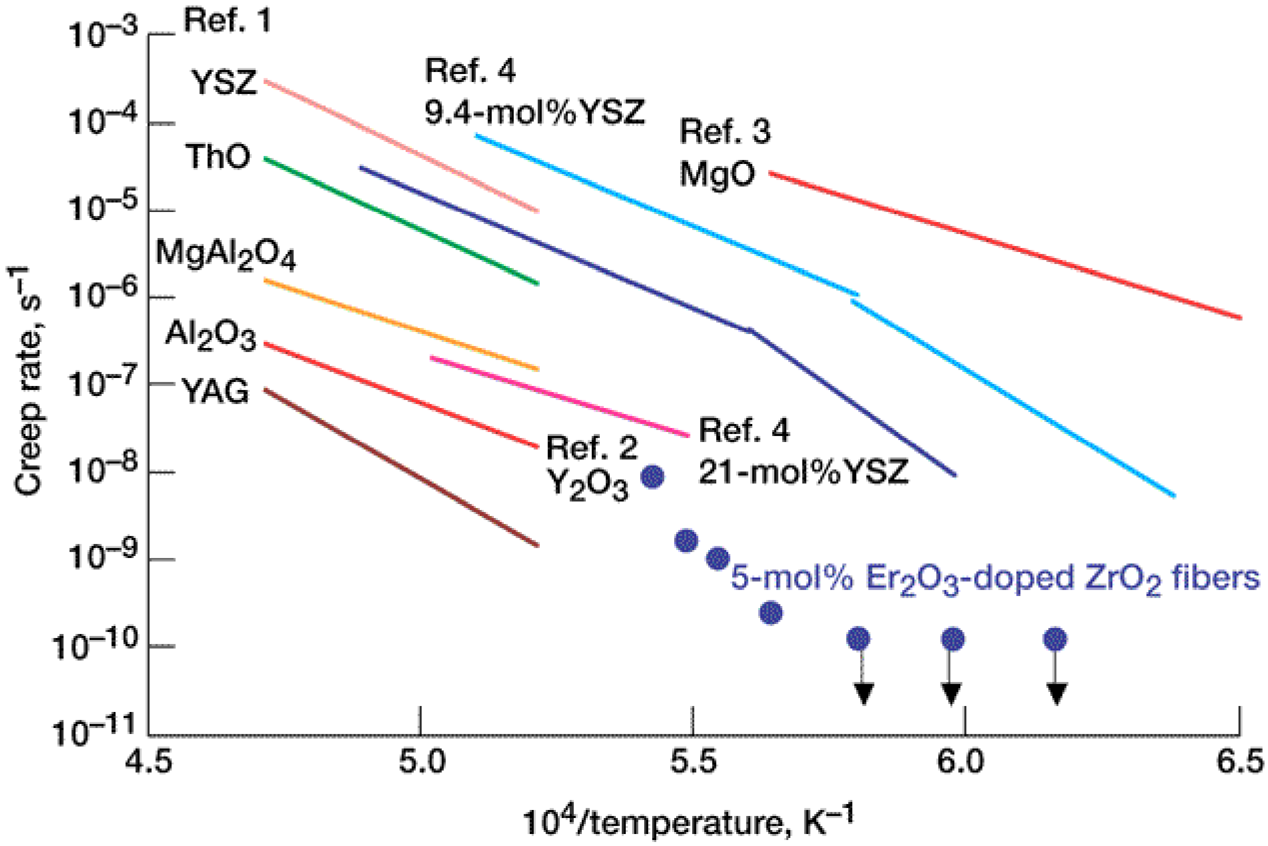
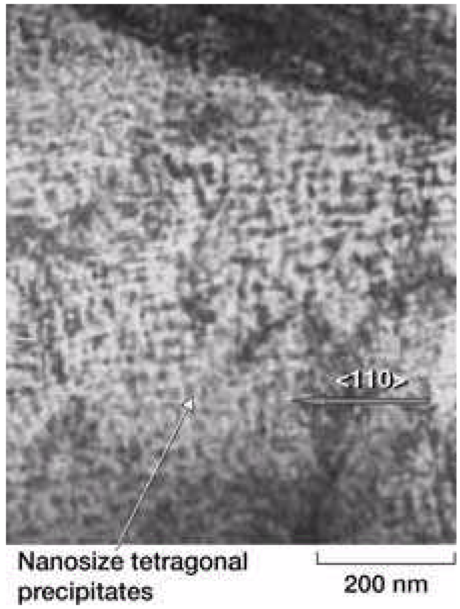
Creep Resistance of ZrO_2 Ceramic Improved by the Addition of a Small Amount of Er_2O_3



Comparison of creep data of high-temperature oxides. Low creep values for Er_2O_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_2O_3 additions. However, Y_2O_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_2O_3) was identified as a promising dopant for improving the creep resistance of. ZrO_2. The selection of Er_2O_3 was based on the strong interactions of point defects and dislocations. Single crystals of 5 mol% Er_2O_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_2O_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_2O_3-doped crystals. Detailed microstructural characterization of ZrO_2-Er_2O_3 single crystals has identified new mechanisms for improving the creep resistance of this class of materials. Adding Er_2O_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_2O_3-doped ZrO_2 is attributed to nanoscale precipitation hardening.

Doping with Er_2O_3 will significantly increase the upper-use temperature limit of ZrO_2. Potential applications include using Er_2O_3-doped ZrO_2 as a high-temperature fiber for structural applications and adding Er_2O_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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