Influence of Cooling Channel Geometry on the Thermal Response in Silicon Nitride Plates Studied

Engine manufacturers are continually attempting to improve the performance and efficiency of internal combustion engines. Usually they raise the operating temperature or reduce the cooling air requirement for the hot section turbine components. However, the success of these attempts depends on finding materials that are lightweight, are strong, and can withstand high temperatures. Ceramics are among the top candidate materials considered for such harsh applications. They hold low-density, high-temperature strength, and thermal conductivity, and they are undergoing investigation as potential materials for replacing nickel-base alloys and superalloys that are currently used for engine hot-section components. Ceramic structures can withstand higher operating temperatures and a harsh combustion environment. In addition, their low densities relative to metals help reduce component mass (ref. 1).

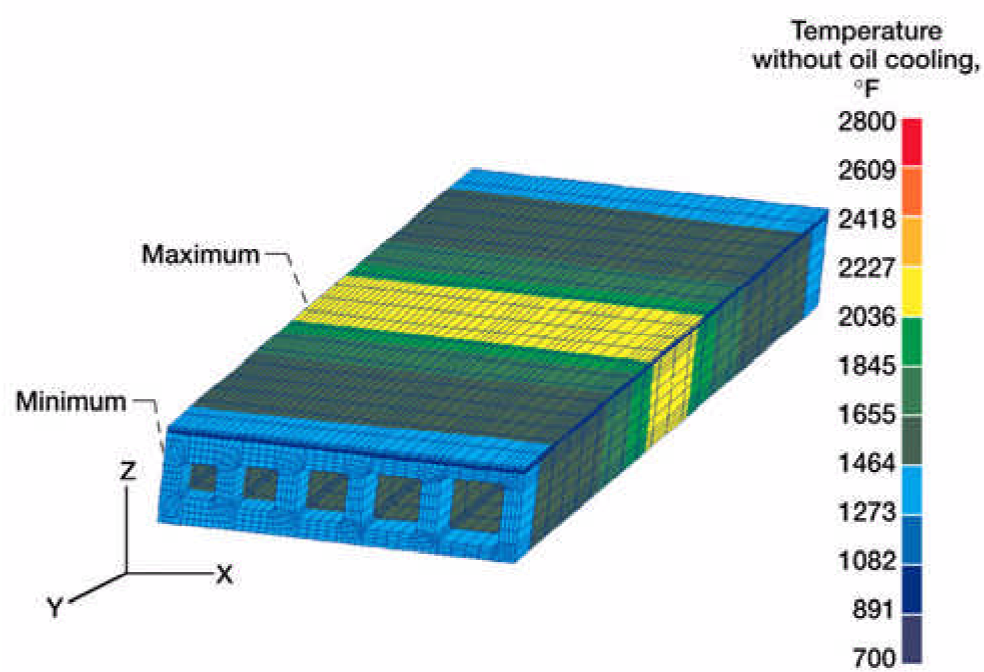
The long-term objectives of the High Temperature Propulsion Components (HOTPC) Project are to develop manufacturing technology, thermal and environmental barrier coatings (TBC/EBC), and the analytical modeling capability to predict thermomechanical stresses in minimally cooled silicon nitride turbine nozzle vanes under simulated engine conditions. Two- and three-dimensional finite element analyses with TBC were conducted at the NASA Glenn Research Center. Nondestructive evaluation was used to determine processing defects.

The study included conducting preliminary parametric analytical runs of heat transfer and stress analyses (ref. 2) under steady-state conditions to demonstrate the feasibility of using cooled Si_3N_4 parts for turbine applications. The influence of cooling-channel shapes (such as circular, square, and ascending-order cooling channels) on cooling efficiency and thermal stresses was investigated. Temperature distributions were generated for all cases considered under both cooling and no-cooling conditions, with air being the cooling medium.

The table shows the magnitude of the maximum and minimum temperature obtained for the plates under air cooling. Each channel's cross-sectional shape delivered a different temperature; however, the two-dimensional analyses for circular and square or equal-side rectangular holes produced close results. Moreover, the model of the panel with ascending-order cooling channels experienced the lowest temperature. A difference of near 260 °C was found among the three cooling-hole configurations investigated. The ascending-order cooling channels arrangement showed superior performance by attaining the lowest temperature (1077 °C) in comparison to the circular (1379 °C) and square (1343 °C) channels for the same cooling-hole size. This indicates that the panel with ascending-order cooling channels is the most suitable configuration regardless of the complexity involved in its manufacture. More details pertaining to this study are reported in reference 3.

TEMPERATURE VARIATION AS A FUNCTION OF COOLING CHANNEL CROSS SECTION WITH AIR COOLING

Cooling channel shape	Temperature, °C	
	Maximum	Minimum
Square	1344	976
Circular	1379	1068
Ascending-order cooling channels	1077	602



Typical temperature distribution of the panel with ascending-order cooling channels.

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