

An Alternative YSZ Powder for Structural Ceramic Applications

In an exciting new development for the ceramic market, Innovnano has produced an alternative to 3 mol-% yttria-stabilised zirconia (3YSZ) powder for physically demanding structural ceramics applications.

The new powder – 2 mol-% YSZ (2YSZ) – is produced using a unique synthesis method that imparts beneficial properties to the powder. Importantly, this includes a balance between two highly desired features of a structural ceramic – outstanding fracture toughness and resistance to ageing.

As a result, pressed ceramic parts formed from Innovnano 2YSZ have immediate short term benefits due to the improved toughness and wear-resistance. In addition, the parts demonstrate good results in cyclic fatigue and hydrothermal/thermal ageing tests, which has long term benefits to the user.

Structural zirconia ceramics

Pure zirconia has many interesting physical and chemical properties that make it a useful material for a variety of applications. This versatility comes as a result of its ability to exist in three different phases, each with unique properties to suit a specific use and requirement.

The transition of zirconia to its tetragonal phase occurs at temperatures above 1175 °C. Following this high temperature exposure, which is often achieved during sintering, a stabilising dopant (in this case yttria) ensures the stability of this phase in the long term and at lower temperatures.

It is the tetragonal phase of stabilised zirconia achieved through the process of sintering at high temperatures and doping that provides many of the highly sought after

Tab. 1 Properties of 2YSZ from Innovnano compared to benchmark 3YSZ

Performance	Benchmark 3YSZ	Innovnano 2YSZ
Fracture toughness [MPa·m ^{0.5}]	5	14
Flexural strength [MPa]	1200	1200
Hardness (HV10)	1250	1250
Wear-resistance [$\Delta\%$ P/P]	0,020	0,028
Cyclic fatigue resistance	50 % of static resistance	87 % of static resistance

properties required of a structural ceramic. This includes exceptional wear resistance, high component and flexural strength, and excellent durability.

The process of doping zirconia with yttria to produce yttria-stabilised zirconia (YSZ) substitutes some of the Zr⁴⁺ ions in the crystal lattice for the slightly larger Y³⁺ ions. It enables YSZ to exhibit all of the desirable properties of the zirconia tetragonal phase even after cooling, making it suitable for industrial and engineering applications under normal operating conditions.

Choosing a structural ceramic material

Different amounts of yttria can be used to stabilise zirconia in its tetragonal form, with the amount of yttria used dependent on the specific requirements of the final pressed ceramic part. In general, a lower amount of yttria correlates with an increase in fracture toughness, and so it would appear beneficial to choose a YSZ that contains less yttria for structural ceramic applications.

This enhanced fracture toughness brings with it a trade-off in the form of reduced mechanical strength and decreased ageing resistance.

However, this relationship between the amount of yttria used for stabilisation and these two important structural ceramic properties does not stand true for 2YSZ from Innovnano.

As a result of its unique synthesis process, tests have shown that this 2YSZ maintains

mechanical strength and ageing resistance values in-line with 3YSZ. The user can therefore benefit from the enhanced fracture toughness inherent to a lower yttria-content zirconia without compromising on mechanical strength or ageing resistance.

An ultra-tough alternative to 3YSZ

Tests have been conducted both in-house at Innovnano and in an independent testing facility to confirm the powder properties and ensure compliance with ISO material standards (Tab. 1).

These tests indicated that the mechanical strength of Innovnano 2YSZ remains above 1000 MPa (biaxial flexure), while fracture toughness is significantly increased from 5 to up to 14 MPa·m^{0.5} (indentation method) when compared to benchmark 3YSZ. A fracture toughness of this value corresponds to an ultra-tough material that can exceed the performance of many structural ceramic powders on the market.

Innovnano
iParque, Lote 13, Apartado 7030
3040-570 Antanhol
Portugal

E-mail: info@innovnano-materials.com
www.innovnano-materials.com

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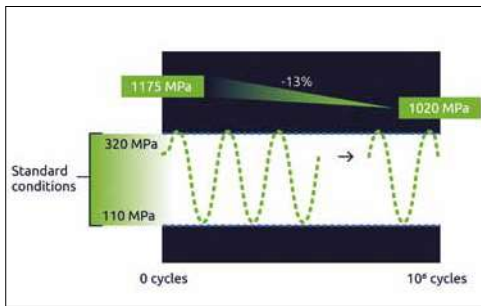


Fig. 1 Standard cyclic fatigue testing of Innovnano 2YSZ showed only a 13 % loss in flexural strength

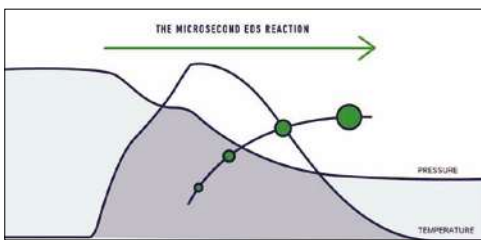


Fig. 2 Schematic representation of Emulsion Detonation Synthesis (EDS)

The wear-resistance behaviour of a pressed ceramic part is another important property for structural ceramic applications. This feature is strongly dependent on the hardness and surface finishing of the ceramic part. Wear-resistance was tested according to the standard test method for abrasion (ASTM G65), which showed Innovnano 2YSZ to have a very similar result to benchmark 3YSZ.

Combining improved mechanical properties with stability

Innovnano has conducted several ageing tests to allay any concerns about using this material due to its lower yttria content. Despite the outstanding fracture toughness

values seen in 2YSZ testing, the lower concentration of yttria inherently suggests that the material will be less stable and subject to more severe ageing effects. However, tests demonstrate that Innovnano 2YSZ powder can rival the current structural ceramic powder of choice, 3YSZ, in terms of stability. Cyclic fatigue testing according to ISO 13356 methodology was carried out to ensure that the mechanical properties of 2YSZ were suitable for applications that involve periodic load requirements. In the case of this test, 2YSZ ceramic parts were prepared by uniaxial pressing followed by cold isostatic pressing and conventional sintering. After 10^6 cycles with a load of 320 MPa (maximum) and 110 MPa (minimum) at 20 Hz frequency, only a 13 % loss in flexural strength was measured (Fig. 1). Further cyclic fatigue testing was also carried out using a hot pressed 2YSZ ceramic part. For this extreme testing, 1100 MPa was used for loading, which is almost three times the amount specified by ISO 13356. The outstanding cyclic fatigue behaviour of Innovnano 2YSZ was demonstrated by the sample resisting the load cycles, even using this much higher maximum pressure. It should also be noted that this stress loading corresponds to almost double the values achieved with benchmark 3YSZ.

In addition to cyclic fatigue behaviour, the hydrothermal ageing of Innovnano 2YSZ was also investigated according to ISO 13356:2015 methodology. 2YSZ pellets produced by uniaxial pressing and sintering were used. To fit the standard, samples must retain 80 % of their flexural strength following 5 h at 134 °C and 0,2 MPa. Innovnano 2YSZ reached and exceeded this standard, retaining 85 % of its flexural strength.

Unique synthesis method

The enhanced properties of 2YSZ are achieved through a synthesis approach termed emulsion detonation synthesis (EDS). This method is proprietary to Innovnano and is accredited with imparting the good ageing resistance that is possible in spite of low yttria content.

EDS is a defined cycle of high temperatures, pressures, and rapid quenching in a fully automated system, based on the detonation of two water-in-oil emulsions in a single-step reaction (Fig. 2). The energetic nature of EDS contributes to the stabilisation of the zirconia, a process that has been extensively tested. The resultant powders have a nanostructure (with increased specific surface area due to smaller grain sizes) to which the improved structural properties of hardness, fracture toughness, flexural strength and resistance to thermal shock are attributed. Using EDS, the purity, chemical structure, morphology and final properties of the synthesised ceramic powders can be controlled. This improves quality and consistency, as well as production capacity, to produce enhanced powders in an efficient and cost-effective way.

Summary

As a result of its unique synthesis method, 2YSZ from Innovnano combines two key structural ceramics needs. It provides a material that benefits from the fracture toughness of a low yttria-containing YSZ, as well as the phase stability of a high yttria-containing YSZ.

This combination of properties places Innovnano 2YSZ as an exciting alternative to the current structural ceramic powder of choice, providing superior fracture toughness with no loss in ageing resistance.