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Experimental study of the thermal expansion of yttria stabilized zirconia ceramics

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Abstract

The thermal expansion behavior of zirconia ceramics from a given powder type can be "tailored" within limits by varying the chemical composition and processing variables. This provides some physical property selection capability for engineering applications. The chemical history of the powders that are used in the ceramic fabrication processes are significant. It should be expected that the physical and thermal properties will not necessarily be the same for materials from different precursors even though their chemical composition and ceramic fabrication parameters are the same

INTRODUCTION

The relatively high thermal expansion of zirconia among refractory oxide ceramics makes it a prime candidate for high temperature structural applications where metal contact is required. In order to thermally cycle zirconia through elevated temperatures while maintaining its structural integrity, it usually must be modified by the addition of a second oxide to stabilize, at least partially, the crystal structure obviating the catastrophic monoclinic–tetragonal phase transformation of unmodified zirconia.

Composition, chemical and thermal history, and other processing variables are known to have a significant effect on the properties of ceramics. This paper illustrates the effect of chemical composition and history on the thermal expansion behavior of zirconia ceramics made from commercially available yttria-modified zirconia powders.

All modified (partially through fully stabilized) powders were obtained from Magnesium Elektron, Inc. (MEI), UK. Two grades of powders with different precursors will be shown here. MEI SC16 grade powders had the yttria stabilizers already added from a chemically precipitated sulphate intermediate. The powders were already calcined and ground in the as-received state. MEI SC5 grade powders originate from a sol–gel process.

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EXPERIMENTAL

Extrusion batches of each of the as-received powders were formulated and 3/8 in. (0.95 cm) diameter bars were extruded. After drying and binder burnout, the zirconia bars were sintered in air at 1575°C for 10 h. The sintered bars were cut and ground flat and parallel to 2.000 ± 0.020 in. (5.080 ± 0.051 cm) lengths for linear thermal expansion measurements. The density was determined by the Archimedes method.

RESULTS AND DISCUSSION

The thermal expansion curves for the ceramic bars from the MEI SC16 powders modified with 2, 4, 6, 8, 10, and 12wt% Y_2O_3 are shown (Figs. 1–4, 6, 7). The curve representing MEI SC5 with 8wt% Y_2O_3 is included for comparison (Fig. 5). All compositions with 8wt% Y_2O_3 or less, show definite hysteresis, that is characteristic of the Martensitic transformation between the monoclinic and tetragonal crystalline phases which involves a considerable volume change.

A summary of the pertinent data from these curves along with the density of each ceramic bar is shown in Table 1.

For the lower Y_2O_3 content compositions, the linear thermal expansion coefficients tabulated represent the high temperature tetragonal phase and were calculated from the high temperature lines on the curves. At high Y_2O_3 content represented by the 10 and 12wt% samples, the zirconia is stabilized in the cubic phase, and no hysteresis is found. For comparison, the SC5 Y8 data are also shown. Although much different from the SC16 Y8, the same trend is observed in this higher density material from the different precursor source. A wider spread between the cooling and heating expansion coefficients is also evident.

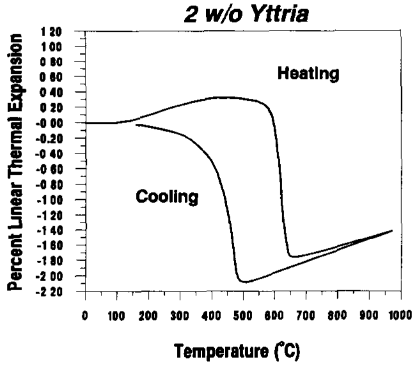


Fig. 1.

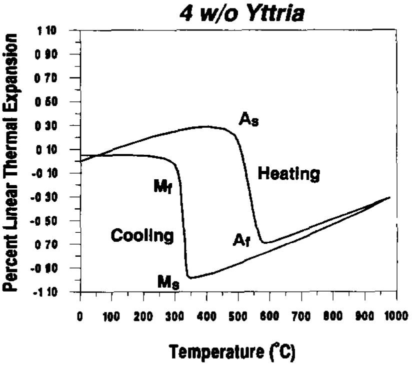


Fig. 2.

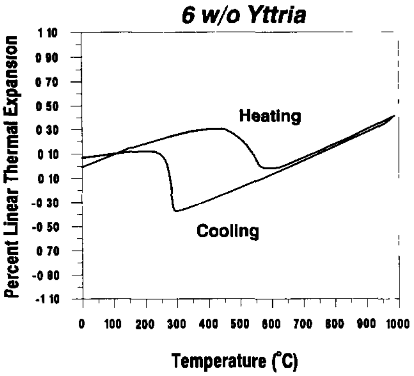
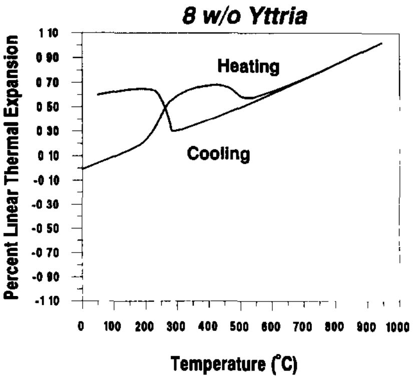


Fig 3



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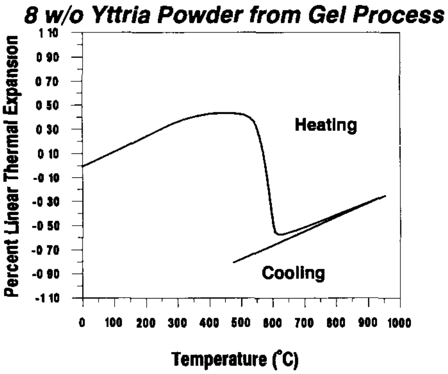

Fig 5

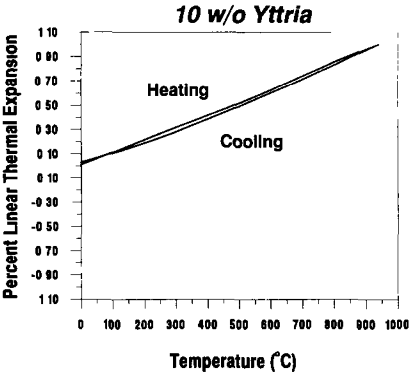

Fig. 6.

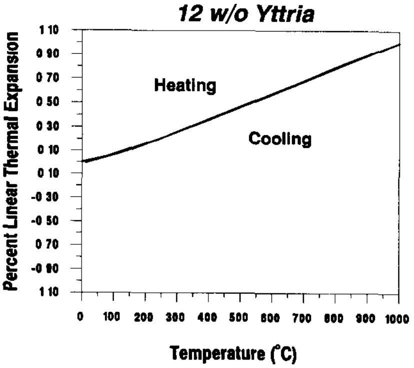

Fig 7.

TABLE 1

Data from the thermal expansion curves

Sample	Expansion coefficient ($\times 10^6$ in in^{-1} °C^{-1})		Density (g cm^{-3})	Heating		Cooling	
	Tetragonal heating	Tetragonal cooling		A_s (°C)	A_f (°C)	M_s (°C)	M_f (°C)
SC16 Y2	6.32	7.78	4.25	460	650	490	≈100
SC16 Y4	4.91	5.79	4.14	425	575	360	150
SC16 Y6	5.57	5.75	5.42	425	575	290	150
SC16 Y8	5.83	6.05	4.75	440	525	290	150
SC5 Y8	5.58	6.09	5.00	450	620		
	Cubic heating	Cubic cooling					
SC16 Y10	5.33	5.33	5.27	*	*	*	*
SC16 Y12	5.30	5.30	5.41	*	*	*	*

* Fully stabilized

The Martinsitic transformation hysteresis loop parameters are also tabulated. The A_s parameter represents the "start" or beginning temperature for the transformation from monoclinic to tetragonal zirconia upon heating. A_f represents the "final" temperature—where the transformation is complete. M_s represents the temperature where the reverse transformation (tetragonal to monoclinic) begins on cooling. M_f represents the temperature at which the transformation has been completed.

Systematic trends for the parameters are observed and are consistent. The SC5 Y8 data illustrate that chemical history is important and that chemical composition and thermal history are not sufficient to determine thermal properties.