Gas Turbine Blade Design and Analysis

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Abstract— Turbine blades play a major role in various sectors of the energy production units such as thermal power plants, hydraulic power plants, gas turbine power plants, wind energy power generation plants and in the aviation sector to propel the vehicles, etc. Development of these turbine blades reached to a matured technology level yet the development of turbine blades specifically in the field of gas turbines is at a constant pace. This is because of the complexities faced in the modeling of the blade which will directly interact with the flames from the combustion chamber in which high temperature and pressure exist. Due to this high temperature and pressures in the combustion chamber of the gas turbine and the direct exposure to the flames, the blade faces stress corrosive cracking and reduced life span if we increase the operating conditions such as temperature and pressure. But in order to achieve high efficiency, the turbine should work at supercritical conditions i.e., the temperature of the working fluid should be greater or equal to 6000 C (T≥ 6000 C). This paper aims at modeling a gas turbine blade which works at super-critical operating conditions using the alloys Ti-6Al-4V and the Alloy 1.2367. The results obtained after the simulation process on gas turbine blade with the alloys Ti-6Al-4V and the Alloy 1.2367 are compared and conclusions are stated. The modeling of the gas turbine blade is done in Solidworks Part Design and the simulations and analysis are performed using Solidworks Simulation.

Key words: Alloy 1.2367, Ti-6Al-4V, Super-critical, Simulations, Solidworks

I. Introduction

Applications of the gas turbine in the field of power generation units and in the aviation sectors are increasing day by day. Many types of research, experiments, review, and evaluations are taking place in order to increase the efficiency of the gas turbine, to reduce the production cost in manufacturing its components, to increase the life span of the gas turbine and its components and metallurgy involved its production.

The modeling of the gas turbine blades is really a complex quest to solve a small change in its profile design reduces the lift caused by the turbine blade which reduces the performance of the complete gas turbine unit. Due to all these challenges faced in its design, the development in the gas turbine blades is limited.

In this paper, detailed process for the modeling of the gas turbine blade which can be installed and used in the gas turbines of in the supercritical gas turbine power plants and the aviation vehicles are discussed. The analysis procedure for the designed gas turbine blade using the alloys Ti-6Al-4V and the Alloy 1.2367 are also stated.

II. Governing Theory

The strategy utilized as a part of the geometric simulations of design in Solidworks Simulation is the Finite Element Analysis (FEA). Finite Element Analysis utilized as a part of simulation software or solvers, for the most part, includes three stages. They are as per the following:

A. Pre-processing:

In this progression, the finite element mesh for the designed model is produced and boundary conditions, material properties, and loads are applied to the composed model.

B. Solution:

In this progression, the solutions for the problems for the given loads and boundary conditions. The outcomes, for example, Von Mises stress, displacements, strain, thermal impacts, and so on. are acquired in this progression.

C. Post-processing:

In this progression, the results are pictured as contours, deformed shapes, and plots. This progression helps in the investigating, confirmation and approval of results.

III. Material Properties

Materials which can sustain at high temperatures and pressures and are resistant to corrosiveness are used in this project. The two alloys used in the project are as follows:

- Ti-6Al-4V
- Alloy 1.2367

The properties of the alloys Ti-6Al-4V and the Alloy 1.2367 are stated in Table 1.

Properties	Ti-6Al-4V	Alloy *1.2367*
Yield strength	8.27371 e+008 N/m^2	2.12e+009 N/m^2
Tensile strength	1.05e+009 N/m^2	2.12e+009 N/m^2
Elastic modulus	1.048e+011N/m^2	2.15e+011 N/m^2
Poisson's ratio	0.31	0.28
Mass density	4428.78 kg/m^3	7850 kg/m^3
Shear modulus	4.10238 e+010 N/m^2	7.9e+010 N/m^2
Thermal expansion coefficient	9e-006 /Kelvin	1.1e-005 /Kelvin

Table 1:

IV. Methodology

Using Solidworks part design the gas turbine blade is modeled and the simulation studies are carried out in Solidworks Simulation.

A. Gas Turbine Blade Design:

The gas turbine blade is designed using the sketch tools and the sketch features in the Solidworks Part Design.

The dimension of the modeled gas turbine blade is shown in Figure 1. The dimensions in the figure1 are in inches.

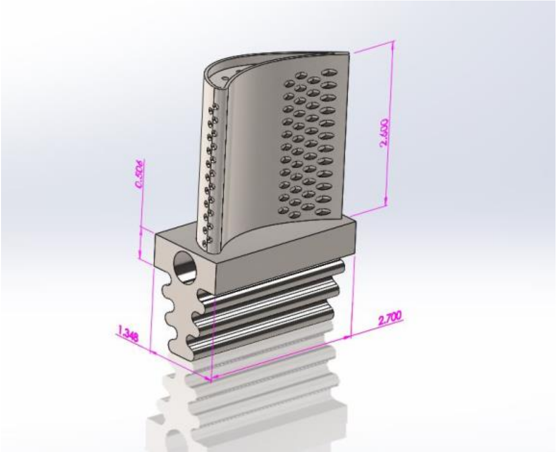


Fig. 1: Gas Turbine Blade Isometric View

Figure 2 Shows the wire frame model of the gas turbine blade

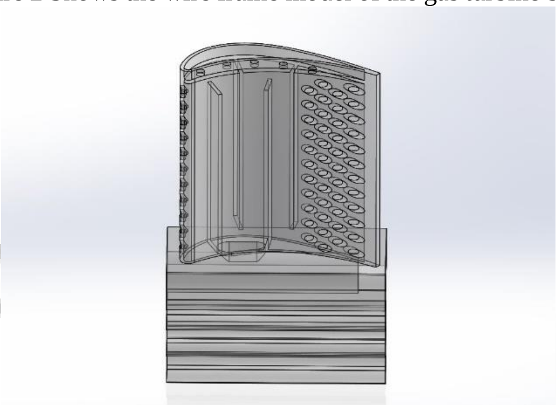


Fig. 2: Gas Turbine Blade Wire Frame Model

B. *Volumetric Properties of Gas Turbine Blade:*

Gas turbine blade volumetric properties using the alloys Ti-6Al-4V and the Alloy 1.2367 are shown in Table 2.

Design With Alloy	Mass (kg)	Volume (m^3)	Density (kg/m^3)	Weight (N)
Ti-6Al-4V	0.296486	6.69453 e-005	4428.78	2.90556
Alloy 1.2367	0.52552	6.69453e-005	7849.99	5.15009

Table 2

C. *Meshing Information of Gas Turbine Blade:*

In the analysis process meshing of the gas turbine blade is done using finite element analysis. The meshing information of gas turbine blade analyzed using the alloys Ti-6Al-4V and the Alloy 1.2367 are shown in Table 3.

Mesh Details	Ti-6Al-4V	Alloy 1.2367
Mesh type	Solid mesh	Solid mesh
Mesh Element Type	Tetrahedron	Tetrahedron
Jacobian points	4	4
Element Size	0.0799562 in	0.0799562 in
Tolerance	0.00399781 in	0.00399781 in
Total Nodes	113490	113490
Total Elements	68309	68309
Maximum Aspect Ratio	18.477	18.477

Table 3:

V. RESULTS AND DISCUSSIONS

The analysis of gas turbine blades gives the results such as Von Mises Stress, Displacements, and Strain. The obtained results are as follows:

A. *Gas Turbine Blade Results:*

In the study conducted on the gas turbine, the applied load value is equal to mg which is the weight of the gas turbine blade. Here m is total mass of the gas turbine blade and g is acceleration due to gravity. The pressure load is applied normal to the walls of the gas turbine blade profile. Fixed supports at the base of the gas turbine blade since they will get fitted in the gas turbine rotor. The results of the gas turbine blade analysis in the study using the alloys Ti-6Al-4V and the Alloy 1.2367 are shown in Table 4, Table 5, and Table 6.

The analysis criterion and the test conditions are:

The gas turbine blade has mass m_1 = 0.296486 kg when analyzed with Ti-6Al-4V and m_2 = 0.52552 kg when analyzed with the Alloy 1.2367. Acceleration due to gravity which is equal to g = 9.8 m/s^2 causes the load L_1 = 2.90556 N when analyzed with Ti-6Al-4V and L_2 = 5.15009 N when analyzed with the Alloy 1.2367. Pressure load of P = 6 Mpa is used on the outer surfaces of the gas turbine blade Temperature load of T = 600^0 C is used in both the cases.

Von Mises stress failure criterion and URES Displacement criterion is used in the study.

Design With Alloy	Von Mises Stress (min)	Von Mises Stress (max)
Ti-6Al-4V	3.206e+002 N/m^2	2.431e+009 N/m^2
Alloy 1.2367	7.508e+003 N/m^2	2.062e+009 N/m^2

Table 4:

Design With Alloy	Displacement (min)	Displacement (max)
Ti-6Al-4V	0.000e+000 mm	2.554e+000 mm
Alloy 1.2367	0.000e+000 mm	1.212e+000 mm

Table 5:

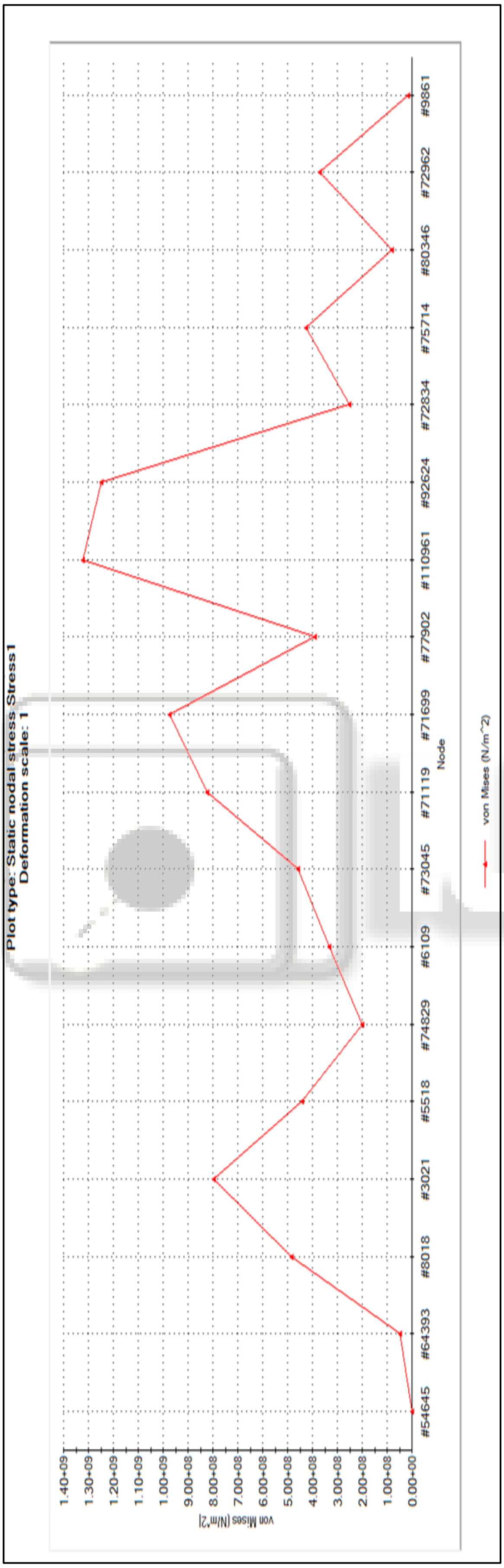
Design With Alloy	Strain (min)	Strain (min)
Ti-6Al-4V	2.518e-009	1.556e-002
Alloy 1.2367	3.518e-008	8.355e-003

Table 5:

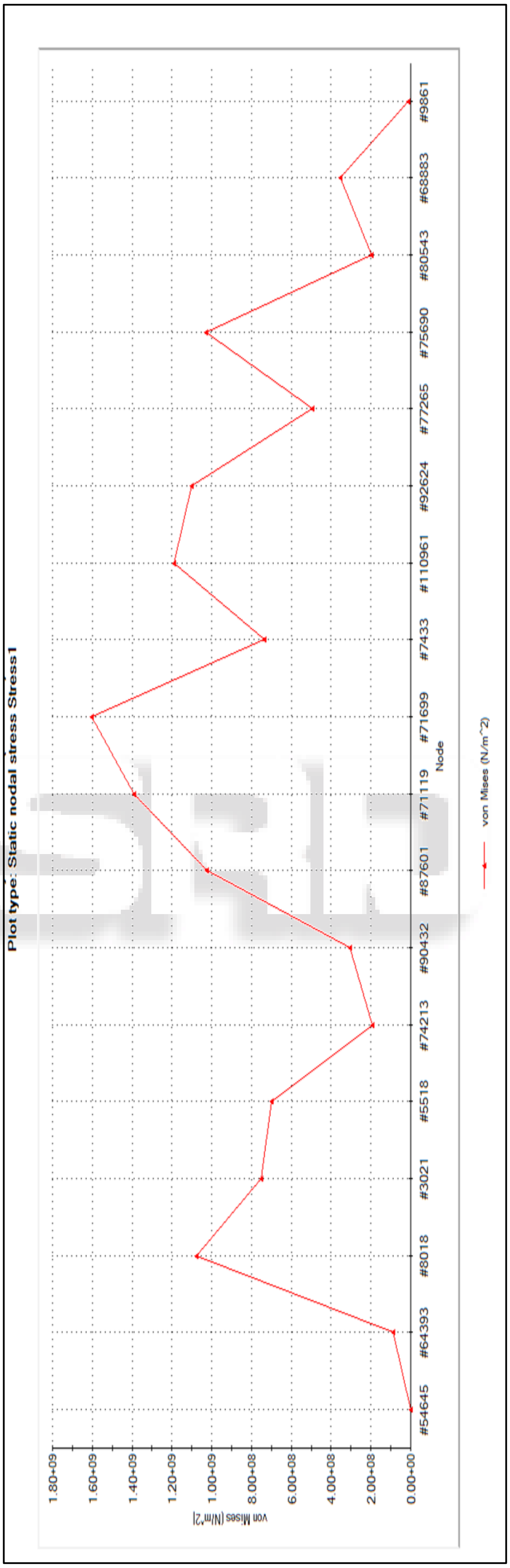
B. *Gas Turbine Blade Results Plots:*

Using the probe tool, the Von Mises Stress is plotted against nodes. The plots show the variation of Von Mises stress at different nodes.

The Von Mises plot for gas turbine blade using the alloy Ti-6Al-4V and the Alloy 1.2367 are shown in Graph 1 and Graph 2.



Graph 1: Von Mises Stress



Graph 2: Von Mises Stress

C. Surface Plots of Gas Turbine Blade Results:

The surface plots show the variation of results on the surface of the gas turbine blade. The surface plots are also called as contours.

1) Analysis with Ti-6Al-4V alloy:

Figure 3, Figure 4 and Figure 5 shows the surface plots of gas turbine blade when analyzed with the Ti-6Al-4V alloy.

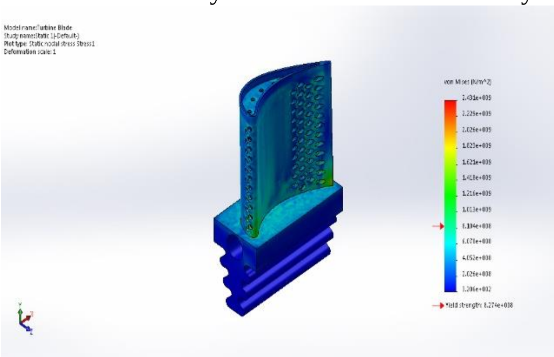


Fig. 3: Von Mises Stress

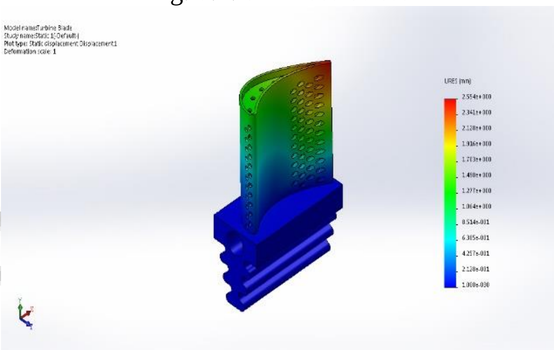


Fig. 4: URES Displacement

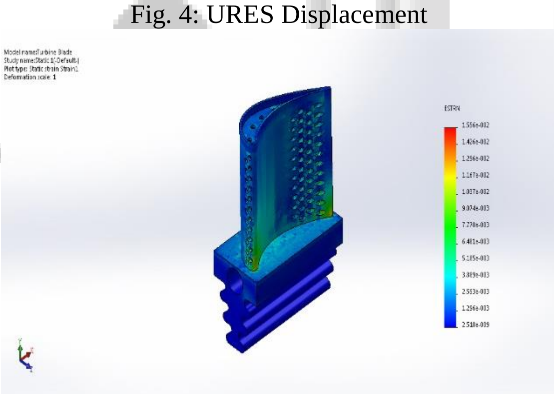


Fig. 5: Strain

2) Analysis with the Alloy 1.2367:

Figure 6, Figure 7 and Figure 8 shows the surface plots of gas turbine blade when analyzed with the Alloy 1.2367.

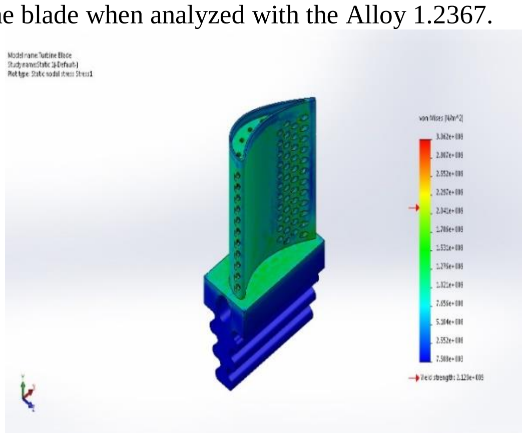


Fig. 6: Von Mises Stress

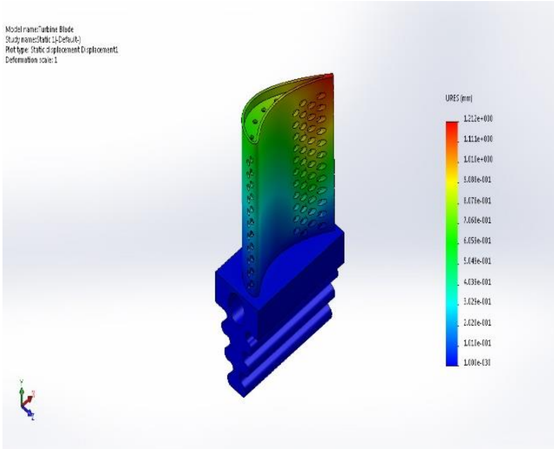


Fig. 7: URES Displacement

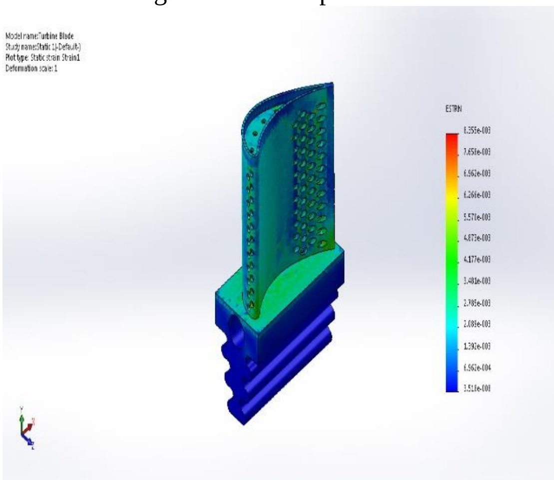


Fig. 8: Strain

3) Results Interpretation:

The gas turbine blade is successfully designed. We can see from the above results that the gas turbine blade designed with the Alloy 1.2367 able to sustain the supercritical thermal conditions. Therefore, the aim of the thesis is achieved.

VI. CONCLUSION

Using Solidworks Simulation package, the modeled gas turbine blade is tested under real working conditions from the study we can observe that:

1) the minimum and maximum values of Von Mises stress for Static studies the alloys Ti-6Al-4V and the Alloy 1.2367 vary in both the studies. In 1 study, the Alloy 1.2367 has the least maximum Von Mises Stress value 2.062e+009 N/m^2 which is less than the values of Ti-6Al-4V, 2.431e+009 N/m$^{2.}$ In this case, Alloy 1.2367 is superior compared to Ti-6Al-4V.
2) But from the study conducted we can observe that the maximum Von Mises stress value of gas turbine analyzed with Ti-6Al-4V is greater than its yield strength. Therefore, the turbine blades fail at the operating conditions.
3) On the other hand, we can observe that the maximum Von Mises stress value of gas turbine analyzed with the Alloy 1.236 is less than its yield strength. Therefore, the turbine blades work successfully at the operating conditions.

Therefore, the study gives the following conclusions that Alloy 1.236 can be used in the gas turbines at supercritical thermal conditions which can sustain for a long period of time even under the optimum working conditions.

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