Thermal Analysis of Barrier Coating Material (TBC) For Gas Turbine Blade

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ABSTRACT: The thermal barrier coating (TBC) material is used to protect the gas turbine blade from high temperature and pressure gas, corrosion, erosion and wear. The bare material which is used for blade may reduce its useful life while in servicing in severe hot combustion gases. The hot combustion gas may induce and increase the thermal stresses and abnormal deformation. In this work, the deformation and von-misses stresses are calculated for bare material and different coating material with appropriate thickness applied on bare material. The gas turbine blade material is Inconel-713, and its coating material is Yattria stabilized zirconia (YSZ), Aluminum oxide (Al₂O₃) and lanthanum Hexaluminate (LHA). The deformation and von-misses stresses are calculated for non-coated Inconel-713 and 0.5 mm thickness coated of Yattria stabilized zirconia (YSZ), Aluminum oxide (Al₂O₃) and lanthanum Hexaluminate (LHA) material. The Finite element method (FEM) is used to calculate the deformation and von-misses stresses for non-coated and different coating materials with 0.5 mm thickness. The comparison is carried out for non-coating and for various coating materials in terms of deformation and von-misses stresses in minimum and maximum temperature.

KEYWORDS: TBC; YSZ; LHA; Al₂O₃; FEM; FEA; CAD; TGO; TC, BC

1. INTRODUCTION

A turbine is a fluid flow machine that translates enthalpy of the operational agent, also preferred to as the thermodynamic agent (stream of exhaust gas) into mechanical work that effects in the turning round of the gas turbine rotor along with blade. The essential advantages of gas turbines contain possibility to develop more power at quite compact dimensions and less bare weight, quite high efficiency of the energy conversion procedure, simple design and high consistent of operation. Conversely, the disadvantages are elevated working temperatures of some components, complicated geometrical shapes of the components, e.g. blade, which creates the manufacturing procedure difficult, in addition to high operational speeds of rotors that implement the require to apply reduction gears, e.g. when turbine-power receivers show restricted rotational speeds. Gas turbines, designed for industrial firm, automobiles, off-seashore applications, power engineering systems, and aeronautical applications offer pretty high efficiency of 30 to 45%. That efficiency relies to a very high extent, on temperature of combustion gases at the turbine inlet. Nowadays, this temperature has risen by more than 450 K, which has effected in substantial improvement in overall efficiency offered by turbines and made it possible to achieve even superior coefficient of unit power. Particular consideration has been paid to boost anti-heat and creep resistance of turbine components, especially of the 1st stage blade. Application of connected cooling systems to compact turbines is connected with unwanted drop in the turbine efficiency. That is why advance improvement of the turbine blade manufacture engineering processes, intended at capabilities to increase temperature upstream the turbine, has been giving consideration on broadening heat-resistant coatings showing outstanding resistance to corrosive elevated-temperature combustion gas, small TC, and high steadiness of the material structure. The operational temperature of gas turbine blades can be sustained within the following periods, depending on structural materials to employ and cooling intensity:

• 1100 - 1200 K (when no committed cooling system is required)
• 1200 - 1300 K (when blade cooling system is required)
• 1300 K and above (when an extreme-cooling system and TBC material is required).
Moreover, blades are covered with materials that permit to raise the blade working temperature. However, a highly complicated design and manufacturing processes increase the production costs. [1]

II. RELATED WORK

Identification of Problem:

“Multidisciplinary analysis of the operational temperature increase of turbine blades in Combustion engines by application of the ceramic thermal barrier coatings (TBC)”.

1) The above research paper is referred as a base paper in which the material for turbine blade used is Inconel-713. Thermal analysis was carried out for inconel-713 without coating and with coating of YSZ material.
2) Further scope of area in the above research paper was to study the effect of temperature on structure such as deformation and von-misses stresses are observed.

Objective of the Study:

By using the same material i.e. Inconel-713, following outcome can be performed

Analysis 1:
1) Thermal temperature (Maximum or Minimum)
2) Deformation
3) Von-misses stresses

Analysis 2:
1) Thermal stress analysis of the gas turbine blade of Inconel-713 without coating.
2) Thermal stress analysis of the gas turbine blade of Inconel-713 with 0.5 mm coating of Al₂O₃ material.
3) Thermal stress analysis of the gas turbine blade of Inconel-713 with 0.5 mm coating of Lanthanum Hexaluminate (LHA) coating and
4) Thermal stress analysis of the gas turbine blade of Inconel-713 with 0.5 mm coating of Yattria Stabilized Zirconia (YSZ).

Comparisons of the results shall be done for the gas turbine blade of Inconel-713 for non coating and coating of thickness 0.5 mm. Coating materials shall be used are Al₂O₃, LHA and YSZ.

III. EXPERIMENTAL RESULTS

THERMAL STRUCTURAL ANALYSIS (FINITE ELEMENT ANALYSIS) OF GAS TURBINE BLADE:

CAD Modeling:

Blade without coating:
Chord Length of Blade = 39.2005 mm
Height of Blade = 40 mm
Trailing edge Thickness = 0.8mm
Leading edge Thickness = 2 mm
Blade with coating (TBC) of thickness of 0.5 mm:
Chord Length of Blade = 39.2005 mm
Height of Blade = 40 mm
Trailing edge Thickness = 0.8mm
Leading edge Thickness = 2 mm
Coating Thickness (TBC) = 0.5 mm

Mesh of blade without coating
No. of Nodes = 3826
No. of Elements = 668
Mesh of blade without coating

No. of Nodes = 5767
No. of Elements = 1112

Boundary condition:
The boundary condition is that the convection from hot gas at an average temperature of 864 °C. [6]

h = 1000 W/m²k
Temp. t = 864 °C

The convection at bottom at hub is
h = 300 W/m²k
Temp. t = 100 °C

The structural boundary condition fixed at bottom (hub)
Ux = 0, Uy = 0, Uz = 0
Result:

4.9. Comparison of Inconel-713, Inconel-713 and YSZ coating, Inconel-713 and Al₂O₃ coating and Inconel-713 and LHA coating:

The following table shows the Comparison of Inconel-713, inconel-713 and YSZ coating, inconel-713 and Al₂O₃ coating and Inconel-713 and LHA coating:

<table>
<thead>
<tr>
<th>Blade Material</th>
<th>Max temp °C</th>
<th>Min temp °C</th>
<th>Deformation in m</th>
<th>Von-misses stress in N/m²</th>
<th>Nodes</th>
<th>Element</th>
</tr>
</thead>
<tbody>
<tr>
<td>Inconel-713</td>
<td>847.758</td>
<td>741.292</td>
<td>4.17E-04</td>
<td>3.28E+09</td>
<td>3826</td>
<td>668</td>
</tr>
<tr>
<td>Inconel-713 + YSZ coating</td>
<td>820.472</td>
<td>686.289</td>
<td>3.53E-04</td>
<td>2.62E+09</td>
<td>5767</td>
<td>1112</td>
</tr>
<tr>
<td>Inconel-713 + Al₂O₃ coating</td>
<td>819.702</td>
<td>714.519</td>
<td>3.58E-04</td>
<td>4.97E+09</td>
<td>5767</td>
<td>1112</td>
</tr>
<tr>
<td>Inconel-713 + LHA coating</td>
<td>824.665</td>
<td>702.541</td>
<td>3.81E-04</td>
<td>4.07E+09</td>
<td>5767</td>
<td>1112</td>
</tr>
</tbody>
</table>

Table no.1

The results clearly indicate the following,

- The Inconel-713 deformation is 4.17 x 10⁻⁴ m and Von-misses stress is 3.28 x 10⁹ N/m². The maximum temperature is 847.758 °C and minimum temperature is 741.292 °C
- The Inconel-713 and 0.5 mm YSZ coating deformation is 3.53 x 10⁻⁴ m and Von-misses stress is 2.62 x 10⁹ N/m². The maximum temperature is 820.472 °C and minimum temperature is 686.289 °C
- The Inconel-713 and 0.5 mm Al₂O₃ coating deformation is 3.58 x 10⁻⁴ m and Von-misses stress is 4.97 x 10⁹ N/m². The maximum temperature is 819.702 °C and minimum temperature is 714.519 °C
- The Inconel-713 and 0.5 mm LHA coating deformation is 3.81 x 10⁻⁴ m and Von-misses stress is 4.07 x 10⁹ N/m². The maximum temperature is 824.665 °C and minimum temperature is 702.541 °C
IV. CONCLUSION

The comparison of Inconel-713 (without coating) and coating (0.5 mm) of different material such as YSZ (Yttria Stabilized Zirconia), Al$_2$O$_3$ (aluminum oxide) and LHA (Lanthanum Hexaluminate) as shown in the above table. From the above comparison, it is found that YSZ coating has minimum deformation and minimum Von-misses stress as compared to Al$_2$O$_3$ coating and LHA coating.

Future Scope of work:

- To improve the obtained results, further in future; one can increase the coating thickness from 0.5 mm to 1 mm or 2 mm by which von-misses stresses and deformation may reduce considerably.
- By providing the holes axially in the blade, may also reduce the temperature of the blade thereby increase the cooling effect which in turn reduces the von-misses stresses and deformation.

REFERENCES


[15] In Hwan Shina, at all,(2013), Assessment of the characteristics of thermal barrier coating applied to Gas turbine blade by thermo-gradient mechanical test.


