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Thermal Stress and Computational Fluid Dynamics Analysis of Coatings for High-Temperature Corrosion

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Abstract : Thermal barrier coatings are among the most popular methods for providing corrosion protection in high temperature applications including aircraft engine systems, external spacecraft structures, rocket chambers etc. Many different materials are available for such coatings, of which ceramics generally perform the best. Motivated by these applications, the current investigation presents detailed finite element simulations of coating stress analysis for a 3-dimensional, 3-layered model of a test sample representing a typical gas turbine component scenario. Structural steel is selected for the main inner layer, Titanium (Ti) alloy for the middle layer and Silicon Carbide (SiC) for the outermost layer. The model dimensions are 20 mm (width), 10 mm (height) and three 1mm deep layers. ANSYS software is employed to conduct three types of analysis- static structural, thermal stress analysis and also computational fluid dynamic erosion/corrosion analysis (via ANSYS FLUENT). The specified geometry which corresponds to corrosion test samples exactly is discretized using a body-sizing meshing approach, comprising mainly of tetrahedron cells. Refinements were concentrated at the connection points between the layers to shift the focus towards the static effects dissipated between them. A detailed grid independence study is conducted to confirm the accuracy of the selected mesh densities. To recreate gas turbine scenarios; in the stress analysis simulations, static loading and thermal environment conditions of up to 1000 N and 1000 degrees Kelvin are imposed. The default solver was used to set the controls for the simulation with the fixed support being set as one side of the model while subjecting the opposite side to a tabular force of 500 and 1000 Newtons. Equivalent elastic strain, total deformation, equivalent stress and strain energy were computed for all cases. Each analysis was duplicated twice to remove one of the layers each time, to allow testing of the static and thermal effects with each of the coatings. ANSYS FLUENT simulation was conducted to study the effect of corrosion on the model under similar thermal conditions. The momentum and energy equations were solved and the viscous heating option was applied to represent improved thermal physics of heat transfer between the layers of the structures. A Discrete Phase Model (DPM) in ANSYS FLUENT was employed which allows for the injection of continuous uniform air particles onto the model, thereby enabling an option for calculating the corrosion factor caused by hot air injection (particles prescribed 5 m/s velocity and 1273.15 K). Extensive visualization of results is provided. The simulations reveal interesting features associated with coating response to realistic gas turbine loading conditions including significantly different stress concentrations with different coatings.

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