

Structural and Thermal Analysis of Gas Turbine Blade with Different Alloy Materials

D. Pratap Reddy, PG student
Department of Mechanical Engineering
CMR Engineering College
Pratapreddy364@gmail.com

K.S Reddy, Professor
Department of Mechanical Engineering
CMR Engineering College
dean.cmrec@gmail.com

Abstract: In present days' efficiency plays a vital role in power generating applications like thermal industries, especially in marine applications. Actually the stage one turbine buckets tends to many failures like cracks due to heavy thermal stresses. So the main objective is to reduce these stresses and to improve the ability of turbine blade material by selecting alloy materials. In this work, structural and thermal analysis is carried out for the gas turbine blade, which is used in aero plane and marine application for power generation and propelling. The alloy materials studied in present work for gas turbine blades are titanium alloy, super alloy and Mnemonic alloy etc.

The modeling is done in CATIAV5R20 and analysis is done using FEM ANSYS 16.0 software. The deformation occurring in three directions and the total deformation is analyzed in structural analysis. In case of

thermal analysis, the temperature distribution and heat fluxes are studied

As per thermal and structural analysis using ANSYS simulation, Titanium alloy is having high thermal stress, Super alloy is having medium thermal stress and Mnemonic alloy is having least thermal stresses. Mnemonic alloy is seen to have less thermal stresses and good structural strength. Hence the Mnemonic alloy is best suited for turbine blade design applications in a conventional manner to increase the power generation in marine applications.

1. Introduction

A turbine is a rotary mechanical device that extracts energy from a fluid flow and converts it into useful work. A turbine is a turbo machine with at least one moving part called a rotor assembly, which is a shaft or drum with blades attached. Moving fluid acts on the blades so that they move and

impart rotational energy to the rotor. A working fluid contains potential energy (pressure head) and kinetic energy (velocity head). The fluid may be compressible or incompressible. Several physical principles are employed by turbines to collect this energy.



Figure 1: Gas turbine blade

A turbine blade is the individual component which makes up the turbine section of a gas turbine. Figure 1 shows a typical Gas turbine rotor with blades. The blades are responsible for extracting energy from the high temperature, high pressure gas produced by the combustor. The turbine blades are often the limiting component of gas turbines. To survive in this difficult environment, turbine blades often use exotic materials like super alloys and many different methods of cooling, such as internal air channels, boundary layer cooling, and thermal barrier

coatings. So for this application the gas turbine blade must be casted with a material which has very good chemical and physical properties. One of such type of materials is Super Alloy. Super Alloy is combination some materials to increase the material properties.

2. Literature Review

V.Veeraragavan.et.al (1) had mainly done the research on the aircraft turbine blades, his specific focus was on 10 C4/60 C50 turbine blade models. He had used various conventional alloys such as Molybdenum, zirconium, super alloys and Titanium for the analyzing the temperature resistance capability. He concluded that the Molybdenum alloys had better temperature resistance capability than the other three metal alloys.

N. Vasudevarao and RDV Prasad had studied different types of the cooling technique which maintain temperature of the blade to allowable limits. Finite analysis was used to examine the steady state thermal and structural performance for N155 and Inconel 718 Nickel-Chromium alloys. Actually four different models consisting of blades with

varying number of holes 5, 9 and 13 holes were analyzed to find out the optimum number of cooling holes. They had used two materials, they are Inconel 155 and Inconel 718. They found that the two materials which were used for analyzing has better thermal properties as the blade temperatures and the stress induced is lesser.

C.J Manjunath.et.al had done design and stress analysis on a gas turbine blade of a jet engine. He used new materials for analyzing and those are Inconel 718 and titanium T6. His attempt has made us to investigate the effect of temperature and induced stresses on the turbine blade. He carried out a thermal analysis to investigate the direction of the temperature flow which is developed due to thermal loading. He had also done the structural analysis to study and investigate the stresses, shear stress, displacements and various loads acting on the turbine blade. The temperature distribution of the blade depends on the thermal conductivity of the material and the heat transfer coefficient for gases. His analysis was carried out for steady state heat transfer conditions.

He observed that that the maximum temperatures were prevailing at the leading edge of the blade due to the stagnation

effects. The temperature of the blade body doesn't vary much in the radial direction. Therefore the temperature falls from the leading edge to the trailing edge. The solid model of the Inconel 718 attained lower blade temperatures marginally. This can be specified that the Inconel 718 has lower thermal conductivity. He also observed that the thermal expansion of titanium T6 is lesser as compared to that of Inconel 718.

S. Gowreesh studied on the first stage rotor blade of a two stage gas turbine has been analyzed for thermal, structural and modal analysis using ANSYS 11.0. He had evaluated the temperature distribution in the turbine rotor blade. The design features of the turbine segment of the gas turbine have been taken from the preliminary design of a power turbine for maximization of an existing turbo jet engine. He had done a detail study on the temperature effects to have a clear understanding of the combined mechanical and thermal stresses.

V. RagaDeepu and R.P Kumar Ropichrla Studied on a Gas turbine. The turbine blades are mainly affected due to static loads. Also the temperature has significant effect on the blades. Therefore the coupled (static and thermal) analysis of

turbine blades is carried out using finite element analysis software ANSYS. In this paper the first stage of rotor blade of the gas turbine is created in CATIA V5 R15 Software. This model has been analyzed using ANSYS11.0. The gas forces namely tangential, axial were determined by constructing velocity triangles at inlet and exist of rotor blades. After containing the heat transfer coefficients and gas forces, the rotor blade was then analyzed using ANSYS 11.0 for the couple field (static and thermal) stresses.

3. Selection of Materials

The Selection of materials is necessary to analyze a material. By this process we come to a clear conclusion that which material has better physical and chemical properties. Three materials have been selected for the analysis procedure and they are mnemonic 80a, super alloy and titanium aluminum alloy. The best material which has ability to withstand structural and thermal loads is preferred. Desired performance achieved through the selection of materials best suited to particular applications. A material should be selected based on its cost, availability and properties. We have the advanced analytical techniques to determine fundamental

properties, characteristics and behavior of various alloys. Its integrity should be tested by conducting the destructive and non-destructive test methods.

Materials Chosen

1. Mnemonic 80 A
2. Super alloy grade X
3. Titanium Aluminum alloy

Table 1: Properties of Materials

Properties	MNEMONIC 80A	SUPER ALLOY GRADE X	TITANIUM ALLOY
Young's Modulus (GPa)	222	160	110
Density (kg/m ³)	8190	9000	4810
Poisson's Ratio	0.35	0.3	0.3
Thermal Conductivity (W/mK)	24.5	22	8.4
Thermal Expansion (c)	16.2e ⁻⁶	10e ⁻⁶	9.4e ⁻⁶

The above table shows the properties of materials which under the structural and thermal analysis.

4. Blade Design Parameters

Inlet flow angle	$\alpha = 18^{\circ}$
Inlet blade angle	$\theta = 45^{\circ}$
Outlet flow angle	$\beta = 36.75^{\circ}$
Outlet blade angle	$\phi = 13^{\circ}$
Diameter of blade mid spam	$= 0.15 + .60 = .75 \text{mm}$
Design speed of turbine	$N = 4500 \text{ rpm}$
Blade velocity	
$V_{bl} = (\pi * D * N) / 60 = 176.714 \text{ m/s}$	
Inlet flow velocity	$V_1 = 360 \text{ m/s}$
Inlet relative velocity	$V_{r1} = 234.28 \text{ m/s}$
Inlet whirl velocity	$V_{w1} = 342.380 \text{ m/s}$
Inlet flow velocity	$V_{f1} = 111.246 \text{ m/s}$
Outlet relative velocity	$V_{r2} = 234.28 \text{ m/s}$
Outlet whirl velocity	$V_{w2} = 51.561 \text{ m/s}$
Outlet flow velocity	$V_{f2} = 52.701 \text{ m/s}$

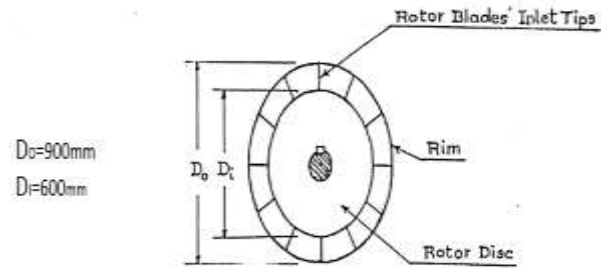


Figure 2: Specifications of rotor

Figure 2 shows the various parts in the rotor of the gas turbine blade. Where D_o represents the outer diameter of the rotor and D_i represents the internal diameter of the rotor.

5. Simulation Methodology

The model which was created in the CATIA V5 R20 is imported to the ANSYS 16.0 software. The engineering data is given as the input for the analysis procedure. The properties of the materials are added to the software because not all the metals are available in the software.

Now considering the geometry of the blade, meshing is done for the entire gas turbine blade. Fine meshing is chosen among course and medium meshing because it based on grid sensitivity studies. The boundary conditions like force, pressure and fixed support have been applied for the blade. To define a model that results in unique solution, we have to specify

information on the dependant variables at the domain boundaries.

6. Results and Discussion

In the Structural analysis of the blade stress distribution and the deformation along x direction, y direction and z direction is analyzed. Finally the total deformation is also analyzed. When coming to the thermal analysis, the temperature developed on the turbine blade is observed, the directional heat flux along x direction, y direction and z direction is analyzed. The total heat flux developed throughout the blade is analyzed. A fixed support has to be taken on the blade, so the base element which is connected to the blade is taken as the fixed support. The front side of the Mnemonic blade material faces the pressures from bottom to the top. The force acted on the turbine blade is 17836 N.

Basically the root of the blade has more strength when compared to the free end of the blade. When we start applying the loads, slowly the pressures begin affecting on the three corners of the blade i.e bottom left, bottom right and top left. Due to the continuous equivalent stresses or von-misses

stress acting on the blade stresses slowly increases on top right corner of the blade.

The deformation limit of the blade for equivalent stresses is between 0 to $4.9303e^8$ Pa. While coming to the directional deformation we are considering x-axis and y-axis.so when we consider the x-axis direction the stresses uniformly increases from the root to the free end of the blade.

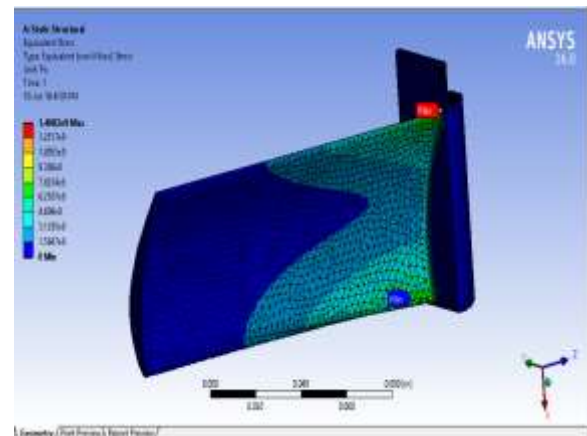


Figure 3: Von-mises stress of Mnemonic Alloy.

When Von-mises stress induced in the material is greater than the yield strength of the material then the material fails. The Mnemonic Alloy material can bear the load of $1.4082e^9$ Pa. The Fig 3 shows the stress induced in the Mnemonic Alloy Blade.

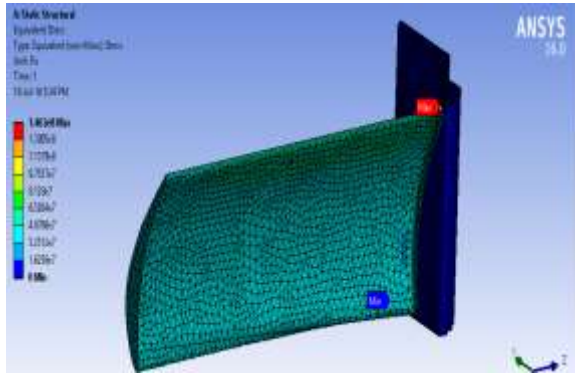


Figure 4: Von-mises stress of Super Alloy

The Super Alloy material has the ability to withstand the load of 1.4082×10^8 Pa. The Fig 4 represents the effect of Von-mises stress acting on the Super alloy Gas turbine Blade.

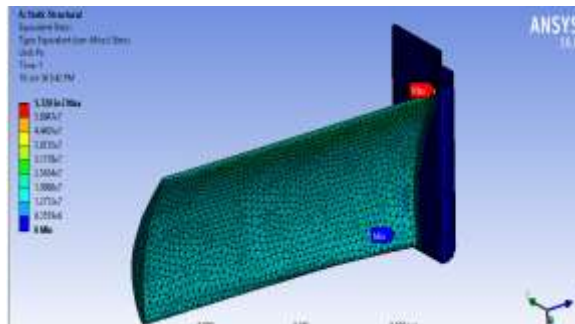


Figure 5: Von-mises stress of Titanium Alloy.

The maximum stress the titanium Alloy can withstand is 5.7203×10^7 Pa. The intensity of the pressures that the blade is undergoing is indicated through the colors. The Von-mises stresses acted on the blade are indicated in the Fig 5. In this process it is seen that the

trailing edge or the bottom left corner of the blade is more tended for the deformation.

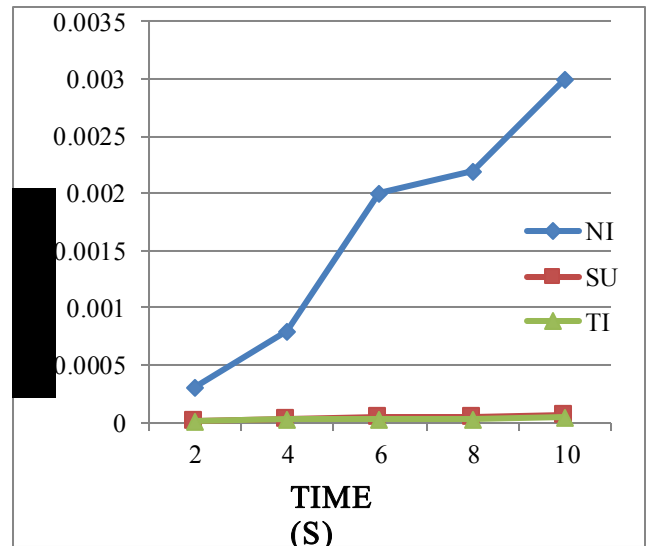


Figure 6: Stress comparison of three materials

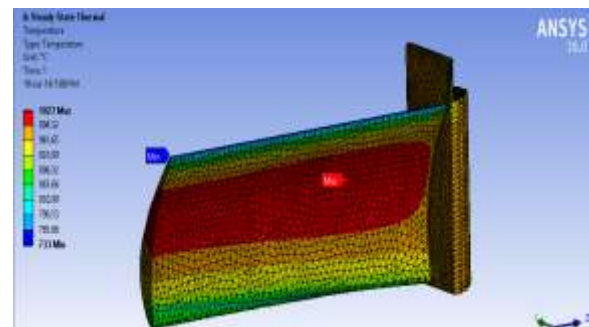


Figure 7: Temperature of Mnemonic Alloy

Figure 7 shows the temperature of the Mnemonic Alloy. In the steady state thermal condition, the temperature developed on the mnemonic alloy material is 1027°C .

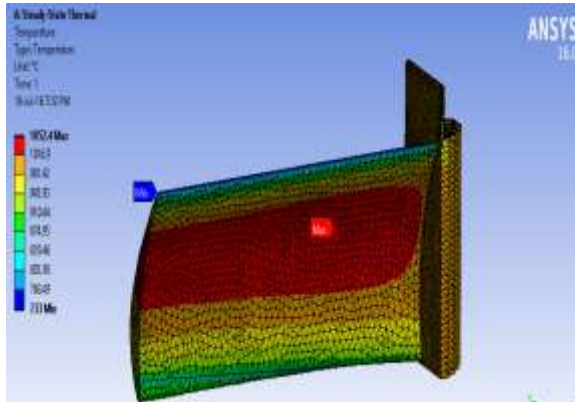


Figure 8: Temperature of Super alloy

The temperature distribution of the super alloy is shown in Fig 8. The maximum temperature developed on the super alloy material is 1052⁰C.

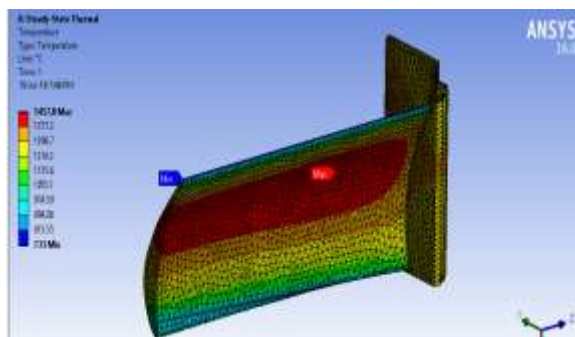


Figure 9: Temperature of Titanium

The temperature developed on the Titanium Alloy is shown in the Fig 9. High thermal stress developed on the Titanium Alloy. The temperature of the titanium aluminum blade is 1457.8⁰C.

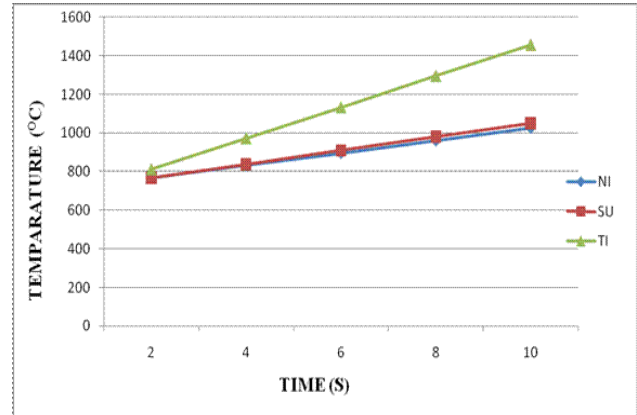


Figure 10: Temperature comparison of three elements

The above graph represents the temperature of all the three elements at different time intervals. It is observed that the Titanium Alloy has high thermal stresses than the other two elements. The Mnemonic alloy has low thermal stress acting on it than Super Alloy and Titanium Alloy.

Table 2: Obtained Stresses

MATERIALS	STRESSES	
	MAX VALUE (N/mm ²)	MIN VALUE (N/mm ²)
Mnemonic 80 A	1.4082e ⁹	0
Super Alloy	1.463e ⁸	0
Titanium Alloy	5.7203e ⁷	0

From Table 2, the von-mises stresses acted on the three different alloy materials are shown. The material which can bear high von-mises stress is Mnemonic Alloy. That means the yield strength of the mnemonic alloy is much higher than other two material. The following material which can bear medium stress is Super Alloy.

Table 3: Temperature

MATERIALS	Temperature	
	MAX (°C)	Min(°C)
Mnemonic 80 A	1027.1	732.24
Super alloy	1057	732.16
Titanium Alloy	1432	730.89

The temperature developed on the three different alloy materials is shown in the Table 3. High thermal stresses are developed on the Titanium Alloy. The best alloy material which is suitable is mnemonic alloy because low thermal stresses are developed on that blade.

7. Conclusion

The Mnemonic Alloy, Super Alloy and Titanium alloys of gas turbine blade have

undergone the structural analysis and thermal analysis. From the analysis on these three elements, we came to a conclusion that the Titanium Alloy has high thermal stresses and it couldn't with stand at high structural loads. The cost of this alloy is not reasonable than other two elements. The deformation of Titanium Alloy is not at a satisfactory level. The Super alloy has medium stress and its results are acceptable. Some grades of super alloy like haste alloy are used in present day applications. Super Alloy is having good mechanical strength and also resistance to thermal creep deformation.

Now finally the Mnemonic Alloy is the material which is better than the Super Alloy because it has good resistance to withstand high structural loads and pressures.

The thermal stresses acting on the mnemonic turbine blade is low comparatively than other two materials. It is a combination of Nickel, Chromium and various sub elements, so it is easily available material. The ultimate tensile strength is this material is high. Finally Mnemonic Alloy is the material is best to opt and suitable to work at safer conditions.

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