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MODELING OF HEAT TRANSFER IN EXHAUST NOZZLE OF GAS TURBINES

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Thermal barrier coatings (TBCs) are applied blades, vanes, combustion chamber walls and exhaust nozzles in gas turbines in order to protect the metallic parts and to increase performance at high temperatures. In this present work, numerical steady-state exhaust nozzle heat transfer mechanisms were studied. Radiation to the external surface of coating and conduction to the coating and superalloy nozzle were modeled. The effective heat transfer coefficient was simulated. This analysis includes the CFD model of gas, coating and metal parts.

INTRODUCTION

Thermal conductivity plays an important role in heat transfer processes in gas turbines because of high turbine temperatures. The last generation hot path components of gas turbines like combustion chambers, transition pieces, turbine blades and vanes, exhaust nozzles are protected against hot gases by ceramic thermal barrier coatings. These coatings can drastically reduce the temperature by 100-300 °C of the internally cooled metallic materials, depending on coating thickness, materials, deposition technique, and pore structure [Cernuschi et al. 2004]. In current industry standard for thermal barrier coatings (TBCs) in metallic parts of gas turbines are yttria-stabilized zirconia (YSZ), deposited either by plasma spraying or physical vapour deposition (PVD) [Altun and Boke 2008]. Plasma sprayed ceramics (Fig. 1), at present, offer the lowest thermal conductivities (0.8 – 1.1 W/mK) but at the expense of surface finish, strain tolerance and erosion resistance [Raghavan et al. 1998, Zhu et al. 2001].

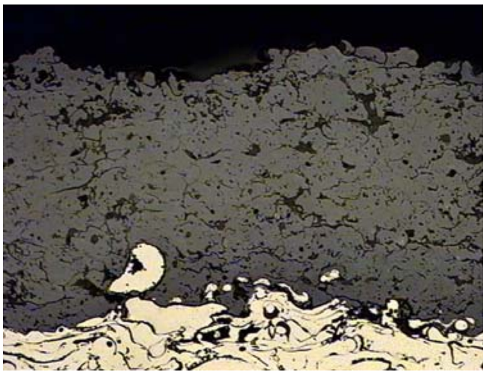

Fig. 1. A plasma sprayed TBC

The main objective of the present paper is to predict the temperature behavior of the TBC and metal component of nozzle oriented CFD code. The behavior of the TBC and metal part will be discussed.

NUMERICAL METHOD

The numerical analyses were conducted by using the commercial CFD code Fluent 6.1.22. Schematic illustration of the problem has been given in Fig. 2. The left and right boundaries of coating and metal substrate, lower and upper surface are taken symmetry boundary condition. Left and right boundaries of the gas region are taken constant temperature.

In CFD analysis, fluid regions on thermal barrier coating has been defined as air and the following acceptance have been made.

a) Steady-state conditions
b) One-dimensional heat transfer by conduction through coating and metal substrate
c) Emissive value of the coating material is taken as 0.5 [Liebert 1978, Zhu et al. 1999].

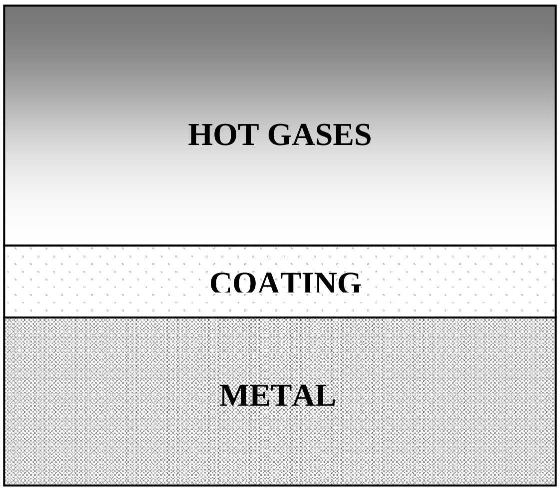

Fig. 2. Model and boundary condition of CFD analysis

There is radiation from the hot gases to the coating surface, and conduction from the coating to the metal substrate. The energy balance,

$$q''_{(con)} - q''_{(rad)} = 0 \tag{1}$$

Fluent 6.1.22 solves the heat and mass transfer problems by finite difference method based on control volume approach. This program solves the Eq. 1 for heat transfer in solid,

$$\frac{\partial}{\partial t}\rho h_d + \frac{\partial}{\partial x_i}\left(u_i \rho h_d\right) = \frac{\partial}{\partial x_i}\left(k\frac{\partial T}{\partial x_i}\right) + q'' \tag{2}$$

where ρ is density of solid, k is thermal conductivity, T is temperature and h_d is enthalpy,

$$h_d = \int_{T_{ref}}^{T} c_p dT \tag{3}$$

and q'' is the rate of energy generation per unit volume, u_i is speed area.

The radiative transfer equation Eq. (4) is solved for a discrete number of finite solid angles,

$$\frac{\partial I_i}{\partial x_i} = (absorption\ +\ emmision\ +\ scattering) \tag{4}$$

The substrate material is steel and the TBC is composed of 8 YSZ (92 wt% ZrO_2 and 8 wt% Y_2O_3). Polynomial expressions for thermal conductivity and specific heat for both substrate and TBC have been derived and taking into account for investigated temperature range:

Steel thermal conductivity (W/mK):

$$K = -116.681 + 1.0974T - 0.0037T^2 + 6.49\times10^{-06}T^3 - 6.262\times10^{-09}T^4 + 3.118\times10^{-12}T^5 - 6.351\times10^{-16}T^6$$

8YSZ thermal conductivity (W/mK):

$$K = 1.1397 + 0.0015T - 5\times10^{-06}T^2 + 8\times10^{-09}T^3 - 7\times10^{-12}T^4 + 2\times10^{-15}T^5 + 5\times10^{-19}T^6$$

Air thermal conductivity (W/mK) [Incropera 1996]**:**

$$K = -0.00219 + 0.00014T - 3.53\times10^{-07}T^2 + 1.142\times10^{-09}T^3 - 2.137\times10^{-12}T^4 + 2.149\times10^{-15}T^5 - 1.097\times10^{-18}T^6 + 2.242\times10^{-22}T^7$$

321 Stainless steel specific heat (J/kg K):

C_p = 500 J/kg K

8YSZ specific heat (J/kg K):

$$C_p = 0.6516 - 0.0027T + 1.2357\times10^{-05}T^2 - 2.4294\times10^{-08}T^3 + 2.56\times10^{-11}T^4 - 1.5041\times10^{-14}T^5 + 4.6457\times10^{-18}T^6 - 5.8813\times10^{-22}T^7$$

Air specific heat (J/kg K) [Incropera 1996]**:**

$$C_p = 1.066 - 0.00041T + 6.7327\times10^{-07}T^2 - 5.935\times10^{-10}T^3 - 1.5782\times10^{-12}T^4 + 1.032\times10^{-15}T^5 - 2.283\times10^{-19}T^6$$

REFERENCES

Cernuschi, F., Ahmaniemi, S., Vuoristo, P., Mäntylä, T. [2004], Modelling of thermal conductivity of porous materials: application to thick thermal barrier coatings, *Journal of the European Ceramic Society*, Vol. 24, pp. 2657-2667.

Altun ,O. and Boke, Y.E. [2008], The Effect of Pore Shape To The Effective Thermal Conductivity of Thermal Barrier Coatings, *ASME Summer Heat Transfer Conference*, Florida, HT2008-56171.

Raghavan, S., Wang, H., Dinwiddie, R.B., Porter, W.D., and Mayo, M.J. [1998], The Effect of Grain Size, Porosity and Yttria Content on the Thermal Conductivity of Nanocrystalline Zirconia, *Scripta Material*, Vol. 39, No. 8, pp. 1119-1125.

Zhu, D., Bansal, N.P., Lee, K.N., Miller, R.A. [2001], Thermal Conductivity of Ceramic Thermal Barrier and Environmental Barrier Coating Materials, *NASA Technical Memorandum TM-*

2001-211122.

Liebert, C.H., [1978], Emittance and Absorptance of The National Aeronautics and Space Administration Ceramic Thermal Barrier Coating, *Thin Solid Films*, Vol. 53, pp. 235-240.

Zhu, D., Miller, R.A. [1999], Thermal Conductivity and Elastic Modulus Evolution of Thermal Barrier Coatings Under High Heat Flux Conditions, *NASA Technical Memorandum TM-1999-20906*.

Incropera, F.P., and Dewitt D.P. [1996], *Introduction to Heat Transfer*, John Wiley & Sons.