ENHANCEMENT OF GAS TURBINE PERFORMANCE WITH REFERENCES TO THERMAL COATINGS ON BLADES

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Abstract

Most of the gas turbine performances evolving the coatings on combustion chambers because of its high temperature withstand ability improves the combustion process. As a part of this some works which is considerable for improving the performances stage wise compressor blades also coming in to consideration. Deterioration of blades also affects the total performance of the turbine, this leads to the engine performances depended on gas turbine efficiency. In order to stream line the minimum gaps occurred in long life cycles of gas turbine linked engines thermal stresses on blades also becoming a needful factor of research. A conceptual based linkage has been applied in the research that the overall performance of the engine relates with the turbine and compressor efficiencies.

Keywords: *Performance, coatings*

Introduction:

One of the most common uses of Thermal barrier coatings is in the combustion sections of turbine engines. With the demand for fuel economy and increased power, combustion temperatures are approaching the design limits of the metal alloys from which turbine components are made. The use of thermal barrier coatings in this and other application enables the use of the alloys at higher temperatures, by reducing the temperature to which the parts are exposed. With the ability of thermal spray to apply an almost limitless number of materials, well-engineered thermal barrier coatings can be produced to solve even some of the most complex thermal barrier problems. When engineering a thermal barrier coatings system, TBC uses its strong expertise in materials engineering and its strength of understanding of the processes of thermal spray. The combination of this knowledge provides application specific solutions to our customers' thermal management problems. Thermal-barrier coatings (TBCs) are refractory-oxide ceramic coatings applied to the Surfaces of metallic parts in the hottest part of gas-turbine engines

A micro gas turbine engine consists of a radial inflow turbine, a centrifugal compressor and a combustor. The micro turbine is one of the critical components in a micro gas turbine engine, since it is used for outputting power as well as for rotating the compressor. Micro turbines are becoming widespread for distributed power and combined heat and power applications. They are one of the most promising technologies for powering hybrid electric vehicles. They range from hand held units producing less than a kilowatt, to commercial sized systems that produce tens or hundreds of kilowatts. The developmental tendencies in obtaining high performance of gas turbines are chiefly connected with an increase in the engine's capacity, its efficiency, lifetime, reliability and a decrease in the fuel consumption. These may be achieved by applying high temperature inlet gases, the pressure increase, using more durable materials and enhancing the method of part manufacture. The main focus is on improving the comprehension of the construction demands and the possibilities of protecting the first stage turbine blades and vanes, together with the cooling systems, indispensable for their proper functioning. Within the last decades, a significant progress has occurred in the improvement of the mechanical properties and the structural stability of nickel and cobalt alloys applied in turbine manufacture. So far, however, the increase in the high temperature creep resistance of these materials was achieved at the expense of their oxidation and hot corrosion resistance. Those materials need to be resistant to the high temperature of the gas stream, which may have a strong oxidizing, corroding or eroding impact. The influence of the destructive environment might be incredibly complex, depending on the engine construction, its working cycle, the used fuel and its operation site.

Literature review:

Dempsey, E et al (1) many studies have demonstrated the benefits of wave rotor application in gas turbine engines. The general performance trends have been generated; however, there is a question of where the most appropriate design space is. The aim of this investigation is to answer this question by showing the generalized performance trends of several four-port wave rotor topping configurations in a multi-dimensional space. Variables include component efficiencies, pressure ratios, and temperatures. Emphasis is on the practical application of the results in industry.

Wellman, R. G et al (2) The application of thermal barrier coatings (TBCs) to components with internal cooling in the hot gas stream of gas turbine engines has facilitated a steep increase in the turbine entry temperature and the associated increase in performance and efficiency of gas turbine engines. However, TBCs are susceptible to various life limiting issues associated with their operating environment including erosion, corrosion, oxidation, sintering and foreign object damage (FOD). This is a review that examines various degradation and erosion mechanisms of TBCs, especially those produced by electron beam physical vapour deposition (EB-PVD). The results from a number of laboratory tests under various impact conditions are discussed before the different erosion and FOD mechanisms are reviewed.

Duhua Wang et al (3) Sol–gel protective coatings have shown excellent chemical stability, oxidation control and enhanced corrosion resistance for metal substrates. Further, the sol–gel method is an environmentally friendly technique of surface protection and had showed the potential for the replacement of toxic pretreatments and coatings which have traditionally been used for increasing corrosion resistance of metals. This review covers the recent developments and applications of sol–gel protective coatings on different metal substrates, such as steel, aluminum, copper, magnesium and their alloys.

Maroco Ferioli (4) formulated the interference diagram to predict the resonant behavior in rotating turbo machinery components. The natural frequency is plotted on y-axis and rotational speed is plotted on x-axis. The region where the natural frequency lines intersect the excitation frequency is the critical region.

Sadowski, T et al (5) The improvement of the temperature resistance of the aircraft engine elements can be obtained by application of a single ceramic thermal barrier coating (TBC) or several composite layers (e.g.. Engine elements protected by TBC can work safely in elevated temperature range above 1000 °C. Continuous endeavour to increase thermal resistance of engine the elements requires, apart from laboratory investigations, also numerical study of the different aero-engine parts.

Methodology:

A conventional way to assess the failure of the TBCs during TCF is identifying the time when the spallation of the top coat reaches 20%. Though the failure criterion is straightforward, the underlying mechanisms leading to failure can be significantly different. From the literature, three different failure modes are usually observed;

a) White failure,

b) Black failure,

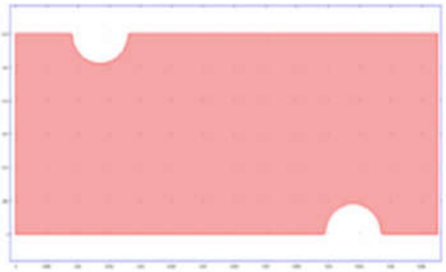
c) Mixed type failure.

White failure refers to the complete failure within the top coat, black failure refers to the failure in the TGO layer and mixed-type failure, as the name indicates, refers to failure partly in the top coat and partly in the TGO. Multiple factors could contribute to the final failure of the TBCs during thermal cycling and they are discussed below. Continuous bond coat oxidation is considered to be the most important cause of TBC failure.

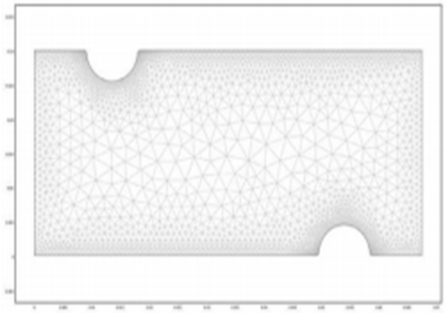
During the high temperature dwell time of TCF cycles, the bond coat is oxidized and a thermally grown oxide (TGO) layer grows at the bond coat/top coat interface. This oxide layer, typically alumina, protects the underlying bond coat and the substrate from rapid oxidation. With longer exposure times at high temperature, the thickness of the oxide layer is increased. Two types of stresses can develop in a TGO. The first one, known as TGO growth stress, is related to the conversion of the high density metal into low density oxide. The second one arises because of the mismatch in the coefficient of thermal expansion (CTE) between the bond coat and the TGO. The total residual stresses in the TGO are then the sum of the TGO growth stresses and stresses due to CTE mismatch.

The magnitude of the growth stresses for alumina at room temperature is approximately -1 GPa and they constitute roughly 30% of the total residual stresses in the TGO. Once the oxide thickness reaches a critical value (generally considered to be in the range of 6-10 μm) the oxide layer spalls off and this marks the end of the coating life. The formation of non-protective spinel oxides can accelerate TBC failure. When the bond coat is oxidized, resulting in the formation of alumina (Al_2O_3), local depletion of Al takes place. In the case of bond coats with low aluminum content this can happen in the early stages of the TCF life. Since the bond coat acts as an aluminum reservoir and promotes the continuous growth of alumina, it is important to retain a certain amount of Al which is critical to alumina formation

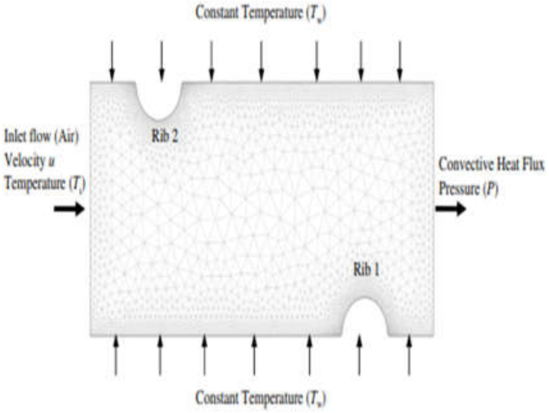
Ribs induce separation and reattachment of flow to enhance the heat transfer by creating turbulent mixing.



(a) Initial model



(b) Meshed model



(c) Model after with boundary and initial conditions

Properties of Forged steel:

Density (kg/m3) : 7850

Melting point (°C) : 1510

Thermal conductivity (W/m°C) : 50.2

Coefficient of linear expansion (µm/m/°C): 11.1

Tensile strength (MPa or N/mm2) : 200

Young's Modulus (MPa) : 3425.9

Properties of inkonel

Density (kg/m3) : 8192

Specific Gravity : 8.19

Melting Range (^{0}c) : 2500-2600°F

Yield Strength Min (MPa) : 550

EN36

Yield Strength MPa : 950

Tensile Strength MPa : 1150

Hardness HB : 340

Ultimate Strength (MPa) : 172

Numerical Issues and Boundary Conditions:

For the discretization of convective terms from the Navier Stokes equations, first and second order upwind numerical schemes are available. The limiters proposed by Barth and Jesperson are used to control the numerical discretization order, mainly for discontinuously regions, and to avoid numerical instabilities in shock regions when upwind based methods are used. The diffusion terms are discretized making the use of the shape functions. This methodology is usual in finite elements method (FEM) and has shown to be very robust for this purpose. The discretization model applied for the convective terms from Navier-Stokes equations was the second-order upwind scheme.

The boundary-conditions were set at several surfaces as described:

- At turbine NGV inlet: total pressure (Pt) = 214,145 Pa, total temperature (Tt) = 990.7 K, turbulent intensity = 5% and α = 19.18°
- At turbine rotor outlet: static pressure (Ps) = 89,891 Pa
- Rotational speed = 27,920 rpm
- Periodicity: blade-to-blade
- At walls: no-slip condition
- Inter-rows: mixing-plane approach

Specifications:

Diameter of blade mid span D = 1.3085 m,

Design speed of turbine N = 3426 rpm

Peripheral speed of rotor blade at its mid span,

U =ΠDN/60 From the velocity triangles in Fig.2, we get,

Whirl velocity Vw1 = 422.74 m/s,

Flow Velocity Vf1 = 186.89 m/s

Relative velocity, Vr1 = 265.09 m/s,

Blade angle at inlet, θ = 135.017

RESULTS AND DISCUSSIONS:

The study was performed on two different geometric models in two cases. The aim of this study is to determine the best model by observing the output results. Furthermore, the two different turbulence models were used in the study, the k-ε and the k-ω SST model.

The comparisons were done considering the temperature, the pressure, the axial velocity and the major species, CH_4, CO_2 and CO.

These properties are calculated on seven locations: mid plane, YZ, YZ1, YZ2, YZ3, YZ4 and YZ.

Mid plane is the bisector of the burner chamber. The other planes are located in the burner. To address the planes we use a dimensionless number as percent. it means how far they are from the combustion chamber entry, 0% and 100% locations are shown in the Figure A1,in the appendix section. The locations of the plane are as follows:

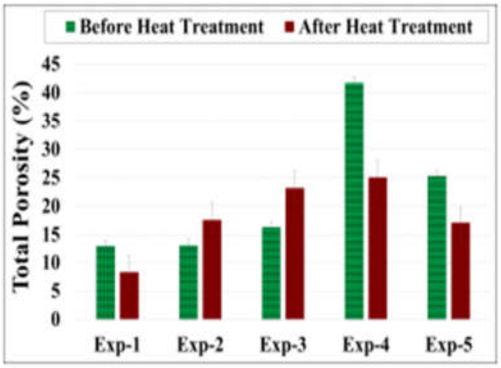
1- YZ @ 0.000%
2- YZ1 @ 3.846%
3- YZ2 @ 9.587%
4- YZ3 @ 18.197%
5- YZ 4 @ 26.808%
6- YZ 5 @ 41.159%

Micro structural Changes after Heat Treatment

A widely reported fact about plasma sprayed ceramic coatings is the closure of pores and cracks due to sintering upon prolonged exposure to high temperatures [28,39]. This can reduce the overall coating porosity compared to the as-sprayed coating. However, the YSZ coatings studied in this work showed either an increase or a reduction in porosity, depending upon the as-sprayed microstructure of the coating prior to heat treatment. As it can be seen from Figure, the coatings Exp showed a significant decrease in porosity. On the other hand, coatings Exp showed an increase in porosity.

Such increase in porosity after heat treatment is extremely unusual in case of conventional APS sprayed YSZ TBCs and rarely reported in the literature to the best of the authors' knowledge. From the results (plotted in Figure 3), the increase in porosity in case of Exp can be seen clearly and such a finding has been reported in literature for SPS TBCs as well. The above porosity increase has been attributed to pore coarsening in case of SPS TBCs. Exner et al. explained the pore coarsening effect in case of several powder compacts during solid state sintering by saying that the pore coarsening can be caused by localized transport of atoms/molecules due to diffusion and or bulk particle rearrangement.

Hence, apart from the anticipated microstructural change caused by sintering, the possibility of pore coarsening that might take place in certain conditions and be responsible for increase in the total porosity as noted in coatings Exp, should also be borne in mind to explain the results observed. It should be noted that as defined earlier pore coarsening is both coalescence of pores and or widening of inter-columnar spacing.

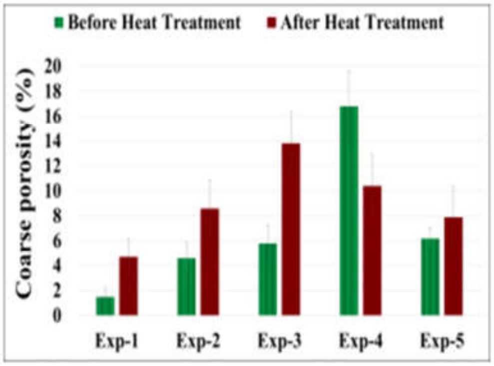


Graph Total Porosity content in % area for all five coatings before and after heat treatment

In order to get a better insight into the influence of long term exposure to high temperature during heat treatment on the coating microstructure, it is educative to separately study the variations in coarse porosity (examined at 500×) and fine porosity (examined at 10000×). The so called "pore coarsening" effect was more specifically observed when only the coarse porosity captured at the lower magnification was considered which is depicted in Figure. It was noticed that all coatings, except Exp (as shown in Figure), revealed an increase in the coarse porosity after heat treatment. This can be primarily attributed to widening or opening up of the cracks or the inter-columnar spaces as clearly visible in Figure in case of Exp.

Such widening of inter-columnar spacing was also observed in literature for EBPVD coatings which was reported to be occurring due to the thermal expansion mismatch between the coating and the substrate (especially when higher thermal expansion coefficient for substrate than the coating was noticed). Exp coating as introduced above did not show as significant change as Exp or others in the inter-columnar spacing after heat treatment, which can be seen from Figure.

In fact, the figure shows a decrease in coarse porosity within the column. This could be the reason that the coating Exp shows an overall decrease in the coarse porosity. It should be noted that, although the micrographs shown in Figure before and after heat treatment are not exactly from the same location, the two metallographic samples were prepared from coupons cut from the same specimen with one of them being subjected to heat treatment. Thus, the above observation is representative and also further ensured by the fact that the data in Figure is an over aged outcome of observations made on 25 separate images.



Graph coarse porosity content in % area for all coatings before and after heat treatment

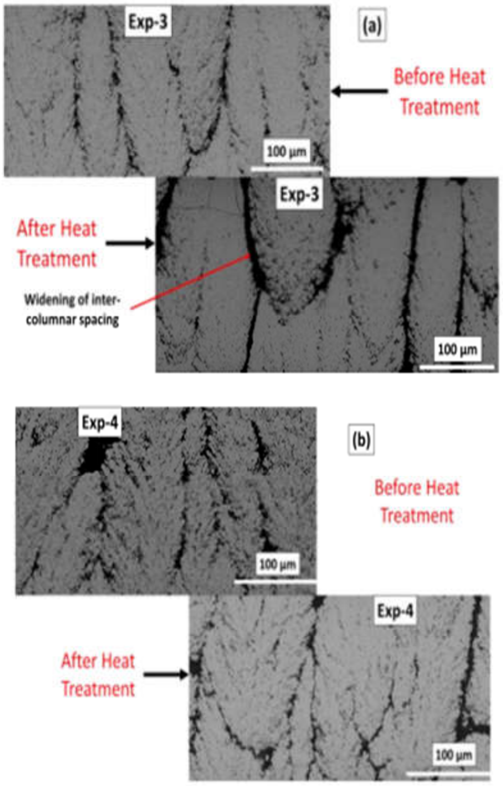


Figure SEM micrograph of the cross-section of coating Exp-3 (a) at lower magnification showing the coarse porosity before (up) and after (down) heat treatment confirming the pore coarsening (widening of inter-columnar spacing)

Conclusion:

For the thermodynamic analysis, the model is an important step forward among other studies, as it uses the second law of thermodynamic in order to identify and quantify the thermodynamic losses in the plant operation. Also, it considers a different mass flow rate though the compressor (just air) and the gas turbine (burned gases), the difference being equal to the mass flow rate of the fuel. This analysis shows that the augmentation of turbine inlet temperature is possible either using coated blades or cooling the elements of first two turbine stages.

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