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# DESIGN AND ANALYSIS OF THERMAL BARRIER COATING ON GASTURBINE BLADE

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**Abstract:** Thermal barrier coatings (TBCs) are deposited on the turbine blade to reduce the temperature of underlying substrate, as well as providing protection against the oxidation and hot corrosion from high temperature gas. Optimal ceramic top-coat thickness distribution on the blade can improve the performance and efficiency of the coatings. Design of the coatings thickness is a multi-objective optimization problem due to the conflicts among objectives of high thermal insulation performance, long operation durability, and low fabrication cost. This work developed a procedure for designing the TBCs thickness distribution of 100µm to 500µm for the gas turbine blade. The base material of blade geometry is created using Nickel alloy and its coating material is selected as partially stabilized zirconia. Three-dimensional finite element models were built using CATIA and analyzed by ANSYS WORKBENCH, and weighted-sum approach was employed to solve the multi objective optimization problem herein. Suitable multi region top-coat thickness distribution scheme was designed with the considerations of manufacturing accuracy, productivity, and fabrication cost.

**Keywords**: Thermal Barrier Coatings; Oxidation; corrosion; Ceramic Top-coat thickness; Durability; Low fabrication co

## 1. INTRODUCTION

The objective of this project is to design and stresses analyze a turbine blade of a jet engine. An investigation for the usage of new materials is required. In the present work turbine blade was designed with two different materials named as Inconel 718 and Titanium T-6. An attempt has been made to investigate the effect of temperature and induced stresses on the turbine blade. A thermal analysis has been carried out to investigate the direction of the temperature flow which is been develops due to the thermal loading. A structural analysis has been carried out to investigate the stresses, shear stress and displacements of the turbine blade which is been develop due to the coupling effect of thermal and centrifugal loads. An attempt is also made to suggest the best material for a turbine blade by comparing the results obtained for two different materials (Inconel 718 and titanium T6). Based on the plots and results Inconel718 can be consider as the best material which is economical, as well as it has good material properties at higher temperature as compare to that of TitaniumT6 [1-5]. In the present work the first stage rotor blade of a two-stage gas turbine has been analyzed for static structural, steady state thermal, modal and high cycle fatigue using ANSYS 17. An attempt has been made to investigate the effect of temperature and induced stresses on the turbine blade. A structural analysis has been carried out to investigate the stresses and displacements of the turbine blade which is been develop due to the coupling effect of thermal and centrifugal loads. A steady state thermal analysis has been carried out to investigate the direction of the temperature flow which is been develops due to the thermal loading. An attempt is also made to suggest the best material for a turbine blade by comparing the results obtained for three different materials such as Titanium Ti 6Al 4V, INCONEL 625 and N-155 that has been considered for the analysis. The turbine blade along with the fir tree joint is considered for the static structural, fatigue, thermal and modal analysis. The blade is modeled with CATIA V5. The geometric model of the blade profile is generated with splines and extruded to get a solid model. [5-10]. Gas turbine play a vital role in the today's industrialized society, and as the demand for power increase, the power output and thermal efficiency of gas turbine must also increase. One method of increasing both the power output and thermal efficiency of the engine is to increase the temperature of the gas entering the turbine. In the advanced gas turbine, the inlet temperature of around 1500°C is used, however, this temperature exceeds the melting temperature of the metal airfoils. Therefore, along with high temperature material development, a refined cooling system must be developed for continuous safe operation of gas turbines with high performance. Gas turbine blades are cool internally and externally. In film cooling, relatively cool air is injected from the inside of the blade which travels through the entire blade length and form a protective film around the blade-surface. In present work attempt has

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been made to analyze the failure of the gas turbine blade through structural analysis. The analysis is conducted for two different blade configurations one is the base line configuration with film cooling cylindrical holes along the entire length and in another configuration is the holes along the leading edge are branched together for anti-vortex considerations. The two configurations is further study for two different pitches to diameter ratio(y/d) of the cooling holes[11-17]

## 3. MODELING OF GAS TURBINE BLADE

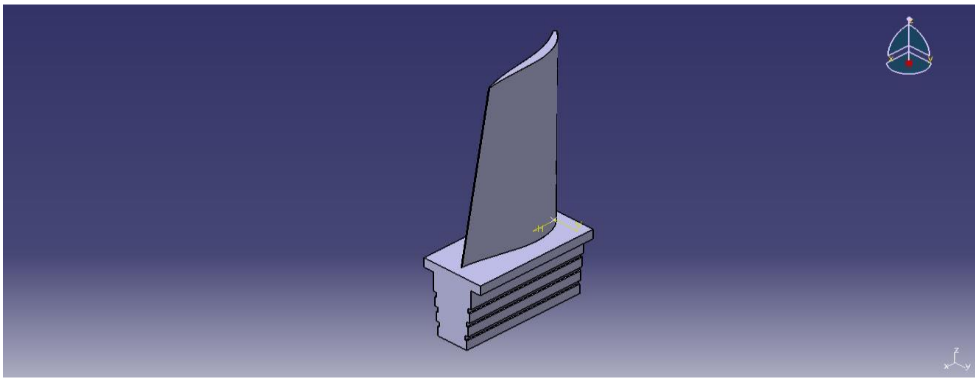

**Figure 1. The gas turbine blade with 100µm coating layer**

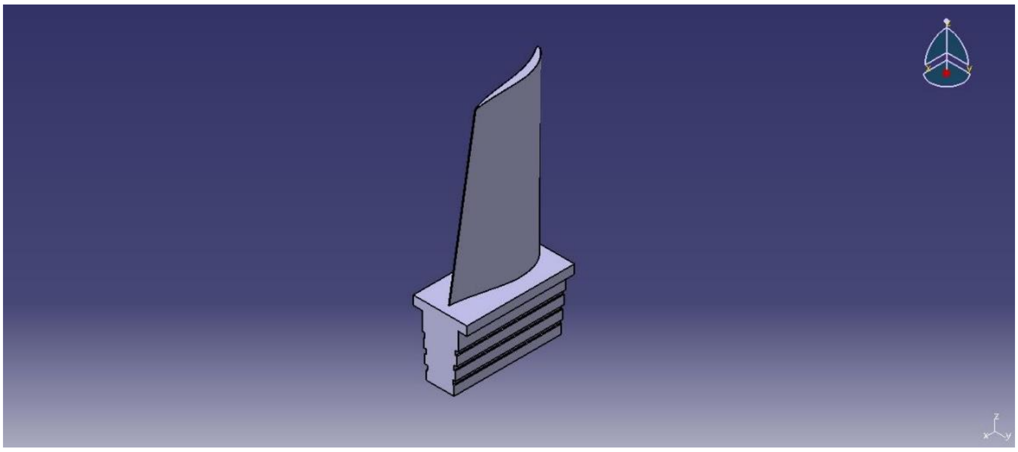

**Figure 2. The gas turbine blade with 200µm coating layer**

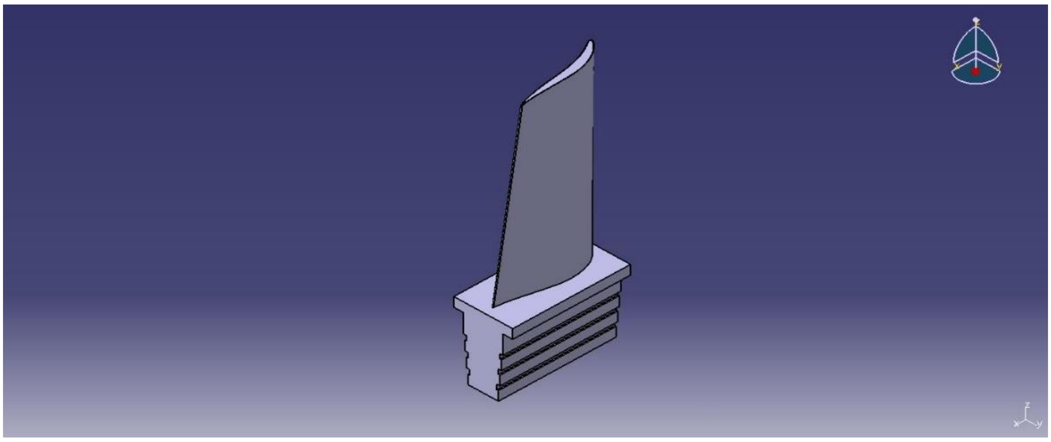

**Figure 3. The gas turbine blade with 300µm coating layer**

  

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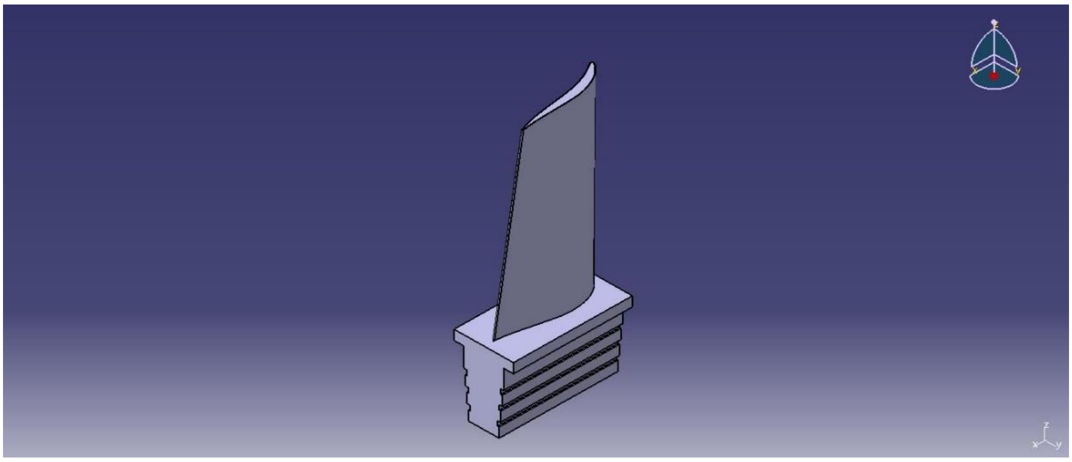

**Figure 4. The gas turbine blade with 400µm coating layer**

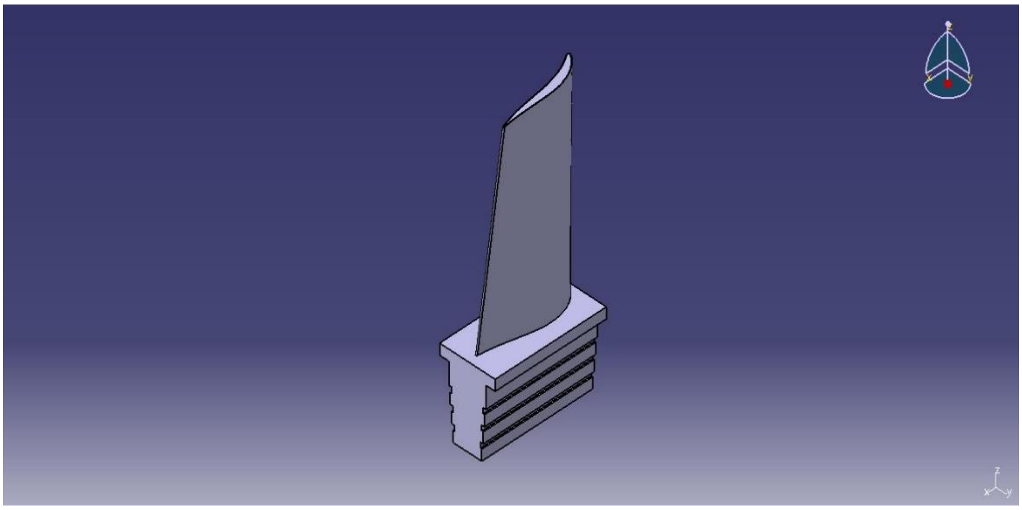

**Figure 5 The gas turbine blade with 500µm coating layer**

## 4.RESULT AND ANALYSIS

### THERMAL ANALYSIS

The ANSYS/ Multi physics, ANSYS/Mechanical, ANSYS/FLOTRAN, and ANSYS/Thermal products support steady-state thermal analysis. A steady-state thermal analysis calculates the effects of steady thermal loads on a system or component. Engineer/analysts often perform a steady-state analysis before doing a transient thermal analysis, to help establish initial conditions. A steady-state analysis also can be the last step of a transient thermal analysis, performed after all transient effects have diminished.

The steady-state thermal analysis is used to determine temperatures, thermal gradients, heat flow rates, and heat fluxes in an object that are caused by thermal loads that do not vary over time. Such loads include the following:

- Convections
- Radiation
- Heat flow rates
- Heat fluxes (heat flow per unit area)
- Heat generation rates (heat flow per unit volume)
- Constant temperature boundaries

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**ANALYZING PROCEDURE**

**Step1**

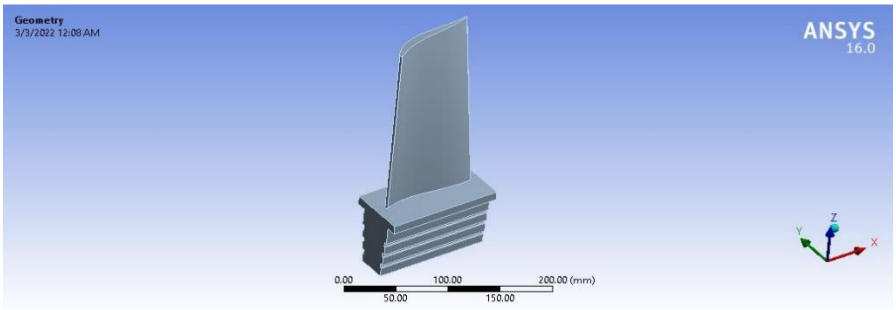


**Figure 6. The model of gas turbine blade is imported in ansys workbench**

**Step2**

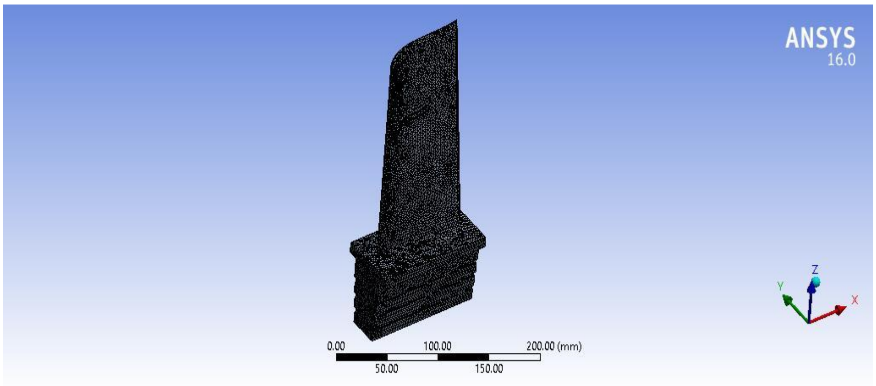


**Figure 7. The meshed view of gas turbine blade**

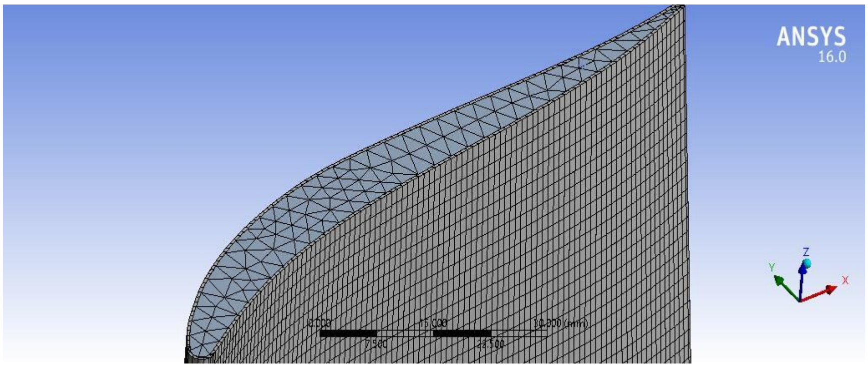


**Figure 8. Details of meshes**

| | |
|---|---|
| Nodes | 379113 |
| Elements | 174041 |

**Figure 9. Quantity of mesh created**

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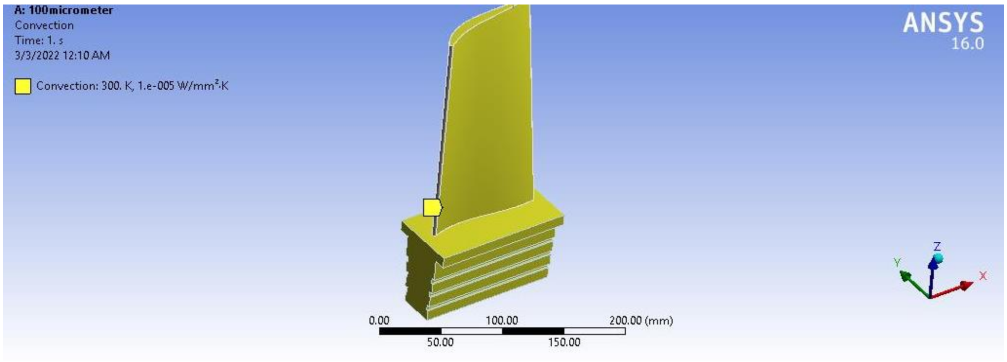
**Step3**



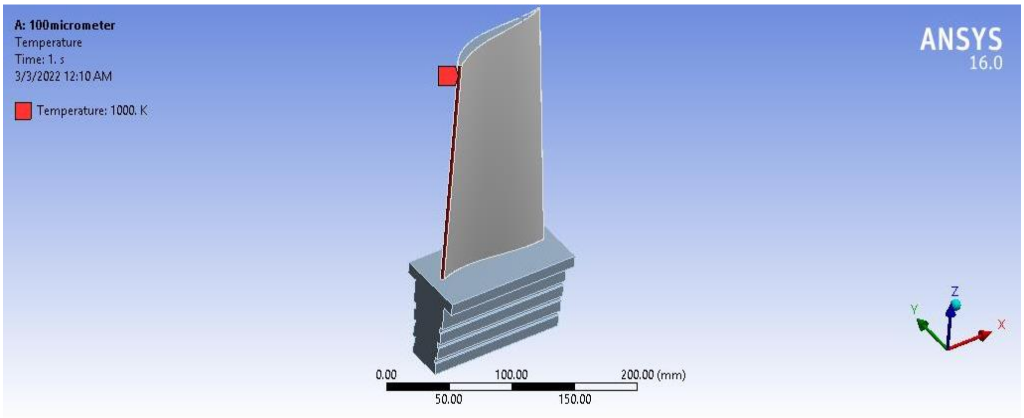




**Figure 10. The temperature is applied at the leading edge of airfoil**

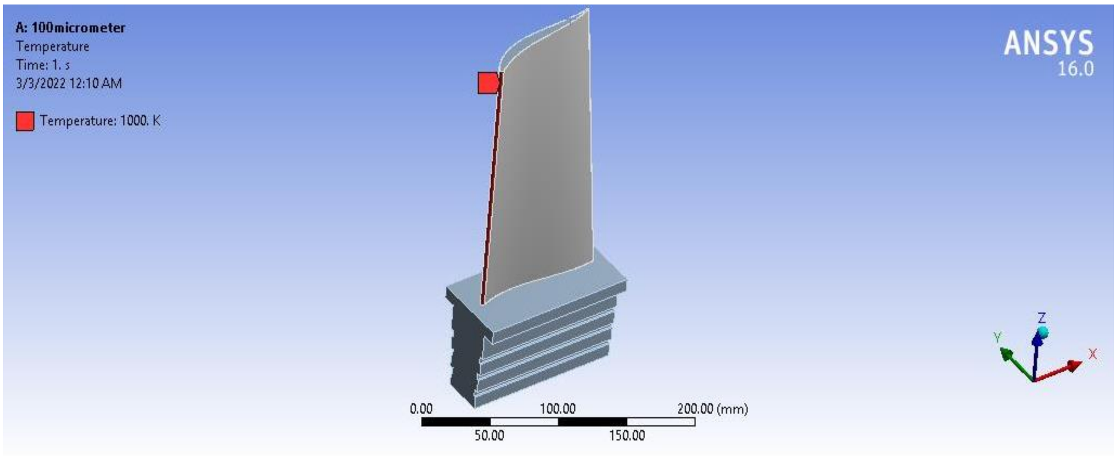



**Figure 11. The convection is provided at the remaining faces of turbine blades to calculate heat transfer**

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**Step5**

**Base metal- Inconel 718**

**Properties of Inconlel 718**

Inconel 718 is a nickel-based super alloy that is well suited for applications requiring high strength in temperature ranges from cryogenic up to 1400°F. Inconel 718 also exhibits excellent tensile and impact strength.

**Chemical Composition of Inconel 718**

The Chemical Composition of Inconel 718 are Carbon 0.08 max, Manganese 0.35 max, Phosphorus 0.015 max, Sulfur 0.015 max, Silicon 0.35 max, Chromium 17-21, Nickel50-55, Molybdenum2.80-3.30, Columbium4.75-5.50, Titanium 0.65-1.15, Aluminum 0.20-0.80, Cobalt 1.00 max, Boron 0.006 max, Copper 0.30 max Tantalum 0.05 max, Iron Balance

**Resistance to Corrosion and Oxidation of Inconel 718**

Inconel 718 has good resistance to oxidation and corrosion at temperatures in the alloy’s

useful strength range in atmospheres encountered in jet engines and gas turbine operations.

## 5.4. COATING MATERIAL

International Syalons supply Zirconia 3Y-PSZ ceramics, suitable for applications in many different testing environments. These ceramics are the toughest monolithic ceramic and was developed to compliment International Syalons range of components for the metal forming industries.

Zirconia 3Y-PSZ is a partially stabilised zirconia characterised by high strength and toughness giving it excellent wear resistance as well as excellent corrosion resistance.

**Physical and Mechanical Properties of Partially Stabilised Zirconia (3Y-PSZ)**

| Properties | Value | Units |
|---|---|---|
| 3 point RT Modulus of Rupture (Specimen 3 x 3 x 50 span 19.05mm) | 1000 | MPa |
| Weibull Modulus | 15 | – |
| RT Unit Tensile Strength | 500 | MPa |
| RT Compressive Strength | >2000 | MPa |
| RT Young’s Modulus of Elasticity | 205 | GPa |
| RT Hardness (HRA) | 91 | – |
| RT Hardness (Vickers $Hv_{0.3}$) | 1350 | $Kg/mm^2$ |
| Fracture Toughness $K^1C$ | 9.0 | $MPam^{1/2}$ |
| Density | 6.03 | g/cc |

  

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| | | |
|---|---|---|
| Porosity | 0 | % |
| Thermal Expansion Coefficient (0-1200°C) | $10.0x10^{-6}$ | $K^{-1}$ |
| RT Thermal Conductivity | 2.0 | W/m/k |
| Thermal Shock Resistance | 250 | ΔT°C quenched in water |
| Maximum Use Temperature | 1000 | °C |
| RT Electrical Resistivity | 109 | ohm m |

**Table 5.4. The table below lists typical mechanical, thermal and electrical property data for Zirconia 3Y-PSZ.**

Typical physical property data obtained under test conditions. All properties have been measured by independent testing authorities. The values given only apply to the test bodies on which they were determined, and therefore can only be recommended values.

## 5.5. RESULSTS OF VARIOUS THICKNESS TBC

### 5.5.1. Results of thermal barrier coating of 100µm

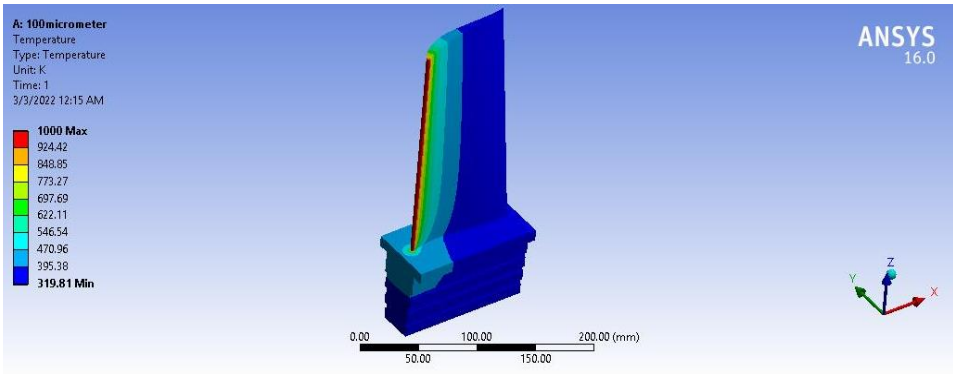


**Figure 5.7.a. Temperature distribution**

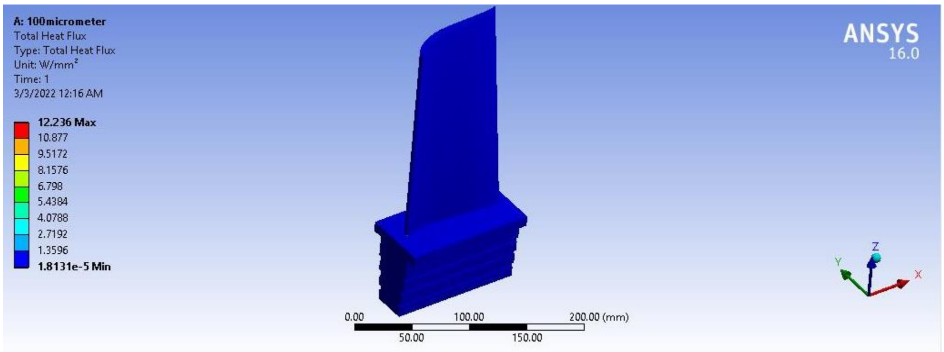


**Figure 5.7.b. Heat flux experienced by the turbine blade structure**

 

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### 5.5.2. Results of thermal barrier coating of 200µm

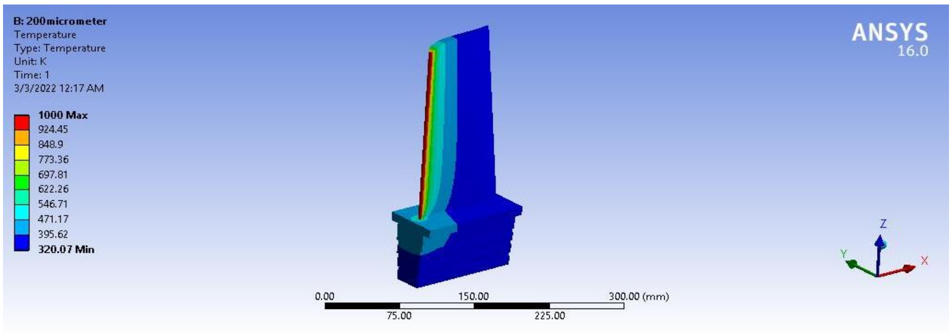


**Figure 5.8.a. Temperature distribution**

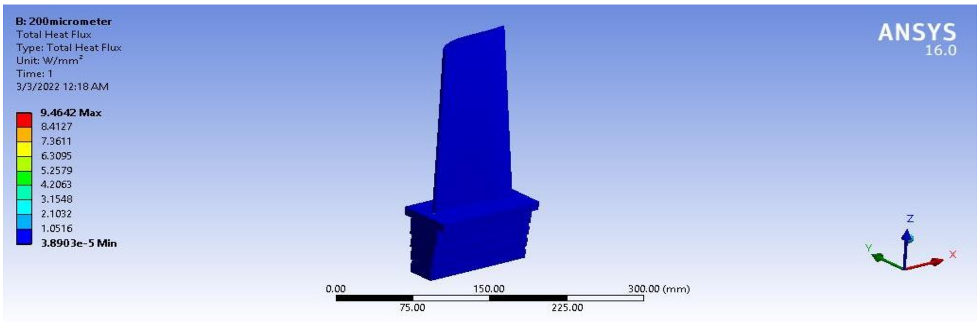


**Figure 5.8.b. Heat flux experienced by the turbine blade structure**

### 5.5.3. Results of thermal barrier coating of 300µm

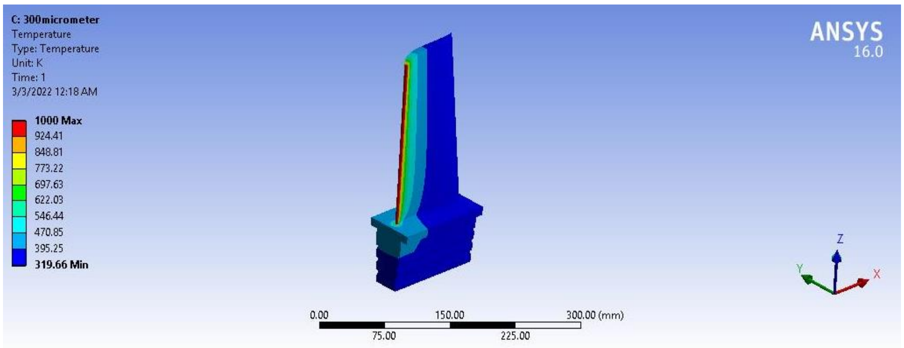


**Figure 5.9.a. Temperature distribution**

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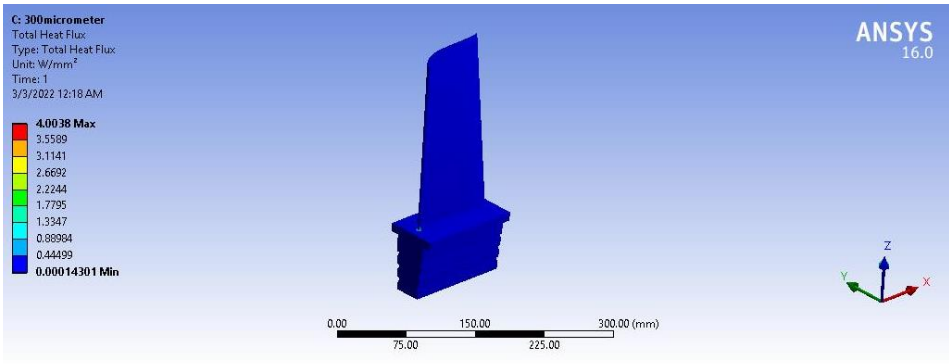


**Figure 5.9.b. Heat flux experienced by the turbine blade structure**

### 5.5.4. Results of thermal barrier coating of 400µm

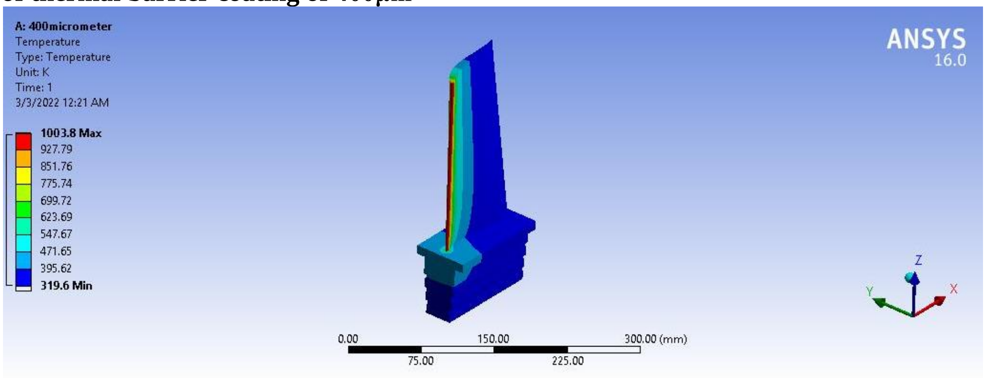


**Figure 5.10.a. Temperature distribution**

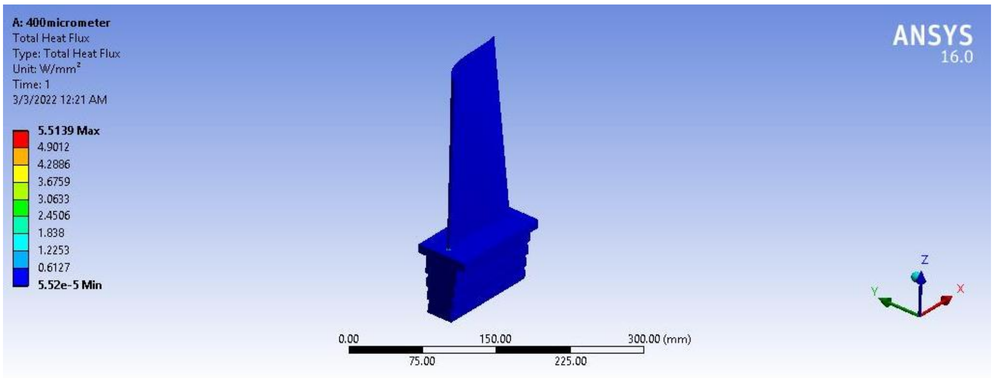


**Figure 5.10.b. Heat flux experienced by the turbine blade structure**

### 5.5.5. Results of thermal barrier coating of 500µm

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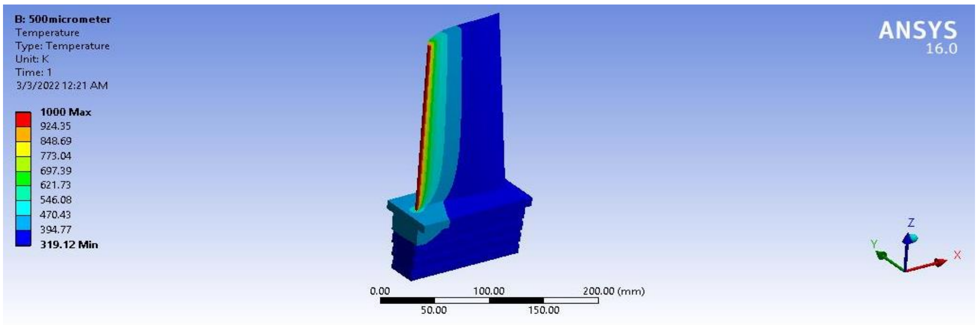


**Figure 5.11.a. Temperature distribution**

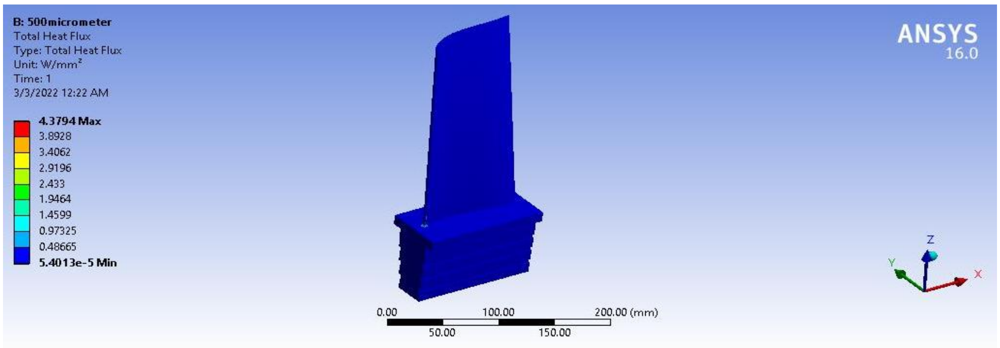


**Figure 5.11.b. Heat flux experienced by the turbine blade structure**

**TABULATED RESULT RESULTS FOR VARIOUS COATING THICKNESS**

| **Coating thicknes (µm)** | **Temperature (K)** | | **Heat flux (W/mm$^2$)** | |
|---|---|---|---|---|
| | **Min** | **Max** | **Min** | **Max** |
| **100** | 319.81 | 1000 | 1.81E-5 | 12.236 |
| **200** | 320.07 | 1000 | 3.89E-5 | 9.460 |
| **300** | 319.66 | 1000 | 1.43E-4 | 4.003 |
| **400** | 319.60 | 1000 | 5.52E-5 | 5.513 |
| **500** | 319.12 | 1000 | 5.40E-5 | 4.370 |

**Table 5.6. Tabulated results for various coating thickness**

## CONCLUSION

A 3D numerical model of turbine blade and TBC with different thicknesses is developed in order to evaluate the protection rule of TBC thickness. The effect of temperature on material properties have been considered and thermal boundary conditions are modeled as heat transfer coefficient. Keeping assembly dimensions unchanged in this study, it is concluded

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that TBC thickness has significant influence on temperature distribution of blade body and consequently on its life. Following results have been obtained:

Results show that TBC acts as an excellent insulation layer on the blade core, which can decrease temperature of blade up to 100 °C when TBC thickness changes from 100 to
500 µm. The temperature drop is not constants in all the regions and increases when movingfrom trailing edge to leading edge along either pressure or suction side.

By increasing TBC thickness, low temperature regions on the blade surface extend against high temperature regions.

By using the results of this simulation, the critical regions of blade surface and TBC, which are likely to failure during turbine operation, can be predicted. In addition, in our next plan, the temperature distribution is used in order to develop a Thermo-Elasto-Plastic model to evaluate stress fields through the blade and TBC. This analysis is important in case of investigation of residual stress in blade as well as crack initiation and propagation in TBC under thermal shock or thermal fatigue.

## REFERENCES

1) T. Sadowski, P. Golewski “Multidisciplinary analysis of the operational temperature increase of turbine blades in combustion engines by application of the ceramic thermal barrier coatings (TBC)”. elsevier Computational Materials Science 50, 2011, pp:1326-1335.
2) M. Gell, D. N. Duhl, D. K. Gupta and K. D. Sheffler, "Advanced superalloy airfoils," Journal of Metals, 1987, pp:11-15.
3) Biao Li, Xueling Fan, Dingjun Li and Peng Jiang.“Design of thermal barrier coatings thickness for gas turbine blade based on finite element analysis”. Mathematical Problems in Engineering Volume 2017, Article ID 2147830,2017,13 pages.
4) Theju V , Uday P S , PLV Gopinath Reddy , C.J.Manjunath. “Design and analysis of gas turbine blade”. International Journal of Innovative Research in Science, Engineering and Technology. Vol. 3, Issue 6, June 2014 pp:13533-13539.
5) W. Zhu, J.W. Wang , L. Yang, Y.C. Zhou , Y.G. Wei, R.T. Wu. “Modeling and simulation of the temperature and stress fields in a 3D turbine blade coated with thermal barrier coatings”. Elsevier Surface and coatings technology 315,2017,pp:443-453.
6) X.Q. Cao, R. Vassen, D. Stoever. “Ceramic materials for thermal barrier coatings”.elsevier, Journal of the European Ceramic Society 24, 2004,pp:1–10.
7) Ebi A. Ogirikia Yiguang G. Li “Effect of fouling, thermal barrier coating degradation and film cooling holes blockage on gas turbine engine creep life” elsevier The Fourth International Conference on Through-life Engineering Services ,2015,pp: 228 – 233.
8) Robert Vaßen , Maria Ophelia Jarligo, Tanja Steinke, Daniel Emil Mack, Detlev Stöver “Overview on advanced thermal barrier coatings” Elsevier Surface & Coatings Technology 205,2010, pp: 938–942.
9) In-Hwan Shin ,Jae-Mean Koo , Chang-Sung Seok , Sung-Ho Yang , Tack-Woon Lee, Bum-Soo Kim “Estimation of spallation life of thermal barrier coating of gas turbine blade by thermal fatigue test” Surface & Coatings Technology 205,2011,pp:S157–S160.
10) In Hwan Shina, Dong Keun Lee, Yong Seok Kim, Jae Mean Koo “Assessment of the characteristic of thermal barrier coating applied to gas turbine blade by thermo- gradient mechanical fatigue test” 6th International Conference on Creep , Fatigue and Creep-Fatigue Interaction [CF-6] , 2013 ,pp:210 – 213.
11) Ogiriki, E. A., Li, Y. G. and Nikolaidis, T.“Prediction and analysis of impact of TBC oxidation on gas turbine creep life", Proceedings of ASMETurbo Expo 2015: Power for Land, Sea and Air, GT2015, June 2015, pp: 15-19.
12) Kurz, R., Brun, K. and Mokhatab, S. "Gas turbine compressor blade fouling mechanisms", Pipeline & Gas Journal, vol. 238, 2011, pp: 18-21.
13) T. E. Strangman, J. Schienle “Tailoring zirconia coatings for performance in a marine gas turbine environment” The American Society of Mechanical Engineers. Setember1989.
14) W.A. Nelson, R.M. Orenstein “TBC Experience in land based gas turbines” Journal of Thermal Spray Technology JITEE5. Vol 6, June 1997 pp: 176-180.
15) Dongming Zhu, Robert A. Miller, and Maria A. Kuczmarski “Development and life prediction of erosion resistant turbine low conductivity thermal barrier coatings” NASA/TM- 2010-215669, February 2010 pp: 1-7.
16) Nitin P.Padture, Maurice Gell, Eric H. Jordan “Thermal barrier coatings for gas-turbine engine applications” Review:Material Science. Vol 296, April 2002 pp: 280-284.

DOI: 10.17148/IARJSET.2022.9606

17) H. Nickel, D. Clemens, W. J. Quadakkers, L. Singheiser ”Development of NiCrAlY alloys for corrosion-resistant coatings and thermal barrier coatings of gas turbine components” Journal of Pressure Vessel Technology. Vol 121, November 1999 pp:384-387.

18) T. Cosack, L. Pawlowski, S. Schneiderbanger, S. Sturlese “Thermal barrier coatings on turbine blades by plasma spraying with improved cooling” Journal of Engineering for Gas Turbines and Power. Vol 116, January1994 pp: 272-276.

19) J.T. DeMasi-Marcin, K.D. Sheffler, S. Bose “Mechanisms of degradation and failure in a plasma-deposited thermal barrier coating”. Journal of Engineering for Gas Turbines and Power. Vol 112, October 1990 pp: 521-526.