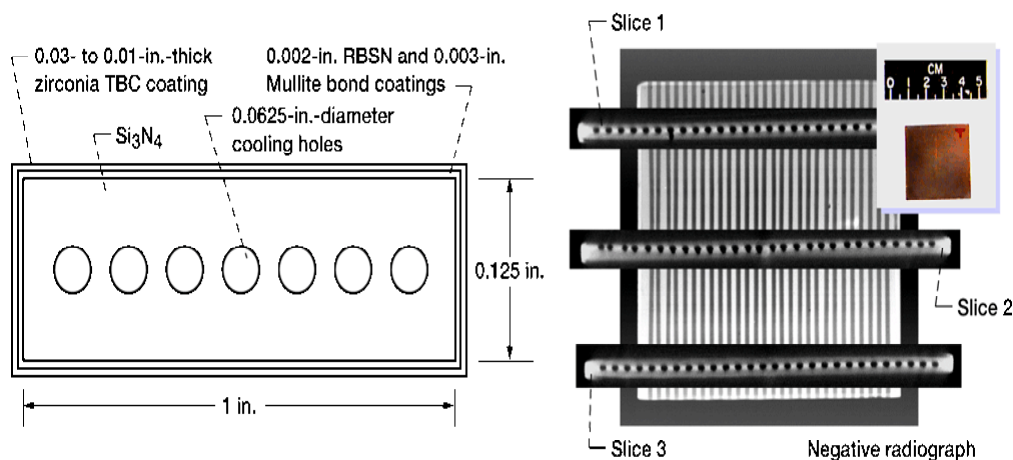


Silicon Nitride Plates for Turbine Blade Application: FEA and NDE Assessment

Engine manufacturers are continually attempting to improve the performance and the overall efficiency of internal combustion engines. The thermal efficiency is typically improved by raising the operating temperature of essential engine components in the combustion area. This reduces the heat loss to a cooling system and allows a greater portion of the heat to be used for propulsion. Further improvements can be achieved by diverting part of the air from the compressor, which would have been used in the combustor for combustion purposes, into the turbine components. Such a process is called active cooling. Increasing the operating temperature, decreasing the cooling air, or both can improve the efficiency of the engine. Furthermore, lightweight, strong, tough high-temperature materials are required to complement efficiency improvement for next-generation gas turbine engines that can operate with minimum cooling.

Because of their low-density, high-temperature strength, and thermal conductivity, ceramics are being investigated as potential materials for replacing ordinary metals that are currently used for engine hot section components. Ceramic structures can withstand higher operating temperatures and other harsh environmental factors. In addition, their low densities relative to metals helps condense component mass (ref. 1).

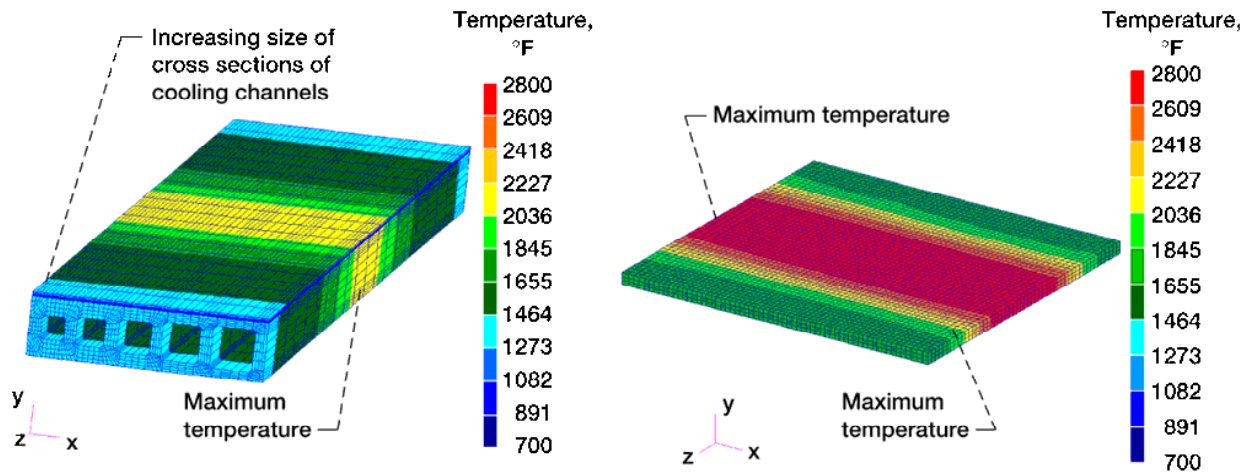
The objectives of this program at the NASA Glenn Research Center are to develop manufacturing technology, a thermal barrier coating/environmental barrier coating (TBC/EBC), and an analytical modeling capability to predict thermomechanical stresses, and to do minimal burner rig tests of silicon nitride (Si_3N_4) and SiC/SiC turbine nozzle vanes under simulated engine conditions. Furthermore, and in support of the latter objectives, an optimization exercise using finite element analysis and nondestructive evaluation (NDE) was carried out to characterize and evaluate silicon nitride plates with cooling channels.



Left: Cooling plate configuration, showing circular cooling channels. Cross section of cooled monolithic silicon nitride (Si_3N_4) plates; test specimen size, 6 by 1 by 0.125 in.

Right: Computed tomography of cooled silicon nitride plate. Location and shape of channels vary in the middle CT slice.

The preceding figure on the left shows the geometric configuration of the plate with cooling channels, illustrating the dimensions including the TBC layers layout. The figure on the right represents a typical computed tomography of the silicon nitride plate with three different cross sections of the cooling channels. The figure indicates NDE analysis, which shows uniformity and spacing of the cooling channels as well as the processing defects such as pores, cracks, and other geometric abnormalities. The following figures show temperature distributions generated via finite element analysis with the ANSYS code (ref. 2) and MSC/PATRAN (ref. 3) for two different cooling channel configurations. Convective flame impingement was imposed over one quarter of the top of the plate, while convective cooling was imposed at the bottom of the plate and inside the cooling channels (ref. 4). The temperature plots were generated under noncooling boundary conditions.



Left: Steady-state temperature distribution of cooling plate with increasing cross-section cooling channel configurations. Right: Steady-state temperature distribution experienced by the cooling plate shown in the second figure.

The results indicate that the maximum temperature is at the middle section of the plate as anticipated, and the influence of the cooling channel configuration is clearly noticed by the temperature difference exhibited between the two plates. A temperature drop of 573 °F is reported. This is due to the difference in the cooling channel configurations, which shows that cooling channel size and shape are a major factor in optimizing a desired thermal profile. Furthermore, this confirms that the material temperature is highly dependent on the cooling channel configuration and the boundary conditions applied. Additional details regarding this work can be found in reference 5.

References

1. Bhatt, Ramakrishna T., et al.: Minimally Cooled Ceramics and Fiber Reinforced Ceramic Matrix Composite Turbine Components: A Progress Report. HITEMP Review 1999, NASA/CP--1999-208915, 1999. Available from the Subsonic

- Systems Office, NASA Glenn Research Center.
2. MSC/PATRAN Graphics and Finite Element Package. Vols. I and II, The MacNeal-Schwendler Corporation, Costa Mesa, CA, 1997.
 3. ANSYS Finite Element Program. ANSYS Release 5.4. ANSYS, Inc., Canonsburg, PA, 1997.
 4. Wolf, Helmut: Heat Transfer. Harper & Row, New York, 1983.
 5. Abdul-Aziz, A.; Baaklini, G.Y.; and Bhatt, R.T.: Design Evaluation of Cooled Silicon Nitride Plates for Turbine Blade Application Using Finite Element. NASA/TM--2001-210819, 2001. <http://gltrs.grc.nasa.gov>

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