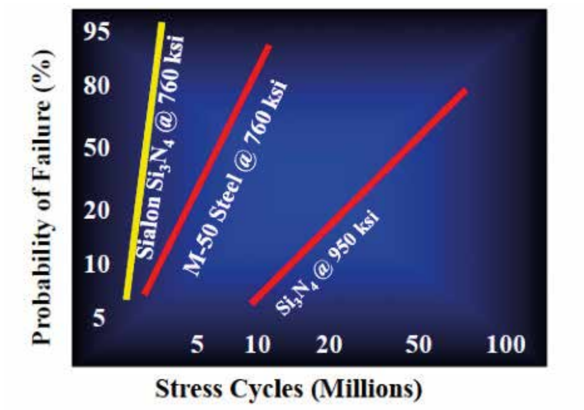


*Fig. 16*
*The Weibull plot shows the superior fatigue life of silicon nitride balls*

## Case studies for hybrid applications

### *Aircraft generator bearing*

Torrington Co. has tested a hybrid bearing for use in an aircraft generator (Fig. 13). The customer's challenge was to increase the bearing life and reduce the maintenance intervals of the system, thus lowering repair costs. Torrington combined silicon nitride balls with its lubrication and raceway system to achieve a 40 °F reduction in bearing temperature during operation. This enabled the lubrication/bearing system to last longer owing to lower friction and less wear on the bearing surface. These improvements reduced the maintenance cost by increasing the bearing service life.

### *Can seaming roll unit*

The use of hybrid bearings in the Angelus Co. seaming rolls (Fig. 14) has a number of performance and durability advantages: longer bearing life and less drag on the seaming roll, for less scuffing, and better seams. This use of advanced materials results in seaming rolls that last longer, turn with less drag and run cooler. This means less lubrication is required, so there is less down time for maintenance, so that the higher investment costs for the more expensive hybrid bearings are offset very quickly. The results are shown in the following picture.

### *Centrifugal pump*

Pumps are often operated at very low flow rates even if they have been originally designed to meet other criteria. Operation under these conditions generates increased radial and thrust loading on the bearing system and pressure pulsations that increase vibration. The resulting high static and dynamic load on the bearing system causes elevated temperatures, ball skidding, and outer race "fretting" which leads to degradation of the lubricant (blackened lubrication). The elimination of this problem included the use of a hybrid thrust bearing with thin dense chrome (TDC) coated raceways and oil flood lubrication.

The dissimilar material pairing (ceramic against steel) eliminates the fretting corrosion problem, and the low operating temperature of the hybrid bearing substantially reduced degradation of the lubricant. The high elastic modulus of the silicon nitride balls increased the overall bearing stiffness, thus reducing vibrations by 50 % in the pump. Pump maintenance is required less often, and higher productivity at lower cost is the consequence.

## Hybrid ball screws

Ball screws utilising the benefits of silicon nitride balls offer a cost-effective upgrade to faster, linear motion sliding mechanisms. The internal friction of the ball screws can be reduced by as much as 45 % by using a steel or other dissimilar material as a spacer ball between the silicon nitride balls.

As a result, there will be wear on the balls and the raceways. Additionally, a spacer ball eliminates sliding between the load-carrying elements (the spacer ball rolls), which also improves the wear rate of the mating surfaces (Fig. 15). The design results in lower lubrication requirements and higher speed capabilities (up to 150 m/min) because friction (heat) is lowered during operation. The benefits of silicon nitride balls go beyond speed, however. Lower temperatures surrounding the nut reduce warping of the screw, a further source of wear.

The benefits can significantly affect machine downtime and ball screw service life. For example, the wing flap actuator ball screws for the Boeing 777 and 737, as well as those of several Airbus models utilize silicon nitride to prevent corrosion caused by false brinelling during operation. The warranty on the Boeing design was increased from three to fifteen years of service. Today, many machine tool ball screws incorporate silicon nitride balls, allowing end-users to match the speed associated with costly linear systems.

## Hybrid bearing load capability

Direct swapping of $Si_3N_4$ balls for steel balls reduces bearing load. $Si_3N_4$ balls increase fatigue stresses in steel raceways. Reduced load capacity is due to limitations of use of steel. Larger balls reduce stress and stiffen bearings.

A constant question regarding performance of hybrid bearings is the load capacity which determines the L10-life. We have seen that the $Si_3N_4$ ball is significantly stiffer than a steel ball and that therefore the contact footprint on the raceway is much smaller. For a given load this means that the stress in the raceway at the contact footprint will be increased, and therefore the theoretical L10-life of the hybrid bearing will be reduced by 20 %. In fact, applications requiring bearings running close to maximum load (i.e., wheel bearings) show lower life time characteristics if steel balls are replaced with $Si_3N_4$ balls.

However, all experience with hybrid spindle tools gained up to now shows that failure is hardly caused by balls, since machine tool spindle bearings run clearly below maximum load conditions. If bearings have to work under higher load conditions, a mere replacement of balls will not be sufficient. In this case the raceways geometry has to be changed and if necessary,

the number of balls has to be increased as well in order to compensate for the disadvantage of higher stiffness.
Finally, the performance of a hybrid bearing depends on the quality of the material and the finishing quality of the balls. Also the other advantages help to compensate for the lifetime disadvantage, i.e. lower wear, less friction and therefore less bearing temperature, longer life of the lubricant etc.

### Fatigue failure of hybrid bearings

Normally silicon nitride balls do not fail as a result of cracking but due to spalling (pitting of the ball surface similar to steel balls). Hybrid bearings are limited owing to the fatigue and wear of the steel raceways and cages. Less than 3 % of all bearings fail as result of fatigue. This is primarily due to vast improvements in the quality of steels. Most machine tool bearings fail owing to contamination, lack of lubrication, improper lubrication, or failure from excessive heat generation. Endurance tests with spindle bearings with contact load during the test of 3 GPa have demonstrated the performance of $Si_3N_4$ balls. The contact load needed for the failure of a steel ball is about 5–7 GPa. The rupture strength of a $Si_3N_4$ balls is 4–5 times higher than that of a steel ball. The contact load necessary for the failure of a $Si_3N_4$ ball is about 25–30 GPa. Even a defective $Si_3N_4$ ball fails only from about 15 GPa.
To draw up a Weibull diagram for the rolling contact fatigue, different loads (760 ksi = 5,3 GPa) had to be chosen for M50 steel and SiAlON, as they will fail instantly at a load of 950 ksi = 6,6 GPa applied to a $Si_3N_4$ ball (Fig. 16).
In general, it can be established that the rolling contact fatigue of silicon nitride is considerably stronger than that of steel. This makes hybrid bearings a preferred bearing, especially for machine tool spindle bearings, and for a lot of applications, as they show significantly better performance: higher spindle speed, reduced vibration level of the spindle, cooler spindle operation, improved spindle run-out, simplified construction of spindle system, longer spindle life and lower spindle repair cost.

### Summary

Today hybrid spindle bearings are indispensable in more and more applications. The combination of higher stiffness, higher hardness, lower weight, superior surface finish and precision of $Si_3N_4$ balls leads to reduced heat generation and allows lower bearing and lubricant temperatures. The stiffness and lower thermal expansion, combined with the lower weight of $Si_3N_4$ balls result in bearings that are stiffer and tolerate higher speeds with less spindle vibration and noise. The electrical resistance and corrosion resistance combined with other ball attributes lead to more lubrication possibilities. All these factors lead to higher bearing speeds and longer life. Hybrid bearings with $Si_3N_4$ balls have clearly set the industrial standard for high-performance machining and high-performance applications, reduced down time and lower total operation cost.

---

## Publication Schedule 2020

| Central Themes | Issue | ED | AD | PD | Additional Circulation at Following Events |
|---|---|---|---|---|---|
| **energy and environmental technology**<br>**mechanical and chemical process engineering**<br>**bioceramic components and medical devices**<br>**electronics and sensors**<br>**wear and corrosion protection**<br>**high-temperature applications**<br>**electronic and magnetic components**<br>**coatings**<br>**additive manufacturing, CIM, metal industry, optics** | 1/2020 | **18.12.19** | **05.02.20** | **05.03.20** | **India ETC;** Gandhinagar/IN; 03.-05.03.2020 (issue 2/2019)<br>**IAPK Symposium;** Aachen/DE; 19.-20.03.2020<br>**IACE Int. Advanced Ceramics Exhibition;** Shanghai/CN; 24.-26.03.2020<br>**MedTech Europe;** Nuremberg/DE; 31.03.-02.04.2020<br>**Hannover Messe;** Hanover/DE; 20.-24.04.2020<br>**Ceramics Expo;** Cleveland/US; 05.-06.05.2020<br>**PCIM Europe**; Nuremberg/DE; 05.-07.05.2020<br>**T4M;** Stuttgart/DE; 05.-07.05.2020<br>**EPHJ–EPMT–SMT;** Geneva/CH; 16.-19.06.2020<br>**Sensor + Test;** Nuremberg/DE; 23.-25.06.2020<br>**Ceramics UK;** Coventry/GB; 08.-09.07.2020<br>**IMTS;** Chicago/US; 14.-19.09.2020<br>**AM Ceramics;** Vienna/AT; Sept. 2020<br>**POWTECH;** Nuremberg/DE; 29.09.-01.10.2020<br>**formnext;** Frankfurt/DE; 10.-13.11.2020<br>**MEDICA + COMPAMED;** Dusseldorf/DE; 16.-19.11. 2020<br>**Ceramics Expo Tokyo**; Tokyo/JP; 02.-04.12.2020 |
|  | 2/2020 | **26.06.20** | **05.08.20** | **01.09.20** |  |

ED = Editorial Deadline, AD = Advertising Deadline, PD = Publication Date

Subject to change!

*Tab. 1*
*Special materials for rolling contact bearing applications developed by hightech ceram Dr. Steinmann + Partner*

| **Properties** | **Symbols** | **Unit** | **$Si_3N_4$-Qualities** | | | **$ZrO_2$-Quality** |
|---|---|---|---|---|---|---|
| Major constituent | | $Si_3N_4$<br>MgO<br>HIPSN | $Si_3N_4$<br>$Al_2O_3$, $Y_2O_3$<br>HIPSN-1 | $Si_3N_4$<br>$Al_2O_3$, $Y_2O_3$<br>GPSN | $ZrO_2$<br>$Y_2O_3$, $Al_2O_3$<br>YPSZA | |
| Density | ρ | [g/cm³] | 3,16 | 3,21 | 3,23 | 5,50 |
| Hardness | HV10 | [kg/mm²] | 1550 | 1600 | 1490 | 1450 |
| Mean grain size | đ | [µm] | 1–7 | 1–8 | <1 | 0,4 |
| Bending strength | σ | [MPa] | >900 | >1000 | 1000 | 1200 |
| Compressive strength | σ | [MPa] | 3000 | 3000 | 3500 | 2300 |
| Young's modulus | E | [GPa] | 320 | 310 | 290 | 260 |
| Poisson number | ν | | 0,26 | 0,27 | 0,27 | 0,30 |
| Fracture toughness | $K_{Ic}$ | [MPa $m^{1/2}$] | >5,5 | >6,5 | 6 | 9,0 |
| Max application temperature | | | | | | |
| – Inert atmosphere | T | [°C] | 1300 | 1200 | 1000 | 1000 |
| – Air | T | [°C] | 1000 | 1000 | 1000 | 1000 |
| Thermal expansion coefficient | α | [$10^{-6}$ K] | 2,9 | 3,7 | 3,5 | 9,5 |
| Thermal conductivity | λ | [W/m·K] | 29 | 34 | 18 | 3 |
| Thermal shock parameter $R_1$ | Tc | [°C] | 534 | 510 | 760 | 290 |

*The data represent typical values, determined on samples. All data are based on the company's latest knowledge and are subject to change without notice. Any patent rights of third parties have to be observed.*

Below another summary in keywords of how the properties of $Si_3N_4$ balls have an impact on the improvement in ball bearings and their advantages for the users of these bearings:

1) Lighter weight →
    - decreased centrifugal force;
    - decreased gyroscopic moment;
    - reduced ball skidding;
    - less friction;
    - lower operating temperature;
    - reduced start-up and running torque;
    - lower raceway stress;
    - less wear;
    - ▸ advantages for the users of hybrid bearings: higher speed + longer life.
2) Harder and stiffer →
    - reduced ball/race contact area;
    - minimum ball deformation;
    - reduced ball skidding;
    - less friction;
    - lower operating temperature;
    - resists hard particle contamination;
    - less wear;
    - more rigid;
    - ▸ advantages: higher speed + longer life + lower noise and vibration + more accurate machining of work piece/more precise running of bearing.
3) Smoother surface and inert material →
    - decreased lube degradation;
    - no cold welding/adhesive wear;
    - less friction;
    - reduced start-up and running torque;
    - lower operating temperature;
    - less wear;
    - eliminates vibration-induced false brinelling;
    - ▸ less lube needed + simpler lube system (grease vs. oil) + greater reliability + reduced energy consumption + lower noise and vibration + higher speed + longer life.
4) Lower thermal expansion →
    - reduced contact angle change;
    - stable running pre-load;
    - minimal ball deformation;
    - lower operating temperature;
    - ▸ higher speed.
5) Corrosion and electrical resistance →
    - less wear;
    - no electrical arcing through balls;
    - harsh environment durability;
    - no ball degradation;
    - reduced raceway pitting/degradation;
    - ▸ longer life + greater reliability + expanded design possibilities.

All these features make bearings using $Si_3N_4$ balls better bearings at lower operating costs.

Originally, hybrid bearings were used where higher speeds (>1 × $10^6$ $D_mN$) had to be achieved. Today, they are used for their better reliability at lower speeds (<500 000 $D_mN$). A further reason is the falling price for balls, as the increased demand has influenced the production cost of the balls, too.

The demand for $Si_3N_4$ balls has now grown strongly worldwide, at such a speed that the lead times are now longer again, since investments have not kept pace with the rise in ball demand. After a period of consolidation and the now beginning use of gas-pressure-sintered $Si_3N_4$ balls, which are now used besides hot isostatically pressed balls, the lead times should come down with time. hightech ceram is at the vanguard, not only for $Si_3N_4$ balls, but along with partner companies for other balls from various ceramics, metals, glass, and plastics for ball bearing and non-bearing applications as well (Tab. 1).