

Comparative Thermal and Structural Analysis of High-Pressure Gas Turbine Blade using Finite Element Method

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Abstract - A turbine blade is a component which complete the turbine section of a gas turbine or steam turbine. The blades of turbine are responsible for withdrawing energy from the high pressure, high temperature gas produced in the combustor. The turbine blades are very often the limiting and critical component of gas turbines. In this paper three most widely used materials are selected such as titanium alloy, IN738 and high strength alloy. For thermal and structural analysis, a 3 D FEM model was created using Creo 2.0 and velocity diagram was prepared for the actual working diagram of the gas turbine. The important parameters are considered for this analysis such as temperature of gas, forces through velocity diagram and ambient temperature and pressure conditions. After FEM analysis using ANSYS workbench 15.0 was analyzed for stress induced due to thermal and structural loading, from the FEM analysis it is found that Titanium alloy is found most promising material for the turbine blade in gas power plants.

Index Terms - Turbine blade, Thermal and Structural Analysis, FEA.

I. INTRODUCTION

The purpose of turbine technology is to extract the maximum quantity of energy from the working fluid. The main component of turbine engine is its blade, turbine blades are the most critical part and without which any of the thing cannot work, so importance of its design, working and life becomes important parameters to consider. Design of turbine blade plays a significant role in deciding the maximum working temperature, kind of cooling to be provided mainly depends upon the designs whether there is sufficient space available also the airfoil of blade is very important factor since these blades are in direct contact with stream of gases so to extract energy from gas there has to be very good surface contact, a small change in turbine leads to a significant change in the work output of the turbine. Turbine blade material is

also important factor which decides the operating and metallurgical limits of the turbine engine. In this paper, thermal and structural analysis of the turbine blade is focused mainly, and their results are illustrated for different type of considered materials using FEA software ANSYS Workbench 15.0. All calculations are based on single stage gas turbine for industrial use.

II. THREE-DIMENSIONAL MODELLING

A three-dimensional model of turbine blade is created in a CAD software Creo 2.0. Fig. 1 shows 3D model of turbine blade and Fig. 2 shows the velocity diagram of turbine. This model is further used in FEM software ANSYS for analysis purpose. This model is used as a model to analyze in the FEA software.

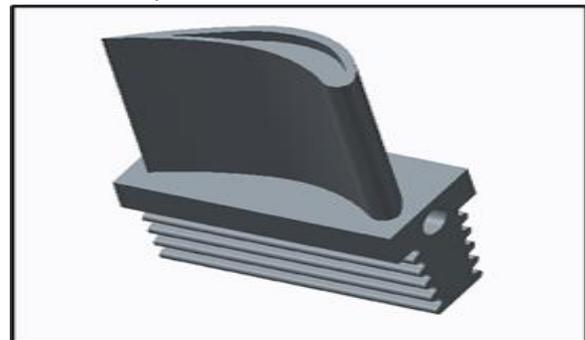


Fig:1 3D model of turbine blade.

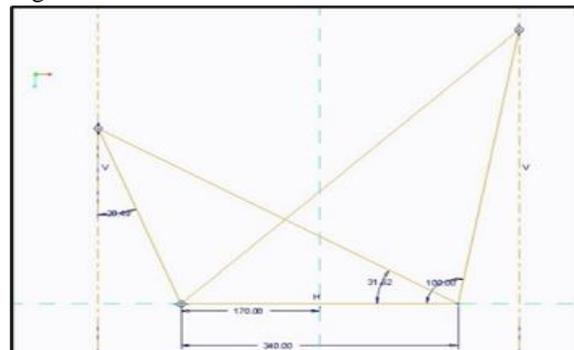


Fig.2: Velocity triangle diagram of turbine blade.

The results obtained after drawing velocity diagram are used to calculate and determine the important angle and geometry of the turbine blade, also the inlet and exit condition of stream of gas is calculated using velocity diagram which is further used to determine the maximum force acting on the turbine blade and used for analysis purpose in FEA software.

Material System

Material selected are Ti-13V-11Cr-3Al, consisting of compositions are IN 738 Carbon (0.15-0.20) %, Co (8.00-9.00) %, Cr (15.70-16.30) %, Molybdenum (1.50-2.00) %, Tungsten (2.40-2.80) %, Tantalum (1.50-2.00) %, Columbium (0.60-1.10) %, Aluminum (3.20-3.70) %, Titanium (3.20-3.70) % Aluminum and titanium (6.50-7.20) % Boron (0.005-0.015) % Zirconium (0.05-0.15) % Iron 0.50% max. Manganese 0.20% max. Silicon 0.30% max. Sulphur 0.015% max. Nickel remainder.

RENE 41 Cr 19%, Co 11%, Mo 10%, Fe 2%, Ti 3.1%, Al 1.5%, B 0.005% and balanced by Nickel [1-3].

III.CALCULATION OF FORCES ACTING ON TURBINE BLADE.

The assumptions made during the calculation of velocity diagram are as per the William Wiberg et al. are as follows.

Mass flow rate, $m = 20 \text{ kg/s}$

Inlet Temperature $T_{01} = 1100 \text{ K}$

Temperature Drop $T_{01} - T_{03} = 145 \text{ K}$

Pressure ratio, $\frac{P_{01}}{P_{03}} = 1.873$

Inlet Pressure = 4bar

Rotational speed, $N = 250 \text{ rev/s}$

Mean blade speed, $U = 340 \text{ m/s}$

Various velocity parameters computed through velocity diagram are as under

$$C_{w2} + C_{w3} = 516.54 \text{ m/s}$$

$$C_3 = 431.5 \text{ m/s}$$

$$V_3 = 593.97 \text{ m/s}$$

$$C_2 = 518.59 \text{ m/s}$$

$$V_2 = 290.25 \text{ m/s}$$

Various forces acting on turbine blades are as under tangential force acting on blade

$$F_t = \dot{m}(C_{w2} + C_{w3})$$

$$F_t = 10330.8 \text{ N}$$

Axial force acting on blade is given by equations

$$F_a = \dot{m}(C_{a2} + C_{a3})$$

$$F_a = 12857.8 \text{ N}$$

Total power produced by turbine is given by

$$P = \dot{m}U(C_{w2} + C_{w3})$$

$$P = 3.512 \text{ MW}$$

Total number of blades in turbine be $n=30$

Tangential force acting per blade

$$F_t = \frac{10330.8}{30}$$

$$= 344.36 \text{ N}$$

Axial force acting on blade is given by

$$F_a = \frac{12857.8}{30}$$

$$= 428.56 \text{ N}$$

The calculation of the parameters being used for the finite element analysis from the velocity diagram and the blade geometry [4-5].

IV.FEA ANALYSIS OF TURBINE BLADE

ANSYS Workbench 15.0 is used for FEA analysis of turbine blade, simulation tests are performed using this software and the mechanical and thermal behaviour is analyzed to study the performance in real time application and their properties are studied. The 3D FEM model is shown in the fig.3.

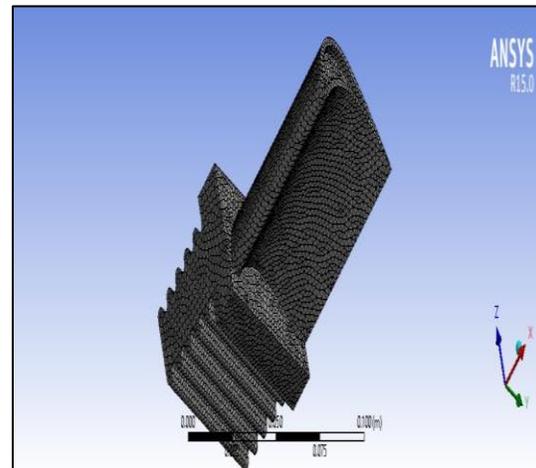


Fig:3 Meshing of turbine blade.

Thermal Analysis

The heat temperature distribution for the materials Ti, IN738, RENE41 are shown in the fig. 4 to 6. The heat flux distribution and the thermal deformation are shown in the fig. 7 to 12 respectively.

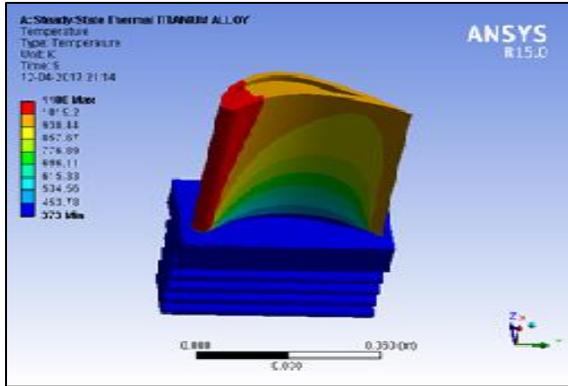


Fig:4 Temperature distribution in Titanium alloy.

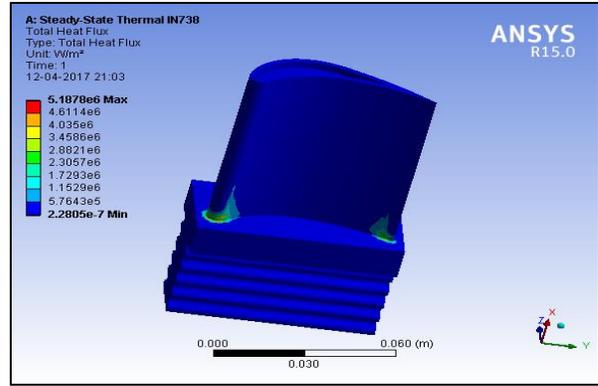


Fig:8 Heat flux distribution in IN738 alloy.

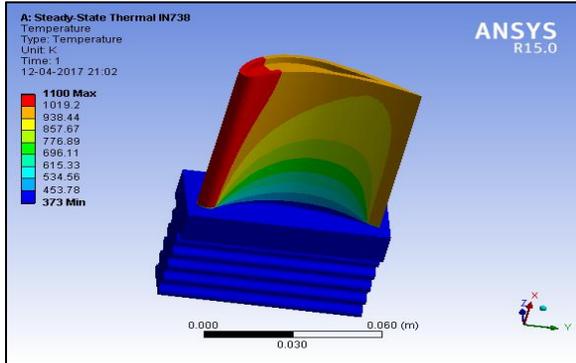


Fig:5 Temperature distribution in IN738.

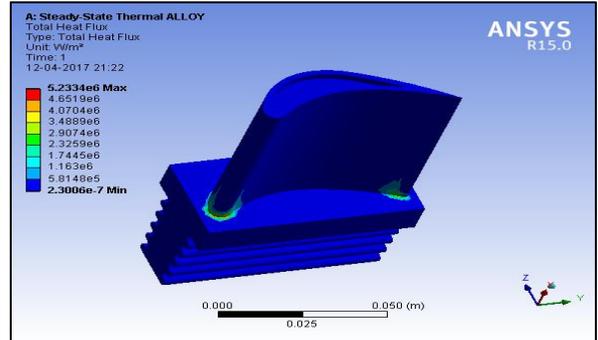


Fig:9 Heat flux distribution in RENE41.

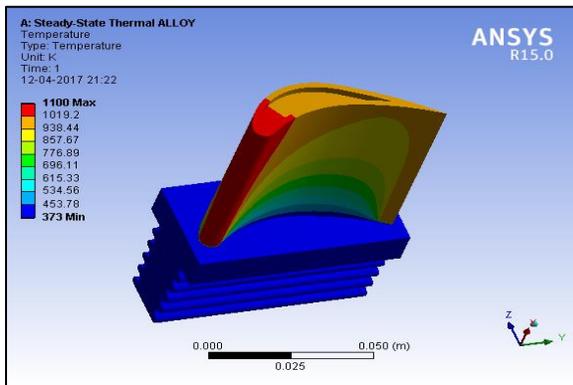


Fig:6 Temperature distribution in RENE41.

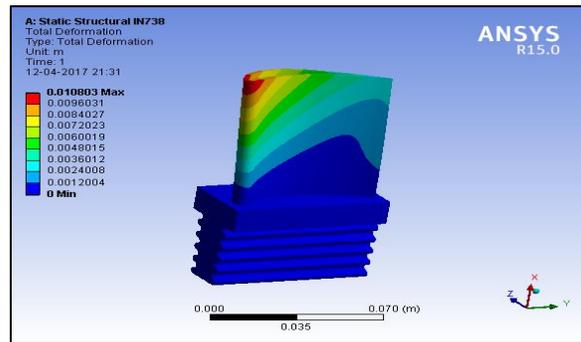


Fig:10 Total Deformation in IN738.

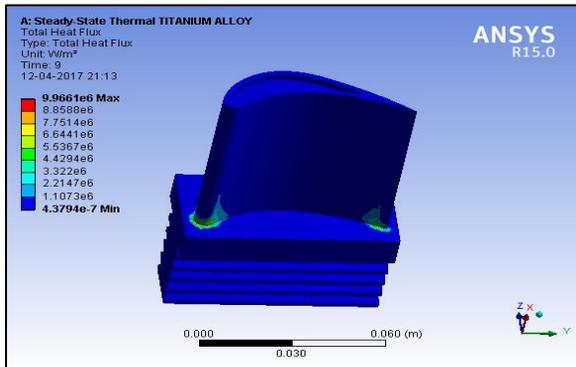


Fig:7 Heat flux distribution in Titanium alloy.

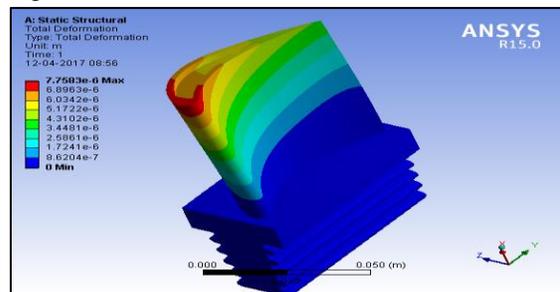


Fig:11 Total Deformation in RENE41.

Structural Analysis

The Von Mises stresses distribution is analyzed and are shown in the fig. 13 and 14. The stresses induced at the blade outer edge are very high.

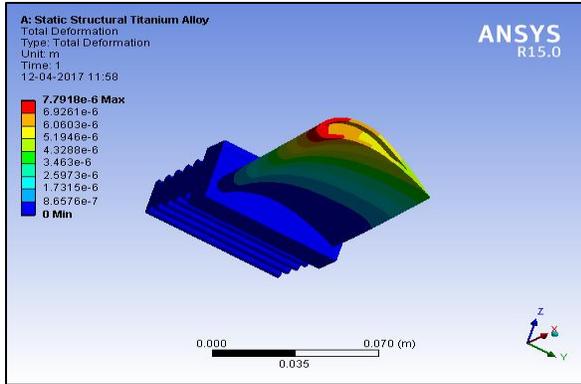


Fig:12 Total Deformation in Titanium Alloy.

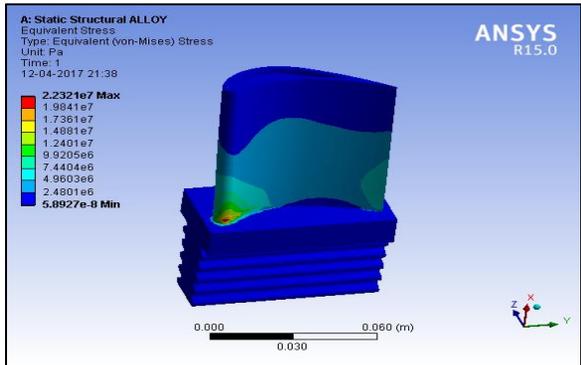


Fig:13 Equivalent (Von Mises) Stress in RENE41.

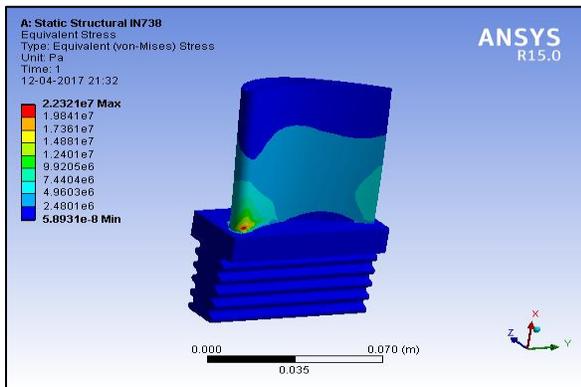


Fig:14 Equivalent (Von Mises) Stress in IN738.

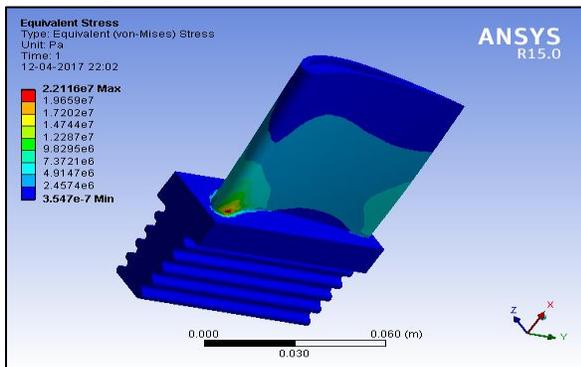


Fig:15 Equivalent (Von Mises) Stress in Titanium Alloy.

V.RESULTS

The deformation of the blade with the height is studied and the titanium have very less deformation and is shown in Fig. 17. The stress distribution is compared from the FEM analysis for all three materials and has shown the very consistent stresses induced in the height of blades and are shown in fig. 18.

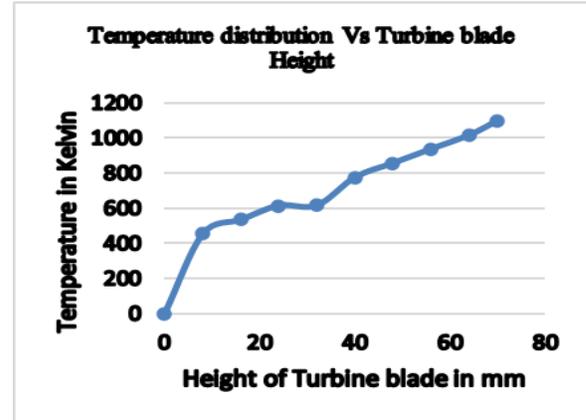


Fig:16 Temperature distribution

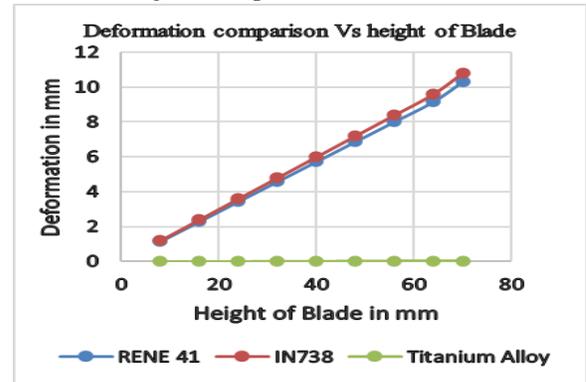


Fig:17 Deformation Vs Height of Turbine blade.

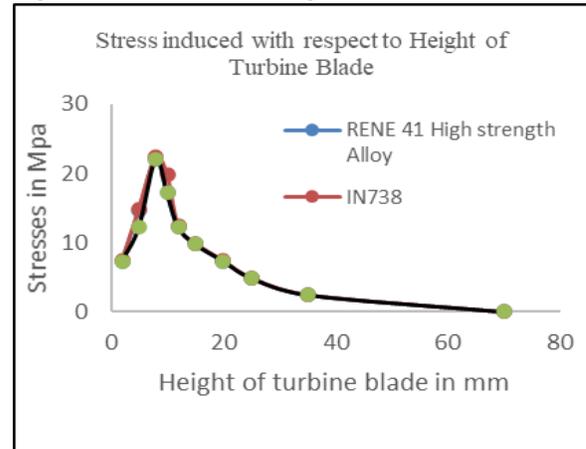


Fig:18 Stress distribution with respect to height of the turbine blade.

Thermal Analysis results

From the FEM thermal analysis, it is found out that temperature distribution is uniform in all materials, whereas maximum heat flux in case of titanium alloy is minimum in IN738. The stress distribution highest value is noted in the Table 1.

Table:1 Thermal Analysis Results.

Property	Titanium Alloy	IN 738	High stress (MPa) Alloy RENE 41
Temperature distribution	Uniform	Uniform	Uniform
Total heat flux(W/mm ²) maximum	9.96	5.18	5.23
Total heat flux(W/mm ²) minimum	0.437	0.228	0.230

Structural Analysis results

After performing structural analysis, it is seen that the maximum deformation is found out in IN738 alloy whereas the new material RENE41 shows less deformation than IN738, however titanium deformed least when compared among them. During equivalent (Von Mises) elastic stress analysis the maximum value of stress induced is found out in IN738 and High Stress Alloy RENE41 are shown in Table 2.

Table:2 Structural Analysis Results.

Property	Titanium Alloy	IN 738	High stress Alloy RENE 41
Total deformation(mm)	0.002	10.80	10.30
Equivalent Elastic stress(N/mm ²) maximum	19.65	22.32	22.32
Equivalent Elastic stress (N/mm ²) minimum	0.35	0.058	0.058

VI.CONCLUSION

In this paper, the analysis of three different materials Ti, IN738, and RENE41 are tested for thermal and structural analysis. The maximum induced stress in

titanium alloy obtained after the analysis through ANSYS is found that 2.2% of Young’s Modulus of Titanium alloy, which is minimum of all the materials selected and obtained after the analysis supports to the original behavior of industrial gas turbine through thermal and structural analysis of turbine. It is also found that titanium alloy is most promising element among all the turbine blades. Finite Element Method is found best suitable method for the analysis of complex and miniature details like in case of gas turbine blade.

REFERENCES

- [1] “William Wiberg and Nicholas Anton” Aerodynamic design of a gas turbine rotor blade for the KTH test turbine.
- [2] “Prof. Satish V. Kailas” Material Science for high temperature creep failure.
- [3] “PK Nag” Engineering Thermodynamics referred for properties of gas.
- [4] “I.H Johnson and Dianne Smart”An experiment in Turbine Blade Design by Ministry of technology aeronautical research council current papers.
- [5] “P. Brandão. V. Infante” A.M. Deus. Thermo-Mechanical modelling of a High-Pressure Turbine Blade of an Airplane Gas Turbine Engine.