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Fatigue Analysis of Axial flow Compressor

*Satish[1], Dr. Shivarudraiah[2], Maibusab[3], Shivaraj H. A[3]
[1,2]P.G Scholar, Department of Mechanical Engineering, University Visveswarayya College of Engineering, Bengaluru, Karnataka, India
[2]Professor, Department of Mechanical Engineering, University Visveswarayya College of Engineering, Bengaluru, Karnataka, India
*Contact Author e-mail: satishchennaveere@gmail.com

ABSTRACT

Axial flow compressors are used in medium to large thrust gas turbine and jet engines. The aerodynamic compressor design process basically consist of mean line prediction is the first step during compressor blade design. In this project design and fatigue analyze of the micro turbine compressor blade is carried with different material and rotational speed for various rotor and stator angles. Based on the given micro turbine output power, the dimensions and physical properties of the compressor blade were calculated. Stainless-steel alloy, Nickel alloy and Titanium alloys, these materials effect on compressor blade are found out by carrying stress and modal analysis.

Keywords : Axial Flow Compressor, Steel Alloy, Nickel Alloy, Titanium Alloy

I. INTRODUCTION

An axial-flow compressor is one in which the flow enters the compressor in an axial direction (parallel with the axis of rotation) and exits from the gas turbine also in an axial direction.

An axial compressor is a compressor that can continuously pressurize gases. It is a rotating, aerofoil-based compressor in which the gas or working fluid principally flows parallel to the axis of rotation, or axially. This differs from other rotating compressors such as centrifugal compressors, axi-centrifugal compressors and mixed-flow compressors where the fluid flow will include a "radial component" through the compressor. The energy level of the fluid increases as it flows through the compressor due to the action of the rotor blades which exert a torque on the fluid. The stationary blades slow the fluid, converting the circumferential component of flow into pressure. Compressors are typically driven by an electric motor or a steam or a gas turbine.

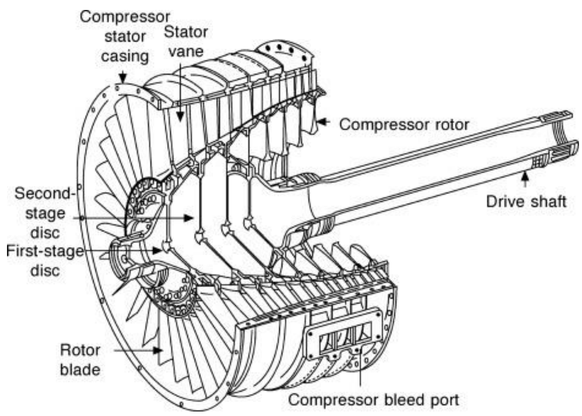
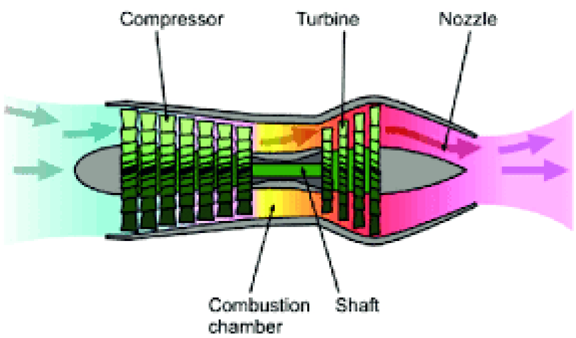


Figure 1. Axial flow compressor

II. METHODS AND MATERIAL

WORKING OF AXIAL FLOW COMPRESSOR

As the fluid enters and leaves in the axial direction, the centrifugal component in the energy equation does not come into play. Here the compression is fully based on diffusing action of the passages. The diffusing action in stator converts absolute kinetic head of the fluid into rise in pressure. The relative kinetic head in the energy equation is a term that exists only because of the rotation of the rotor. The rotor reduces the relative kinetic head of the fluid and adds it to the absolute kinetic head of the fluid i.e., the impact of the rotor on the fluid particles increases its velocity (absolute) and thereby reduces the relative velocity between the fluid and the rotor. In short, the rotor increases the absolute velocity of the fluid and the stator converts this into pressure rise. Designing the rotor passage with a diffusing capability can produce a pressure rise in addition to its normal functioning. This produces greater pressure rise per stage which constitutes a stator and a rotor together. This is the reaction principle in turbomachines. If 50% of the pressure rise in a stage is obtained at the rotor section, it is said to have a 50% reaction.



Working Flow of compressor

Koduru. Srinivas, Kandula. Deepthi, K.N.D.MalleswaraRao [1], An axial flow compressor is one in which the flow enters the compressor in an axial direction (parallel with the axis of rotation), and exits from the gas turbine, also in an axial direction. The axial-flow compressor compresses its working fluid by first accelerating the fluid and then diffusing it to obtain a pressure increase. In an axial flow compressor, air passes from one stage to the next, each stage raising the pressure slightly. The energy level of air or gas flowing through it is increased by the action of the rotor blades which exert a torque on the fluid which is supplied by an electric motor or a steam or a gas turbine. An axial flow compressor is designed and modelled in 3D modelling software Pro/Engineer. The present design has 30 blades, and in work, replaced with 20 blades and 12 blades. The present used material is Chromium Steel; it is replaced with Titanium alloy and Nickel alloy. Structural analysis is done on the compressor models to verify the strength of the compressor. CFD analysis is done to verify the flow of air.

Ujjawal A. Jaiswal and Prof. S. J. Joshi [2]-The objective of work presented is to design Axial flow compressor by using mean line method for a given mass flow rate and required pressure ratio. The parameters determined also include thermodynamic properties of the working fluid, stage efficiency, number of rotor and stator blades, tip and hub diameters, blade dimensions (chord, length and space) for both rotor and stator, Mach number, flow and blade angles (blade twist)

P. Lakshmi and B Bapi Raju [3] An axial flow compressor will be designed and modelled in 3D modelling software Pro/Engineer. The present designs will be modified by changing the aspect ratios. The present used material is Chromium Steel, it will be replaced with Titanium alloy and Nickel alloy. Structural analysis will be done on all the compressor models using steel, titanium alloy and nickel alloy to verify the strength of the compressor using finite element analysis software Ansys. CFD analysis will also be done to determine the fluid behaviour in Ansys Fluent.

Kiran D Chaudhari, Prof. Dr. N. A. Wankhede [4], The performance of axial flow compressor has major impact on overall performance of gas turbine engine. The paper deals with numerical analysis of a single stage, subsonic axial flow compressor using commercial CFD code of AxSTREAM. The aerodynamic design and blade profiling has been carried out using CFD software. The research starts with design of the high pressure ratio compressor blade sections which yield a single stage pressure rise up to 1.21, the constant tip diameter of the compressor rotor blade for 15.5 kg/s, 14800 RPM, 276.5 KW power with a tip speed 167.7 m/s. Further the design is optimized for minimum total pressure loss. Analytical results compared with the numerical analysis.

III. OBJECTIVE AND SCOPE

Objective

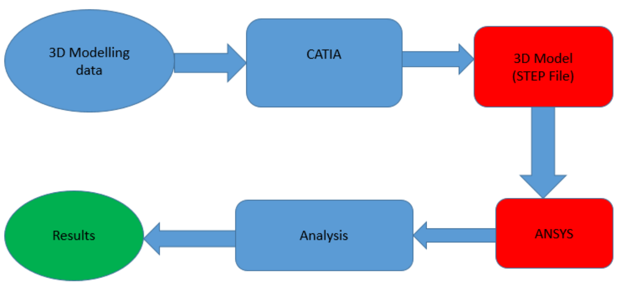
The objective of this study is to model a micro turbine compressor blade and conduct stress analysis and fatigue analysis based on its rotation per minute for different stator and rotor angles.

Scope of work

The scope of study consists of following major parts

1. Problem study & input data finalization.
2. Design the dimension of the compressor based on the given output power.
3. Mesh the model as per quality requirements.
4. Investigate the stress acting on the compressor using structural analysis and Fatigue analysis of the model for different rotational speed using the finite element analysis program.
5. Project documentation with plots/sketches & result study observation
6. ANSYS is the software used for analysis.
7. 3D model obtained from CATIA is imported to ANSYS in STEP file format.

Geometrical Modelling



Compressor Materials

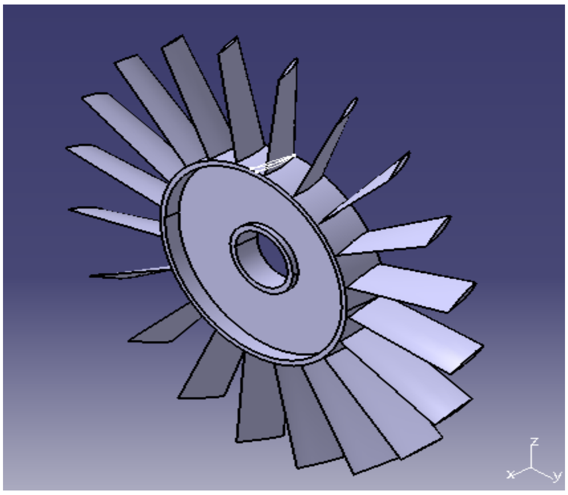
The material for the compressor blade is chosen into three different materials.

Materials	Items	Parameter	Value
Stainless Steel	Modulus of Elasticity	E (GPa)	210
	Density	ρ (kgm³)	7850
	Ultimate Tensile Strength	UTS (MPa)	460
	Yield Strength	σ (MPa)	250
	Poisson Ratio	N	0.3
Titanium Alloy	Modulus of Elasticity	E (GPa)	96
	Density	ρ (kgm³)	7850
	Ultimate Tensile Strength	UTS (MPa)	1070
	Yield Strength	σ (MPa)	930
	Poisson Ratio	N	0.36
Nickel alloy	Modulus of Elasticity	E (GPa)	245
	Density	ρ (kgm³)	8650
	Ultimate Tensile Strength	UTS (MPa)	2300
	Yield Strength	σ (MPa)	2100
	Poisson Ratio	N	0.325

ANALYSIS

Analysis has been carried out by using FEA software ANSYS.

ANSYS Workbench 16 is the software used for analysis. 3D model obtained from CATIA is imported to ANSYS in STEP file format.



Finite Element Method (FEM)

Finite Element Method (FEM) is also called as Finite Element Analysis (FEA). Finite Element Method is a basic analysis technique for resolving and substituting complicated problems by simpler ones, obtaining approximate solutions Finite element method being a flexible tool is used in various industries to solve several practical engineering problems. In finite element method it is feasible to generate the relative results.

ANSYS Software

ANSYS is an Engineering Simulation Software (computer aided Engineering). Its tools cover Thermal, Static, Dynamic, and Fatigue finite element analysis along with other tools all designed to help with the development of the product. The company was founded in 1970 by Dr. John A. Swanson as Swanson Analysis Systems, Inc. SASI. Its primary purpose was to develop and market finite element analysis software for structural physics that could simulate static (stationary), dynamic (moving) and heat transfer (thermal) problems. SASI developed its business in parallel with the growth in computer technology and engineering needs. The company grew by 10 percent to 20 percent each year, and in 1994 it was sold. The new owners took SASI's leading software, called ANSYS, as their flagship product and designated ANSYS, Inc. as the new company name.

IV. RESULTS AND DISCUSSIONS

The results are analyzed for different angles of stator and rotor with respect to materials.

1. Case 1: rotator angle 12.1^0, stator angle 24.9^0
2. Case 2: rotator angle 26.4^0, stator angle 29.0^0

Steel alloy

In structure analysis results are achieved through analyzing the von misses stress, strain, total deformation, and fatigue tool.

<table>
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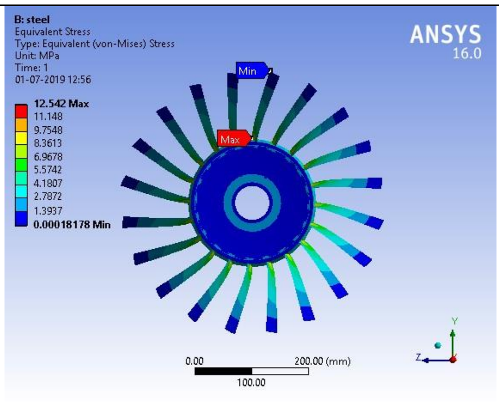
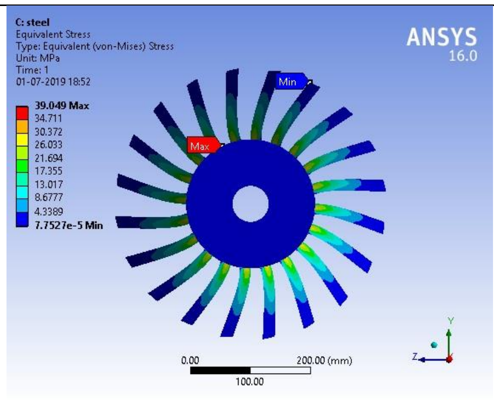
<tr><td>
</td><td>
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<tr><td colspan="2">Fatigue Safety factor</td></tr>
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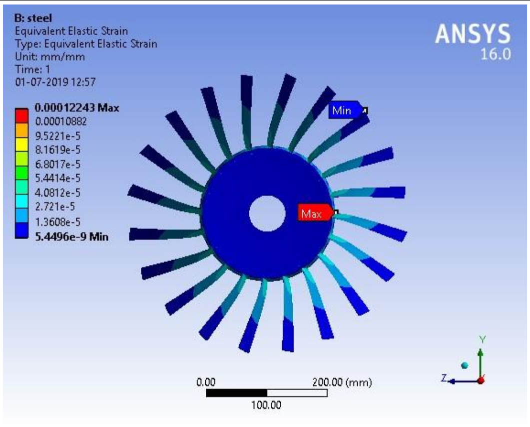
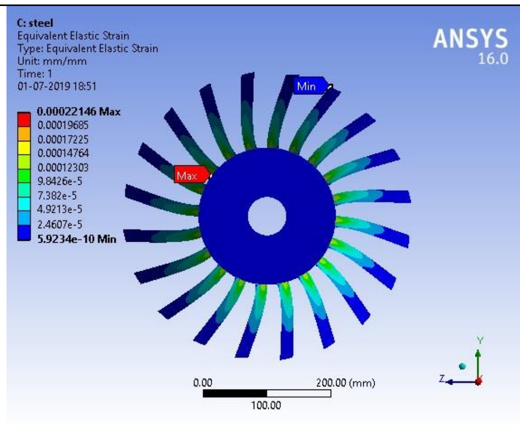
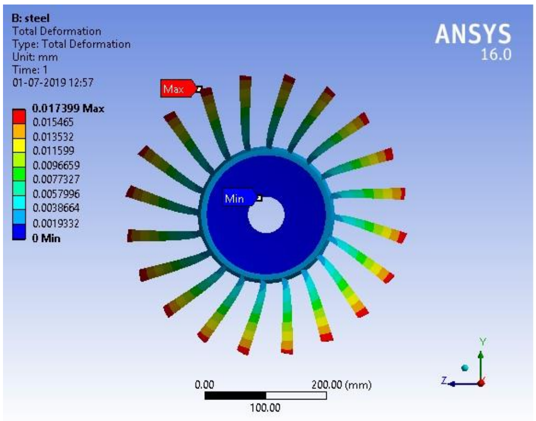
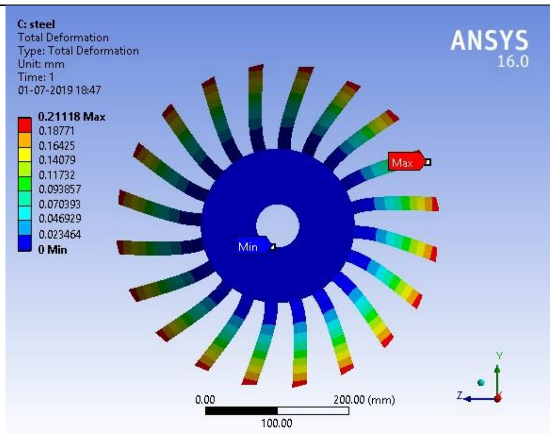


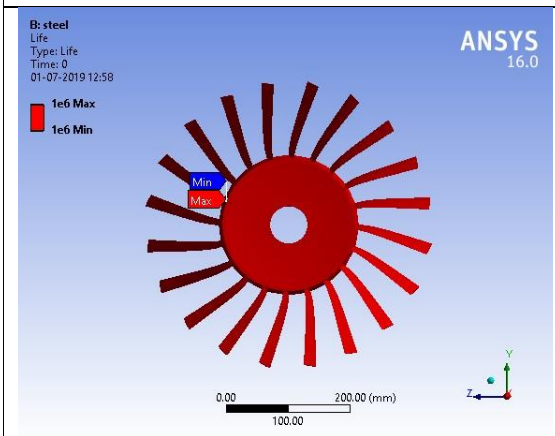


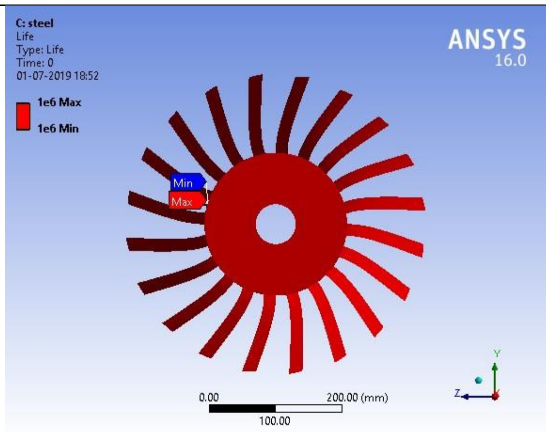
Equivalent strain



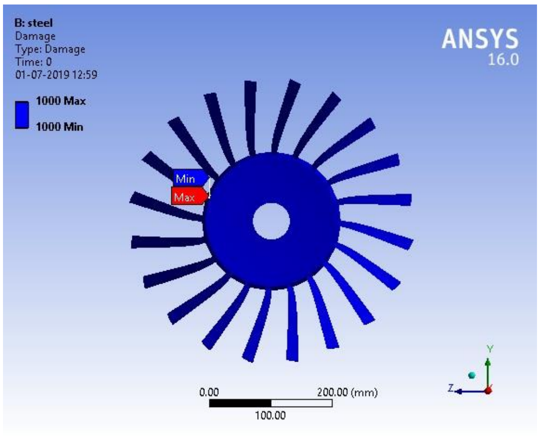


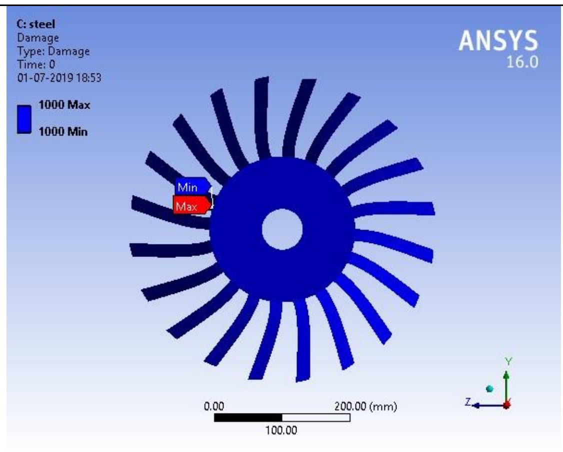
Total deformation



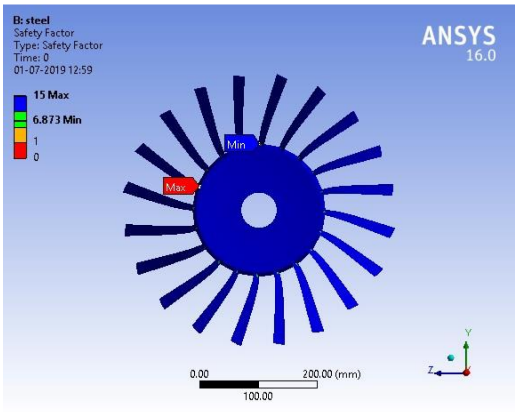


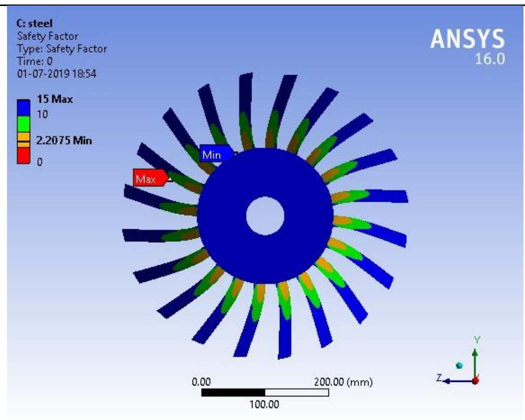
Fatigue Life





Fatigue Damage



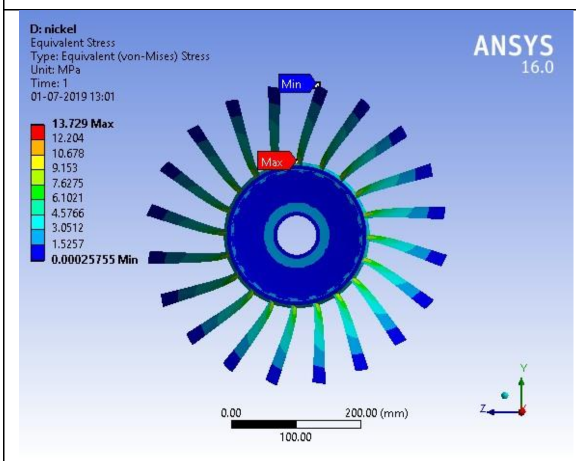


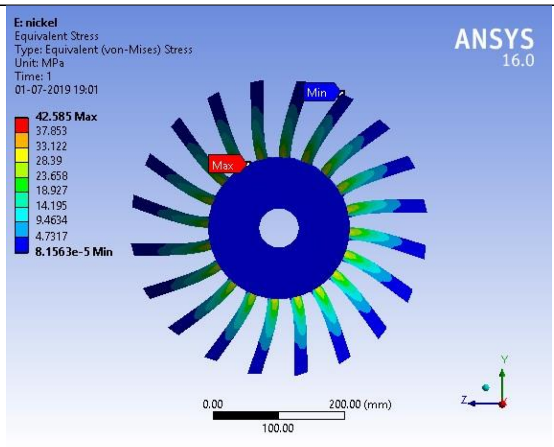
Fatigue Safety factor

Nickel alloy

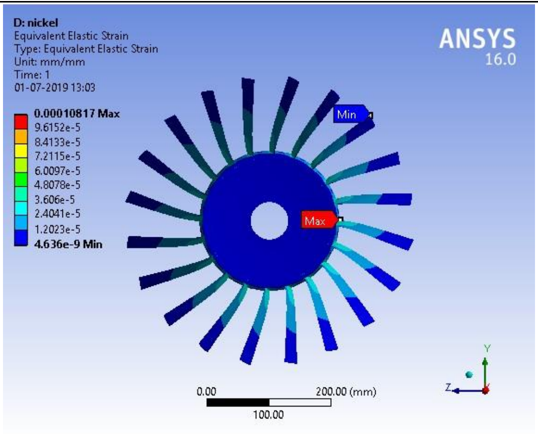
In structure analysis results are achieved through analysing the von misses stress, strain, total deformation, and fatigue tool.

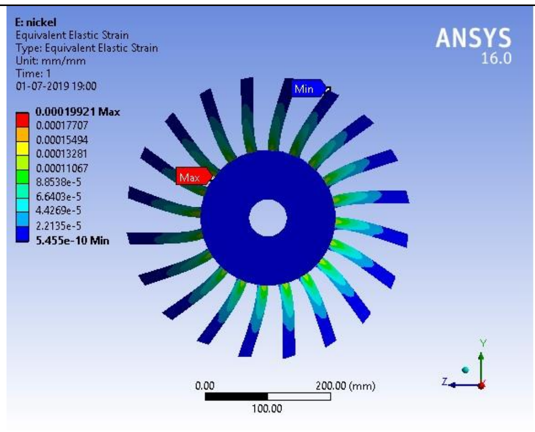
CASE 1	CASE 2



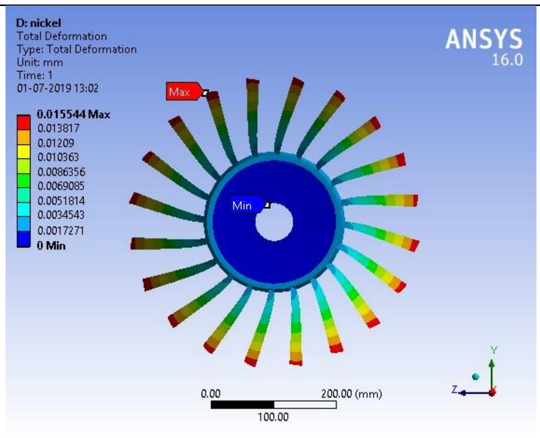


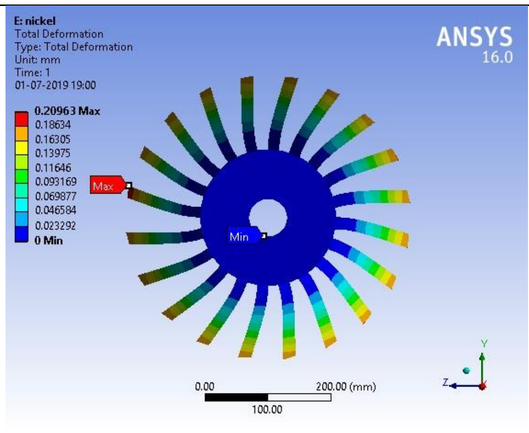
Equivalent (von-mises) stress



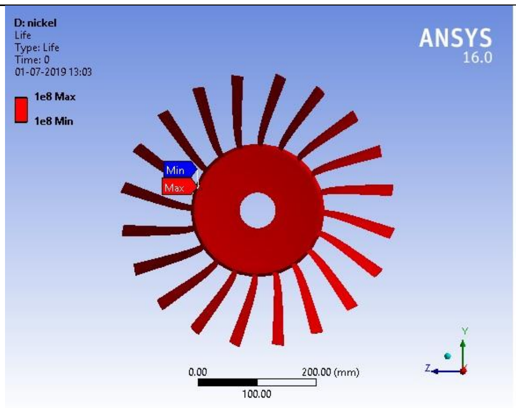


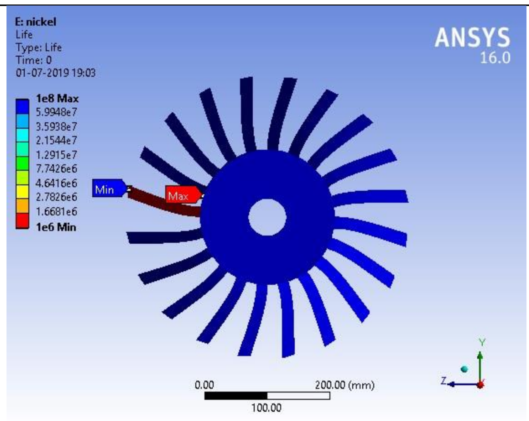
Equivalent strain



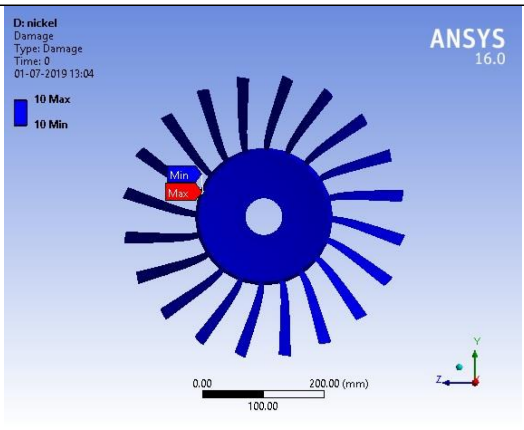


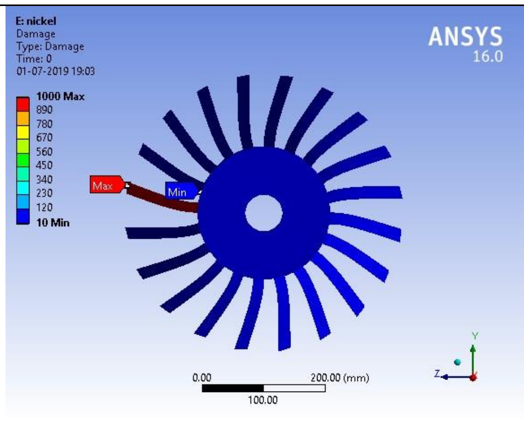
Total deformation



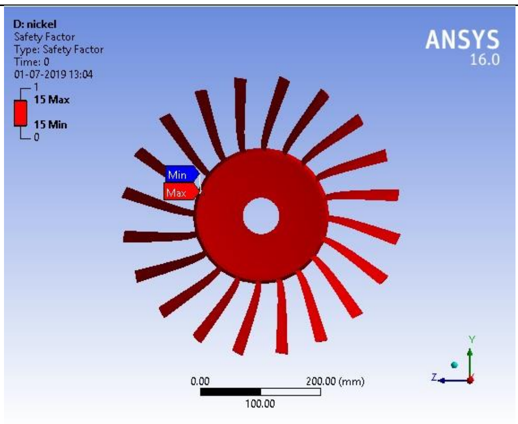


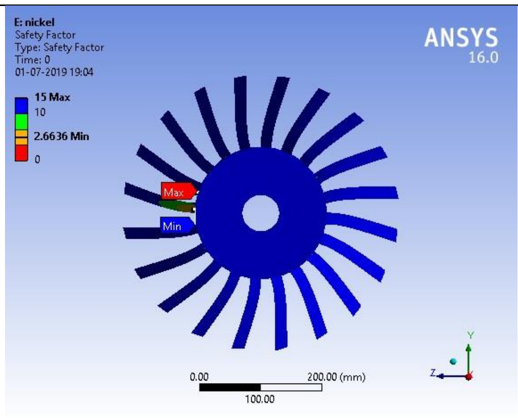
Fatigue Life





Fatigue Damage



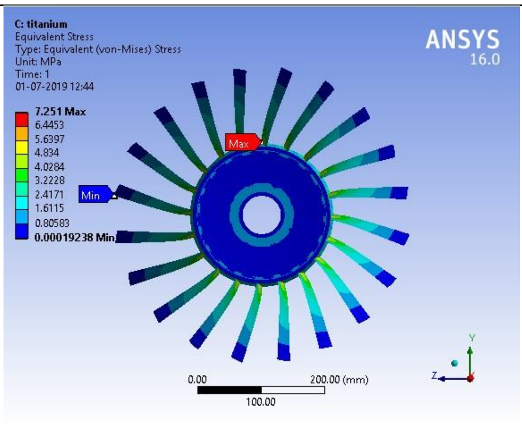


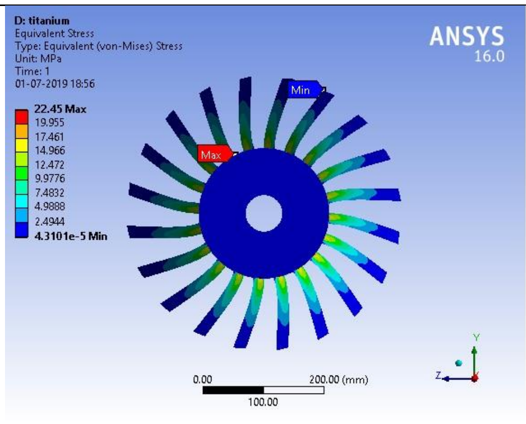
Fatigue Safety factor

Titanium alloy

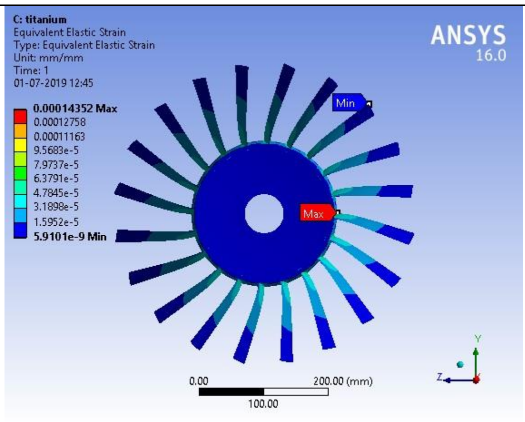
In structure analysis results are achieved through analyzing the von misses stress, strain, total deformation, and fatigue tool.

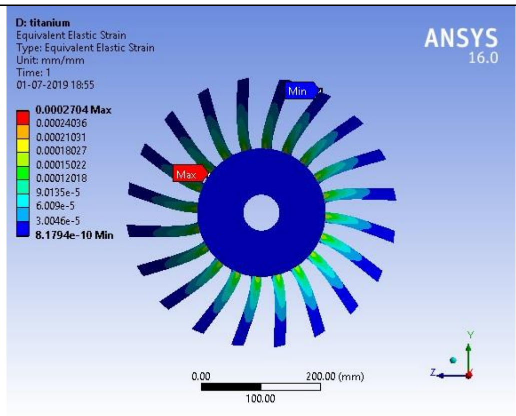
CASE 1	CASE 2



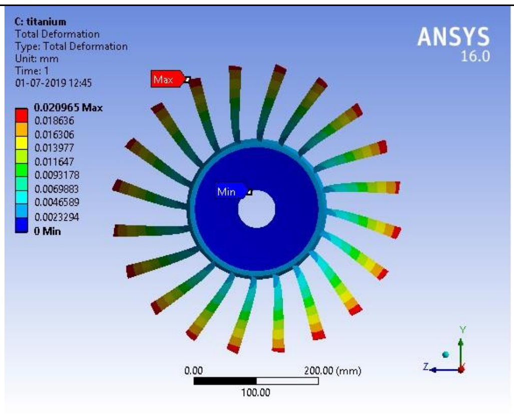


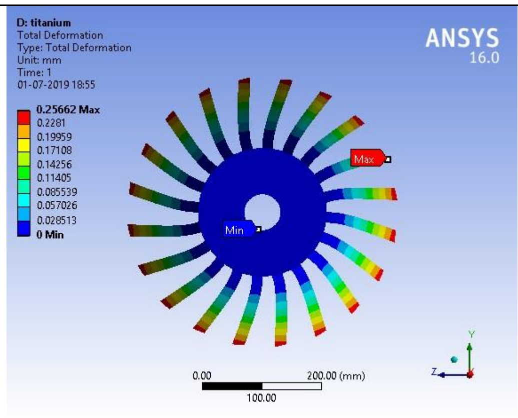
Equivalent (von-mises) stress



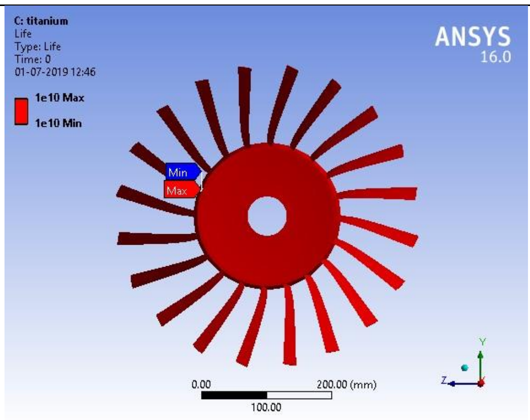


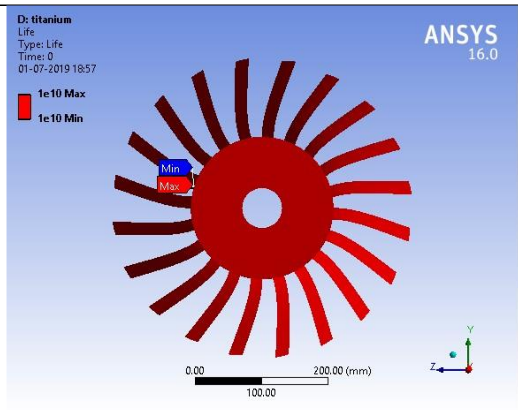
Equivalent strain



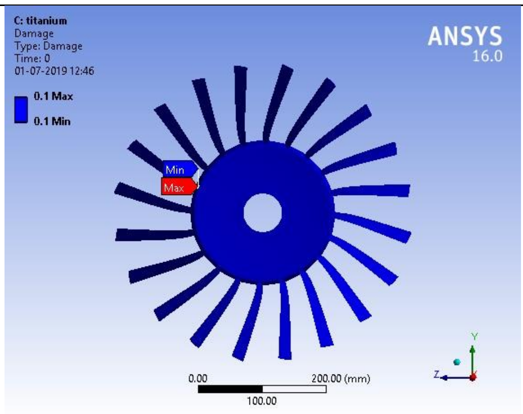


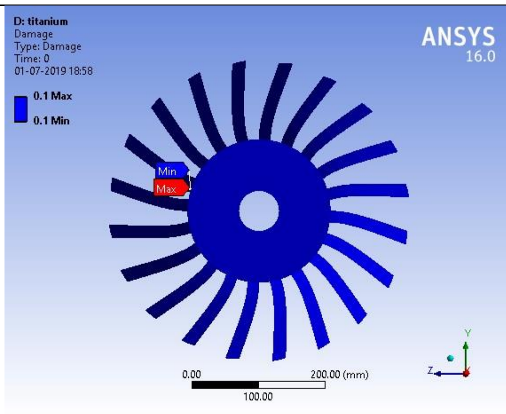
Total deformation



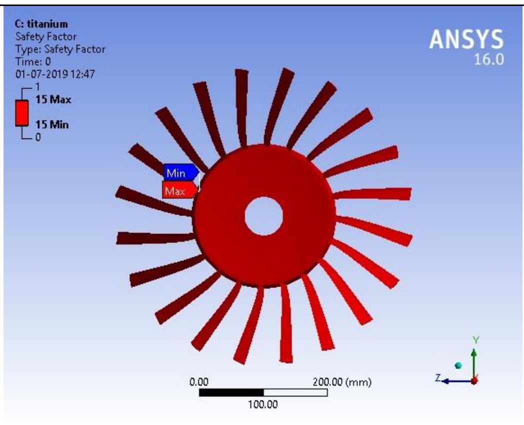


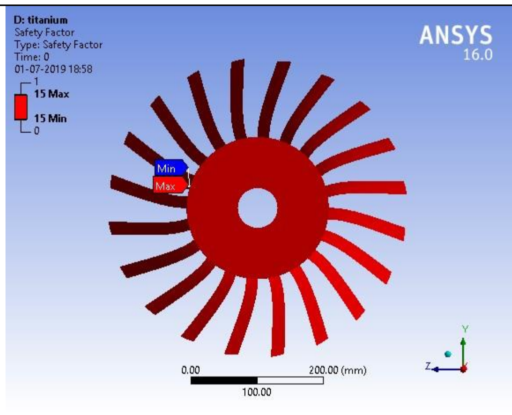
Fatigue Life





Fatigue Damage

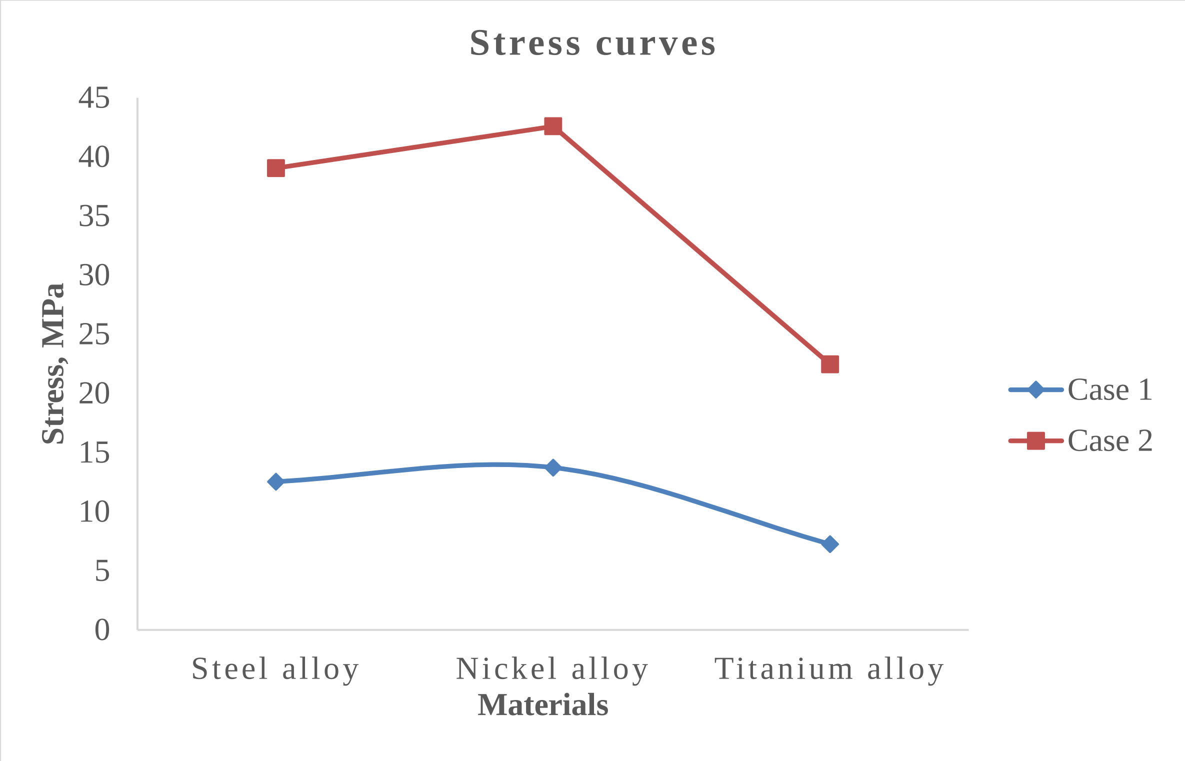




Fatigue Safety factor

Results and Discussion Table

Material	Properties	Case 1	Case 2
Steel alloy	Von-mises Stress	12.54 MPa	39.049 MPa
	Strain	0.00012243	0.00022146
	Total Deformation	0.01739 mm	0.21118 mm
	Fatigue Life	1×10^6 cycles	1×10^6 cycles
	Fatigue Damage	1000	1000
	Fatigue Safety factor	15	15
Nickel alloy	Von-mises Stress	13.729 MPa	42.585 MPa
	Strain	0.00010817	0.0001992
	Total Deformation	0.01554 mm	.20963 mm
	Fatigue Life	1×10^8 cycles	1×10^8 cycles
	Fatigue Damage	10	1000
	Fatigue Safety factor	15	15
Titanium alloy	Von-mises Stress	**7.251MPa**	**22.45 MPa**
	Strain	0.00014353	0.0002704
	Total Deformation	0.0206 mm	0.25662 mm
	Fatigue Life	**1×10^{10} cycles**	**1×10^{10} cycles**
	Fatigue Damage	0.1	0.1
	Fatigue Safety factor	15	15



Stress v/s Strain Curve

V. CONCLUSION

- The compressor blade is modelled by using 3D modeling Software CATIA V5R14 2018. In this case stress analysis and Fatigue analysis of different materials is carried out using analysis software ANSYS 16.
- This analysis shows that Titanium alloy blade gives better safety factors compared to other alloys.
- Titanium is chosen as the best material for rotor blade in terms of stress and fatigue life analysis

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