Design and Analysis of a Steam turbine Blade

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Abstract **A turbine blade is the individual component which makes up the turbine section of a gas turbine or steam turbine. The blades are responsible for extracting energy from the high temperature, high pressure gas. In such cases turbine failures may occur due to blade cracking and erosion.**

The present work focuses on the turbine blade and the solid model of turbine blade is created by using SOLID WORKS software and the performance is analyzed by the ANSYS software under considerations of static and thermal loading conditions. In this content three different materials Aluminium alloy, Magnesium alloy, Titanium Alloy are chosen and the results has been compared .The analysis was carried out to know the mechanical stresses ,thermal stresses and deformation developed by the turbine blade. By comparing all results suitable material is suggested for the manufacturing of turbine blade.

Keywords — Blade cracking, erosion, SOLID WORKS, thermal loading, mechanical stresses, Aluminium alloy, Magnesium alloy Titanium Alloy

I. INTRODUCTION

A Turbine is a rotary mechanical device that extracts energy from a fluid flow and converts it into useful work. The work produced by a turbine can be used for generating electrical power when combined with a generator. 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. Early turbine examples are windmills and waterwheels.

Gas, steam, and water turbines have a casing around the blades that contains and controls the working fluid. Credit for invention of the steam turbine is given both to Anglo-Irish engineer Sir Charles Parsons (1854–1931) for invention of the reaction turbine, and to Swedish engineer Gustaf de Laval (1845–1913) for invention of the impulse turbine. Modern steam turbines frequently employ both reaction and impulse in the same unit, typically varying the degree of reaction and impulse from the blade root to its periphery.

II. TURBINE BLADE FAILURES:

A common failure mode for turbine machine is high cycle of fatigue of compressor and turbine blades due to high dynamic stress caused by blade vibration and resonance within the operating range of machinery

CORROSION FAILURE:

A corrosion failure occurs when the metal wears away or dissolves or is oxidized due to chemical reactions, mainly oxidation. It occurs whenever a gas or liquid chemically attacks an exposed surface, often a metal. Corrosion is accelerated by warm temperatures and by acids and salts. Unacceptable failure rates of mostly blades

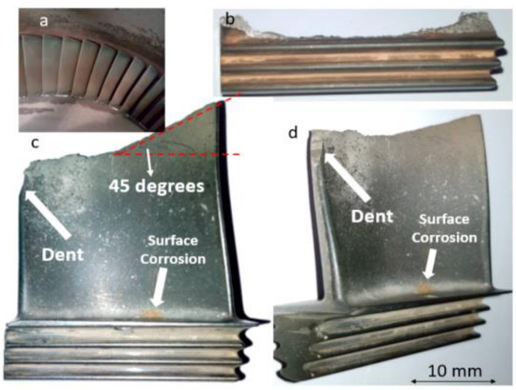

Fig 1 : Corrosion Failure

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FRETTING FATIGUE FAILURE:

In gas turbine engines is one of critical components which can fail due to fretting fatigue. Although this joint is nominally fixed, micro-scale relative movement at the interface occurs between contacting bodies experience both centrifugal and oscillatory tangential movement vibrations resulting in damage and causes a in fatigue life. This phenomenon is known as fretting fatigue

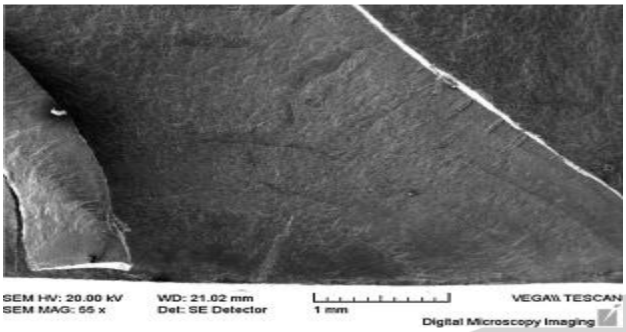

Fig 2: Fretting Fatigue Failure

FATIGUE-CREEP FAILURE:

Steam/Gas turbine blades are subjected to very high levels of stress and temperature during each engine operating cycle and due to vibrations produced in the turbine during transient loads the predominant blade failures are due to fatigue.

Fig 3: Fatigue Creep Failure

PROBLEM STATEMENT

All modern steam power plants use impulse-reaction turbines as their blading efficiency is higher than that of impulse turbines. Last stage of steam turbine impulse-reaction blades are very much directly affect efficiency of plant. With the information that an understanding of the forces and stresses acting on the turbine blades is vital importance, in this work we will compute such a force acting on a last stage Low Pressure (LP) blade of a large steam turbine rotating at 3000 rpm.

In order to estimate the failure happens in the blades and it is based on material stresses at the blade root only and to estimation of these things structural and thermal analysis of blade using FEA for this work and by use of the operational data have performed by using FEA (ANSYS) and this work involved the analyze blade and check FEA data of blade with various material.

III. METHODOLOGY

- The objective of this work is to make a steam turbine blade with 3D model and estimate the static - thermal behaviour of the steam turbine blade with different materials i.e Al, Mg, Ti alloy by performing the finite element analysis.
- To generate 3-dimentional geometry model of the steam turbine blade in SOLID WORKS.
- To perform structural analysis on the model to determine the stress, shear stress, deformation of the component, under the static-thermal load conditions.
- To compare analysis between three different materials analysed by the ANSYS.
- From all these analysis results suitable material is to be proposed.

SELECTION OF MATERIALS IN THE DESIGNING

The basic work is depends on consideration of these three different materials

S.NO.	MATERIAL PROPERTY	ALUMINIUM ALLOY (Al-6061)	MAGNESIUM ALLOY (AZ31)	TITANIUM ALLOY (TI-6A1-4V)
1.	Density	2.7g/cm3	1.77g/cm3	4.43g/cm3
2.	Poisson's Ratio	0.33	0.35	0.342
3.	Young's Modulus	68.9GPa	456GPa	113.8GPa
4.	Tensile Yield Strength	276MPa	200MPa	880MPa
5.	Ultimate Tensile Strength	310MPa	255MPa	950MPa
6.	Thermal Conductivity	167 W/m-k	96 W/m-k	6.7 W/m-k

Table 1 : Materials and Properties

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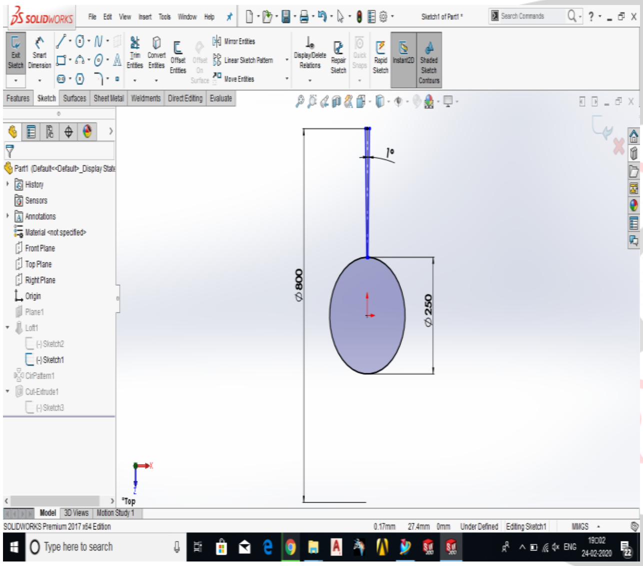
After working on these materials finally we conclude that which material gives the good performance on applied condition

IV. DESIGN PROCESS

INPUT DESIGN PARAMETERS

- Inner Diameter (Di) = 250mm
- Outer Diameter (Do) = 800mm
- Shaft Diameter (Ds) = 120mm
- Blade thickness (t) = 40mm
- Blade Length (L) = 550mm
- Blade angle (θ) = 1deg
- Hub Dimensions (l x b) = 20x8mm
- Number of blades (n) = 40

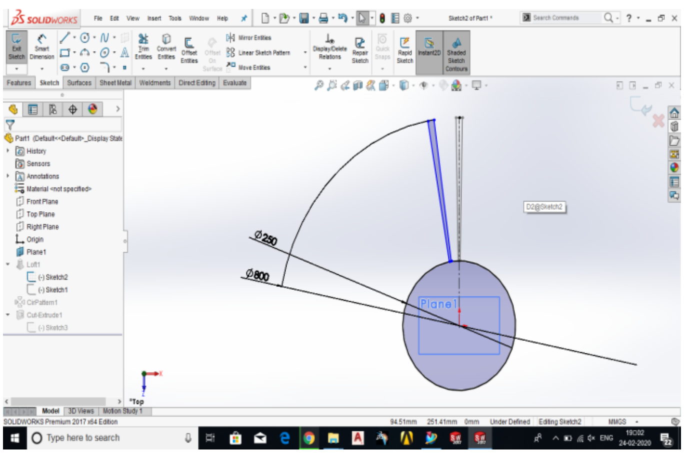
STEP 1:



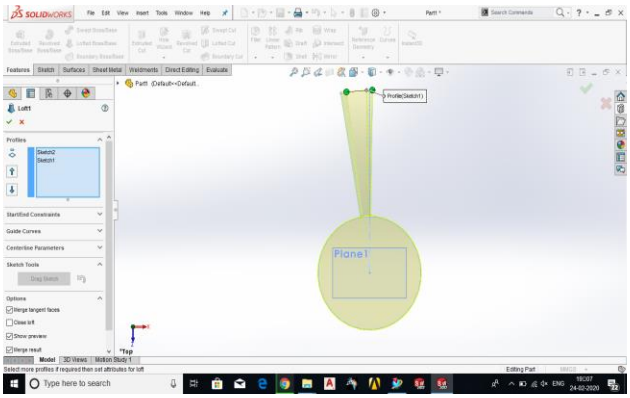
Click Sketch < Circle < Plane 1 < Smart Dimensions < Ok

STEP 2:

Click Sketch < Circle < Plane 2 < Smart Dimensions < Ok



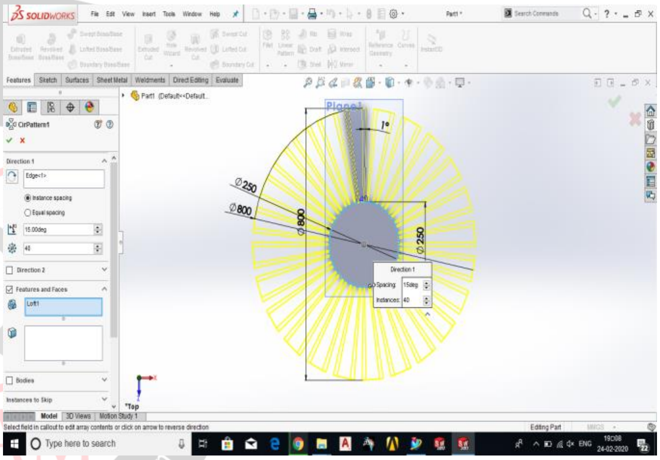
STEP 3 :



In the process to use the loft base command. In the first plane in select the first point on the blade and another plane in select the end point on the blade

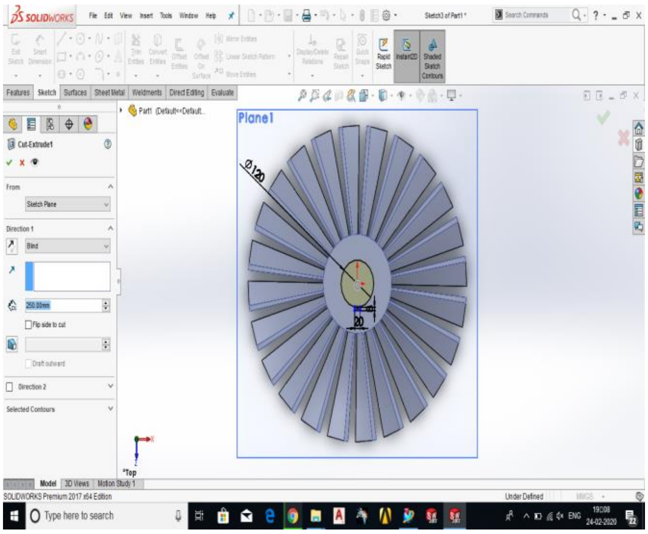
STEP 4 :

Loft base < Circular pattern < Spacing < Number of blades < Ok



STEP 5 :

Select sketch < Circle < Smart dimensions < Sketch < Rectangle < Smart dimensions < Ok



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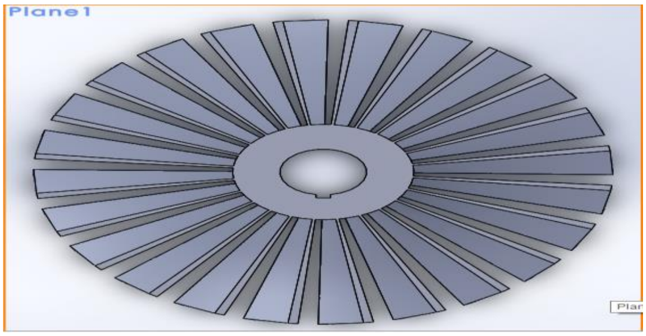
STEP 6 :

Finally the 3-D modeling is completed for the designing of turbine blade with accurate dimensions.



V. ANALYSIS

WORKING COMPONENTS ON ANALYSIS

Static Structural Analysis:

In this static structural analysis we working on following results using three different materials

- Total Deformation
- Equivalent stress
- Equivalent strain
- Shear strain
- Shear stress

Steady State Thermal Analysis:

In this steady state thermal analysis we are working on following results using three different materials

- Total Heat Flux
- Temperature Distribution
- Directional Heat flux (x ,y, z)

INPUT PARAMETERS

These are the input parameters which are given to the analysis part

- Force = 400N
- Temperature = 230^0 c
- Ambient temperature = 23 ^{0}c
- Film coefficient = 0.0025
- Fixed support
- Convection

STATIC STRUCTURAL ANALYSIS:
TOTAL DEFORMATION

<u>ALUMINIUM ALLOY</u>:

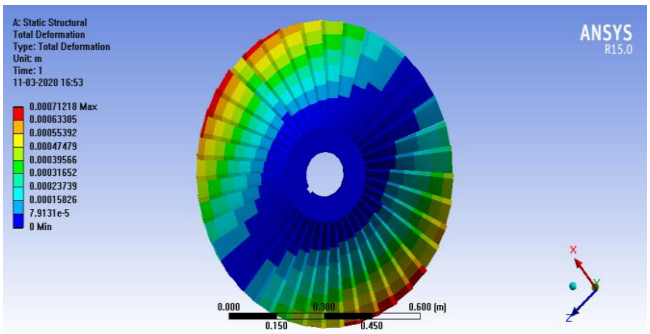


Figure 4: Total Deformation

Maximum Value = 0.00071218 M
Minimum Value = 0 M

<u>MAGNESIUM ALLOY :</u>

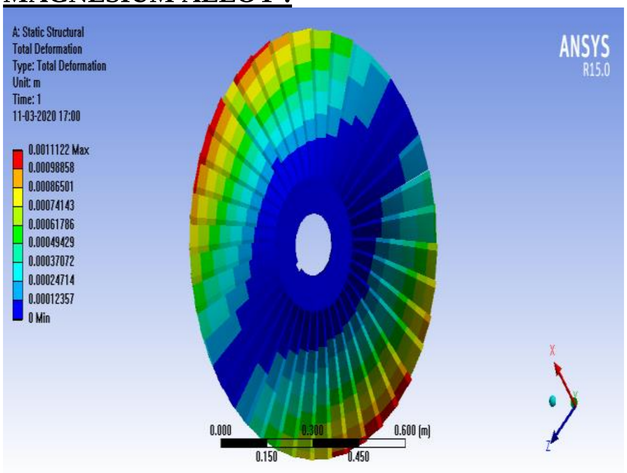


Figure 5: Total Deformation

Maximum Value = 0.0011122 M
Minimum Value = 0 M

<u>TITANIUM ALLOY :</u>

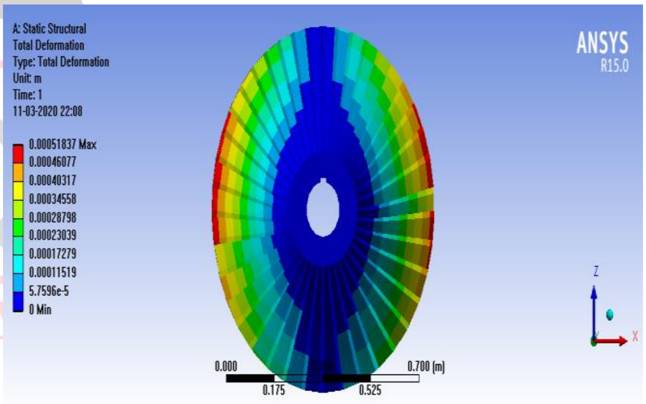


Figure 6: Total Deformation

Maximum Value : 0.00051837 M
Minimum Value : 0 M

EQUIVALENT STRESS

<u>ALUMINIUM ALLOY</u> :

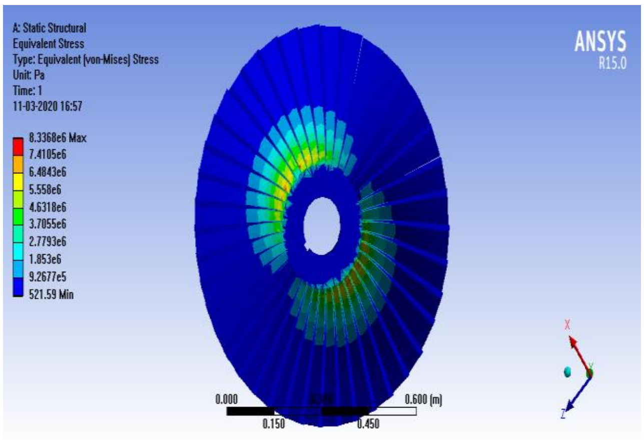


Figure 7: Equivalent Stress

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Maximum Value : 8.336e^6 Pa
Minimum Value : 521.59 Pa

MAGNESIUM ALLOY :

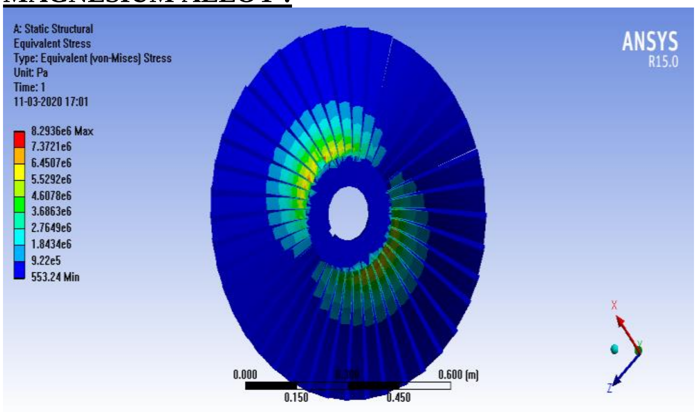

Figure 8: Equivalent Stress

Maximum Value : 8.2936e^6 Pa
Minimum Value : 553.24 Pa

TITANIUM ALLOY :

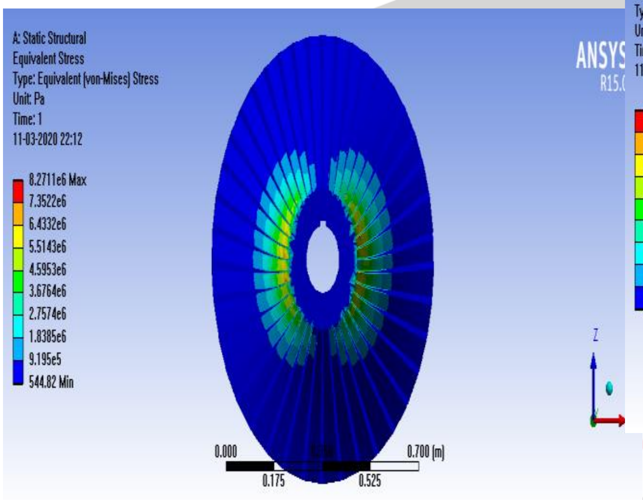

Figure 9: Equivalent Stress
Maximum Value : 8.2711e^6 Pa
Minimum Value : 544.82 Pa

EQUIVALENT STRAIN
ALUMINIUM ALLOY :

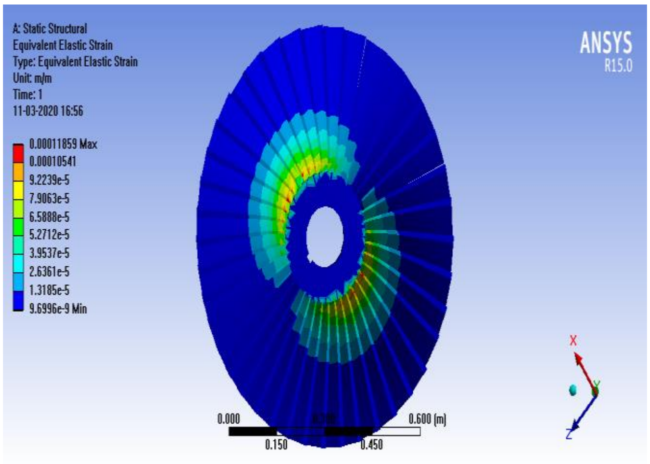

Figure 10: Equivalent Strain

Maximum Value : 0.00011859

Minimum Value : 9.6996e^-9

MAGNESIUM ALLOY

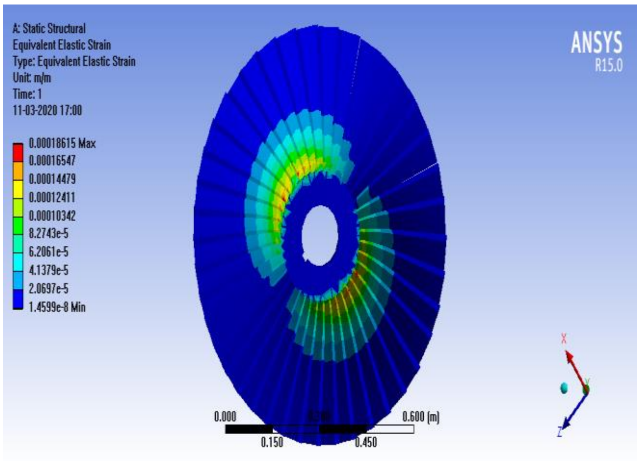

Figure 11: Equivalent Strain
Maximum Value : 0.00018615
Minimum Value : 1.4599e^-8

TITANIUM ALLOY :

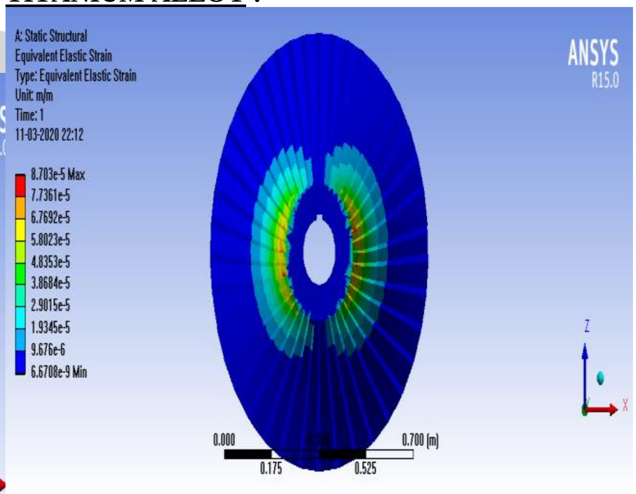

Figure 12: Equivalent Strain
Maximum Value : 8.703e^-5
Minimum Value : 6.6708e^-9

SHEAR STRAIN
ALUMINIUM ALLOY :

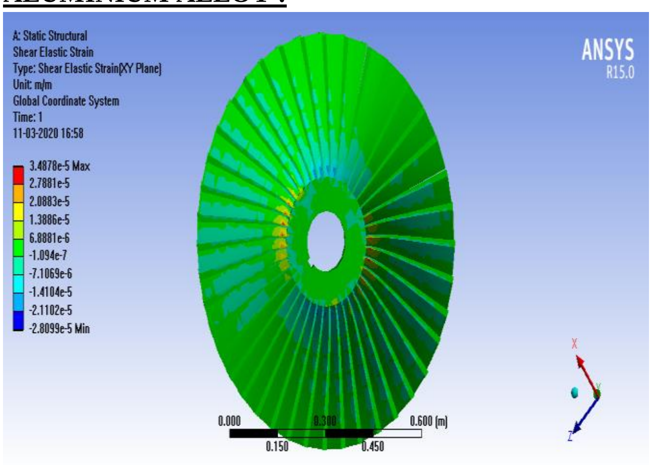

Figure 13: Shear Strain

Maximum Value : 3.4878e^-5

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Minimum Value : -2.8899e^-5

MAGNESIUM ALLOY

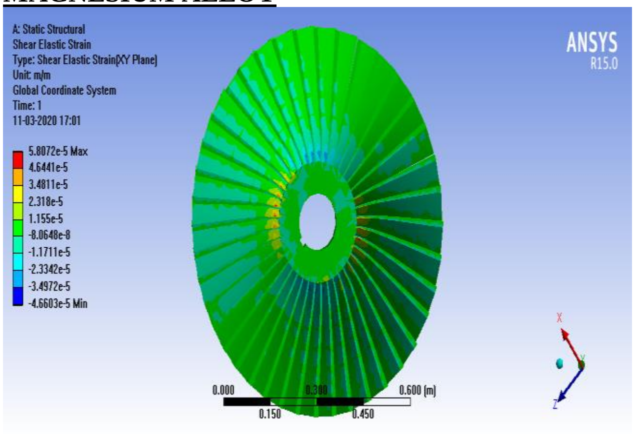

Figure 14: Shear Strain

Maximum Value : 5.8072e^-5

Minimum Value : -4.6603e^-5

TITANIUM ALLOY

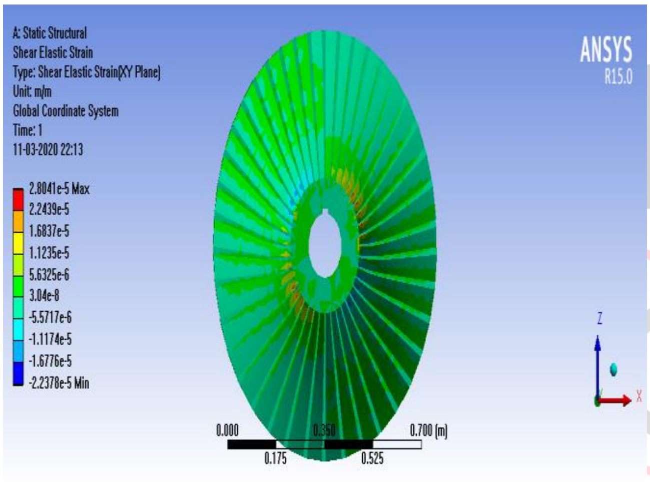

Figure 15: Shear Strain

Maximum Value : 2.8041e^-5

Minimum Value : -2.2378e^-5

SHEAR STRESS

ALUMINIUM ALLOY

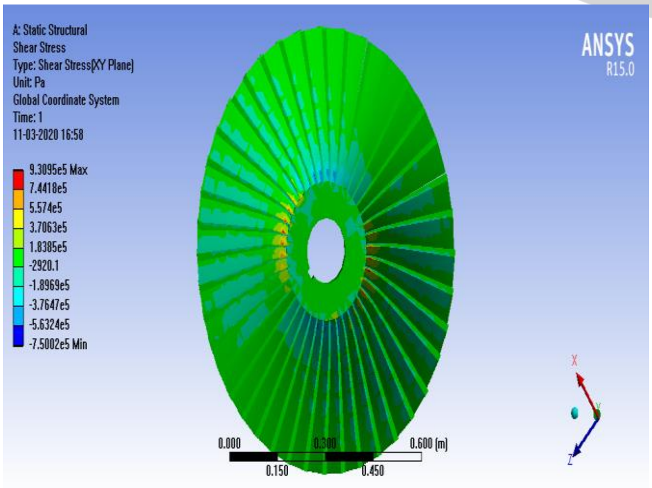

Figure 16: Shear Stress

Maximum Value : 9.3095e^5

Minimum Value : -7.5002e^5

MAGNESIUM ALLOY

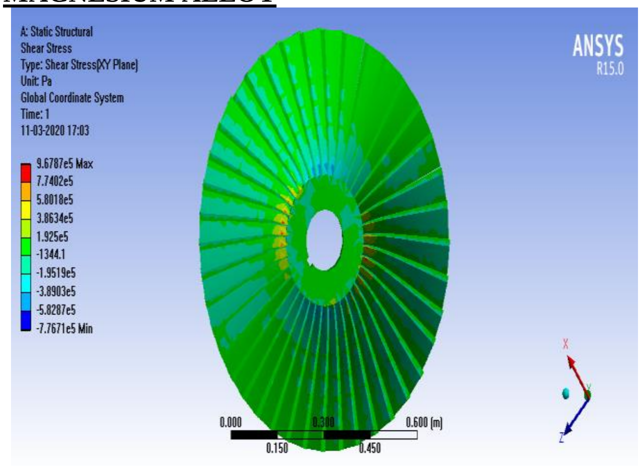

Figure 17: Shear Stress

Maximum Value : 9.6787e^5

Minimum Value : -7.7671e^5

TITANIUM ALLOY

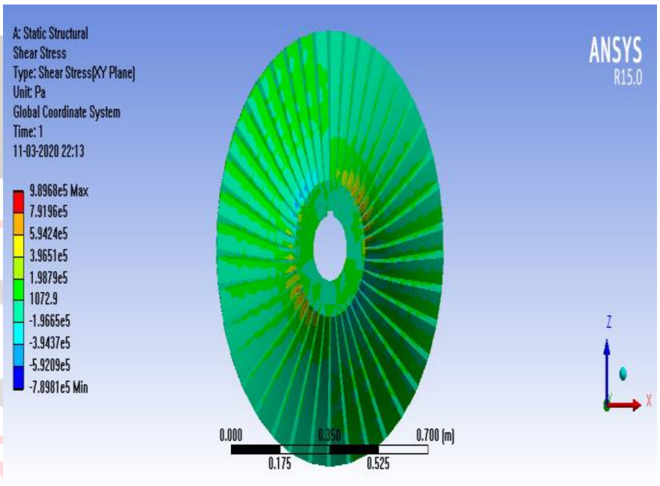

Figure 18: Shear Stress

Maximum Value : 9.8968e^5

Minimum Value : -7.8981e^5

STEADY-STATE THERMAL ANALYSIS

TOTAL HEAT FLUX

ALUMINIUM ALLOY

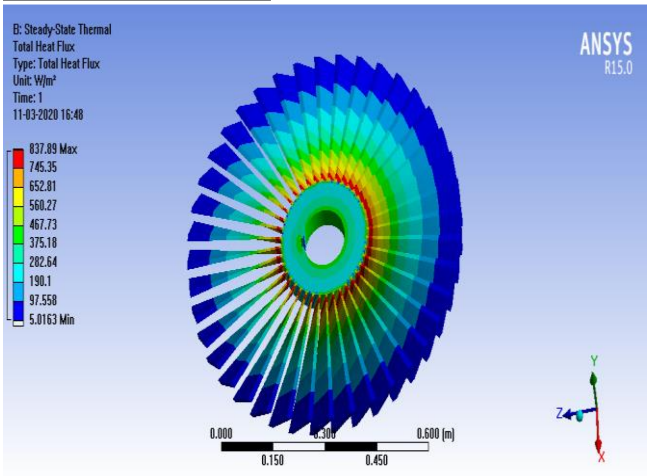

Figure 19: Total Heat Flux

Maximum Value : 837.89W/M^2

Minimum Value : 5.0163 W/M^2

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MAGNESIUM ALLOY

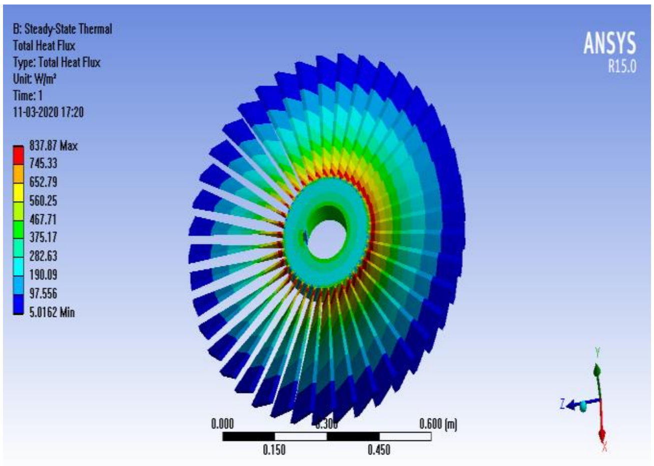

Figure 20: Total Heat Flux

Maximum Value : 837.87 W/M^2
Minimum Value :5.0162 W/M^2

TITANIUM ALLOY

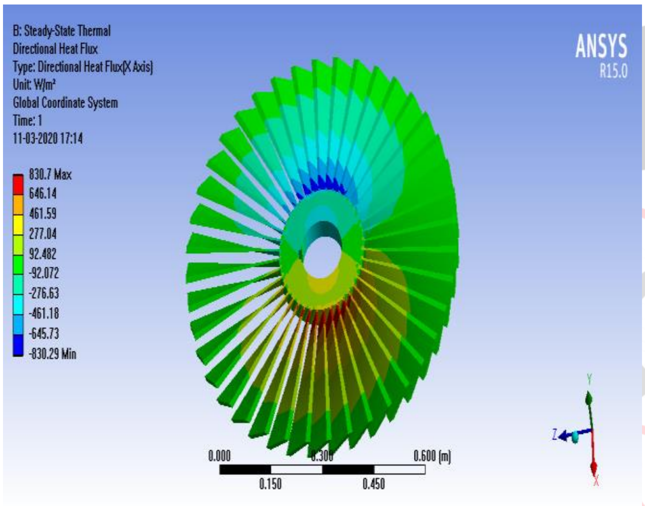

Figure 21: Total Heat Flux

Maximum Value : 894.31 W/M^2
Minimum Value : 4.0152 W/M^2

TOTAL HEAT FLUX - IN X,Y,Z –DIRECTIONS:

ALUMINIUM ALLOY

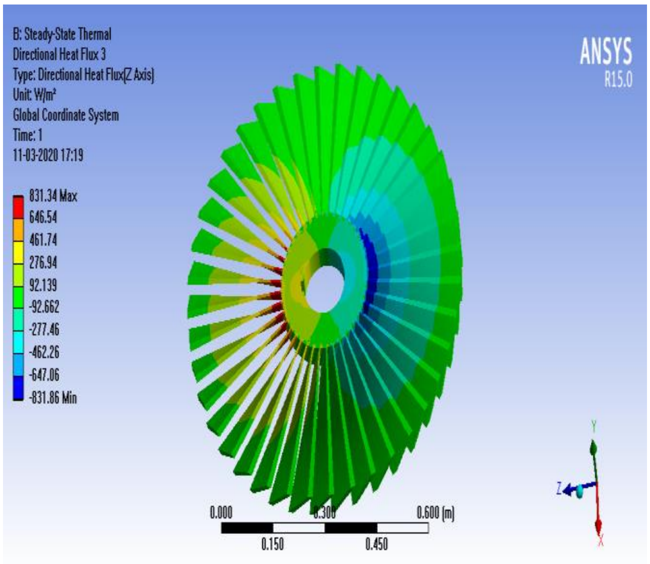

Figure 22: Directional Heat Flux in X-Direction

Maximum Value : 830.7 W/M^2
Minimum Value : -830.29 W/M^2

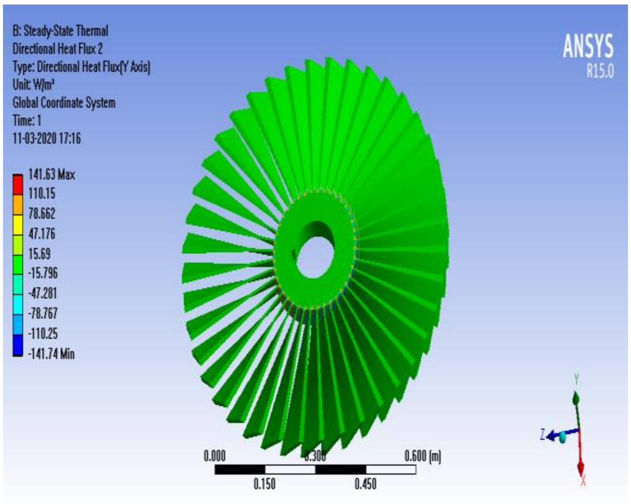

Figure 23: Directional Heat Flux in Y - Direction

Maximum Value :141.63 W/M^2
Minimumvalue : -141.74 W/M^2

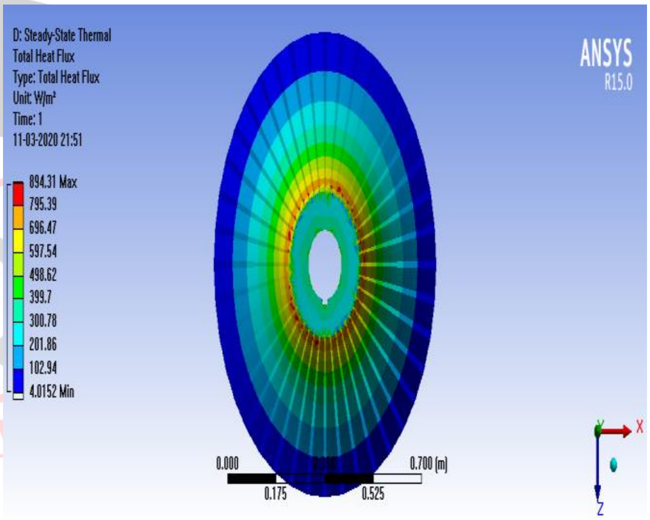

Figure 24: Directional Heat Flux in Z- Direction

Maximum Value : 831.34 W/M^2
Minimum Value : -831.86 W/M^2

MAGNESIUM ALLOY

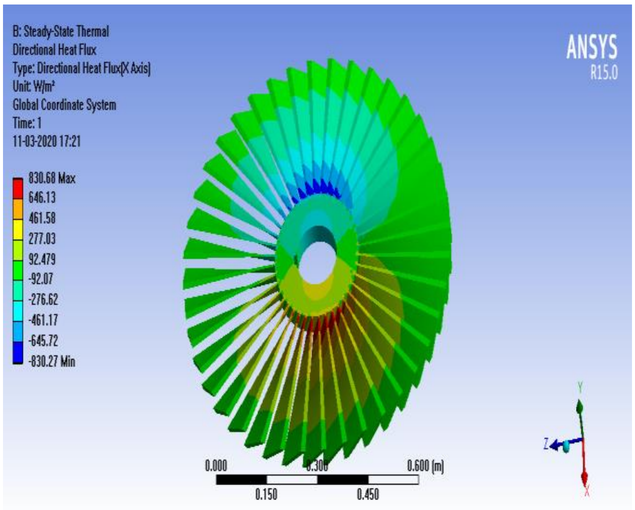

Figure 25: Directional Heat Flux in X- Direction

Maximum Value : 830.68 W/M^2

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Minimum Value : -830.27 W/M^2

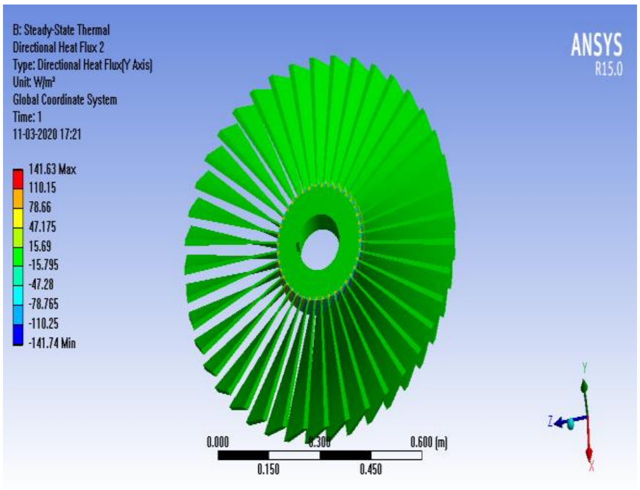

Figure 26:Directional Heat Flux in Y- Direction

Maximum Value :141.63 W/M^2

Minimum Value :141.74 W/M^2

<u>TITANIUM ALLOY</u> :

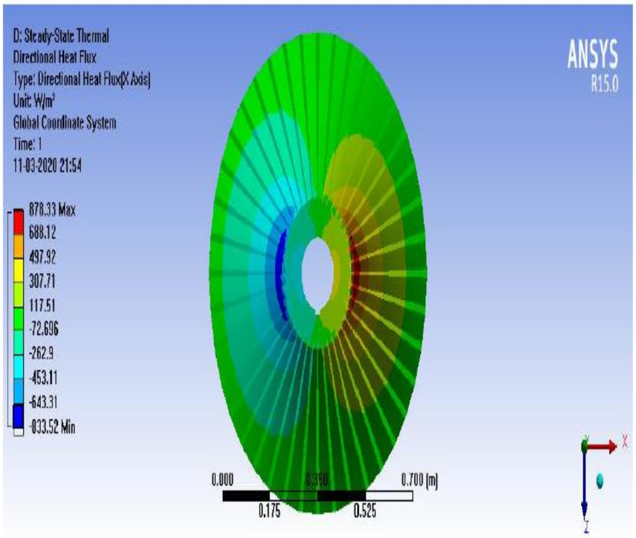

Figure 27: Directional Heat Flux in X-Direction

Maximum Value : 878.33 W/M^2

Minimum Value : -833.52 W/M^2

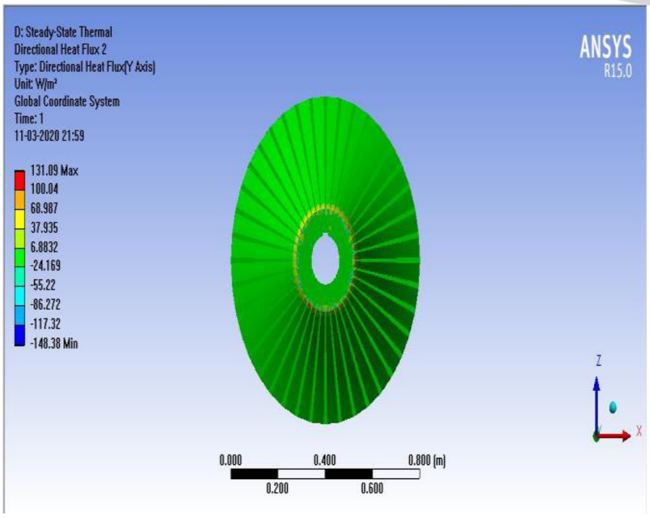

Figure 28: Directional Heat Flux in Y -Direction

Maximum Value : 131.09 W/M^2

Minimum Value : -148.38 W/M^2

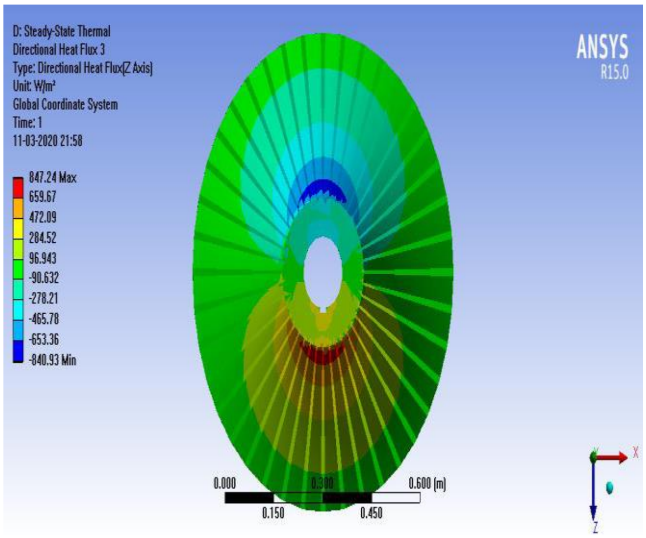

Figure 29:Directional Heat Flux in Z –Direction

Maximum Value : 847.24 W/M^2

Minimum Value : -840.93 W/M^2

VI. RESULTS AND DISCUSSIONS

STRUCTURAL ANALYSIS

Material	Deformation (m)	Equivalent stress (Pa)	Equivalent strain	Shear stress (pa)	Shear strain
Aluminium Alloy	0.00071218	8.336e^6	0.00011859	9.3095e^5	3.4878e^-5
Magnesium Alloy	0.0011122	8.2936e^6	0.00018615	9.6787e^5	5.8072e^-5
Titanium Alloy	0.00051837	8.2711e^6	8.703e^-5	9.8968e^5	2.8041e^-5

Table 2 :Structural Analysis Results

STEADY STATE THERMAL ANALYSIS

Material	Total Heat Flux(W/M^2)	Total Heat Flux In X-Direction (W/M^2)	Total Heat Flux In Y-Direction (W/M^2)	Total Heat Flux In Z-Direction (W/M^2)
Aluminium Alloy	837.89	830.7	141.63	831.34
Magnesium Alloy	837.87	830.68	141.63	831.32
Titanium Alloy	894.31	878.33	131.09	847.24

Table 3 :Steady State Thermal Analysis

The results have been observed for turbine blade in two different analysis like structural and thermal by chosen three different materials like Aluminium Alloy , Magnesium Alloy, Titanium Alloy .

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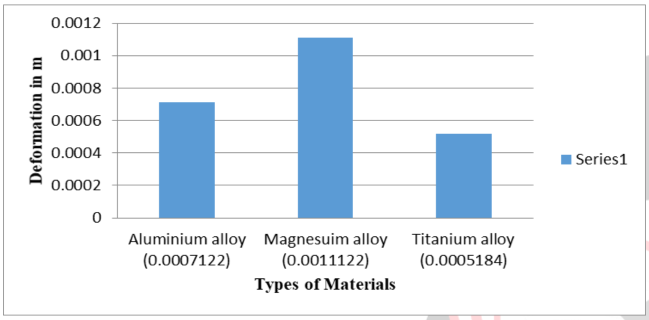
- In this criteria deformation, stresses, strains and heat flux values has been compared.
- According to deformation in Titanium Alloy is 0.00051837m and it is very low compare to remaining two materials.
- In case of Aluminium Alloy , Magnesium Alloy and Titanium Alloy also the equivalent stress values are 8.336e^6 Pa, 8.2936e^6 Pa and 8.2711e^6 Pa and when compared to all materials Titanium alloy has low stress so the design is safe.
- In case of Thermal analysis also by comparing three materials Aluminium Alloy , Magnesium Alloy and Titanium Alloy thermal behaviour is good i.e that is heat flux value should be maximum so it is in safe condition.

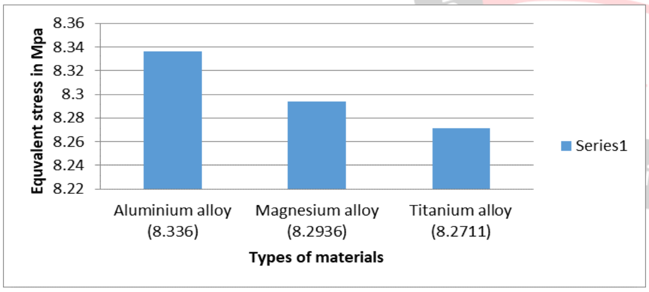
VII. COMPARISON WITH GRAPHS

Deformation



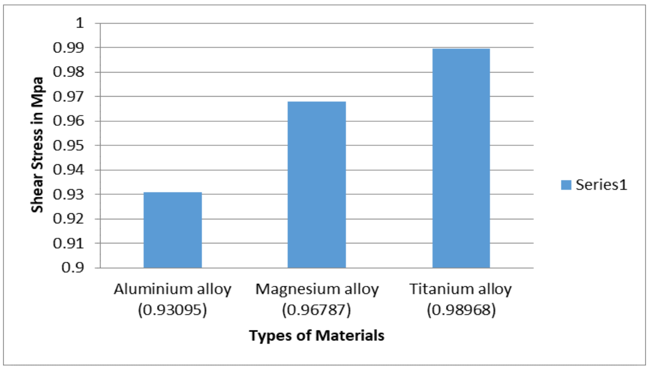
Deformation graph for Aluminium alloy vs Magnesium alloy vs Titanium alloy

Equivalent Stress



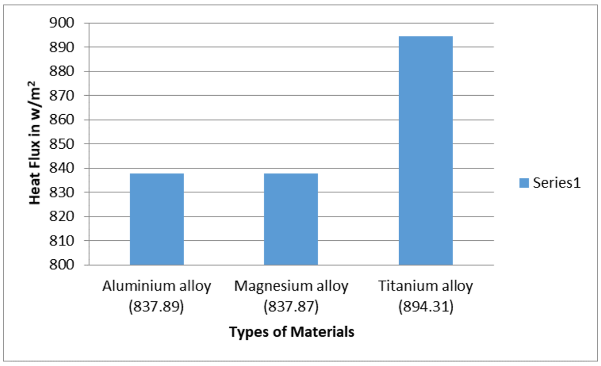
Equivalent stress graph for Aluminium alloy vs Magnesium alloy vs Titanium alloy

Shear Stress



Shear stress graph for Aluminium alloy vs Magnesium alloy vs Titanium alloy

Heat Flux



Heatflux graph for Al alloy vs Mg alloy vs Titanium alloy

VIII. CONCLUSION

In this work turbine blade has been designed for steam turbines by using solid works and also Structural analysis, Thermal analysis was carried out by chosen different materials like Aluminium alloy, Magnesium alloy and Titanium alloy. In this analysis criteria of both static and thermal behaviour of turbine blade different stresses,strains,deformation ,and heat flux values has been carried out for comparison.

By observing the results with three materials in Titanium alloy the stress values are less than their respective permissible yield stress values so our design is safe. In case of Thermal analysis also by comparing three materials, in Titanium Alloy thermal behaviour is good that is heat flux value should be maximum so it is in safe condition.

Finally by concluding this project from all analysis results suitable material Titanium alloy is to be proposed.

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