CeramaZirc Nano HIP – a New Generation of High-Performance Zirconia Ceramic Materials

The constant increase in demand for improved mechanical properties, reliability and resistance to aggressive environments has led to the development of a new generation of hot isostatically pressed zirconia (ZrO_2) materials with a greatly improved performance.

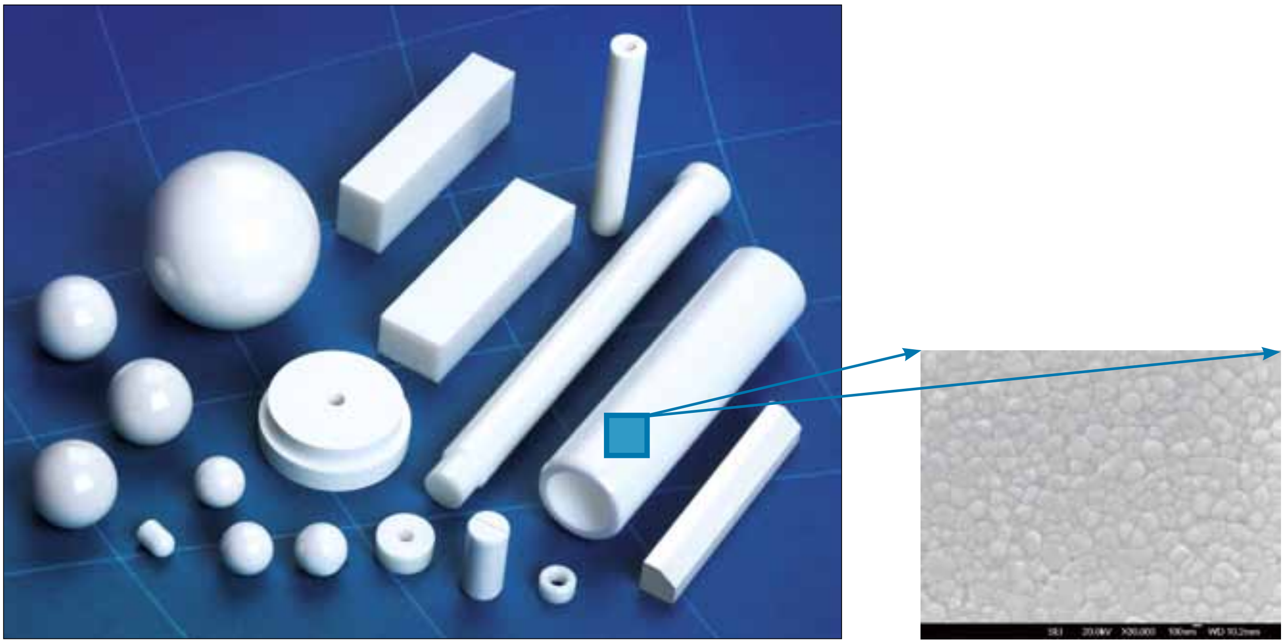

Fig. 1
CeramaZirc Nano HIP components and microstructure

With a recognised need to operate at much higher pressures, the modern pumping systems used in the oil, gas and offshore industries as well as the pharmaceutical and food and drink sectors are facing a mounting challenge in terms of material suitability. Even high-quality steel alloys can only take so much stress before they fail, however, thanks to Precision Ceramics, there is now a superior material. CeramaZirc Nano HIP is just one of the company's new portfolio of "in-house" manufactured ceramics which is set to provide a new level of reliability and performance.

Dubbed "ceramic steel" zirconia (ZrO_2) offers a unique combination of high hardness, wear and corrosion resistance while still maintaining one of the highest figures for fracture toughness amongst ceramic materials.

It sounds like the perfect solution, but even zirconia has it limits .

Keywords
nano-zirconia, hot isostatic pressing (HIP), high-pressure pumping equipment, oil and gas, high-pressure homogenisers, pharmaceutical

Technical background

While zirconia offers excellent fracture toughness, there has always been a de-

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sire to improve its wear properties which can only be achieved by increasing the hardness. Additionally, the type of zirconia that offers the best mechanical properties is stabilized with yttria. Unfortunately, in a process known as hydrothermal ageing, the mechanical properties of yttria-stabilized zirconia are significantly reduced when exposed to heat and water vapours over a prolonged period of time.

There are a few explanations for hydrothermal ageing and why it has this very negative effect on zirconia. The most accepted one is that the water molecules penetrate the surface and interact with yttria based stabilising element along the grain boundaries. Not only does this reaction reduce the ability of yttria to stabilize the crystalline structure, it also causes a martensitic phase transformation which creates a volumetric change. The end result is that when exposed to water and heat, a perfectly solid piece of zirconia will lose all mechanical properties and eventually transform into a pile of powder. Of course, time is a factor and this does not happen all at once, however, the consequences are no less catastrophic.

It is clear that grain boundaries and grain size play an important role in hydrothermal ageing. Coincidently, grain size is also directly related to materials hardness. It is well-known that a finer, or even nano-size grain structure, can increase the hardness of a material significantly.

If the grain size is kept small enough, the surface area of the grain boundaries is sufficiently reduced to mitigate the opportunity for a reaction to occur between the yttria and water. Thus, reducing the grain size improves the hardness/wear resistance and reduces the susceptibility to hydrothermal ageing. It's almost too good to be true but this is exactly what has been achieved with the development of CeramaZirc Nano HIP.

Precision Ceramics recently developed this type of high-performance zirconia specifically to address the challenge of increasing the mechanical properties, delay the onset of hydrothermal ageing and achieve full densification with very limited or even completely absent porosity with no significant increase in grain size.

Tab. 1
Technical properties of CeramaZirc Nano HIP

Properties	Values
Density [g/cm³]	6,07
Flexural strength [MPa]	1400
Compressive strength [MPa]	2100
Young's modulus [GPa]	200
Poisson ratio	0,30
Hardness $HV_{0,5}$ [GPa]	145
Fracture toughness K_{Ic}* [MPa/m²]	8
Max. use temperature [°C]	1000
Thermal expansion coefficient [$\times 10^{-6}$/°C]	10
Thermal conductivity [W/m·K]	2
Thermal shock resistance [ΔT °C]	250

*K_{Ic} toughness as measured by the indentation method

N.B. Values presented are mean values for the samples tested, and are given as an indication only for the purpose of comparing between different materials. The properties of the actual material might vary slightly, and could be affected by the shape and size of the part.

CeramaZirc Nano HIP: ultra-high performance zirconia

At the heart of this technology and indeed special manufacturing route lies the high-pressure hot isostatic pressing where pressure is employed as the main driver for densification rather than temperature. This procedure starts with very special and high-quality raw materials followed by a carefully controlled multi-step sintering schedule which results in an extremely uniform and fine grain size as it can be seen in Fig. 1. It is this very fine microstructure and full densification which is responsible for the impressive set of mechanical properties specific to CeramaZirc Nano HIP (Tab. 1).

As previously mentioned, this process is carried out entirely in-house in a brand new facility at Precision Ceramics' headquarters in Birmingham/GB. Here, a new high-temperature/high-pressure hot isostatic press has been installed and fully commissioned in addition to all the associated pressing, sintering, green machining and diamond grinding facilities necessary to produce this new range of materials.

Product portfolio

The company is already world-renowned for the engineering and machining of technical ceramics such as Tokuyama's Shapal Hi-M Soft, Corning's Macor machinable glass-ceramic and Saint Gobain's consolidated hexagonal boron nitride. High-performance ceramic manufacturing is just one of the latest additions to the company's already impressive list of capabilities.

Research and development is crucially important for Precision Ceramics with new oxide and non-oxide materials in the pipeline. After all, this is how CeramaZirc Nano HIP has been developed.

A current example which is also "a bit different" from what is regarded as conventional is a very interesting boron carbide/silicon-carbide composite material combining the strength and toughness of silicon carbide with the exceptional hardness of boron carbide. This unique combination makes the material suitable for applications where severe abrasive wear is a problem and even for ballistic protection due to reduced specific weight. This novel composite is currently in the last phase of development and due to enter the market very soon.