Ceramic Bearings in Water Processing, Water Filtration and Liquid Handling

Bearings are essential mechanical components of machinery used in a variety of industries. A bearing's purpose is to help facilitate desired motion, limit undesired movement, and reduce friction. Bearings are thought to date back as far as the ancient Egyptian era, when wooden bearings were used to assist with the movement of heavy objects. Since then, the concept has developed considerably; bearings now come in a variety of forms, and are made from many different types of materials. Bearings are an essential component in the majority of mechanical designs and equipment. It is important to consider the most effective materials when designing industrial machinery, especially in applications where water, or other liquids are present. Many materials will be unable to overcome the challenges associated with operating in a wet or corrosive environment.

To overcome the challenges faced by industries involved in water processing, water filtration and liquid handling, full ceramic bearings should be used. This paper will outline the properties of full ceramic bearings, and enable you to determine whether they are the most appropriate type for your mechanical processes.

Fig. 1
Full ceramic bearing

Comparing full ceramic materials' properties

There are a number of ceramic materials that can be used to produce full ceramic bearings. While these share a number of properties, they also offer distinct characteristics, which will help to determine the most suitable material for the machinery.

Zirconia (ZrO_2)

Zirconia was first used in the 1960s. It was used in space travel, creating a thermal barrier to enable space shuttles to enter the Earth's atmosphere. It copes well with high temperatures, but doesn't handle thermal shock resistance to the same extent as alternative ceramic materials, such as silicon nitride. It's best used in high temperature environments that involve minimal loads. It's highly resistant to corrosion, which makes zirconia the perfect choice for use with highly corrosive liquids. It's an incredibly strong material, which also makes it ideal for use in mechanical applications involving fracture risk. ZrO_2 has an operating temperature range of –85 °C to 400 °C.

Keywords
zirconia, silicon nitride, alumina, silicon carbide, ceramic bearings, hybride bearings

BOCA BEARING COMPANY
1420 Neptune Dr. Suite A
Boynton Beach, FL 33426
USA

E-mail: info@bocabearings.com

Fig. 2
Various types of ceramic bearings

Silicon nitride (Si_3N_4)

Silicon nitride is a ceramic material produced using a series of chemical reactions, creating a full ceramic material with distinctive properties. The material is dark in colour, and is one of the most superior types of ceramic material in terms of quality and durability. This material is relatively expensive, but the extra cost is worthwhile as it that can withstand high temperatures and harsh mechanical conditions. In terms of withstanding high temperatures, silicon nitride is superior to alternative metallic solutions, and it has a lower thermal expansion coefficient than many alternative ceramic materials. This makes it an excellent choice when thermal shock resistance is a high priority. Si_3N_4 has an operating temperature range of –100 °C to 900 °C.

Alumina (Al_2O_3)

Alumina is the most popular ceramic ball material, and its common uses expand far beyond the realms of ceramic bearings. It's produced through the process of calcination of aluminium hydroxide, which creates a durable and highly resistant ceramic material. This material is best known for its high compression strength, and its ability to resist corrosion when faced with a variety of abrasive chemicals, even when the environment involves extremely high temperatures. Less expensive than some of the

Tab. 1
Ceramic bearing vs. steel bearing material comparison chart

Item	Si_3N_4	ZrO_2	Al_2O_3 (99,5 %)	SiC	Bearing Steel
Density [g/cm³]	3,23	6,05	3,92	3,12	7,85
Water absorption [%]	0	0	0	0	0
Coefficient of linear thermal expansion [10^{-6}/$^{-1}$]	3,2	10,5	8,5	3	12,5
Modulus of elasticity (Young's modulus) [GPa]	300	210	340	440	208
Poisson's ratio	0,26	0,3	0,22	0,17	0,3
Hardness (Hv) [MPa]	1500	1200	1650	2800	700
Flexural strength (@ R.T.) [MPa]	720	950	310	390	520 (tensile strength)
Flexural strength (700 °C) [MPa]	450	210	230	380	/
Compressive strength (@ R.T.) [MPa]	2300	2000	1800	1800	/
Fracture toughness, K_b [MPa·$m^{1/2}$]	6,2	10	4,2	3,9	25
Thermal conductivity (@ R.T.) [W/m·k]	25	2	26	120	40
Electrical resistivity (@ R.T.) [Ω·mm_2/m]	$>10^{13}$	$>10^{15}$	$>10^{16}$	$>10^{3}$	0,1~1
Max. use temperature (no loading) [°F]	1050	750	1500	1700	1700
Corrosion resistance	Excellent	Excellent	Excellent	Excellent	Poor

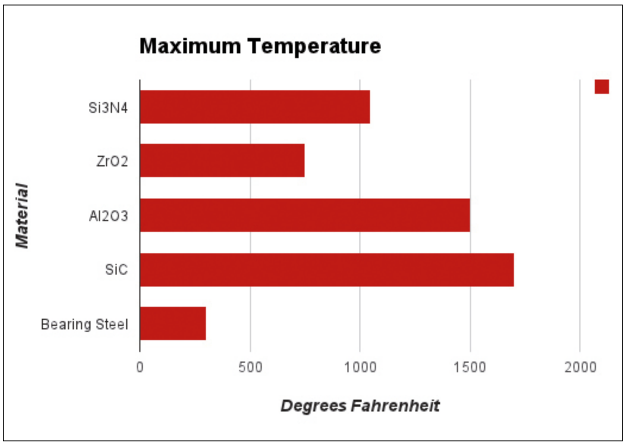

Fig. 3
Application temperature of various materials

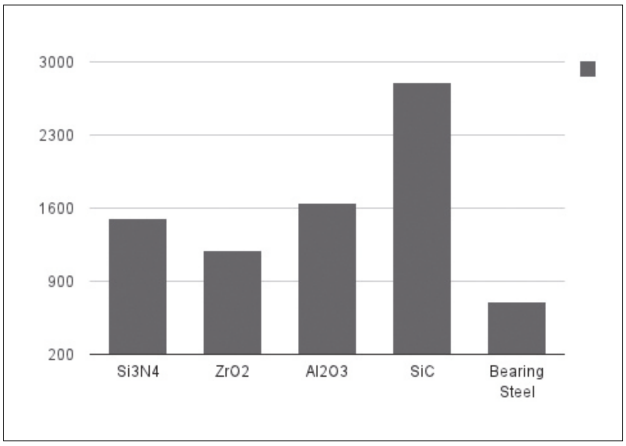

Fig. 4
Material hardness

alternative ceramic materials, aluminium oxide is readily available and is the most popular choice ceramic bearing for projects in which the available budgets are limited.

Silicon carbide (SiC)

Silicon carbide is produced by chemically combining carbon and silicon atoms. It has excellent mechanic properties, which makes it a fantastic choice for use in the creation of bearings. Grains of silicon carbide have been used for many years as an abrasive, most commonly in the form of sandpaper. However, these grains can be combined through sintering to create the highly durable ceramic material used to create silicon carbide bearings. This is a strong, durable ceramic material with a low density, low rate of thermal expansion, and fantastic thermal shock resistance, making it suitable for use in a wide variety of applications.

Ensuring extensive lifespan of bearings

Generally speaking, ceramic materials are extremely durable. Most of them are man made using chemical processes, and consequently can withstand extremely high temperatures and corrosive materials.

Full ceramic bearings have a much longer lifespan than hybrid ceramic bearings or the steel alternatives, particularly when they aren't placed under a considerable load. This can be attributed to many properties of full ceramic bearings. Firstly, ceramics are much stronger. As a result, the balls or races of the bearing do not become distorted when placed under load. However, the superiority of full ceramic material increases with the load, and full ceramic materials are still at risk of premature failure in these cases.

The main limitation of ceramic bearings is the fact they can be quite brittle. Consequently, you must analyse the load to ensure the chosen material can cope with the stress. Zirconia will handle large loads better than the rest of the full ceramic materials.

Electrical insulation with ceramic bearings

The ceramic bearings are also non-magnetic, and, with the exception of silicon carbide, provide good electrical insulation. Silicon nitride offers the best electrical resistance, but is closely followed by zirconia, which is readily available and fits within most budgets.

Improved performance of bearing in water and other liquids

Research has demonstrated that full ceramic bearings perform better than any alternatives when placed in water. Depending upon the material used, the lifespan can be up to 70 times longer than stainless steel bearings, a common alternative. The best ceramic materials for use in water processing environments are silicone nitride and zirconia. Hybrid ceramic bearings also perform better than steel, but their lifespans are significantly shorter than full ceramic materials, which in some cases have a lifespan 5 times longer.

Resistance to corrosion

It is not feasible to use metallic bearings within industries handling water or other liquids, as they will corrode rapidly. When selecting the most appropriate material for the ceramic bearings, you should also consider the types of liquids the bearing will encounter. If the bearings will be used in environments containing corrosive materials, the lifespan will be significantly altered. Silicon nitride offers good resistance to the majority of chemicals, so is often a good choice when the budget permits.

Temperature considerations

When deciding which material to use, it's important to consider the technical properties of each material to evaluate their suitability. One of the most important aspects to consider, particularly when working with liquids that may reach high temperatures, is the temperature of the environment in which you will be using the bearings.

Silicon nitride can be used in environments reaching up to 1050 °F, without loading. However, this can change significantly when used in industries handling liquids, as the bearings can encounter significant loading.

The coefficient of thermal expansion is possibly a more useful characteristic, as it provides you with an indication of the materials ability to cope in response to heating and cooling. Full ceramic bearings offer relatively low coefficients, compared to the non-ceramic alternatives. For example, silicon nitride has a coefficient of $3,2 \times 10^{-6}$ K^{-1} and silicon carbide offers 3×10^{-6} K^{-1}. Zirconia and alumina are considerably higher, at $10,5 \times 10^{-6}$ K^{-1} and $8,5 \times 10^{-6}$ K^{-1} respectively, but both of these are much lower than bearing steel, which has a coefficient of $12,5 \times 10^{-6}$ K^{-1}. In environments with considerable temper-

Tab. 2
Material properties

	Silicon Nitride		Silicon Carbide			
Grade	**RBSN**	**SSN**	**RBSC**	**SSC**	**Macor**	**Shapal - M**
Nominal composition	Si_3N_4	Si_3N_4	SiSiC	SSiC		
Density [g/cm^3]	2,50	3,25	3,10	3,12	2,52	2,9
Mechanical Properties						
Flexural strength 20 °C [MPa]	190	690	400	410	94	300
Flexural strength 800 °C [MPa]	190	450	400	410		
Compressive strength [MPa]	550	2000	2000	2000	345	1200
Modules of elasticity [GPa]	170	290	390	450	66,9	190
Poisson's ratio	0.27	0,24	0,24	0,17	0,29	0,31
Hardness [$Hv_{0,3}$]	1100	1500	3000	2800	230	390
Fracture toughness (K_{10}) [MPa$^{1/2}$]	3,0	8,0	4,0	4,0	1,53	
Thermal Properties						
Max. use temperature [°C]	1150	1150	1350	1400	800	1000
Thermal expansion coeff. [$\times 10^{-6}$/°C]	3	3	3	3	9,3	4,4
Thermal conductivity [W/m·K]	16	25	150	100	1,46	90
Thermal shock resistance [°C]	600	600	400	380	400	
Specific heat capacity [J/kg·K]	800	800	1100	1000	790	480
Electrical Properties						
Resistivity 25 °C [Ω·cm]	1010	1011	10	100		

ature changes, Silicon Nitride and Silicon Carbide are the best choices. These materials also offer good thermal shock resistance (up to 1112 °F in silicon nitride, and 752 °F in silicon carbide), which indicates minimal risk of fracture due to the changing temperatures.

Resistance to fracture under load

The material's ability to resist fracture is essential when used with liquids, such as water processing, as pressure is increased when submerged. Therefore, another characteristic that must be considered is fracture toughness. This indicates how capable the material is at resisting fractures in high-pressure environments. Zirconia offers the best resistance, with a fracture toughness of 10 MPA*m$^{1/2}$, closely followed by silicon nitride at 6,2 MPA*m$^{1/2}$. These are consequently the best materials to use in a high-pressure environment, where the risk of cracks and fractures is high.

Success story

Wild Goose Engineering is an engineering and machining company in Colorado/US. They partnered with a local brewery to develop an automated canning line specially designed for the craft beer industry. The canning system they created was not without its challenges. When you are dealing with any liquid, corrosion becomes a potential concern. Frequent washdowns and the beer itself can cause some mechanical components to corrode, gum up, or fail completely. One such issue they found was that in their can lift and seamer, the constant spray of beer was causing the bearings to go bad very quickly. Downtime is a problem in any automation process.

Wild Goose Canning turned to Boca Bearing Company for help. They were able to identify the issues with their application and were able to offer the solution in the form of full ceramic bearings for the can lift and seamer. Ceramic bearings don't need lubrication, so there was no danger of chemical contamination, and they are FDA certified, and most importantly, ceramic won't corrode if it is exposed to water, cleaning chemicals, or the beer.

Boca Bearing Company and Wild Goose Canning are helping breweries to can their beers, and keep them operating safer, longer and more efficiently, so at the end of the day, they can kick back and enjoy a cold one.

The development of mechanical equipment for use in wet environments is no easy task, and selecting the right materials is vital to ensure the success of your business. Mistakes can be expensive, so it's important to understand the properties of the available resources. When it comes to bearings, metallic or hybrid options are simply not an option if significant contact with water is expected. Instead, full ceramic materials should be used to ensure the machinery will be built to last, and will operate efficiently for the duration of its use.

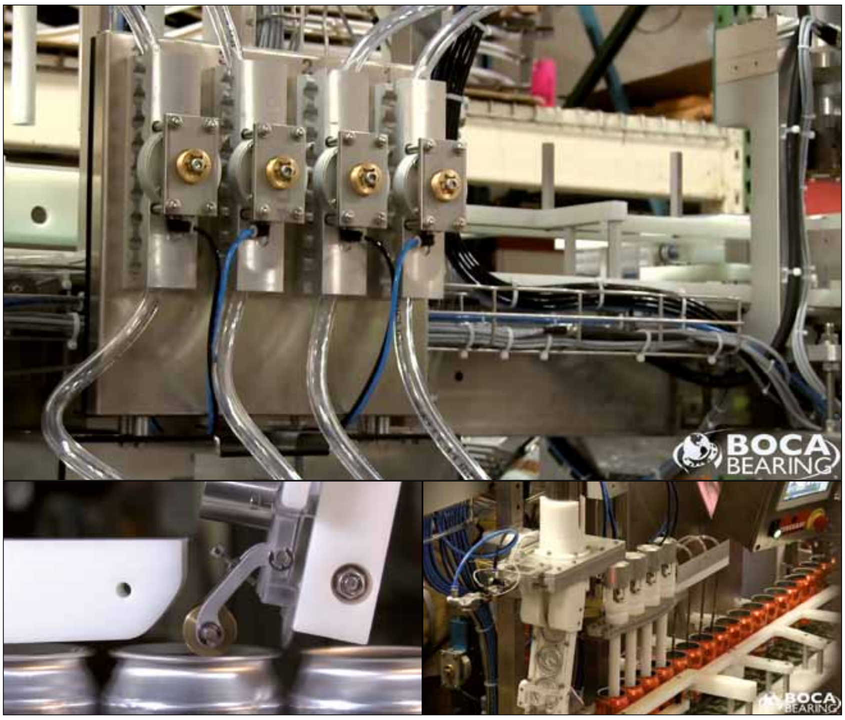

Fig. 5
Full ceramic bearings for the can lift and seamer