A Review Paper on Thermal Barrier Coatings (TBC) to Improve the Efficiency of Gas Turbine

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Abstract— Gas Turbine are widely used for aircraft propulsion. To increase the efficiency of gas turbine inlet Temperature should be high as possible. The turbine inlet temperature in modern gas turbines are far above the permissible metal temperature. This in turn increases thermal loading to the blade leading to high temperature and thus considered one of the primary sources of blade failure. So that thermal barrier coatings are need to improve for insulation. The TBC must provide significant thermal insulation at the external surface of the turbine blade. for a given Superalloy substrate, the coating performance is dependent upon the type of bond coat. Conversely, for a given bond coat, the performance becomes a function of the Superalloy composition used in the application. To achieve the best TBC performance for a given application, it is important to select the bond coat/superalloy combination as a composite system rather than as separate entities. so by applying TBC efficiency of the gas turbine increase and also the life of the turbine blade also increase.

Key words: Thermal Barrier Coatings (TBC), Bond Coat, Super Alloy, Failure

I. INTRODUCTION

A. *Gas Turbine*

In a Gas Turbine Engine, a single turbine section is made up of a disk or hub on which all the blades are attached. This turbine section is directly connected to the compressor section via disc or shaft. That holds many turbine blades. That compressor section can either be axial or centrifugal depending upon type of application. Air is directly taken from atmosphere this air is compressed to high pressure and temperature. So that this high temperature and pressure air directly goes into the combustion chamber where the supply of fuel take place and with the help of fuel this air gets more high temperature and pressure. This high temperature and pressure air is directly thrown into the turbine section where we can get the output work from the turbine. In turbine section all the energy from hot gases is taken away and reduce the temperature and pressure of the gases .this low pressure and temperature gases exhausted into atmosphere.[1]

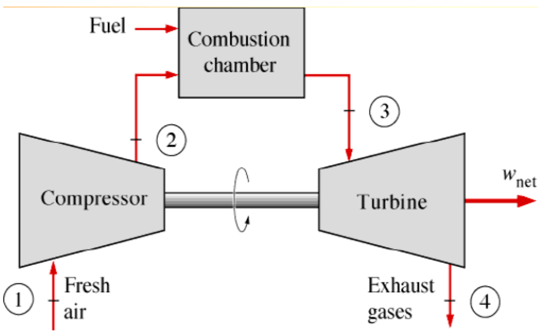

Fig. 1: Simple Open Cycle Gas Turbine

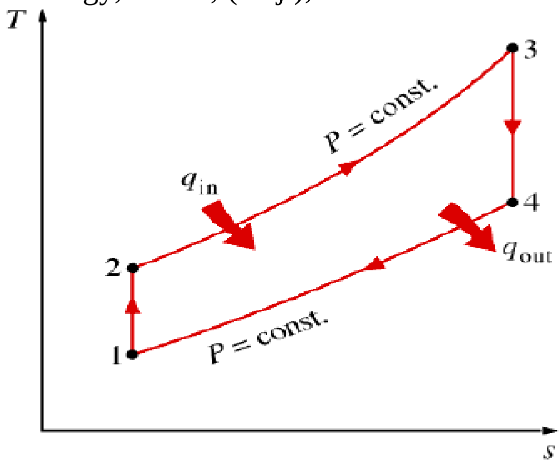

Fig. 2: T-s diagram of gas turbine

Gas turbine efficiency mainly depends upon compression ratio, compressor inlet temperature, and turbine inlet temperature .as compression ratio is increase efficiency increase but at higher compression ratio efficiency remains constant .so we have to obtain optimum compression ratio. Compressor inlet temperature we can't lower temperature beyond atmospheric condition .so efficiency mainly depends on turbine inlet temperature (TET).as we are going to increase turbine inlet temperature efficiency increase.[2]

B. *Methods to Improve Gas Turbine Efficiency*

- Regeneration
  Regeneration involves the installation of heat exchanger through which turbine exhaust gases pass. the compressed air is then heated in the exhaust gas heat exchanger before the flow enters the heat exchanger.
  This can increase the efficiency upto 5-6%.
- Reheat
  The output of turbine can be increased by increasing enthalpy of gases entering the lower stages of turbine .this is achieved by expanding the gases in two stages with reheater between the stages.
  This can increase efficiency by 1-3%.
- Inter cooling
  Inter cooling means the removal of heat from compressed air between the stages of compression so that work input in compression is reduced.
- Cooling of turbine blade
  Cooling of turbine blade means cool the turbine blade by using air & liquid cooling.
- Coating of turbine blade
  Coat the blade by different coat material.to get protection against high temperature.

These are all various methods can be use for increase in gas turbine efficiency. Regeneration, reheat & inter cooling methods are based on plant configuration.

Blade cooling & coating are only depend on blade configuration.[3-5]

A TBC is a thin (100-500 μm), thermally insulating ceramic coating that is applied over the conventional oxidation-resistant aluminide diffusion coating on the superalloy. The TBC must provide significant thermal insulation at the external surface of the part.[6]

Current thermal barrier coatings consist of two layers: a metallic bond coat and a ceramic top coat. The bond coat has two key functions: It provides the bonding between the ceramic top coat and the superalloy substrate and protects the superalloy from the environmental degradation. The key function of the ceramic top coat is to reduce the alloy surface temperature by insulating it from the hot gas. [7]

Current bond coats are diffusion aluminide coatings based on β-NiAl phase and MCrAlY (M = Ni, Co, or NiCo) coatings based on a mixture of β-NiAl and γ'-Ni_3Al or γ phases. Bond coats oxidize upon thermal exposure, even in the presence of a ceramic top coat, forming an oxide scale, known as TGO (thermally grown oxide). Current top coat is yttria-stabilized zirconia (YSZ: ZrO_2 doped with 7~8 wt% Y_2O_3). YSZ has several important characteristics for a successful top coat. It has a high melting point, a low thermal conductivity and a high thermal expansion coefficient and is thermodynamically stable in contact with alumina that grows on bond coat. The ZrO_2-7~8 wt% Y_2O_3 composition also has good erosion resistance compared with other ceramics and good phase stability at temperatures <1200ºC.[7]

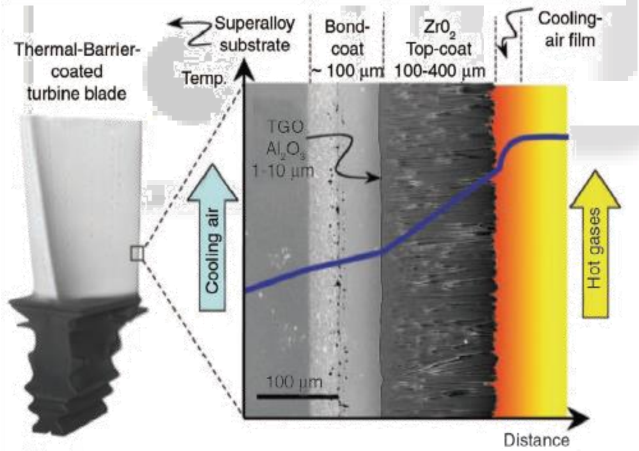

Fig. 3: Structure of TBC

II. LITERATURE REVIEW

A. Turbine Blade Failure

S. Qu *et al*. [8] illustrated The failure analysis of the first stage blades in a gas turbine made of nickel-base Inconel 738 is presented. The failure of the gas turbine occurred at approximately 1069 operating hours with 58 starts after the last overhaul. Several examinations were carried out to identify the blade failure's root cause: macroscopic inspection, microscopic examination, and metallographic analysis. It is found that one of four fractured blades had initially cracked by a fatigue mechanism over a period of time, and then fractured by the overload at last moment and the other three fractured blades are all instant fracture with the dendrite morphology, which resulted in the initiation of fatigue crack at the porosity metallurgical defects in the trailing edge of blade due to the stress concentration aroused by these porosity defects and cavitations.

Sweety Kumari *et al*.[9] Researcher has carried out the failure analysis of the stage I, II and III turbine rotor blades of an aircraft engine. The blades were made out of Ni-based superalloys of different grades with ceramic coating provided at outer surface of blade.

Two blades of I stage were found broken at the top and several blades of this stage were also found with deep cuts on one of the edges. Further, dents and nicks were found to be on II and III stage turbine blades on their leading/trailing edges. Several inspection and visual examination were carried out on failed/damaged turbine blade surfaces like fractography, micro structural examination, chemical analysis and hardness measurement was carried out to identify the cause of the failure of the blades. The inspection has revealed the results that first localized oxidation attack to I stage turbine blade 'A'. This oxidation leads to the formation of oxide at interface between coating and substrate. As shown in figure 4 four main causes of failure were found the failure of coated turbine blades (1) Damaged coatings (2) Oxygen diffusion (3) Subsurface oxide layer (4) Coating dislodgement. After that due to this fatigue cracks have initiated at these pits and propagated during service life and led to the fracture of the first stage blade. Subsequently, the broken pieces of the first stage blade impact on the first stage as well as the second and the third stage turbine blades. This can lead to the formation of dents and nicks on leading/trailing edges of turbine blades.

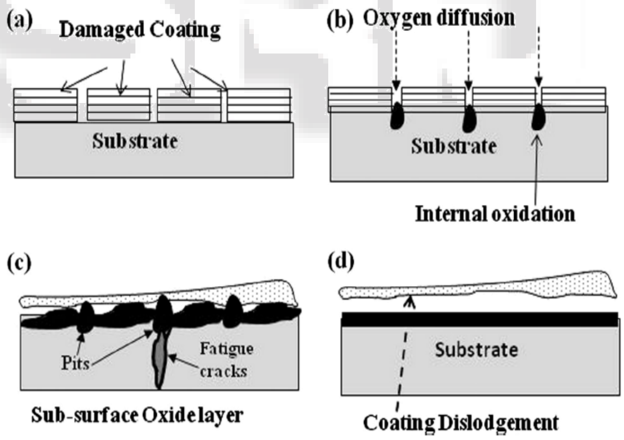

Fig. 4: Mechanism for Blade Failure

Yongseok Kim *et al*. [10] worked on Thermo-mechanical fatigue(TMF) testing method to evaluate the material properties and behaviors under the start-up and shut-down conditions of a gas turbine. In this study, to evaluation of the performance for GTD-111 both coated and uncoated specimen and also for in-phase and out-phase condition carried out. Results shows that for uncoated specimen more stress and strain amplitude is produced on the surface than coated specimen. Life of the coated material higher than the uncoated material . This is because of TBC provides insulation at the outer surface of specimen. Microstructural analysis of TMF specimen had also been carried out.

B. Thermal Barrier Coating Parameters

R. Rajendran *et al*. [11] metallurgical investigation that was carried out on discoloured low pressure turbine rotor blade (LPTR) for its platinum modified aluminium coating integrity and overheated high pressure turbine rotor blade (HPTR) for its blade material and coating integrity. LPTR blades were found to be in good condition so it can be reuse for working operation. Heat tinting, EDS and XRD were carried out to present the harmonized inference that the coating was in good condition. HPTR blades were sectioned to study under SEM. Regions of platinum modified aluminide coating degradation and DS CM 247 LC base material cracking were observed which make the particular lot unusable.

H.M. Tawancy *et al*. [12] In this paper experimental analysis had been carried out by using three type of platinum modified coatings and three nickel based superalloy. And top coat is taken as YSZ for all three types of coating materials. This top coating is developed by electron beam physical vapour deposition (EB-PVD). Thermal exposure test at 10500C is carried out in air for 24 hour cyclic period. By this test the performance analysis is carried out for ranking the performance of the coating systems. Work is placed upon the role of composite systems consisting of bond coat and superalloy substrate in determining the performance and useful life of thermal barrier coatings using yttria-stabilized zirconia as top coat processed by electron beam physical vapor deposition. Figure 2.12 shows Three different different types of bond coat structure used for the analysis purpose.

It is shown that for a given superalloy substrate, the coating performance is dependent upon the type of bond coat. Conversely, for a given bond coat, the performance becomes a function of the superalloy composition used in the application. However, in both cases, coating failure is found to be predominated by loss of adhesion between the thermally grown oxide and bond coat indicating that the respective interface is the weakest link in the system. Differences in the behavior of various bond coat/superalloy combinations are correlated with: i) oxidation rate of the bond coat, ii) inter diffusion between the bond coat and superalloy substrate and iii) phase transformations in the bond coat. To achieve the best TBC performance for a given application, it is important to select the bond coat/superalloy combination as a composite system rather than as separate entities.

C. TBC with FEA

Daniel Dragomir-Stanciu *et al*. [13] work carried out in order to prevent high thermal stresses in turbine blade. The analysis will be done by considering two factors:gas turbine blade with cooling holes & also with & without ceramic themal barrier coatings. This all work can be carried out using ANSYS 13 software. the ceramic material for thermal barrier coatings is $Zro_2/20\%Y_2O_3$.

L. Yang *et al*. [14] was developed a finite element model for a turbine blade with thermal barrier coatings to investigate its failure behavior under cyclic thermal loading. Based on temperature and stress fields obtained from finite element simulations, dangerous regions in ceramic coating were determined in terms of the maximum principal stress criterion. The results show that damage preferentially occurs in the chamfer and rabbet of a turbine blade with thermal barrier coatings and its thermal fatigue life decreases with the increase of thermal stress induced by high service temperature. As shown in Fig. 5 and 6 we can easily saw the difference between with and without thermal barrier coating analysis results.

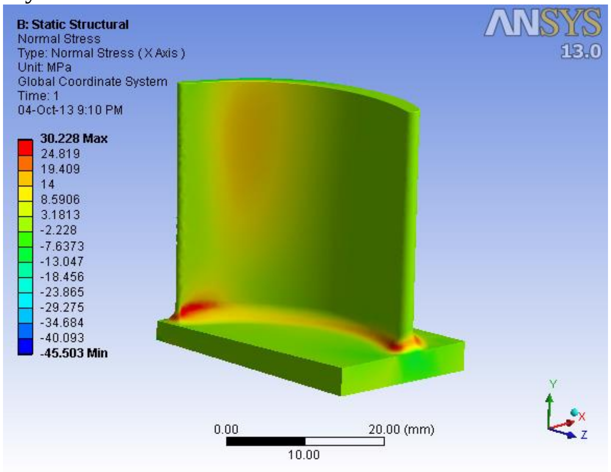

Fig. 5: Blades without thermal Barrier Coatings-Normal Stress

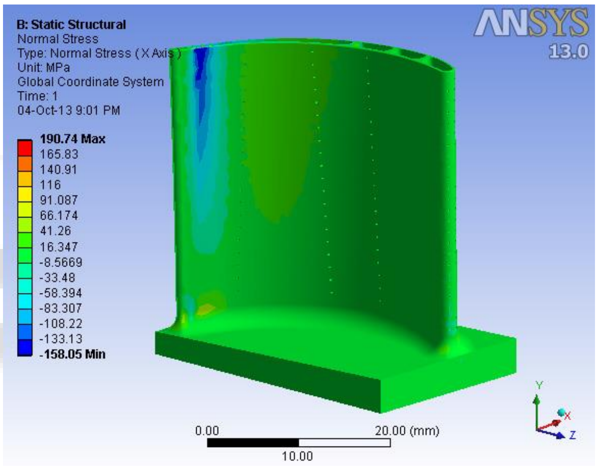

Fig. 6: Blades with thermal Barrier Coatings- Normal Stress

D. Performance Analysis

Min Tae Kim *et al*. [15] In this paper to know the effect of situ oxidation- resistant coatings on gas turbine components were evaluated experimentally and analytically. For this an axial type 100 kW class gas turbine power generation system which is equipped with an additive supply system is tested and evaluated. This gas turbine is operated at 74,000 RPM and inlet temperature is 1200^0C.

Results shows that by providing protecting layer of situ deposits silicate turbine inlet temperature was increased upto TIT $>950^0$ much higher than it's design temperature of 850^0. As shown in Figure 7 if the turbine inlet temperature increase upto 100^0 C than this will increase turbine rotation speed upto 5% and also engine power output increased by 42% . It will also increase thermal efficiency from 12% to 14% which was well accorded with the performance analysis.

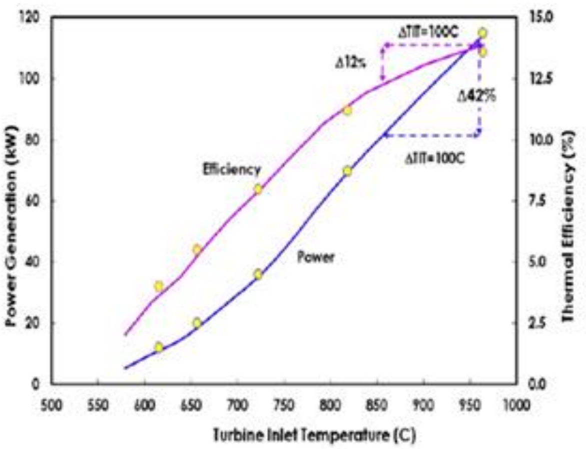

Fig. 7: TIT vs Power and Efficiency

Majid Rezazadeh Reyhani *et al*. [16] In the present paper, method for calculating blade temperature was described and validated with experimental results. After that a set of sensitivity analysis for the prediction of remaining life of the turbine blade was carried out. Two parameters were analyzed (1) blade coating thickness, (2) gas turbine load variation.

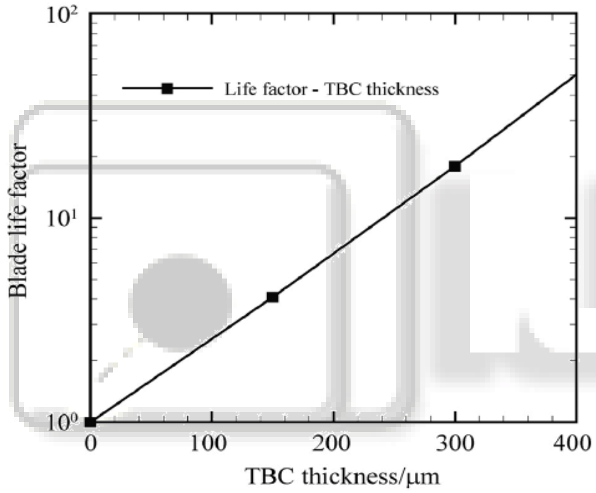

Fig. 8: Effect of TBC on blade life

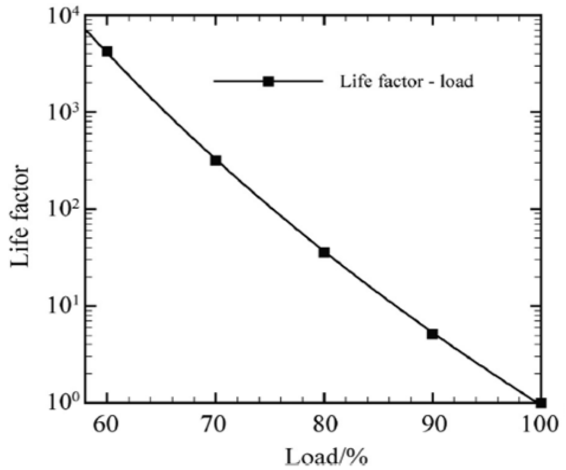

Fig. 9: Blade life factor in various Loading

Results show that increasing thermal barrier coating thickness increased by 3 times, leads to rise in the blade life by 9 times. In addition, if internal cooling of turbine blade is provided this can also have a great effect on the blade life. One of the important point is that if we are operating gas turbine at the base load or 100% load for one hour it is equal to the gas turbine operating at 70% load for 300 hour operations.

III. Conclusion

- Regeneration, Reheat, intercooling can increase turbine efficiency upto 10-12%.
- The TBC must provide significant thermal insulation at the external surface of the turbine blade.
- The ceramic currently used for TBCs is a yttria stabilized zirconia (YSZ) with 6-8 wt.% yttria. YSZ has one of the lowest thermal conductivities of all ceramics and a thermal expansion coefficient that approaches that for superalloy substrates.
- There are mainly two types of problem occur turbine blade coating:
  - Thermally grown oxide (TGO)
  - Adherence to the substrate of bond coat
- For a given superalloy substrate, the coating performance is dependent upon the type of bond coat. Conversely, for a given bond coat, the performance becomes a function of the superalloy composition used in the application.
- Differences in the behavior of various bond coat/superalloy combinations are correlated by
  - oxidation rate of the bond coat
  - interdiffusion between the bond coat and superalloy substrate
  - phase transformations in the bond coat.
- To achieve the best TBC performance for a given application, it is important to select the bond coat/superalloy combination as a composite system rather than as separate entities.
- Thermal Barrier Coatings(TBC) improves the life of the blade.
- Increase the efficiency of the gas turbine by using turbine blade coating .

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