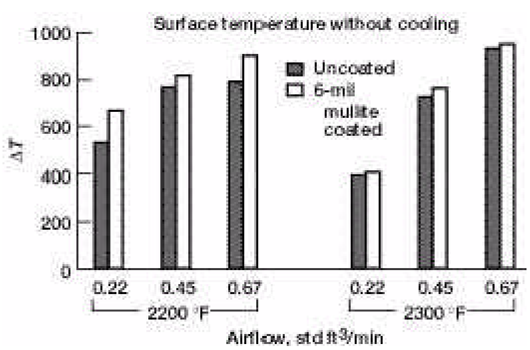
Feasibility of Actively Cooled Silicon Nitride Airfoil for Turbine Applications Demonstrated

Nickel-base superalloys currently limit gas turbine engine performance. Active cooling has extended the temperature range of service of nickel-base superalloys in current gas turbine engines, but the margin for further improvement appears modest. Therefore, significant advancements in materials technology are needed to raise turbine inlet temperatures above 2400 °F to increase engine specific thrust and operating efficiency. Because of their low density and high-temperature strength and thermal conductivity, in situ toughened silicon nitride ceramics have received a great deal of attention for cooled structures. However, the high processing costs and low impact resistance of silicon nitride ceramics have proven to be major obstacles for widespread applications. Advanced rapid prototyping technology in combination with conventional gel casting and sintering can reduce high processing costs and may offer an affordable manufacturing approach.

Researchers at the NASA Glenn Research Center, in cooperation with a local university and an aerospace company, are developing actively cooled and functionally graded ceramic structures. The objective of this program is to develop cost-effective manufacturing technology and experimental and analytical capabilities for environmentally stable, aerodynamically efficient, foreign-object-damage-resistant, in situ toughened silicon nitride turbine nozzle vanes, and to test these vanes under simulated engine conditions.



Variation of DT *(surface temperature minus maximum internal temperature) with cooling airflow for an uncoated and a thermal-barrier-coated silicon nitride plate with cooling holes.*

Starting with computer aided design (CAD) files of an airfoil and a flat plate with internal cooling passages, the permanent and removable mold components for gel casting ceramic slips were made by stereolithography and Sanders machines, respectively. The gel-cast part was dried and sintered to final shape. Several in situ toughened silicon nitride generic airfoils with internal cooling passages have been fabricated. The uncoated and thermal-barrier-coated airfoils and flat plates were burner rig tested for 30 min without and with air cooling. Without cooling, the surface temperature of the flat plate reached ~2350 °F.

With cooling, the surface temperature decreased to ~1910 °F--a drop of ~440 °F (see the figure). This preliminary study demonstrates that a near-net-shape silicon nitride airfoil can be fabricated and that silicon nitride can sustain severe thermal shock and the thermal gradients induced by cooling and, thus, is a viable candidate for cooled components.

Glenn contact: Dr. Ramakrishna T. Bhatt, 216-433-5513,
Ramakrishna.T.Bhatt@grc.nasa.gov
Author: Dr. Ramakrishna T. Bhatt
Headquarters program office: OAT
Programs/Projects: Propulsion and Power Systems R&T