2YSZ – High Fracture Toughness Combined with Superior Shock Absorption

Zirconia is a versatile material with interesting physical and chemical properties. When stabilised with yttria, it is especially useful for demanding industrial applications that require high strength/wear and fracture-resistance. 3 mol-% yttria-stabilised zirconia (3YSZ) is widely used in structural ceramic applications due to its desirable mechanical properties that include high flexural strength and fracture toughness.

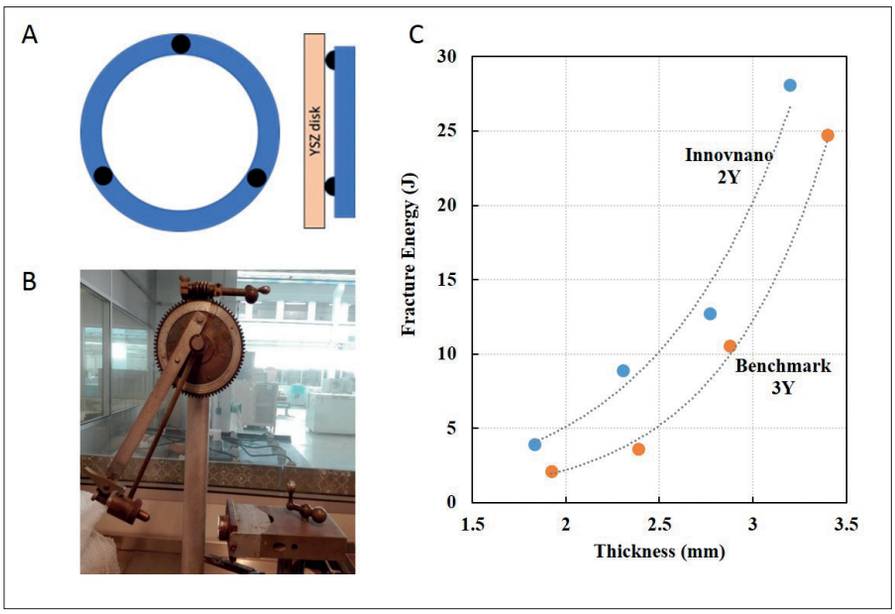

Fig. 1 Shock absorption testing of Innovnano 2YSZ and benchmark 3YSZ: a 3-point support system (A) was used and a pendulum dropped (B) to obtain fracture energy values at different thicknesses for Innovnano 2YSZ and benchmark 3YSZ (C)

An alternative for demanding structural ceramic applications

In an exciting new development for the ceramic market, Innovnano's Emulsion Detonation Synthesis (EDS) technology is able to produce an excellent alternative to 3YSZ for structural ceramic applications – 2 mol-% yttria-stabilised zirconia (2YSZ) with outstanding fracture toughness.

Maximising fracture toughness

It is well known in the industry that fracture toughness can be tailored by adjusting the stabiliser content. Generally, lowering the amount of yttria leads to increased fracture toughness. However, there is a trade-off, with lower yttria-containing powders demonstrating decreased mechanical strength and ageing resistance.

The EDS approach from Innovnano has made it possible to manufacture a higher fracture toughness structural ceramic (2YSZ) alternative to 3YSZ, without losing the mechanical strength and ageing resistance. It involves 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. 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 – to which the improved structural properties of hardness, fracture toughness, flexural strength and resistance to thermal shock are attributed.

Using EDS, Innovnano produces a 2YSZ with all the desired properties of 3YSZ, as well as the much sought-after added benefit of improved fracture toughness, inherent in lower yttria content zirconia. It offers a flexural strength >1000 MPa, with fracture toughness significantly increased from 5 to higher than 14 MPa · $m^{0,5}$ when compared with 3YSZ. It therefore provides an excellent alternative for structural ceramic applications, either as a ready-to-press powder or as the zirconia component in zirconia-toughened alumina toughened or alumina-toughened zirconia (ZTA/ATZ) and cermets.

Testing ageing resistance

Independent stability and ageing tests have been carried out to ensure the lower yttria content does not adversely affect important structural ceramic properties.

Cyclic stress-strain ageing tests in saline solution (on Innovnano 2YSZ bars that have undergone cold isostatic pressing [CIP] and conventional sintering) were carried out, with the test pieces all passing the

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Tab. 1 Properties of Innovnano 2YSZ 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 [% ΔP/P]	0,020	0,028
Cyclic fatigue resistance	50 % of static resistance	85 % of static resistance

ISO 13356 standard methodology of 1 million cycles at 320 MPa (maximum) and 20 Hz frequency, without failure.

The four-point bending strength was determined for 2YSZ bars before and after cyclic stress-strain experiment, and after 10^6 cycles under the described conditions only 13 % of flexural strength was lost.

In addition, further cyclic stress-strain ageing experiments were successfully performed (20 Hz, 10^6 cycles) using 1100 MPa as maximum pressure, highlighting the outstanding resistance of Innovnano 2YSZ powders to mechanical ageing. When compared to studies using 3YSZ in the literature, the superior performance of Innovnano 2YSZ is further demonstrated, with one study reporting that of 13 specimens tested at a maximum pressure of 650 MPa, none achieved 10^6 cycles [1]. Hydrothermal ageing was also investigated according to ISO 13356 : 2015 methodology using 2YSZ pellets produced by uniaxial pressing and sintering. To fit the standard, samples must retain 80 % of their flexural strength following 5 h at 134 °C and 0,2 MPa. Innovnano 2YSZ exceeded this standard to retain 85 % of its flexural strength.

Testing shock absorption

Shock absorption tests were carried out using Innovnano 2YSZ and benchmark 3YSZ. YSZ disks were placed in 3-point support and a pendulum dropped from a certain position (Fig. 1) to determine a fracture energy, which is the sum of the impact energies needed for disk failure.

Fig. 1 shows the experimental results obtained using samples of variable thicknesses. A better performance was observed for Innovnano 2YSZ in the assessed thickness range, with Innovnano 2YSZ demonstrating twice the energy absorption capability without failure. In other words, it is possible to produce parts from Innovnano 2YSZ that are 15 % thinner, and therefore with less material consumption, but that still demonstrate the same fracture energy as 3YSZ parts. These results are in line with literature, with a recent US patent report demonstrating that the 2YSZ studied showed impact damage at 1,75 J, while the 3YSZ showed damage at 0,85 J [2].

Summary

Using its unique synthesis method, Innovnano produces a disruptive product with outstanding potential for structural ceramics applications that uniquely combines the benefits of high fracture toughness with scale-up reliability and desirable ageing/shock absorption capabilities.

References

[1] Souza, R.C.; et al.: Performance of 3Y-TZP bioceramics under cyclic fatigue loading. Mater. Research **11** (2008) [1] 89–92

[2] US patent 2018/0079686 A1