ISSN No: 2348-4845
International Journal & Magazine of Engineering, Technology, Management and Research
A Peer Reviewed Open Access International Journal

Design Shape Optimization to Ceramic Turbine Vane Using Fem and Matlab

P.Ramakrishna
M.Tech (Machine Design) Student
Department of Mechanical Engineering
Chaitanya Engineering College.

P.Santhi
Assistant Professor
Department of Mechanical Engineering
Chaitanya Engineering College.

ABSTRACT

The objective of this work was to develop design concepts for a cooled ceramic vane to be used in the first stage of the Low Heat Load (LHL). Here, an effort to design an airfoil with minimized heat load is reported. The work performed under this contract can be divided into three broad categories. The first was an analysis of the cycle benefits arising from the higher temperature capability of Ceramic Matrix Composite(CMC) compared with conventional metallic vane materials. The second category was a series of structural analyses for variations in the internal configuration of first stage vane for the Low Heat Load (LHL) of a CF6 class commercial airline engine. The third category was analysis for a radial cooled turbine vanes for use in turboshaft engine applications. The size, shape and internal configuration of the turboshaft engine vanes were selected to investigate a cooling concept appropriate to small CMC vanes. Specifically this research investigates manufacturing variability and its effect on first stage turbine blades through the use of a parametric CAD model, automated CAD regeneration software, and a parametric finite element thermal model. Probabilistic analysis is performed using Monte Carlo simulation on both the finite element model as well as response surfaces built from the finite element model. Blade-to-blade cooling flow variability, especially as a result of film-hole diameter variability in critical locations is identified as the most likely candidate for parameter tolerance. More promising is a combined two-factor tolerancing scheme which additionally tolerances gas path temperature.

This thesis analyses the variation in operating point of a gas turbine .In the scope of this study a dynamic simulation of a gas turbine vane has been developed using MATLAB. Furthermore, a preliminary engine design of optimised gas turbines.

Introduction

Historically, the design of turbine components specifically for reduced heat transfer has been done to a rather limited extent, perhaps due to the extensive complexities of accurately modeling heat transfer in realistic turbine environments which often contain three-dimensional, unsteady, secondary, transonic, and turbulent flows. In addition, efforts focused on understanding turbine airfoil heat transfer have been commonly overshadowed by work done on the associated aerodynamics. Current standards in aircraft engines and research engines of the future demand affordable, efficient, light weight, and increasingly durable technologies, suggesting that further exploration of heat transfer issues relating to turbine component failure is in order. Turbine entry-temperatures are commonly well above the allowable metal temperatures of its components. Since aircraft engines of the future demand ever-increasing performance levels, higher turbine inlet temperatures, and higher thrust-to-weight ratios, and maximum thermal efficiencies, turbinerelated heat transfer issues and its accuracy of prediction are becoming more critical to gas-turbine research and design. Figure 1 below is a plot of the advancement trend of gas-turbine engine performance in the form of specific core power versus turbine inlet temperature. Clearly, increased performance characteristics relate to higher temperatures. Therefore, as turbine designers pave the way to future gas-turbine technologies, the primary concern should pertain to designing. components that perform well under increasing heat loads and thus have superior durability with respect to previous engine designs.

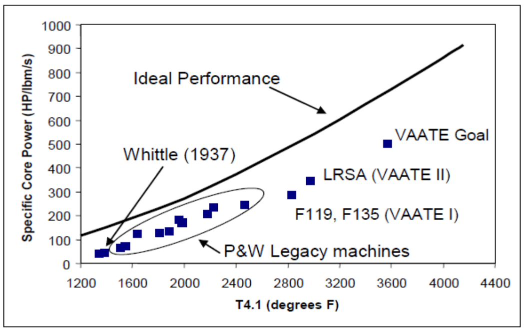


fig: Engine State-of-the-Art as a function of turbine inlet temperature

Gas-turbine engine components are renowned for being designed for optimum aerodynamic performance for high pressure loading and minimized loss. However, turbine component durability issues are becoming the focus of more turbine design programs as many engine test failures are ultimately traceable to a problem of heat transfer. Therefore, a lucid picture of thermodynamic properties in turbine components should ideally precede primarily designing for aerodynamic performance. For example, supporting a turbine that has traded-off some aerodynamic qualities in favor of good thermal performance and yields a relatively long life is indisputably better than nurturing a turbine with optimum aerodynamic qualities and a shortened operating life due to a subpar thermal design. Turbine components subject to significant thermal stresses and hightemperatures are constantly susceptible to failure mechanisms such as cracking, hot corrosion, high-temperature oxidation, and thermal fatigue. Concepts including internal cooling passages, external film cooling, high-tech ceramic materials, and thermal barrier coatings, to name a few, have all been implemented by industry in an effort to combat the unfavorable effects of excessive surface heat transfer.

Structure of the Thesis

The remainder of this thesis will be divided into the following five main sections denoted by a roman numeral and starting with the next section:

- A review of literature pertaining to: the study of gas-turbine heat transfer in experiments, numerical heat transfer prediction and development efforts, and modern airfoil optimization techniques.
- The computational methodology executed as it pertains to the validation of the 2-D flow solver code and the re-design and optimization of the “Low Heat Load” (LHL) airfoil.
- The methodology of the experimental design and setup of the linear cascade shock tube tests for observed heat transfer assessments.
- A discussion of the results and solutions of each part of the thesis pertaining to the validation, optimization, and experimentation efforts as well as how it compares with past research efforts in the respective areas.
- A summary of conclusions to be taken away from this large volume of work, a discussion of possible sources of error in the entire work, and logical suggestions and recommendations for appropriate follow-on work to be done as a result of this cumulative effort.

1.1 Need and Objective:

The stress analysis in the fields of civil, mechanical and aerospace engineering, nuclear engineering is invariably complex and for many of the problems it is extremely difficult and tedious to obtain analytical solutions. In these situations engineers usually resort to numerical methods to solve the problems. With the advent of computers, one of the most powerful techniques that have been developed in the engineering analysis is the finite element method and the method being used for the analysis of structures/solids of complex shapes and complicated boundary conditions.

Due to development of computers and subsequent development of numerical methods, it is now possible to model the components, simulate the conditions and perform testing on computer without actual model making, one of the most popular numerical methods used is the Finite Element (FEM) offered by the existing CAD/CAM/CAE. The most popular software, which is based on Finite Element Analysis, is “ANSYS” package, which is used in this work

2. REVIEW OF LITERATURE

Qian and Dutta [1] implemented with mathematical formulation for the turbine blade design. using B-spline to represent the turbine blade, using diffusion equation to generate material composition variation, using finite element method to solve the constrained diffusion equation.

Naeem et al. [2] carried out the failure analysis of gas turbine blades made of nickle-base alloy in two discrete sections, they are Mechanical and Metallurgical by using Ansys work bench software and metallurgical investigation was carried out by using visual examination.

Dhopade and Neely [3] investigated the effects of low cycle and effects of high cycle fatigue interaction on the aerodynamic and structural behavior of a blade. A numerically based analysis through the interaction of CFD and FEM referred to Fluid- structure interaction.

Bhatti et al. [4] focused on the transient heat transfer characteristics, centrifugal and thermal stresses arising in the disk. Maximum stresses obtained are found to be within the yield strength of materials

Parks et al. [5] aimed at foresting the development of a new generation of band-based gas turbine systems with overall efficiencies significantly for improving environmental impact and decrease cost.

Kim et al. [6] examined on the effect on the oxidation of superalloy blade for providing excellent protection against oxidation during the operations of turbine rotation at a speed of 35,000rpm.

2.1 Scope of present work

The free and mapped mesh is taken into consideration to carry out the following work:

1) To determine thermal stresses due to high temperature gradient.
2) To determine maximum stress induced in blades.
3) To determine the temperature distribution along the blade profile.
4) To determine the parameters influencing the stress concentration in rotor blades.
5) To determine Thermal Stresses by Varying Materials and profiles.

This enables the designers to develop the analysis of gas turbine rotor blade more effectively and easily.

METHODOLOGY

3.1 Introduction

The purpose of turbine technology are 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 gas 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. To get a high pressure of order 4 to 10 bar of working fluid, which is essential for expansion a compressor, is required. The quantity of ten 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. If after compression the working fluid were to be expanded in a turbine, then assuming that there were no losses in either component, the power developed by the turbine can be increased by increasing the volume of working fluid at constant pressure or alternatively increasing the pressure at constant volume. Either of these may be done by adding heat so that the

ISSN No: 2348-4845
International Journal & Magazine of Engineering, Technology, Management and Research
A Peer Reviewed Open Access International Journal

temperature of the working fluid is increased after compression. To get a higher temperature of the working fluid a combustion chamber is required where combustion of air and fuel takes place giving temperature rise to the working fluid.

S.NO.	MATERIAL	YOUNGS MODULES (MPA)	POSSION RATIO	DENSITY (KG/M3)	CO-EFFICENT OF THERMAL EXPANSION(C-1)	THERMAL CONDCTIVITY (W/m•° K)	SPECIFIC HEAT (kJ/(kg K)
1	STRUCTURAL STEEL	2.00E+05	0.3	7850	1.20E-05	45	0.12
2	SI3N4	3.10E+05	0.23	3290	3.30E-06	30	0.19
3	SI3	3.86E+05	0.17	3100	4.00E-06	120	0.17

What is the Solution?

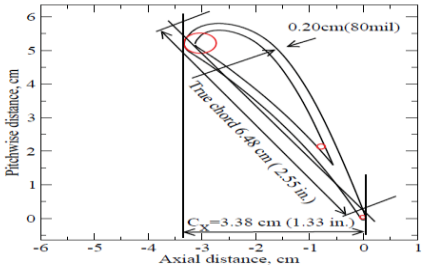
In the solution phase of the analysis, the computer takes over and solves the simultaneous equations that the finite element method generates. The results of the solution are:

a) Nodal degree of freedom values which form the primary solution and

b) derived values, which form the element solution. The element solution is usually calculated at the element integration points.

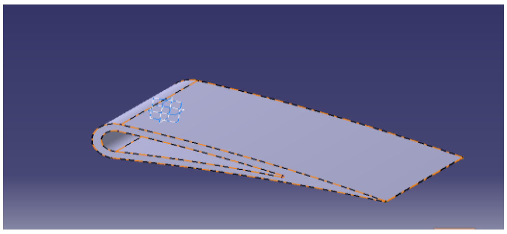
Several methods of solving the simultaneous equations are available in the ANSYS programme, frontal solution, sparse direction solution, Jacobi Conjugate Gradient solution, Precondition Conjugate Solution and an automatic iteration solver option. The frontal solver is the default.

Turbine Blade Cross-Section

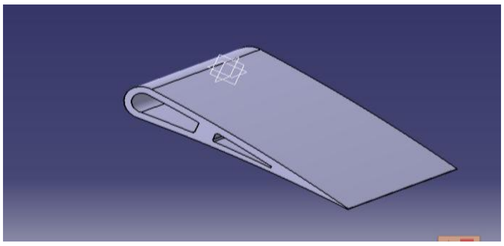


Modeling of Turbine Blade by using Catia

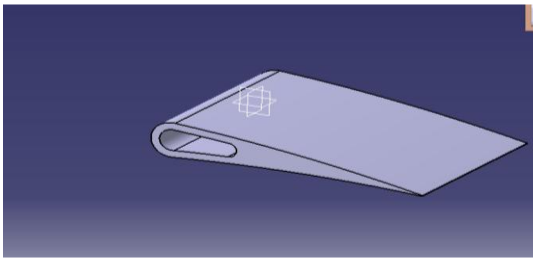
MODEL-1



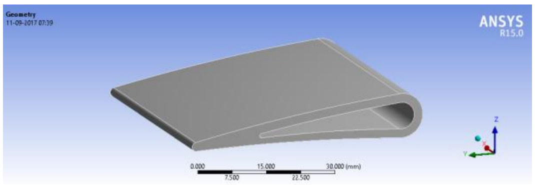
MODEL-2



MODEL-3



CASE-1 MODEL-1



GEOMETRIC VIEW OF A BLADE

S.NO.	MATERIAL	YOUNGS MODULES (MPA)	POSSION RATIO	DENSITY (KG/M3)	CO-EFFICENT OF THERMAL EXPANSION (C-1)	THERMAL CONDCTIVITY (W/m•°K)	SPECIFIC HEAT (kJ/(kg K)
1	STRUCTURAL STEEL	2.00E+05	0.3	7850	1.20E-05	45	0.12

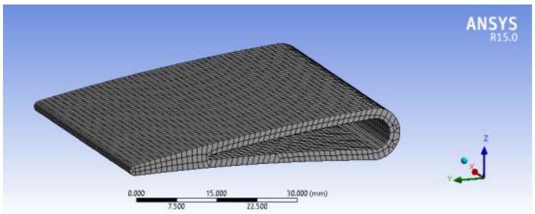
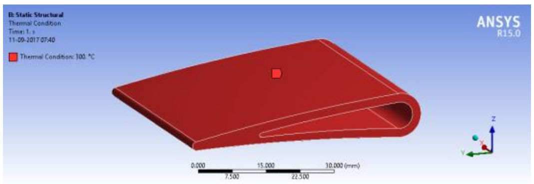


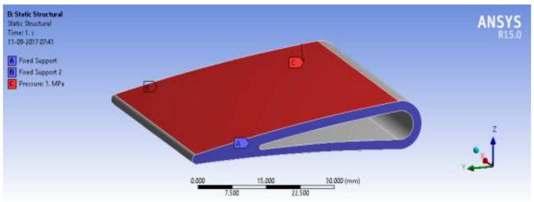
Fig 6.2 Meshing of a Blade MODEL-1

Table 6.2 Mesh statistics

Bodies	1
Active Bodies	1
Nodes	48730
Elements	8789
Mesh Metric	None



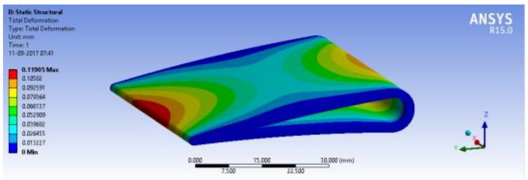
6.3 Static Thermal with temperature load



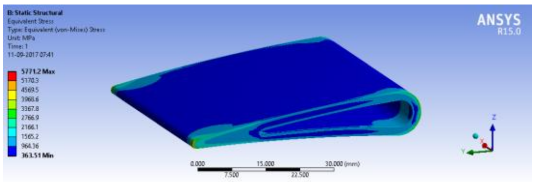
6.4 Static with Pressure load

Results:

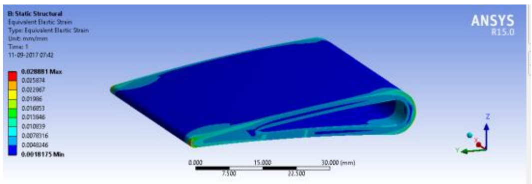
Model and Material Structural Steel:



6.5 Total Deformation for model 1 with material of Structural Steel



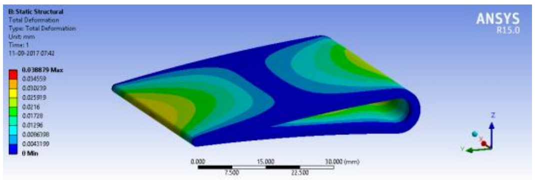
6.6 Total Von Misses Stress for model 1 with material of Structural Steel



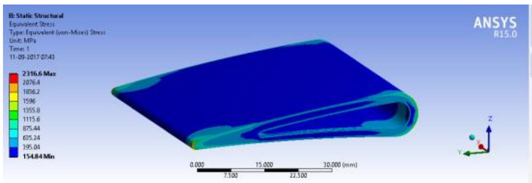
6.7 Total Von Misses Strain for model 1 with material of Structural Steel

Tables 6.3 Model1 & Material 2 :

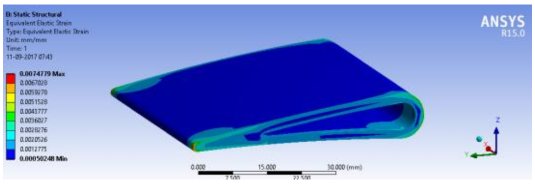
S.NO.	MATERIAL	YOUNGS MODULES (MPA)	POSSION RATIO	DENSITY (KG/M3)	CO-EFFICENT OF THERMAL EXPANSION(C-1)	THERMAL CONDCTIVITY (W/m•°K)	SPECIFIC HEAT (kJ/(kg K)
2	SI3N4	3.10E+05	0.23	3290	3.30E-06	30	0.19



6.8 Total Deformation for model 1 with material of SI3N4



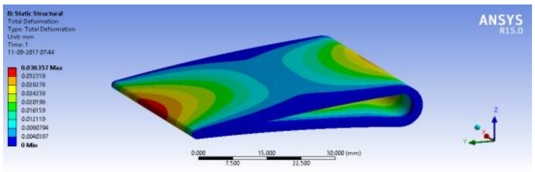
6.9 Total Von Misses Stress for model 1 with material of SI3N4



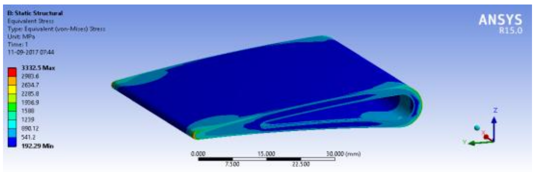
6.10 Total Von Misses Strain for model 1 with material of SI3N4

Table 6.4 Model1 & Material 3 :

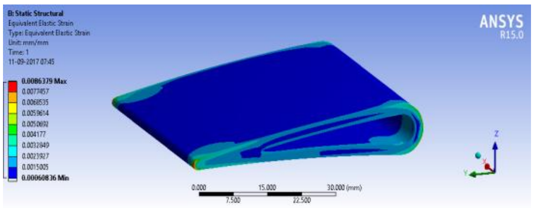
S.NO.	MATERIAL	YOUNGS MODULES (MPA)	POSSION RATIO	DENSITY (KG/M3)	CO-EFFICENT OF THERMAL EXPANSION(C-1)	THERMAL CONDCTIVITY (W/m•°K)	SPECIFIC HEAT (kJ/(kg K)
3	SI3	3.86E+05	0.17	3100	4.00E-06	120	0.17



6.11 Total Deformation for model 1 with material of SI3

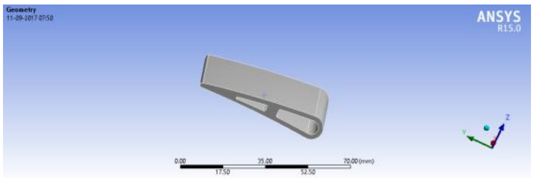


6.12 Total Von Misses Stress for model 1 with material of SI3

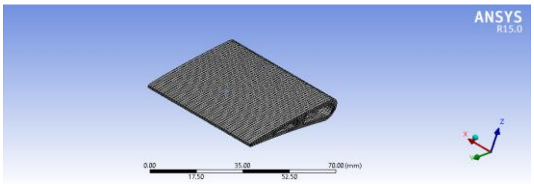


6.13 Total Von Misses Strain for model 1 with material of SI3

Case Study2:



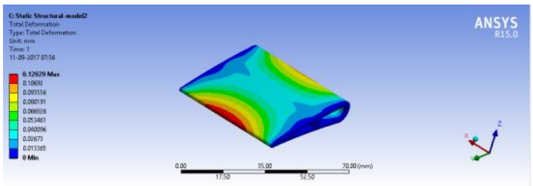
Ansys Imported Model from CATIA V5



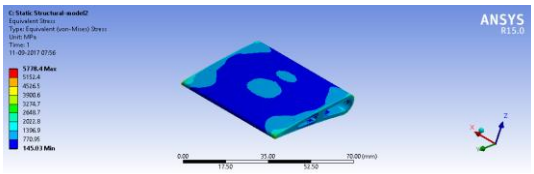
Mesh Model with Brick Mesh

Bodies	1
Active Bodies	1
Nodes	59808
Elements	11468
Mesh Metric	None

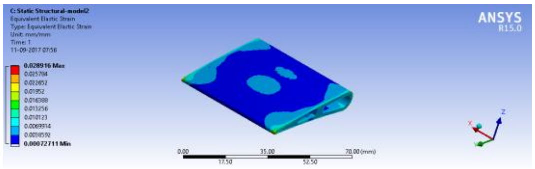
Model 2 and Material Structural Steel:



6.14 Total Deformation for model 2 with material of Structural Steel

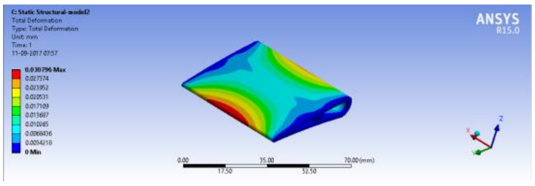


6.15 Total Von Misses Stress for model 2 with material of Structural Steel

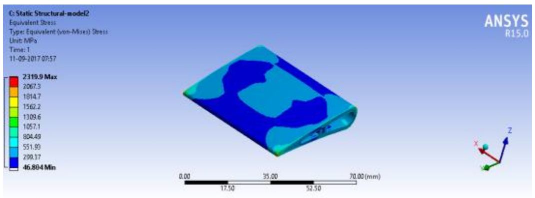


6.16 Total Von Misses Strain for model 2 with material of Structural Steel

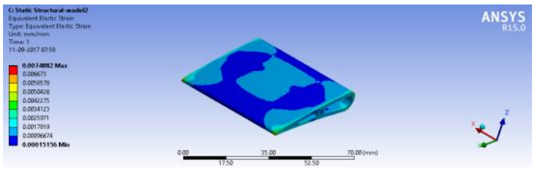
Model2 & Material 2 :



6.17 Total Deformation for model 2 with material of SI3N4

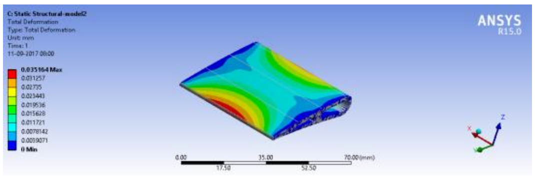


6.18 Total Von Misses Stress for model 2 with material of SI3N4

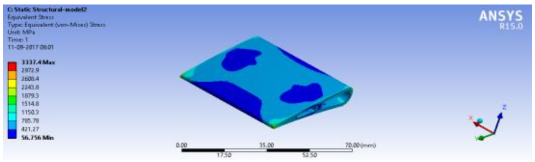


6.19 Total Von Misses Strain for model 2 with material of SI3N4

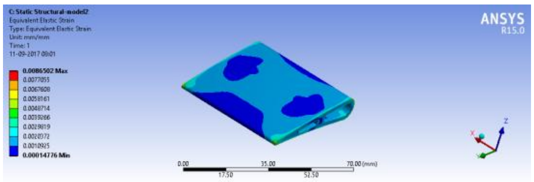
Model2 & Material 3 :



6.20 Total Deformation for model 2 with material of SI3

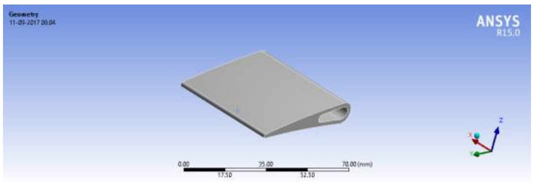


6.21 Total Von Misses Stress for model 2 with material of SI3

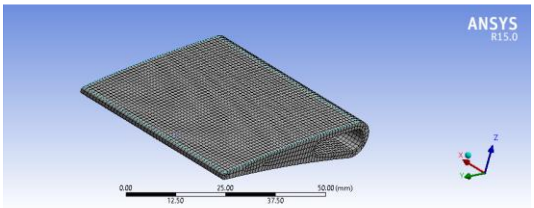


6.22 Total Von Misses Strain for model 2 with material of SI3

Case Study3:

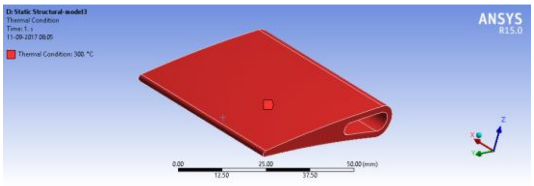


Ansys model imported from CATIA V5

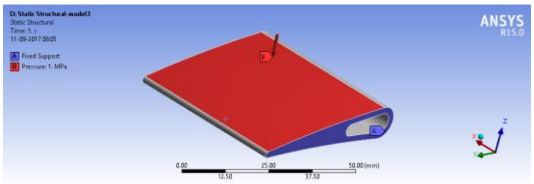


Mesh Model with Brick Mesh

Bodies	1
Active Bodies	1
Nodes	53748
Elements	10622
Mesh Metric	None

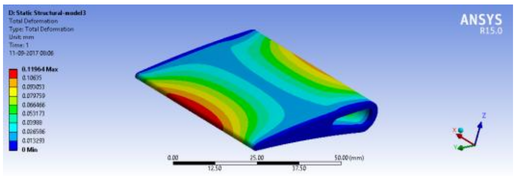


6.23 Temperature load on Static Case Study -3

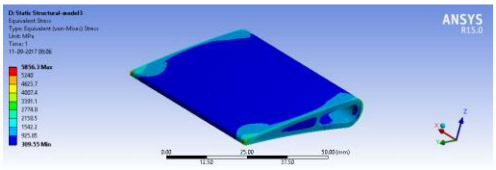


6.24 Pressure Load with Boundary Condition for Case Study -3

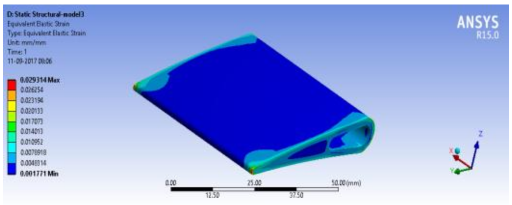
Model 3 and Material Structural Steel:



6.25 Total Deformation for model 3 with material of Structural Steel



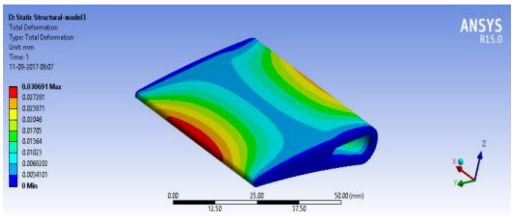
6.26 Total Von Misses Stress for model 3with material of Structural Steel



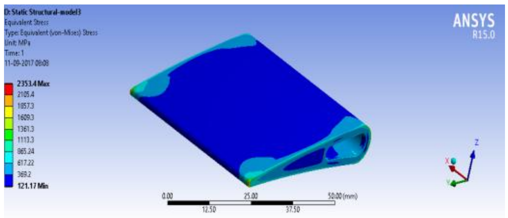
6.27 Total Von Misses Strain for model 3 with material of Structural Steel

Table 6.5 Model3 & Material 2 :

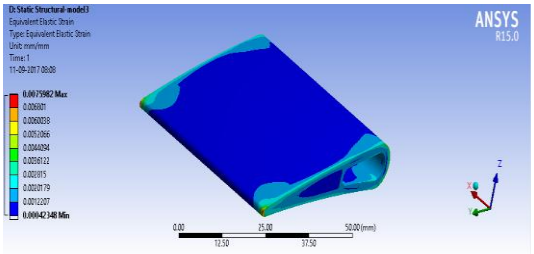
S.NO.	MATERIAL	YOUNGS MODULES (MPA)	POSSION RATIO	DENSITY (KG/M3)	CO-EFFICENT OF THERMAL EXPANSION(C-1)	THERMAL CONDCTIVITY (W/m•°K)	SPECIFIC HEAT (kJ/(kg K)
2	SI3N4	3.10E+05	0.23	3290	3.30E-06	30	0.19



6.28 Total Deformation for model 3 with material of SI3N4



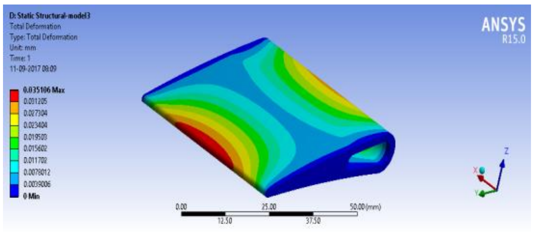
6.29 Total Von Misses Stress for model 3 with material of SI3N4



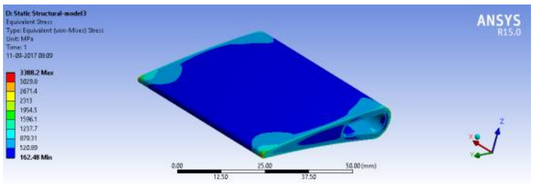
6.30 Total Von Misses Strain for model 3 with material of SI3N4

Table 6.6 Model2 & Material 3 :

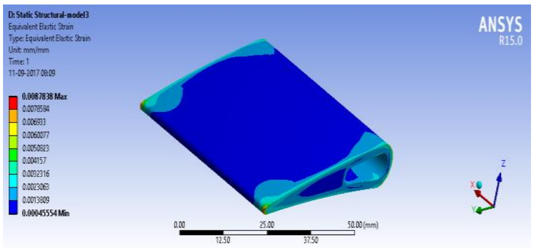
S.NO.	MATERIAL	YOUNGS MODULES (MPA)	POSSION RATIO	DENSITY (KG/M3)	CO-EFFICENT OF THERMAL EXPANSION(C-1)	THERMAL CONDCTIVITY (W/m•°K)	SPECIFIC HEAT (kJ/(kg K)
3	SI3	3.86E+05	0.17	3100	4.00E-06	120	0.17



6.31 Total Deformation for model 3 with material of SI3



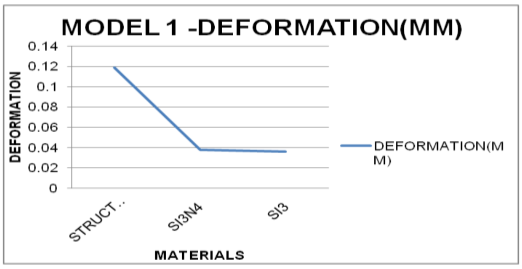
6.32 Total Von Misses Stress for model 3 with material of SI3

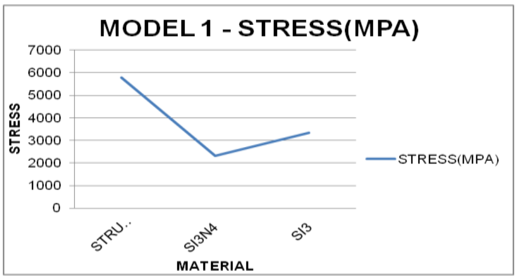


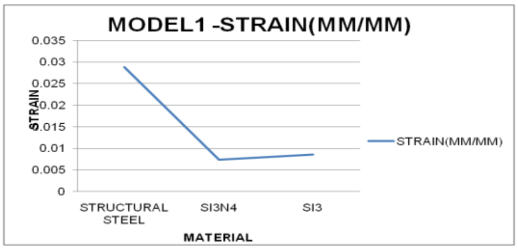
6.33 Total Von Misses Strain for model 3 with material of SI3

RESULTS AND DISCUSSION

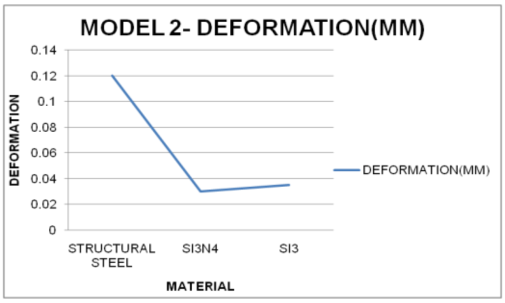
CASE1

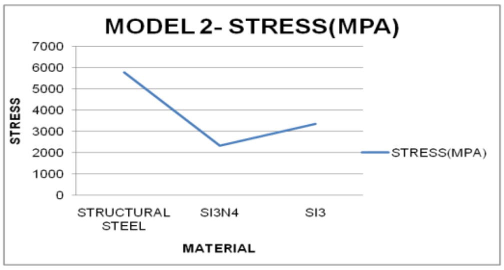


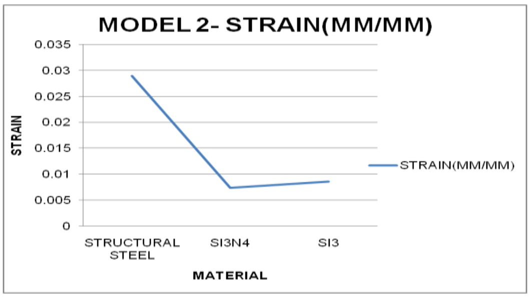


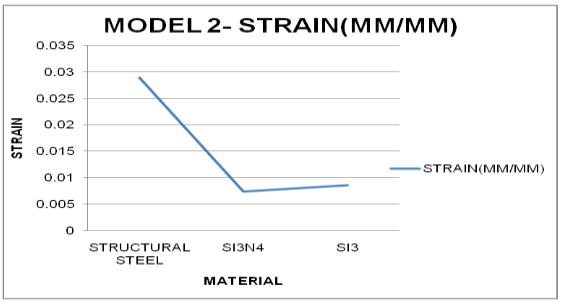


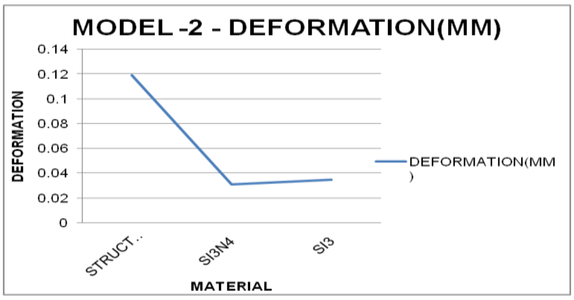
CASE2



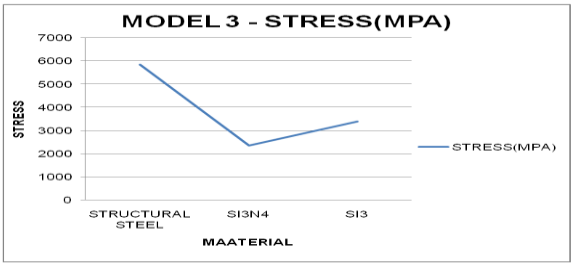


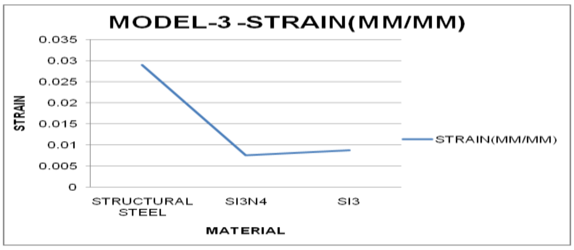






CASE3





CONCLUSIONS

The finite element analysis of gas turbine rotor blade is carried out using 20 nodes brick element. The static and thermal analysis is carried out. The temperature has a significant effect on the overall stresses in the turbine blades. The following conclusions are made from the above analysis:

1. Stress obtained for the turbine blade without holes is 209.48N/mm^2
2. When the size of the hole is 2mm stress obtained is 159.18N/mm^2 therefore stresses are reduced by 50N/mm^2
3. For blade with 3mm hole stress increased by 37N/mm^2 whereas for the blade with 4mm holes stress results were quite different, it decreased by 35N/mm^2
4. The no. of cycles for blade without hole is 3.26 x 10^5, for blade with 2mm and 3mm hole no. of cycles remains constant i.e. 10^6 whereas for 4mm blade its 4.76 x 10^5
5. Stresses are reduced and fatigue life increased for blades with holes.
6. On the whole it is noticed that the equivalent stresses are reduced up to 23% for the blades with holes as compared to blade without hole.

Thus blade with 2mm hole is better for using because the stress obtained is less and the number of cycles increased when compared to blades with 2mm, 3mm and 4mm holes

REFERENCES

1. Xiaoping Qian, Deba Dutta (2001) Design of heterogeneous Turbine Blade vol.35 pg.(319- 329).
2. Mehdi Tofighi Naeem, Seyed Ali Jazayeri, Nesa Rezamahdi (2008) Failure Analysis of Gas Turbine Blades. Paper 120, ENG 108.
3. P. Dhopade, A.J. Neely (2010) Fluid- structure interaction of Gas Turbine Blades vol.17 pg.(5-9).
4. Sukhvinder Kaur Bhatti, Shyamala Kumari, M L Neelapu,C Kedarinath, Dr. I N Niranjan Kumar (2006) Transient State Stress Analysis On an Axial

Flow Gas Turbine Blades Using Finite Element Procedure vol.4, pg. (323-330).

5. W.P. Parks, E.E. Hoffman, W.Y. Lee, and I.G. Wright (1997) Thermal Barrier Coatings Issues in Advanced Land-Based Gas Turbines Vol6, pg. (187-192).
6. Min Tae Kim, Doo Soo Kim, and Won Young (2010) Deposition of Silica Layers during the Operation of a Micro-Gas Turbine and Their Effect on the Oxidation of Superalloy Blades Vol. 16, pp. 129-136.
7. V. A. Borysenko, O. H. Arkhypov, and H. V. Lipko (2006) Failures of the parts of Turbines of Compression of Pyrolysis Gases Vol. 42, pg. (560-562).
8. H.J. Dai, N. D’souza, And H.B. Dong (2011) Grain Selection in Spiral Selectors During Investment Casting of Single-Crystal Turbine Blades: Part I. Experimental Investigation DOI: 10.1007/s11661-011-0760-6.
9. B. Deepanraj, P. Lawrence and G. Sankaranarayanan (2011) Theoretical Analysis Of Gas Turbine Blade By Finite Element Method Scientific World, Vol. 9, pg. (29-33).
10. L. Chen et al. (2007) Power-exponent function model for low-cycle fatigue life prediction and its applications – Part II: Life prediction of turbine blades under creep–fatigue interaction vol.29, pg. (10-19).

Author Details

P.Ramakrishna
M.Tech. [Machine Design] Student
Department of Mechanical Engineering
Chaitanya Engineering College

P.Santhi
Assistant Professor
Department of Mechanical Engineering,
Chaitanya Engineering College