Creep Resistance of ZrO$_2$ Ceramic Improved by the Addition of a Small Amount of Er$_2$O$_3$

Comparison of creep data of high-temperature oxides. Low creep values for Er$_2$O$_3$-doped ZrO$_2$ obtained in this study are shown as filled circles.
Nanosized precipitates in the microstructure are responsible for the improved creep resistance of ZrO$_2$. Nanosize tetragonal precipitates are visible (dark contrast) within the cubic matrix (light contrast) in the transmission electron micrograph.

Zirconia (ZrO$_2$) has great technological importance in structural, electrical, and chemical applications. It is the crucial component for state-of-the-art thermal barrier coatings and an enabling component as a solid electrolyte for solid-oxide fuel cell systems. Pure ZrO$_2$ is of limited use for industrial applications because of the phase transformations that occur. Upon the addition of “stabilizers,” cubic (c-ZrO$_2$) and tetragonal (t-ZrO$_2$) forms can be preserved. It is the stabilized and partially stabilized forms of zirconia that function as thermal barrier coatings, solid electrolytes, and oxygen sensors and that have numerous applications in the electrochemical industry. The cubic form of ZrO$_2$ is typically stabilized through Y$_2$O$_3$ additions. However, Y$_2$O$_3$-stabilized zirconia is susceptible to deformation at high temperatures (>900 °C) because of the large number of slip systems and the high oxygen diffusion rates, which result in high creep rates at high temperatures. Successful use of ZrO$_2$ at high temperatures requires that new dopant additives be found that will retain or enhance the desirable properties of cubic ZrO$_2$ and yet produce a material with lower creep rates.

At the NASA Glenn Research Center, erbium oxide (Er$_2$O$_3$) was identified as a promising dopant for improving the creep resistance of ZrO$_2$. The selection of Er$_2$O$_3$ was based on the strong interactions of point defects and dislocations. Single crystals of 5 mol% Er$_2$O$_3$-doped ZrO$_2$ rods (4 mm in diameter) and monofilaments (200 to 300 µm in diameter and 30 cm long) were grown using the laser-heated float zone technique, and their creep behavior was measured as a function of temperature. The addition of 5 mol% Er$_2$O$_3$ to single-crystal ZrO$_2$ improved its creep resistance at high temperatures by 2 to 3 orders of magnitude over state-of-the-art Y$_2$O$_3$-doped crystals. Detailed microstructural characterization of ZrO$_2$-Er$_2$O$_3$ single crystals has identified new mechanisms for improving the creep resistance of this class of materials. Adding Er$_2$O$_3$ to ZrO$_2$ results in a microstructure of stable and metastable tetragonal precipitates that with thermal treatment
evolve to a tweed structure of nanosize tetragonal lamellae. The superior high-temperature creep resistance of Er$_2$O$_3$-doped ZrO$_2$ is attributed to nanoscale precipitation hardening.

Doping with Er$_2$O$_3$ will significantly increase the upper-use temperature limit of ZrO$_2$. Potential applications include using Er$_2$O$_3$-doped ZrO$_2$ as a high-temperature fiber for structural applications and adding Er$_2$O$_3$ to reduce the sintering rates of ZrO$_2$ thermal barrier coatings. This work was conducted at Dpto. de Física de la Materia Condensada, Universidad de Sevilla, Spain, and at NASA Glenn.

References


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