Glenn Research Center
Cleveland, Ohio 44135

Technical Support Package

Scandia-and-Yttria-Stabilized Zirconia for Thermal Barriers

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Technical Support Package

for

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Scandia-and-Yttria-Stabilized Zirconia for Thermal Barriers

Brief Abstract

A range of compositions in the scandia, yttria stabilized zirconia system has been discovered that exhibits excellent high-temperature phase stability. Current state-of-the-art ceramic thermal-barrier coatings are made from yttria stabilized zirconia. In normal use, the yttria stabilizer serves to maintain the zirconia in the yttria-rich, so-called "non-transformable tetragonal" crystallographic phase, thus preventing transformation to the monoclinic phase with an associated deleterious volume change. However, at high enough temperatures such as 1,400 °C, there is sufficient atomic mobility that the equilibrium, transformable zirconia phase is formed. This phase transforms upon cooling to the monoclinic phase, with an associated volume change, with deleterious effect on the integrity of the coating. The new compositional region in the scandia/yttria co-stabilized zirconia system maintains the non-transformable tetragonal phase even after a severe heat treatment of 140 hours at 1,400 °C. This attribute of the material makes it a candidate for use in very-high-temperature applications.

Section I—Description of the Problem

Ceramic thermal barrier coatings (TBCs) on structural metallic substrates have enjoyed considerable success and acceptance as a workable high-temperature material in jet-engine and gas-turbine applications. These coatings have porous and microcracked structure, which can accommodate strains induced by thermal-expansion mismatch and thermal shock.

Despite the development, problems remain with the implementation of TBCs. Short coating lifetimes impair their economic attractiveness; robust ultra-high-temperature TBCs have not been developed; and TBCs can be degraded by hot corrosion. Zirconia is an attractive coating material, with its high melting point, low thermal conductivity, high reflectance, and a suitably high coefficient of thermal expansion. However, zirconia depends upon a phase-stabilizing additive to prevent transitions between the monoclinic, tetragonal, and cubic phases, with their accompanying volume changes, which would otherwise occur. The current state-of-the-art stabilized zirconia TBC relies upon an yttria stabilizer content, which is greater than that of the equilibrium tetragonal phase. The presence of this metastable, so-called "non-transformable tetragonal" phase is associated with the longest coating lifetimes and is thought to confer toughness to the coating. However at elevated temperatures (and particularly rapidly above 1,200 °C), the yttria-rich “non-transformable tetragonal” phase does in fact transform to a mixture of cubic and (transformable) equilibrium tetragonal phases. Upon cooling, the tetragonal phase transforms to the monoclinic phase, with a large volume change and generally catastrophic effect on the mechanical integrity of the coating. Thus for very-high-temperature applications the current state-of-the-art yttria-stabilized zirconia TBC is not suitable.

Recent work, undertaken in part in collaboration with Naval Research Laboratory had identified scandia as an alternate stabilizer to yttria. Scandia itself is particularly resistant to reaction with vanadium salts, and the solid solution of scandia in zirconia is also more resistant to these hot corrosion reactions than yttria-stabilized zirconia. Furthermore, dual-stabilized compositions of scandia, yttria-stabilized zirconia, (i.e., zirconia employing both scandia and yttria as stabilizers, termed SYSZ) with about 6 mole percent scandia and 1 mole percent yttria demonstrated remarkable phase stability at temperatures of 1,400 °C in simple aging tests. However, scandia is an expensive constituent and a more affordable composition is sought that is suitable for ultra-high-temperature applications..

Section II—Technical Description

A region of the scandia-yttria-zirconia composition space has been identified that shows promise as a candidate composition for ultra-high-temperature TBCs. Results from recent experiments have illustrated the region where these stabilized zirconias fully maintain their tetragonal phase even after a severe high-temperature treatment of 140 hours at 1,400.°C. Based on the currently available limited data, the locus of this favored compositional region can be described by this simple equation:

$$\text{(Mole percent yttria)} = -1.5\text{(Mole percent scandia)} + 8.55$$

between and near compositional endpoints of:

4.9 mole percent scandia and 1.2 mole percent yttria, and
3.7 mole percent scandia and 3.0 mole percent yttria.

Additionally it appears that compositions with a somewhat lower stabilizer content, in the proportions of about 3 mole percent scandia and about 2.5 mole percent yttria, may also confer the desired 1,400 °C phase stability.

By comparison, current state-of-the-art yttria stabilized zirconia materials have about 3.9 mole percent yttria. After 140 hours at 1,400 °C, followed by cooling to room temperature, a significant portion of this material exhibits the monoclinic phase (32 percent in one of our experiments). A key, significant feature of the new technology is that these synthesized and tested phase-stable compositions contain substantially less of the expensive scandia component than the previously identified composition of 6 mole percent scandia and 1 mole percent yttria, which also conferred excellent phase stability at 1,400 °C.

Section III—Unique or Novel Features

The particular combination of scandia and yttria as co-stabilizers for zirconia allows the material to retain its nontransformable tetragonal crystallographic phase even after severe thermal anneals, for example, exposures of 140 hours at 1,400 °C. This is a marked improvement over the current state-of-the-art TBC material, yttria stabilized zirconia, which exhibits a substantial degree of conversion to the monoclinic phase following a 1,400 °C anneal.

When thermal barrier coatings of this material are developed, these TBCs can replace traditional yttria stabilized zirconia TBCs in demanding high-temperature applications, such as combustor cans, nozzles, vanes, and blades. Where the need for low conductance requires current coatings to be quite thick, e.g., 2 mm, the outermost or flame-side portion of the coating that gets the hottest can be made from scandia/yttria co-stabilized zirconia. Once SYSZ coatings are shown to be durable at high temperatures, then designers of heat engines can design for higher turbine inlet temperatures with increased thermodynamic efficiency and the concomitant benefits of reduced parasitic energy loss to the blade cooling fluid.

It should be noted that engine developers need convincing evidence of the superiority and improved life cycle economics of SYSZ TBCs, not just promising phase stability data gleaned from powder. There is some limited data that show significantly increased cyclic burner rig life for scandia stabilized zirconia TBCs; thus, SYSZ TBCs exhibit great promise for commercialization as high-temperature materials.

Section IV—Potential Commercial Applications

There is significant potential for SYSZ material in high-temperature applications in aerospace and energy markets. Both plasma-sprayed and electron-beam physical vapor deposition (EBPVD) coatings of SYSZ will be of interest to engine developers and coating vendors. At the time of preparing this document, companies producing stabilized zirconia plasma spray powders for the high-temperature aerospace and energy markets included Metco and Praxair. Companies who plasma sprayed these kinds of powders to form TBCs included Engelhard and Chromalloy. Chromalloy at the time of reporting this information has been a leader in the development and commercial production of EBPVD coatings. Companies that manufactured heat engines containing ceramic-coated components in the hot sections included General Electric, ABB, Westinghouse, and Pratt & Whitney.

For further information, contact

Derek Mess, President
Cambridge Microtech, Inc.
19 Ward Street
Somerville, MA 02143