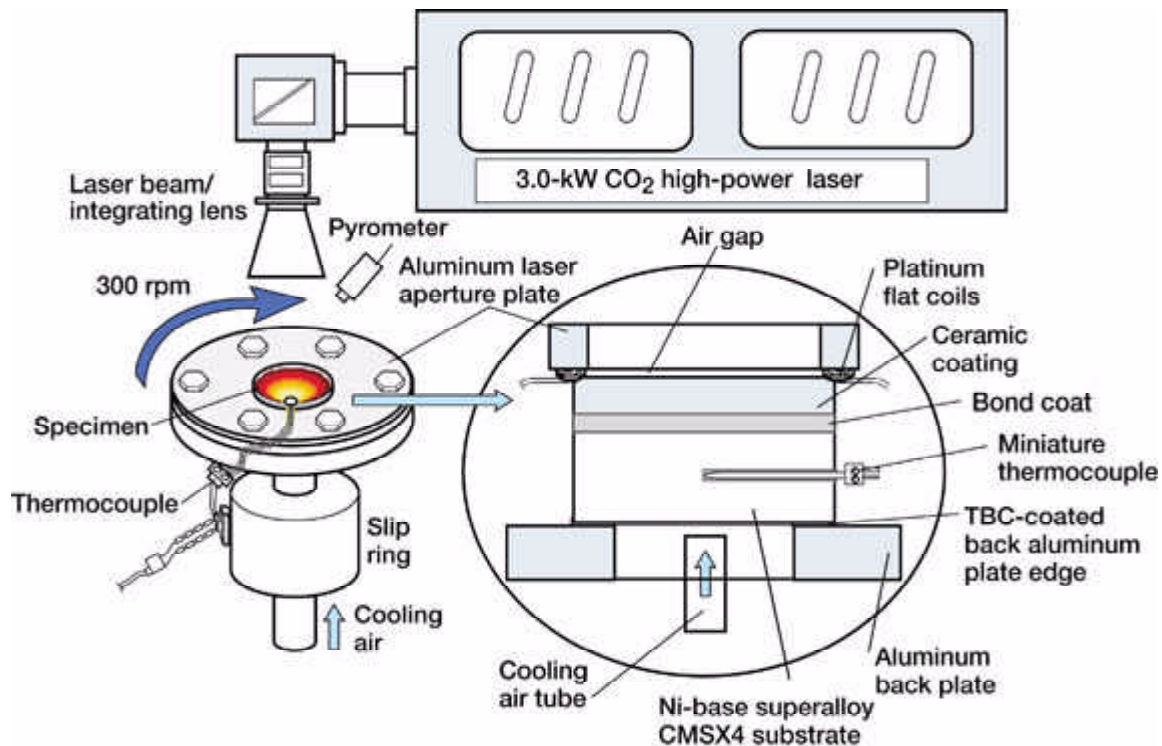# Thermal Conductivity Change Kinetics of Ceramic Thermal Barrier Coatings Determined by the Steady-State Laser Heat Flux Technique

Ceramic thermal barrier coatings (TBC's) are being developed for advanced gas turbine engine components to improve engine efficiency and reliability. However, the durability of the coating systems remains a crucial issue under the increased operating temperatures and extended hot exposure times that will be encountered in next-generation engines. The temperature-dependent change kinetics of the coating thermal conductivity are among the most important parameters required for coating design and life prediction. Increase in thermal conductivity due to ceramic sintering can reduce thermal coating insulation and increase bond coat/substrate oxidation. Therefore, the determination of the thermal conductivity change kinetics of thermal barrier coatings at high temperatures is of great importance.

Laser high heat flux rig for determining the thermal conductivity change kinetics of thermal barrier coatings. During the test, the ceramic surface and the metal backside temperatures are measured by infrared pyrometers. The metal substrate midpoint temperature can be obtained by an embedded miniature type-K thermocouple. The interfacial temperatures and the actual heat flux passing through the thermal barrier

coating system are, therefore, determined under the steady-state laser heating conditions by one-dimensional heat transfer models (ref. 1).

A steady-state laser heat flux technique has been developed at the NASA Glenn Research Center at Lewis Field to obtain critical thermal conductivity data of ceramic thermal barrier coatings under the temperature and thermal gradients that are realistically expected to be encountered in advanced engine systems (ref. 1). The preceding schematic diagram shows the laser thermal conductivity rig used in this technique. This test rig consists of a 3.0-kW CO_2 continuous-wave laser (wavelength, 10.6 µm), a motor-driven rotating test station, and temperature measurement instruments such as a thermography system and infrared pyrometers. The laser surface heating and the backside air cooling determine appropriate steady-state temperature gradients across the coating systems. An integrating ZnSe lens combined with the specimen rotation can ensure a uniform laser power distribution for the specimen heating. Overall thermal conductivity changes can, thus, be continuously monitored in real time by measuring the temperature difference across the ceramic coating.
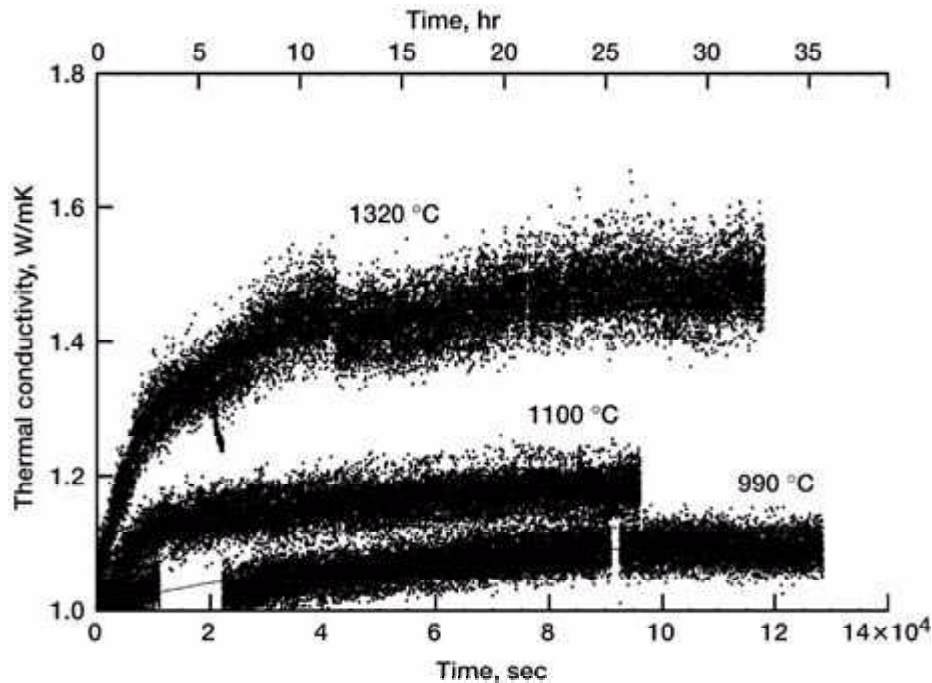
Overall thermal conductivity change kinetics of the ZrO_2-Y_2O_3 thermal barrier coating determined by real-time laser heat flux testing.

In this study, thermal conductivity change kinetics of a plasma-sprayed, 254-µm-thick ZrO_2-8 wt % Y_2O_3 ceramic coating were obtained at high temperatures. During the testing, the temperature gradients across the coating system were carefully measured by the surface and back pyrometers and an embedded miniature thermocouple in the substrate. The actual heat flux passing through the coating system was determined from the metal substrate temperature drop (measured by the embedded miniature thermocouple and the back pyrometer) combined with one-dimensional heat transfer models. The radiation heat

loss and laser absorption corrections of the ceramic coating were considered in the calculations by incorporating the coating's measured total emissivity and reflectivity. From the test results shown in the preceding graph, a significant thermal conductivity increase was observed during the laser steady-state high heat flux testing. For the ZrO_2-8 wt %Y_2O_3 coating, the overall thermal conductivity increased from an initial value of 1.0 W/m-K to 1.15, 1.19, and 1.5 W/m-K after 30 hr of testing at surface temperatures of 990, 1100, and 1320 °C, respectively. The effects of heating time and temperature on the overall ceramic thermal conductivity are approximately described by the $\ln(k)$ versus Larson-Miller relationship as shown in the following graph. The average slope of the Larson-Miller plot for the ZrO_2-Y_2O_3 coating was about 2.93×10^{-5} for the thermal barrier coating system. The increase in thermal conductivity in the thermal barrier coating systems was attributed to sintering-induced microporosity gradients under the laser-imposed high thermal gradient conditions (refs. 1 and 2). The test technique provides a viable way to obtain coating data for use in the design, development, stress modeling, and life prediction of various thermal barrier coating applications.
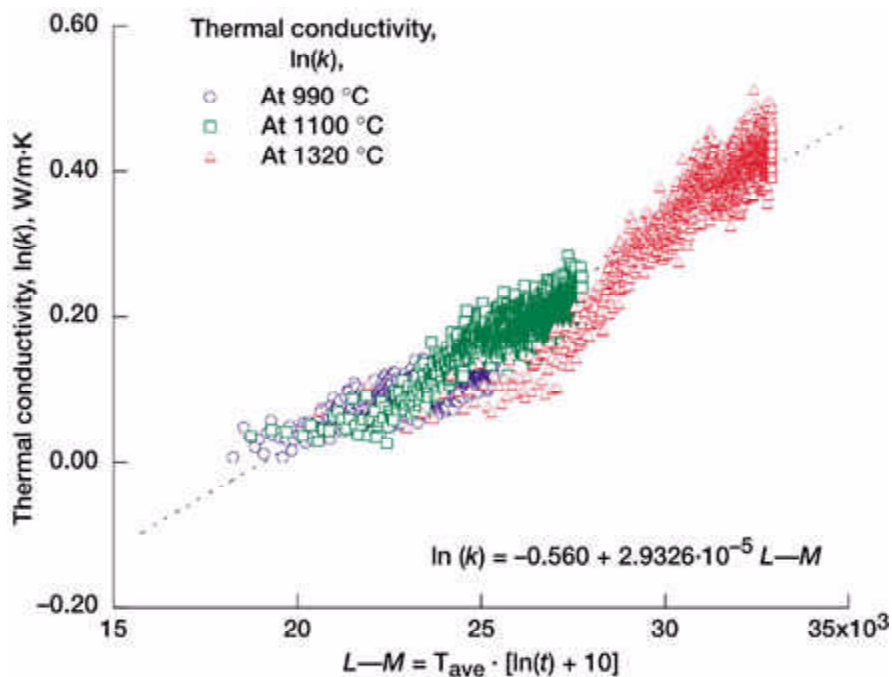
Ceramic thermal conductivity ln(k) as a function of Larson-Miller (L–M) parameter (L–M = T_{ave}[ln(t) + C], where t is the heating time in seconds, T_{ave} is the average temperature in the ceramic coating in kelvin, and C is a fitting constant that equals 10 in this study). The effects of heating time and temperature on the overall ceramic thermal conductivity are approximately described by the conductivity to Larson-Miller relationship.

References

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209069, 1999.

2. Zhu, D.; and Miller, R.A.: Determination of Creep Behavior of Thermal Barrier Coatings Under Laser Imposed High Thermal and Stress Gradient Conditions. J. Materials Res., vol. 14, no. 1, 1999, pp. 146–141.

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