Steady State Thermal Analysis of Gas Turbine Blade

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Abstract- *Gas turbines are used extensively for aircraft propulsion, power generation and industrial applications. In recent years, there has been an increased interest in the design and analysis of critical components in gas turbines. Rotor blade is the very critical component in the field of turbo machines. The stress and displacement analysis of the rotor blade of any turbo machine in the field of design played a very important role.*

The current project deals with the structural thermal analysis of the Gas turbine blade to investigate the thermal stresses and the heat distribution on a turbine blade to obtain the optimized condition analysis of the turbine blade is done with 3 different materials out of these three which is the better material to decide based of the temperature distribution the three materials are inconel625 , steel and nimonium.

Keywords- gas turbine , Thermal , Inconel , Nimonium Turbine , Blade

I. INTRODUCTION

The major cause of break down is due to different loadings such as fluid or gas forces, inertia load, centrifugal forces are acting on the turbo machines rotor blades Hence, the proper mechanical design of the turbo machine blade plays an important role in the proper functioning of the turbo machine.Finite element analysis is used to calculate the stresses for complex geometry of rotor blades. The stress analysis is performed to determine the critical section as well as the stressing pattern.

I(a) The finite element method

The finite element method has become a powerful tool for the numerical solution of a wide range of engineering problems. Applications range from deformation and stress analysis of automotive, aircraft, building, and bridge structures to field analysis of heat flux, fluid flow, magnetic flux, seepage, and other flow problems.

The finite element method includes with three basic features that account for its superiority over other competing methods:

- Geometrically complex domain of the problem is represented as a function of geometrically simple sub domains called “finite elements”.
- Over each finite element the approximation, functions are derived using the basic idea that any continuous function can be represented by a linear combination of algebraic polynomials.
- Algebraic relations among the undetermined co efficient are obtained by satisfying the governing equation often in a weighted integral sense over each element.

I(b) GAS TURBINE AND THEIR COMPONENTS

Gas turbine is a rotating internal combustion engine, which takes air from the atmosphere and compresses it to high pressure in a compressor and the compressed air flows into the combustion chamber, where fuel is admitted and ignited with the help of a spark plug, the products of combustion are used as a working fluid for developing power in the turbine section of the gas turbine.

I(c)Working principle of gas turbine

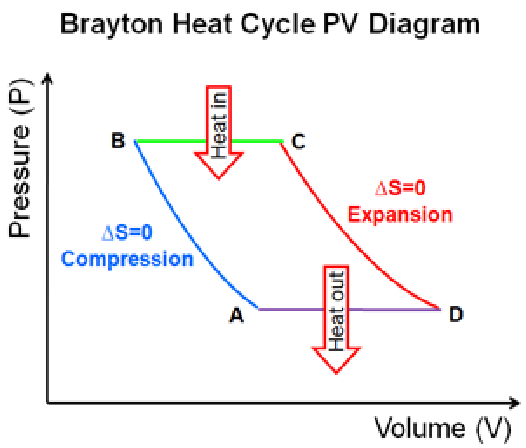


Figure 1. Indicator diagram of gas turbine

1-2 isentropic compression (in a compressor)
2-3 Constant pressure heat addition
3-4 isentropic expansion (in a turbine)
4-1 Constant pressure heat rejection (cooling process)

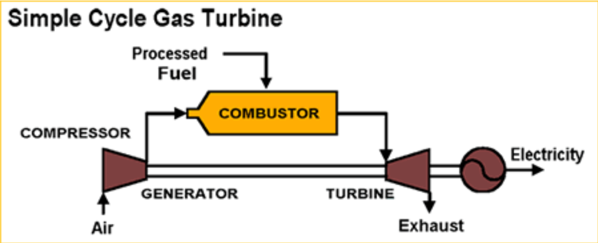


Figure 2. Simple open cycle gas turbine

The key components are:

The Compressor
The Combustor and
The Turbine

Compressor usually sits at the front of the engine. There are two main types of compressor, the centrifugal compressor and the axial compressor. The compressor will draw in air and compress it before it is fed into the combustion chamber, to obtain the required high pressure. The turbine drives the compressor so it is coupled to the turbine shaft.

The combustor module contains the combustion chambers, igniter plugs, and fuel nozzles. It burns the fuel-air mixture and delivers the products of combustion to the turbine at temperatures within design range.

The turbine obtains its power by utilizing the energy of burnt gases and the air which is at high temperature and pressure by expanding through the several rings of fixed and moving blades. The turbine consists of several stages. Each stage comprises of a stationary blow of nozzles where, the velocity of the high energy gases is increased and directed towards a rotating row of buckets (aero foils) attached to the turbine shaft. The high velocity gases impinge on the buckets, converting kinetic energy of gas to shaft power

The rotor blades of the turbo machine are very critical components and reliable operation of the turbo machine as a whole depends on their repayable operation. The major cause of break down in turbo machine is the failure of rotor blade. The failure of the rotor blade may lead to catastrophic consequences both physically and economically. Hence, the proper design of the turbo machine blade plays a vital role in the proper functioning of the turbo machine.

I(d) NEED AND OBJECTIVE: -

The main cause of turbine blade failure is high cycle fatigue. The fatigue life of a structural member i.e. the number of load cycles it can survive is in general determined by the magnitude of the stress cycles. The exact relation between the magnitude of the stress and the fatigue life depends on the material properties of the structural member

In the present work the first stage rotor blade of a two-stage gas turbine has been analyzed for structural, thermal using ANSYS 12, which is a powerful Finite Element Software, for different materials, so as to obtain an optimum blade design, without an actual model making.

I(e) PROBLEM DEFINITION

The present study attempts to understand and analyze the turbine blade subjected to centrifugal forces due to rotational speed and gas forces through Finite Element Modeling with a view to determine the Thermal stresses and displacement for complex geometry of rotor blades. Stress and displacement analysis can be viewed by postprocessor phase

II. LITERATURE REVIEW

Moving blades in the turbine are meant for conservation of the kinetic energy of the flowing gas into the mechanical work on the turbine shell, the work done by working fluid is transmitted to the shaft through the disc on which the blades are mounted. Turbo machine rotor blades are subjected to different types of loading such as fluid or gas forces, inertia loads and centrifugal forces. Due to these forces various stresses are induced in rotor blades. So stress and strain mapping on a rotor blade provide a vital information concerning the turbo machine design and lead to the detection of critical blade section. Analysis of static and dynamic behavior of a rotor blade is a basic problem in aero elasticity of turbo machine blades. The present paper deals with the stress analysis of a typical blade made up of nickel super alloy, which is subjected to centrifugal loading. The analysis results shows that stress is sever due to centrifugal forces, when compared, due to dynamic gas forces. Here in this case the effect of thickness, twist and taper of the blade was considered at the root of the blade where generally failure is occurring. The various blade shapes viz. rectangular, aerofoils with some angle twist, taper aerofoil are taken into consideration. In this paper linear static analysis for determining von mises stresses, deformation in Z direction was determined using Finite element analysis software. The Solid brick 20-node element is used.

Turbine blades operate at speed range 5000 to 15000 r.p.m., with temperature ranging from 50 to 900 degree centigrade. Hence depending on the stage of operation, blading material is usually an AL alloy, stainless steels, titanium alloys and nickel-based alloys. The tolerances on the blades are usually in the range of 0.05 mm to 0.15 mm on the aerofoil. The blades have a complex aerofoil structure and with varying aerofoil shape at different sections along the length of blade. There is always twisting in the aerofoil sometimes of the order 60 degrees. These complex configurations are required as the gases are to be smoothly guided along the different stages of the compressor and turbine without turbulence to achieve maximum thrust from the engine.

Umamaheswararao et al[1]. have investigated the stress distribution and temperature distribution on gas turbine blade and have stated in paper titled "Design and analysis of a gas turbine blade by using FEM". In this paper the first stage rotor blade of a gas turbine has been analysed for structural, thermal analysis using ANSYS (Finite Element Analysis Software). The material used for the blade was specified as INCONEL 718. The thermal boundary conditions applied on the rotor blade are taken from the reference. The temperature distribution across the blade is obtained. The maximum stress up to which the blade can withstand is known and the stress distributions across the blade are obtained accordingly. The obtained results are compared with N-155, Mild Steel and the most suitable material is discussed. In final the actual fir tree model blade root compared with I-section model blade root,

P.V.Krishnakanth et al[2]. have summarized the design and analysis of Gas turbine blade in paper titled "Structural & Thermal Analysis of Gas Turbine Blade by Using F.E.M" in which CATIA V5 is used for design of solid model of the turbine blade with the help of the spline and extrudes options, ANSYS 11.0 software is used analysis of F.E. model generated by meshing of the blade using the solid brick element present in the ANSYS software itself and thereby applying the boundary condition. This project specifies how the program makes effective use of the ANSYS pre-processor to analyse the complex turbine blade geometries and apply boundary conditions to examine steady state thermal & structural performance of the blade for N 155, Haste alloy x & Inconel 625 materials. Finally stating the best suited material among three from the report generated after analysis. From this the results are stated and reported.

Barhm Abdullah Mohamad et al [3]. have worked on paper with title "Failure analysis of gas turbine blade using finite element analysis" related to failure analysis of the turbine blade of a gas turbine engine 9E GE type, installed in a certain type of simple systems consisting of the gas turbine driving an electrical power generator. A non-linear finite element method was utilized to determine the stress state of the blade segment under operating conditions. High stress zones were found at the region of the lower fir-tree slot, where the failure occurred. A computation was also performed with excessive rotational speed. Attention of this study is devoted to the mechanisms of damage of the turbine blade and also the critical high stress areas

Murali. K et al[4] . have worked on the first stage rotor blade of the gas turbine in the paper titled with "Design and Fatigue Analysis of Turbine Rotor Blade by Using F.E.M". The first stage rotor blade of the gas turbine is analysed for the static and thermal stresses resulting from the tangential, axial and centrifugal forces. The gas forces namely tangential, axial were determined by constructing velocity triangles at inlet and exist of rotor blades. The rotor blade was then analysed for the temperature distribution. For obtaining temperature distribution, the convective heat transfer coefficients on the blade surface exposed to the gas have to feed to the software. After containing the temperature distribution, the rotor blade was then analysed for the combined mechanical and thermal stresses and also the fatigue life. Gas turbine is an important functional part of many applications. Reducing the stresses and increasing the fatigue life is the major concern since they are in high temperature environment. Various techniques have been proposed for the increase of fatigue life and one such technique is to have axial holes along the blade span. Finite element analysis is used to analyse thermal and structural performance due to the loading condition, with material properties of N155, NIMONIC 80A & INCONEL 600 We are analysed to find out the optimum number of holes for good performance. Counter plots for stresses for design 7 holes and for fatigue sensitivity it is found that when the number of holes of the blades is increased, the stresses are reduced and no. of Cycles are increased. Thus, the blade configuration with 7 holes of 2mm size is found to be optimum solution. This project specifies how the program makes effective use of the ANSYS workbench pre-processor to analysis the complex turbine blade geometries.

S.Gowreesh et.all[5] studied on The first stage rotor blade of a two stage gas turbine has been analysed for structural, thermal, modal analysis using ANSYS 15.0.which is a powerful Finite Element Method software. The temperature distribution in the rotor blade has been evaluated using this software. 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 The purpose of turbine technology is to extract the maximum quantity of energy from the working fluid to convert it into useful work with maximum efficiency by means of a plant having maximum turbo jet engine. it has been felt that a detail study can be carried out on the temperature effects to have a clear understanding of the combined mechanical and thermal stresses.

Kauthalkaret.al.[6] the purpose of turbine technology is to extract, maximum quantity of energy from the working fluid to convert it into useful work with maximum efficiency. That means, the Gas turbine having maximum reliability, minimum cost, minimum supervision and minimum starting time. The gas turbine obtains its power by utilizing the energy of burnt gases and the air. This is at high temperature and pressure by expanding through the several rings of fixed and moving blades. A high pressure of order 4 to 10 bar of working fluid which is essential for expansion, a compressor is required. The quantity of working fluid and speed required are more so generally a centrifugal or axial compressor is required. The turbine drives the compressor so it is coupled to the turbine shaft.

John.vet.al.[7] studied on the design and analysis of Gas turbine blade, CATIA is used for design of solid model and ANSYS software for analysis for F.E.modelgenerated, by applying boundary condition, this paper also includes specific post-processing and life assessment of blade .HOW the program makes effective use of the ANSYS pre-processor to mesh complex turbine blade geometries and apply boundary conditions. Here under we presented how Designing of a turbine blade is done in CATIA with the help of co-ordinate generated on CMM. And to demonstrate the preprocessing capabilities, static and dynamic stress analysis results, generation of Campbell and Interference diagrams and life assessment. The principal aim of this paper is to get the natural frequencies and mode shafe of the turbine blade.

V.RagaDeepuet.al.[8] Studied on a Gas turbine is a device designed to convert the heat energy of fuel in to useful work such as mechanical shaft power. Turbine Blades are most important components in a gas turbine power plant. A blade can be defined as the medium of transfer of energy from the gases to the turbine rotor. 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.

A.K.Matta et.al.[9] studied the stress analysis for N – 155 & Inconel 718 material. On solid blades it is reported that Inconel 718 is better suited for high temperature operation.

III. METHODOLOGY

The purpose of turbine technology is to extract the maximum quantity of energy from the working fluid to convert it into useful work with maximum efficiency by means of a plant having maximum reliability, minimum cost, minimum supervision and minimum starting time.

The stress analysis of the rotor blade being the key phase of the turbo machine design, requires careful determination of the blade loading to get realistic results. As the blade vibration is also a cause of failure in many cases, the determination of natural frequencies is considered, so as to avoid resonance, which is an undesirable phenomenon.

III(a) PRODUCTION OF BLADES

Blades may be considered to be the heart of turbine and all other member exist for the sake of the blades. Without blading there would be no power and the slightest fault in blading would mean a reduction in efficiency and costly repairs. The following are some of the methods adopted for production of blades.

1) Rolling: - Sections are rolled to the finished size and used in conjunction with packing pieces. Blades manufactured by this method do not fail under combined bending and centrifugal force.

2) Machining: - Blades are also machined from rectangular bars. This method has more or less has the same advantage as that of first. Impulse blading are manufactured by this technique.

3) Forging: - Blade and vane sections having airfoil sections are manufactured by specialist techniques. The simplest way is to determine the profile required at the hub and tip and join then by straight ruled lines. Once the geometry of the ruled line is established they may be machined by a milling machine, rest carefully by each line to generate the shape required in a master block from which the forging die may be copy machined. This method ensures the accurate forging of blades to their finished size, requiring only finishing. Broaching often does the machining of the fir-tree root and electrochemical machining may be used in some parts to avoid the conventional cutting processes.

In advance methods, computers are used to determine the blade shape required by aerodynamic and stress criteria. The computer may then instruct a numerically controlled milling machine to prepare the dies.

4) Extrusion: - Blades are sometimes extruded and the roots are left on the subsequent machining. This method is not reliable as rolled sections, because of narrow limits imposed on the composition of blade material.

III(b) BLADE MATERIALS

Proper selection of blade material plays an important role in blade design. The factors that influence the selection of blade materials are: -

1) Method of manufacture
2) Ease of machining
3) The ability to produce blade sections free from flaws.
4) Ductility both allow of rolling of shapes.
5) The capacity for being welded.
6) Ease of forging easily.
7) Condition of operations.
8) Suitable tensile strength at high temperature.
9) Resistance to creep.
10) Cost.

The commonly used blade materials are: -

Brass: - Brass (70 to 72 % Cu and 28 to 30 % Zn) is suitable for temperature up to 230 deg. This is rarely used now days.

Copper Nickel: - This is an alloy containing about 80 % Cu, 19 % Ni and fraction of iron and magnesium.

Nickel Brass: - It is suitable for temperature range up to 230 and contains 50 % Cu, 40 % Zn and 10 % Ni.It may be cold drawn.

Manganese copper: - Its composition is 95 to 96 % Cu, 4 to 5 % Mn and small amounts of iron, carbon and leads. It is not suitable for high stress and temperature .It may be cold drawn and cold rolled.

Phosphor Bronze: - This is copper tin alloy with a small amount of phosphorous. Its composition is 86 % Cu, 14 % tin and 1 % phosphorous for hard bronze.

Monel Metal: - The composition of Monel metal is 67 % Ni and 28 % Cu with a small amount of iron, carbon, manganese. It is resistant to corrosion and is suitable for high temperature. It is used for marine work.

Mild steel: - In the past, it was used in many turbines but now it is rarely used. It corrodes very soon with wet steam but it is very inexpensive.

Nickel steel: - This alloy is more resistant to corrosion than is mild steel. It may be forged or machined but not welded. Generally steel with 3 to 5 % Ni is used. It is used in many turbines.

Stainless steel: - It is an alloy of iron, chromium and carbon containing 12 to 14 % chromium and normal percentage of carbon. It is very resistant to corrosion and erosion. It is also very hard. It may be rolled, easily machined and welded.

Table 3.1 Material properties

material	Density	Thermal conductivity
Inconel 625	8.44 g/cc	9.182533086w/mk
Nimonic 75 alloy	8.37 g/cc	11.8 w/mk
steel	7.8g/cc	9 w/mk

III(c) THERMAL BOUNDARY CONDITIONS APPLIED ON THE ROTOR BLADE MODEL

A new file was opened in ANSYS and the thermal module of ANSYS was activated. The rotor blade model was copied into this file from which the previous structural analysis file 'X'. The structural boundary conditions that were applied previously on the rotor blade model were deleted.
The element type was stitched from structural to its equivalent thermal element type. The material properties were same as those in the previous file of structural analysis.

Two boundary conditions namely Heat flux and Convection were applied on the rotor blade model.

The solution part of ANSYS was opened and Heat flux = 0 was applied on the areas shaded and numbered in figure

Heat flux = 0 fro areas 1,2… to 16

Areas 1,2,3 and 8,9,10 come in contact with similar areas on the adjacent rotor blades. Hence due to symmetry boundary conditions, these areas are assumed to be insulated.

Areas 4,5,6 and 11,12,13,15 on account of their small dimensions are assumed to be insulated. In the convective boundary condition, the convective heat transfer coefficient (h) and temperature of surrounding gases (T) have to be specified on the areas subjected to convection.

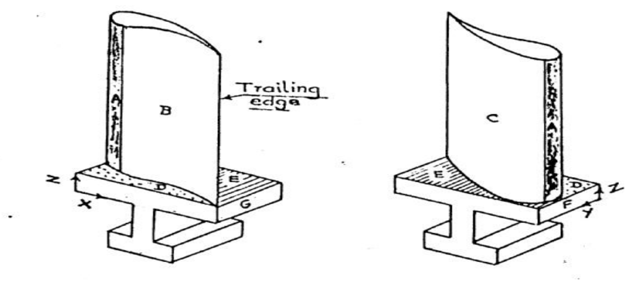


Figure 3. Thermal Boundary conditions

The Above discussed model is designed in 3d model the two types of Designes are made to investigate the heat transfer and thermal distribution on the turbine blade

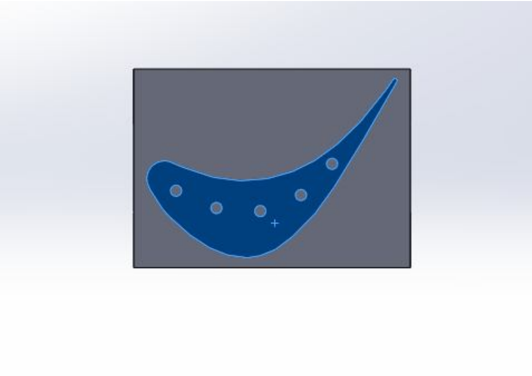


Figure 4. 3d Cad model designed

IV. RESULTS

Followed by the theory discussed in the Chapter the main objective of the current project is to determine the thermal loads distribution on the turbine blade with or without the cooling holes to achieve this we have designed two different models and analyzed the 3d model in Ansys workbench using FEA approach. Each case is Analyzed with the different materials I.e. Inconel, nimonic and Steel. Beow is the Simulation procedure and the results obtained.

IV(a) Importing the Geometry

Any software consists of its own user interface including the coding and the generating structure of a model to import an external geometry file we need to save the Cad UI file to universal file format STEP.

Then the file designed in the solidworks must be feasible for importing into the Ansys workbench user interface.

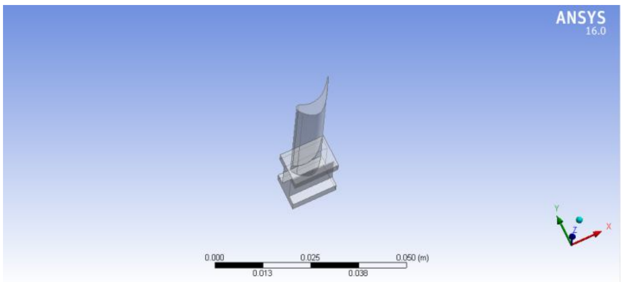


Figure 5. Imported cad interface geometry

IV(b) Work Flow

Work flow s nothing but the step by step procedure for obtaining the desired results with the proper setup of a problem like every simulation software the workflow of Ansys is given below

1. Geometry.
2. Mesh.
3. Setup.
4. Solution.
5. Result.

IV(c) Meshing.

The concept of meshing and discretization is discussed in chapter 3 with in detail explanation here in the Ansys for the two different models we have designed different type of element patterns and element sizes have obtained.

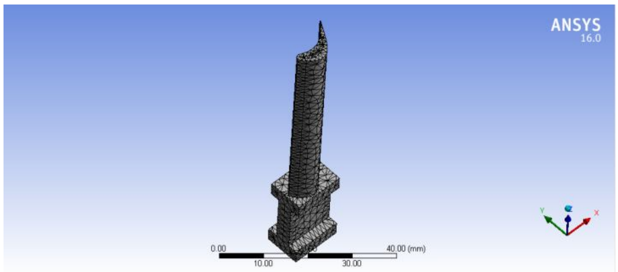
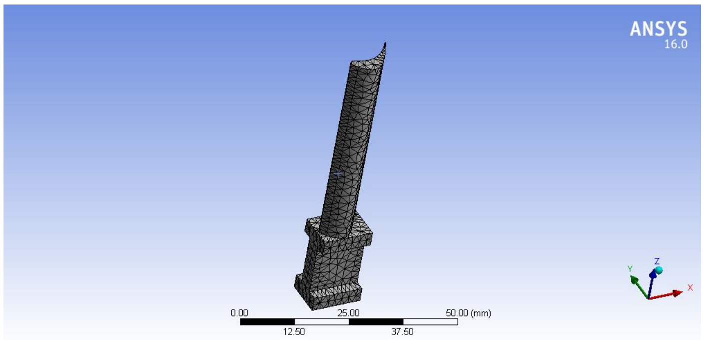


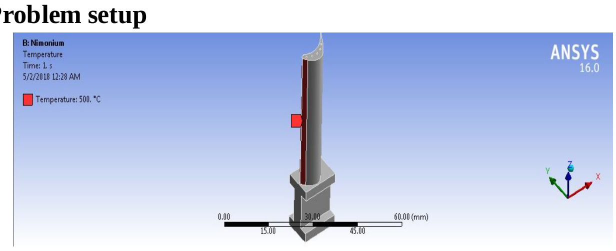
Figure6. Meshing

Mesh ForPlane Blade



Nodes	8619
Elements	4328

Problem setup



In the above figure the blade is subjected to the 500k Temperature at the tip of the gas turbine blade.

Figure 7. Plane gas turbine Blade with steel Nimonium and Inconel

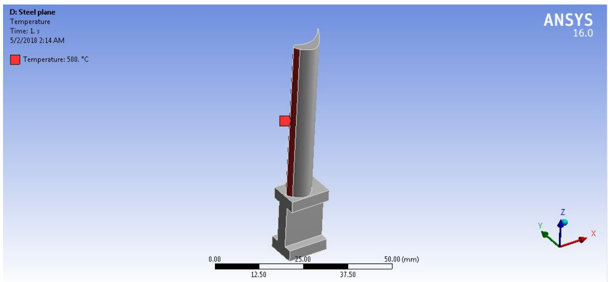


Figure 8. Boundary condition

Case1 Inconel

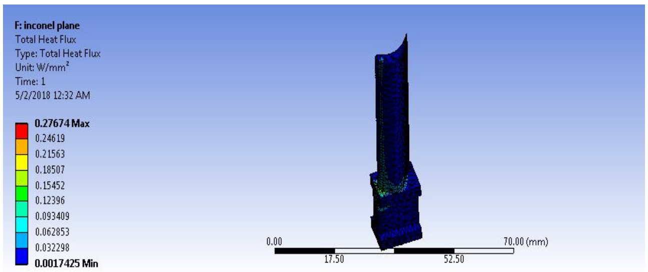


Figure 9. Heat flux distribution of the Gas turbine blade without cooling holes

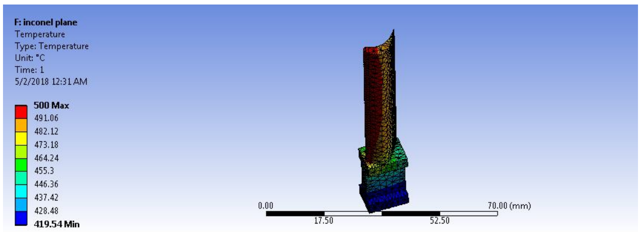


Figure 10. Temperature distribution of the Gas turbine blade without cooling holes

Time [s]	Minimum [°C]	Maximum [°C]
1.	419.54	500.

Case 2 Nimonium

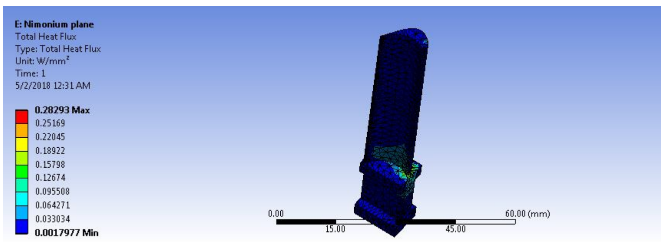


Figure 11. Heat flux distribution of the Gas turbine blade without cooling holes

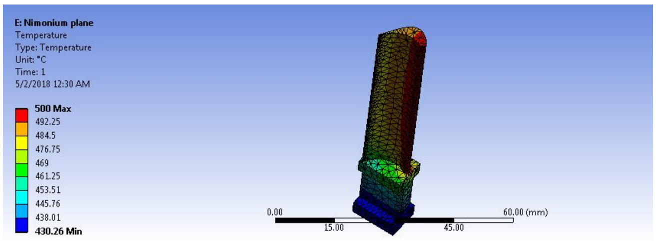


Figure 12. Temperature distribution of the Gas turbine blade without cooling holes

Time [s]	Minimum [°C]	Maximum [°C]
1.	430.26	500.

Case 3 Steel

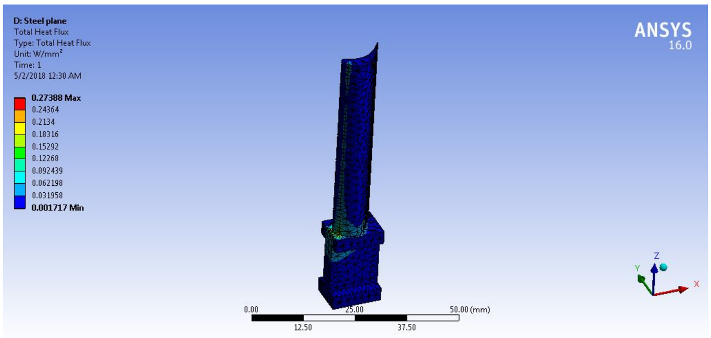


Figure 13. Heat flux distribution of the Gas turbine blade without cooling holes

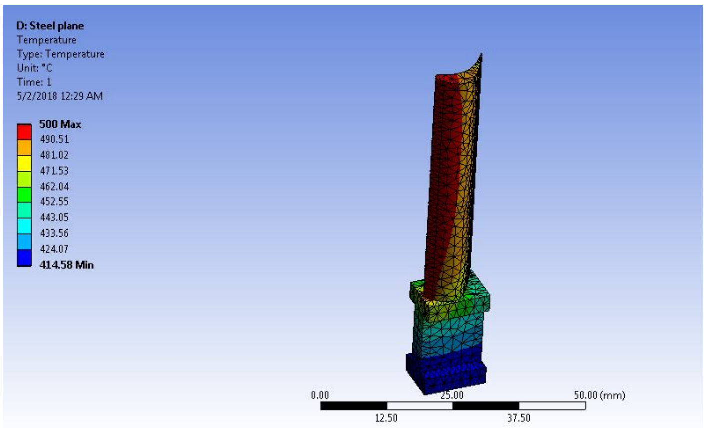
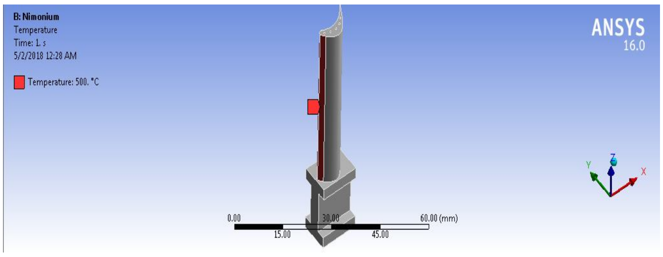


Figure 14. Temperature distribution of the Gas turbine blade without cooling holes

Time [s]	Minimum [°C]	Maximum [°C]
1.	414.58	500.

IV(d) Simulation of Gas turbine blade with Cooling holes.



CaseInconel

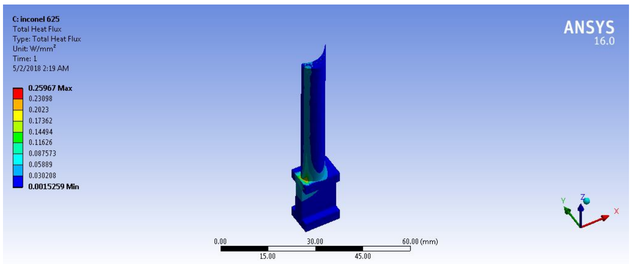


Figure 15. Heat flux distribution of the Gas turbine blade with cooling holes

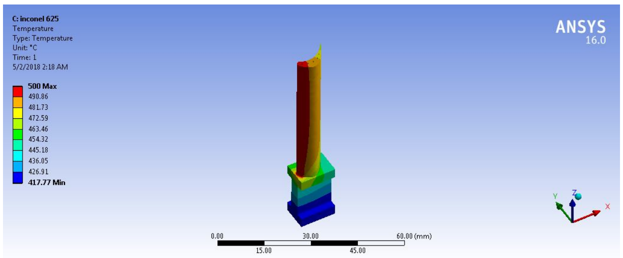


Figure 16. Temperature distribution of the Gas turbine blade with cooling holes

Time [s]	Minimum [°C]	Maximum [°C]
1.	417.77	500.

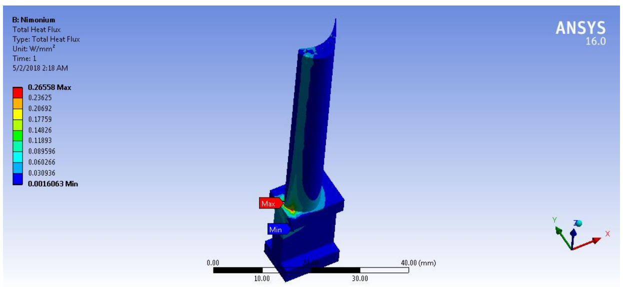


Figure 17. Heat flux distribution of the Gas turbine blade with cooling holes

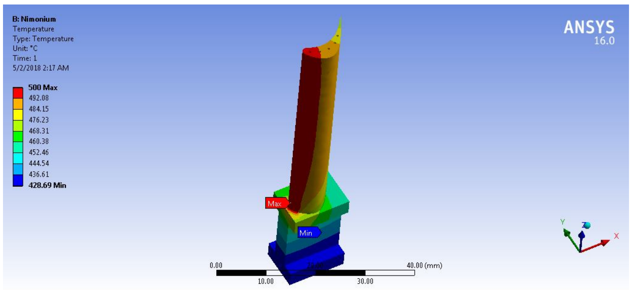


Figure 18. Temperature distribution of the Gas turbine blade with cooling holes

Time [s]	Minimum [°C]	Maximum [°C]
1.	428.69	500.

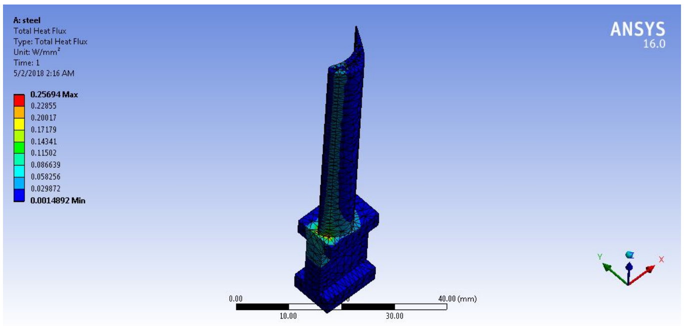


Figure 19. Heat flux distribution of the Gas turbine blade with cooling holes

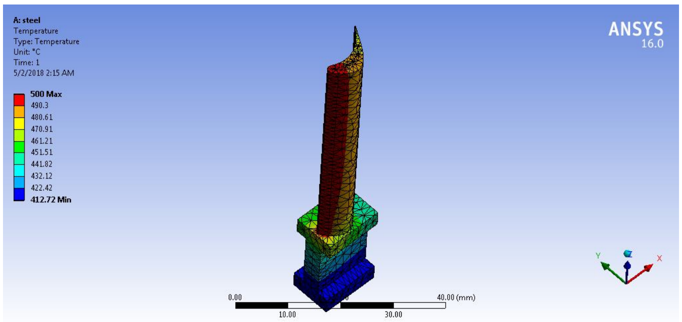


Figure 20. Temperature distribution of the Gas turbine blade with cooling holes

Time [s]	Minimum [°C]	Maximum [°C]
1.	412.72	500.

Comparisons Graph

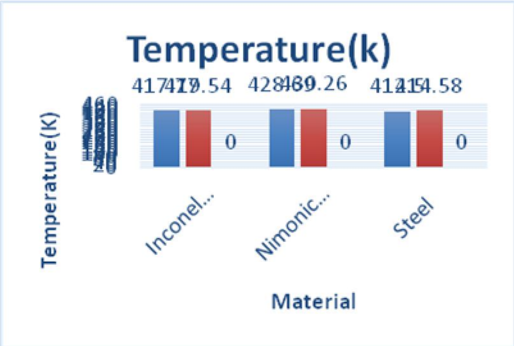


Figure 21. Comparison Graph of temperature Distribution.

V. CONCLUSION

The temperature has a significant effect on the von Mises stress in the turbine blade. Maximum elongation and temperatures are observed at the blade tip section and minimum elongation and temperature variations at the root of the blade. The thermal stresses are predominant in the analysis when compared to the Pressure and Centrifugal forces. Deformations gradually increase along the blade length from root to the tip portion of the blade.

The distribution of the Temperature and the heat flux have been observed the new techniques possess with new materials where the distribution of the temperature have been observed in the project where as the steel Inconel and the nimonic materials have performed significantly from the simulation and the models done to reduce the effect nimonic 75 material have suggested for fabrication because of low cost and the optimal performance in the reduced weight.

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