Experimental and CFD erosion study of high-temperature aircraft gas turbine micro-coating behaviour
Kadir, A, Jouri, W, Habib, KA, Beg, OA and Beg, TA

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<td>Conference or Workshop Item</td>
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<td>Published Date</td>
<td>2019</td>
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High-temperature corrosion protection is a critical area in modern gas turbine engine (GTE) design. It continues to motivate extensive studies aimed at developing robust thermal barrier coatings for enhancing the protection of components from extremely corrosive working environments. Corrosive gases also induce erosion of the surface coating which may lead to spalling, crack propagation etc. In this presentation we describe recent HVOF (high velocity oxy-fuel) experiments conducted on micro-coated stainless steel samples to simulate high-temperature behaviour of gas turbine blades. The rectangular steel test sample used is 220 x 10 x 6 mm. The AISI 304 steel is used since it has excellent tolerance to high temperature with reference to oxidation and has good mechanical properties since it is known to increase the strength, efficiency and life span of the blades [1]. Results are presented for NiCrAlY as a coating material via the HVOF technique on the AISI 304 sample at 750, 800 and 900 Celsius respectively for synthetic air environments over a 100 hour duration. Additionally a comprehensive discrete phase model (DPM) CFD analysis [2] is conducted in ANSYS Fluent software via the simple algorithm for the micro-coated sample. This allows a prediction of particle erosion and recession rates can be monitored at wall boundaries. The k-epsilon turbulence model [3] is employed. Extensive visualisation of vorticity contours, erosion rate, pressure distribution and turbulent kinetic energy are shown. CFD simulations capture the surface spalling on the coating and also crack generation zones identified in the experimental results. The study provides insight into actual thermal barrier coating performance.

2. EXPERIMENTAL ASPECTS

High-velocity oxy fuel (HVOF) is a thermal spray coating technique which achieves higher density and harder coatings with less porosity, better adhesion strength, and minimum oxidation while much smaller compressive residual stresses are produced because the powder particles acquire a high kinetic energy during the spray process and the flame temperature is lower. The sample is sand-blasted and ultrasonically degreased in acetone for 15 minutes and finally cleaned with ethanol prior to coating. The bonding material (adhesive) is composed of SA (super alloy Nicaloy) and is applied on the specimen (all-surface) using a HVOF device at 3400 Celsius. This is the bond coat. Following this the sample is micro-coated with aluminium-titanium oxide coating materials (50:50 ratio) again using HVOF also at 3400 Celsius. After completion of the coating process, the resulting sample is cleaned in asin and then secured inside a Thermobrass (TG2 52-16 Satanam) in synthetic air (1 bar pressure) commencing from room temperature (20 Celsius) and heating up to 1000 Celsius at a rate of 30°C/min. During this heating process the coated sample is exposed to a circular top zone in the Thermobrass, for a period of 72 hours. Following this it is cooled again at a rate of 40 Kelvin/minute. All tests were conducted at the University of Jaume I, Castellón, Spain in September 2018.

3. THERMOGRAVIMETRIC ANALYSIS (TGA)

The rate of oxidation is a key factor influencing corrosion in high temperature gas turbine engine environments. Oxidation rate provides an approximation of the design life of the metal which will be used as a component in a specific temperature and environment. In addition it produces data and information regarding how fast the sample is losing mass and the life expectancy of the material employed under certain atmospheric and thermal conditions. High resistance of the stainless steel is in general associated with the face centered cubic oxide, Cr₂O₃. The oxidation process involves changes. There is generation and growth of a protective oxide scale on the sample, and the rate at which that happens, as well as the thickness of the scale produced is usually smooth and bonds. It does not spall, break or sustain damage. However in other cases there may be significant spallation or even fracture (crack) formation which continues to propagate.

4. DPM CFD EROSION SIMULATIONS

The CFD analysis is used to generate a representative pressure and thermal field. This grid refinement is conducted in the solver phase of the simulation to avoid altering the main mesh of the structure and avoiding distortion. The standard k-epsilon turbulence model [2] was used in this simulation to probe enough refinement in the velocity field and simultaneously avoid excessive computation times required with alternate turbulence models (e.g. RNG). When using k-epsilon turbulence we switched on to achieve more elegant results of the interfacial heat transfer between the coating surface and the corrosive hot gas. Corrosion could not be simulated. However erosion is modelled with the DPM solver. The energy equation is actuated to allow a 3-dimensional heat transfer analysis to be conducted on the classical Froude law (i.e. thermal relaxation effects are neglected). The CFD option is also mobilised to simulate hot gas injection as a continuous stream of high temperature uniform air particles normally used in gas impingement on the blade sample onto the model. This provides a facility for computing the corrosion damage induced by hot gas turbine environments. The particles were set at a speed of 5 m/s with a temperature of 1273.15 K (900 Celsius corresponding exactly to the lab. testing conditions). Boundary conditions where left unaltered with the exception of the inlet with a similar velocity condition to that of the injected particles.

5. CONCLUSIONS

Generally good prediction of surface erosion rates has been achieved with the ANSYS DPM simulations. These correlate quite well with the experimental results described earlier, in particular the same localisation of erosion in the central circular zone is computed. Furthermore the alternation in vorticity, turbulent kinetic energy and pressure distribution on the surface of the coating is correctly simulated. The next stage in the analysis is to plug a chemical corrosive gas model which can simulate the deposition of oxide layer and thereafter the corrosion-erosion coupled dynamic boundary value problem.

REFERENCES