Investigation of Novel Thermal Barrier Coating Materials by Minimum Thermal Conductivity

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Abstract:

Thermal barrier coatings are used to increase the efficiency of gas turbine engines. The current thermal barrier coating is yttria-stabilized zirconia, however, other material systems with superior properties are being sought for the next generation of turbine engines. This study examines the effect of ion exchange, zirconia with hafnia, on intrinsic thermal conductivity. To achieve this goal, thermal diffusivity of the ceramic mixtures is measured with the Flashline 3000. The effects of ion combinations on the thermal diffusivity are then examined in an attempt to search for potential new thermal barrier coatings.

Introduction:

With technology rapidly advancing, there exists a growing need for materials that are applicable at elevated temperatures. Rising efficiency of gas engines and higher power-to-weight ratios mean operating temperatures are also expected to climb. Standard coatings, such as yttria-stabilized zirconia, will no longer be suitable. Thus materials with lower thermal conductivity must be sought.

Thermal barrier coatings have low thermal conductivity, which enables the minimal transfer of heat from the exterior to the superalloy's surface, significantly lowering the operating temperature. This prevents temperature related damage incurring upon the engine. As illustrated in Figure 1, the thermal barrier coating is bonded to the superalloy via bond coat. These interactions between layers create a complex system, however, in this study, only the thermal barrier coating is considered.

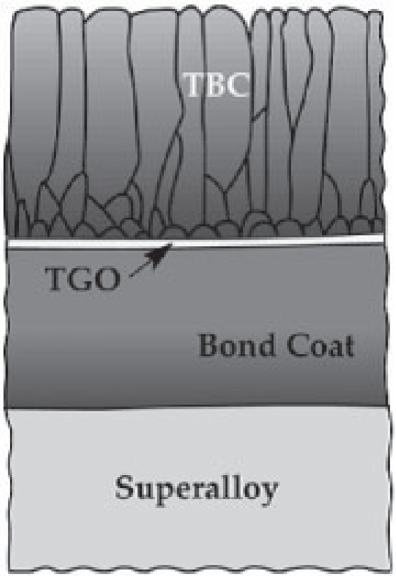

Figure 1: Schematic of a thermal barrier coating, thermally grown oxide, bond coat and superalloy.

The significance of a thermal barrier coating lies in its ability to vastly lower initial contact temperature (operating temperature) that a superalloy undergoes. This is represented by the quantified measure of thermal conductivity, which relates to the transfer of energy within a material. The experimentally measurable property of thermal diffusivity describes propagation of heat by conduction during time dependant temperature changes. A higher thermal diffusivity value indicates more rapid heat propagation, whereas thermal conductivity describes the quantity of heat that passes through the unit area (of a plate) in unit time with a temperature gradient present.

In the high temperature setting typical for thermal barrier coating operation, heat, which can be considered vibrational energy or a phonon, may be scattered by obstacles such as pores or lattice stains. Materials allowing heat to easily travel through possess high conductivity, whereas materials with low conductivity allow fewer phonons to travel. Thermal barrier coatings operate at such high temperatures that phonons travel at the nano scale, thus any scattering mechanisms must be of the atomic level.

In this study, effects of ion exchange on thermal conductivity are examined. In the past, the mixture of two ions resulted in observable change of thermal conductivity. Following this lead, for the study, the two ions, hafnia and zirconia, were chosen. While possessing equivalence in size, atomic charge, radius, and bonding, the mass of hafnia near doubles that of zirconia. Although thermal conductivity cannot be directly measured, thermal diffusivity and other values can be related. The effects of the ion exchange between the two were examined through measuring the thermal conductivity of samples with increased hafnia content.

Procedure:

Thermal conductivity is not directly measured; rather determined with use of thermal diffusivity, heat capacity, and density values. Ten pellets (zirconia to hafnia ratios: 1:8, 1:3, 1:1, 3:1, and 8:1) were batched, pressed, and sintered to theoretical density. Removing all pores ensures that any phonon scattering stems from the ion exchange. The effect of yttria content was also examined with the first set of five pellets having low yttria content and the second set having higher yittria content. This low and high yttria pairing allowed for further examination of the yttria content's effect on thermal properties. Pellets were then tested for thermal diffusivity in the Flashline 3000 with a pyroceram reference.

Results and Conclusions:

Testing produced several sets of thermograms for each sample at various temperatures. The highest, 1000°C, was of primary concern due to the high operating temperatures of gas turbine engines. The thermograms were analyzed with the Clark and Taylor method to produce thermal diffusivity values (α), indicated in Figure 2. Along with the density (ρ) and heat capacity (C_p), the relationship, $\kappa = \alpha * \rho * C_p$, produces a thermal conductivity of (κ).

The thermal diffusivity and density values have been determined. Coupled with the pyroceram reference and specimen densities, and pyroceram heat capacities, the heat capacity and resulting thermal conductivity of the specimen can be calculated.

Finding a thermal barrier coating with lower thermal conductivity than yttria-stabilized zirconia is yet to be fulfilled. Illustrated in Figure 3, the comparison of the thermal diffusivity values with increasing hafnia content at 1000°C describes issues for further investigation. Although the thermal diffusivity values do not correlate directly with thermal conductivity, compositions with 1:3 and 3:1 zirconia to hafnia ratio exhibit an interesting increase. Also noted, is that the thermal diffusivity values are comparable to the diffusivity values for yttria-stabilized zirconia, roughly 0.6 mm^2s^{-1}. This, however, does not eliminate the hafnia zirconia ion exchanged mixtures as a potential future coating, as the heat capacity values are yet to be determined.

Future Work:

With the collected thermal diffusivity values, the specific heat and thermal conductivity values are remaining to be calculated. Along with more testing, the thermal conductivity values would be ready for comparison to yttria-stabilized zirconia with the goal of creating a potential new thermal barrier coating.

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References:

[1] Clarke, D. R. and Levi, C. G. "Materials Design for the Next Generation Thermal Barrier Coatings." Annual Reviews of Materials Research: Vol. 33, 383-417 (2003).

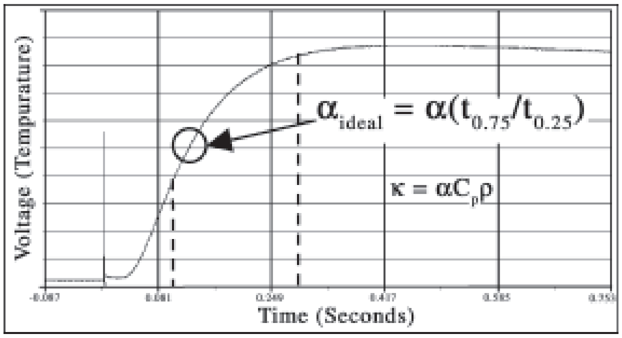

Figure 2, above: Thermal diffusivity calculation and thermogram.

Figure 3, below: Thermal diffusivity values with increasing hafnia at 1000°C.