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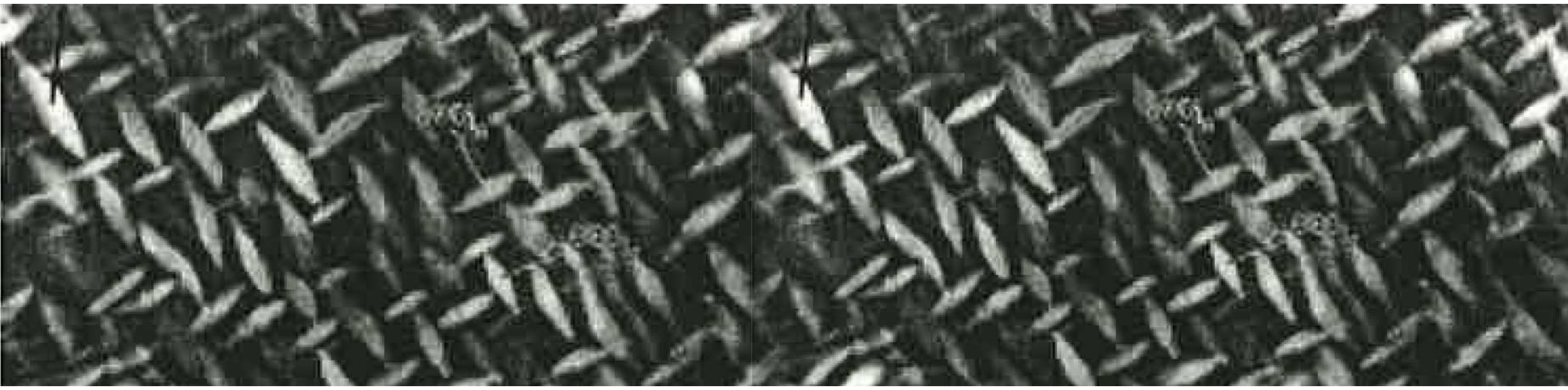
MAGNESIA STABILIZED ZIRCONIA (MSZ): WHY DOES MSZ HAVE A BETTER HIGH TEMPERATURE STRENGTH THAN YTZP?



OVERVIEW

When zirconia is doped with Yttria, it yields a fine-grained microstructure that is mostly (94% by volume) tetragonal zirconia (t-ZrO_2). While the resulting properties are outstanding at room temperatures, YTZP has been dubbed the “ceramic analogue of steel”. Due to its fine microstructure, super plastic deformation can result at higher temperatures due to grain boundary sliding. If the material is used under load and above 600C, the material may likely creep and demonstrate some form of deformation hence having poor creep resistance properties.

YTZP’s suggested use is limited to a maximum of 500C due to lack of toughening above these temperatures. As pointed out earlier, the toughening mechanism is due to the transformation of tetragonal to monoclinic crystal structure. Another undesirable property of YTZP material is the low temperature (250C range) degradation in humid environments. This is a well known and recognized application short coming of this family of materials.

It is for these reasons that Magnesia Stabilized Zirconias (MSZ’s) are beneficial at higher temperatures (above 500C) due to their higher *transformation toughening mechanism.* As seen on the phase diagram, the tetragonal transformation is over 900C and therefore Magnesia Stabilized Zirconia’s may be better suited for higher temperature (>500C) applications. The large cubic grains present may also be responsible for improved creep resistance and dimensional stability at elevated temperatures.

When Zirconia is doped with ~3.5 wt? magnesia (MgO); the resulting matrix structure is cubic; the latter is inherently more stable at high temperatures. The tetragonal “lamellae structure” precipitates within the cubic grains are due to specific heat treatment temperatures cycle. The lamellae structures are long and lens-shaped in nature within the cubic phase of Zirconia. This is where the toughening takes place and mechanical properties are enhanced.

MAGNESIA STABILIZED ZIRCONIA (MSZ)

In an earlier STC White Paper, we described how the strength and toughness of zirconia ceramics can be improved through a phenomenon known as *transformation toughening* via the addition of Yttria (Y_2O_3) within the ceramic known as YTZP. Under the influence of the stress field around a crack, the oxide particles change their crystal structure from a tetragonal to a monoclinic pattern. Because the monoclinic crystal structure is bigger by volume, this transformation makes the crystals expand, which compresses the surrounding matrix, and squeezes the crack shut.

When zirconia is doped with Yttria, it yields a fine-grained microstructure that is mostly (98%) tetragonal zirconia (T-ZrO2). While the resulting properties are outstanding at normal temperatures - YTZP has been dubbed the 'ceramic analogue of steel' - the relatively homogeneous, fine and equiaxed tetragonal grain structure is not stable at very high temperatures; grain-boundary sliding can cause superplastic deformation at high temperatures. Structural YTZPs are recommended for use below 500°C and can degrade at temperatures lower than this, particularly in the presence of moisture.

For high-temperature applications, it is therefore necessary to choose a zirconia ceramic that is not vulnerable to phase transformations at elevated temperatures; and has a more heterogeneous microstructure to protect against grain boundary sliding and the joining up of cracks.

This is why Magnesia Stabilized Zirconias (MSZ) are so useful. Whilst they benefit from the same self-sealing, transformation toughening phenomenon that strengthens YTZP, they do not have the same weakness at high temperatures, because their microstructures are much more complex.

Firstly, when zirconia is doped with ~4wt% magnesia (MgO); the resulting matrix structure is not tetragonal but cubic; the latter is inherently more stable at high temperatures. Secondly, the tetragonal zirconia crystals - which are long and lens-shaped - precipitate on the faces of this cubic matrix in an intra-granular fashion, adding strength and dissuading grain boundary sliding. Thirdly, careful aging and heat treatments allow the microstructure of MSZ to be finely tuned to improve the ceramic's thermomechanical properties.

TREATING MAGNESIA STABILIZED ZIRCONIA

The fabrication of MSZ is far more complex than YTZP because the ceramic's properties are manipulated in the post-sintering cycle. The process is called aging. The tetragonal precipitates nucleate and grow to optimize size that improves strength and thermal shock resistance.

Recent research has shown that the presence of at least five different phases in MSZ: tetragonal (t), monoclinic (m), cubic (c), orthogonal (o) and the delta phase $Mg_2Zr_5O_{12}$ (∂). It is thought that by aging the material with certain heat treatment cycles, the thermal shock resistance increases.

SPECIFICATIONS

	Property	ASTM Method	Units	MSZ (Magnesia Stabilized)
General	Crystal Size (Average)	Thin Section	Microns	30
	Color	--	--	Ivory or Yellow
	Gas Permeability	--	atms-cc/sec	gas tight $<10^{-10}$
	Water Absorption	C 20-97	%	0
Mechanical	Density	C 20-97	g/cc	5.72
	Hardness	Vickers 500 gm	GPa (kg/mm^2)	11.7 (1200)
	Hardness	--	R45N	78
	Fracture Toughness	Notched Beam	MPam$^{1/2}$	12
	Flexural Strength (MOR) (3 point) @ RT	F417-87	MPa (psi x 10^3)	620 (90)
	Tensile Strength @ RT	--	MPa (psi x 10^3)	310 (45)
	Compressive Strength @ RT	--	MPa (psi x 10^3)	1862 (270)
	Elastic Modulus	C848	GPa (psi x 10^6)	206 (29.8)
	Poisson's Ratio	C848	--	0.28
Thermal	C.T.E. 25 - 100° C	C 372-96	x 10^{-6}/C	8.9
	C.T.E. 25 - 300° C	C 372-96	x 10^{-6}/C	9.7
	C.T.E. 25 - 600° C	C 372-96	x 10^{-6}/C	10.0
	Thermal Conductivity @ RT	C 408	W/m K	3
	Max Use Temp	--	Fahrenheit (°F)	2200
		--	Celsius (°C)	1200
Electrical	Dielectric Strength (.125" Thick)	D 149-97A	V/mil	300
	Dielectric Constant @ 1 MHz	D 150-98	--	22.7
	Dielectric Constant	D 2520-95	--	29.2
	@ Gigahertz			6.2
	Dielectric Loss @ 1 MHz	D 150-98	--	0.0016
	Dielectric Loss	D 2520-95	--	0.0018
	@ Gigahertz			6.2
	Volume Resistivity, 25°C	D 257	ohms-cm	$> 1 \times 10^{13}$
	Volume Resistivity, 300° C	D 1829	ohms-cm	5×10^7
	Volume Resistivity, 500° C	D 1829	ohms-cm	1×10^7
	Volume Resistivity, 700° C	D 1829	ohms-cm	2×10^6

APPLICATIONS

MSZ materials are used in a wide range of applications such as structural, refractory, wear, forming dies, grinding and attrition devices, pump pistons and liners and many other applications where abrasion and strengths are primary properties being sought. The higher possible use temperatures of the MSZ materials further expands its application into the many challenging environments that YTZP based materials have been proven unsuitable for use.

MSZ RELATED SERVICES**

- Powder Preparation
- Forming
- Green Machining
- Firing
- Grinding and Cleaning
- Glazing / Coating
- Metalizing and Plating
- Metrology

CONTACT US

For more information call or email us. You can also learn more about our extensive capabilities at www.ceramics.net

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