

DEVELOPING THE STEAM TURBINE BLADES BY USING VARIOUS MATERIALS INSTEAD OF EXISTING ONE AND CONDUCTING THE STRESS ANALYSIS

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Abstract- A steam turbine is a prime mover in which rotary motion is obtained by the gradual change of momentum of the steam. In a steam turbine the force extracted on the blades is due to the velocity of the steam. This is due to the fact the curved blades by changing the direction of the steam receive a force or impulse. The action of steam in this case is said to be dynamic. As a consequence of the significant amount of time spent away from the design point, the result of negligible pressure drop across the rotor is no longer valid and an appreciable axial force is present. Finite element stress analysis results must also be evaluated, but the fact that stress analysis is so much more. It may be noted that, considering the thermal analysis carried out on the different materials which shows the heat losses due to transfer must be less so that total heat is fully converted to mechanical energy; this may cause the increases in percentage of output power.

KeywordS: Steam Turbine, Turbine Blades and Ansys Software

I. INTRODUCTION

A steam turbine is a prime mover in which rotary motion is obtained by the gradual change of momentum of the steam. In a steam turbine the force exerted on the blades is due to the velocity of the steam. This is due to the fact the curved blades by changing the direction of steam receive a force or impulse. The action of steam in this case is said to be dynamic. Thus the dynamical pressure of steam rotates the vanes, buckets or blades directly. The turbine blades are curved in such a way that the steam directed upon them enters without shock though there is always some losses of energy by the friction upon the surface of blades. In general a steam turbine essentially consists of a following two parts.

NOZZLE

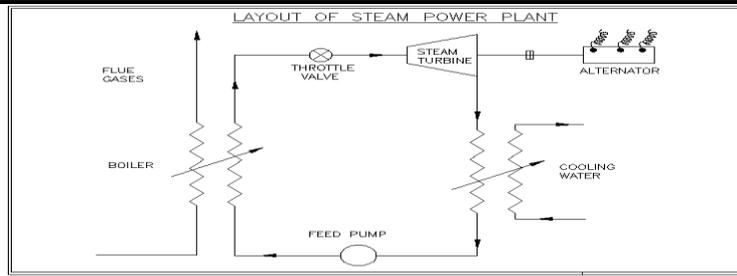
The nozzle in which the heat energy of high pressure steam is converted into kinetic energy. So that the steam issues from the nozzle with a very high velocity.

BLADES

The blades which change the direction of steam issuing from the nozzle so that a force acts on the blades due to change of momentum and propel them. Thus the basic principle of operation of a steam turbine is the generation of high velocity steam jet by the expansion of high pressure steam and then conversion of kinetic energy so obtained into mechanical work on rotor blades. Some aspects of the steam turbine cycle employed in such plants are also included. Sometimes the major role of a steam plant is to supply process steam and electric power is only a by-product or vice versa. Unlike power plant turbines the low output industrial turbines can be made smaller in size by increasing the rotational speeds. In doing so they may require reduction gear boxes for certain applications. **Fig - 1: Layout of Steam Power Plant.**

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II. LITERATURE SURVEY

G.G.sozhamanan, S.Balasivanandhaprabhu, V.S.K. Venkatagalapathi. Conventional stir casting process has been employed for producing discontinuous particle reinforced metal matrix, composites for decades. The major problem of this process is to obtain sufficient wetting of particle by liquid metal and to get a homogenous dispersion of the ceramic particle. In the present study, aluminum metal matrix composites were fabricated by different processing temperatures with different holding time to understand the influence of process parameters on the distribution of particle in the matrix and resultant mechanical properties. The distribution is examined by micro structure analysis, hardness distribution and density distribution. Aluminum metal matrix composites (MMCs) with Al-7075 matrix reinforced with Al₂O₃ particulates were prepared by liquid metallurgy route of stir casting. A 2-level factorial design of experiments (DOE) was used to study the influence of process parameter like size and weight fraction of reinforcement, sintering temperature and sintering time on micro hardness and impact strength of the composites. Mathematical model were developed to investigate which parameter significantly affects the selected mechanical properties. The results of the study indicate the both micro – hardness and impact strength Al-7075/ Al₂O₃ composites are affected by individual parameters as well as their 2-factor interaction. These models can be used to select the optimum process parameter for obtaining composites possessing desired hardness and impact strength within the range of experimental frame work. However, more detailed investigation undertaken by the authors to gain a deeper insight into the behavior of these composites.

Aluminum alloy-based metal matrix composites (AMMCs) have been by now established them as a suitable wear resistant material especially for sliding wear applications. However, in actual practice engineering components usually encounter combination of wear type. An attempt has been made in the present paper to highlight the effect of dispersing sic in 2014 base alloy adopting the liquid metallurgy root on different modes like sliding, abrasion, erosion and combination of wear mode like cavation erosion, erosion abrasion, sliding abrasion and the results obtained compared with the base alloy. It is found that there are a no of contributing factors for the resulting wear and all are not necessarily derogatory in nature. The limits within which the AMMCs can exhibit superior performance over the base alloy have been discussed. Worn surfaces and the subsurface studies have been out to understand the mechanism of material removal and role the different contributing factors to material removal. Wear mechanism that have been prevalent have been suggested and the possibility of making wear resistant components from MMCs is discussed based on the experimental results obtained.

III. AIMS AND SCOPE OF WORK

It is an important loss in both the impulse and reaction turbines, which occurs when the steam glides over the blades. This loss takes place due to friction of the surface of blades. As a result of the blade friction the relative velocity of the steam is reduced while gliding over the blade. Moisture loss is a loss in both the turbines which takes place due to moisture present in the steam. This loss occurs when the steam passing through the lower stages, becomes wet. The velocity of water particles is less than that of steam. As a result of this the steam has to drag the water particles, which reduce the kinetic energy of the steam.

The ultimate purpose of this study is to reduce the losses by replacing the different materials for blades of Impulse turbine with for Therefore, as the starting point, it was decided to use four different materials for turbine blades. The blades were manufactured using FDM Rapid prototyping machine using materials like austenitic alloy, Titanium alloy, Plastic Reinforced Carbon and 304 stainless steel. Before going for this type of manufacturing technique, a detailed stress, thermal and fatigue analysis was carried out for above mentioned materials. This paper reports the findings of those analyses, which provided the base for the manufacture of blades.

Designing products with plastics such as plastic reinforced carbon is more complicated than with metals. Metals display short properties that hold well for the long term at moderate temperatures, only exhibiting phenomena such as creep in high temperature applications such as gas turbine blades. But thermoplastics show these properties at room temperature, and these must be considered when designing in thermoplastics.

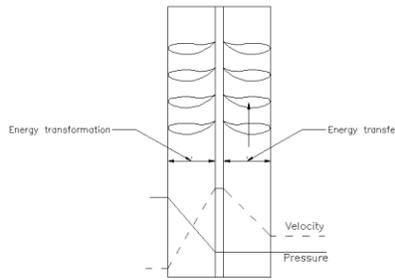


Fig – 2: Blades

IV. DESIGN OF BLADE MATERIALS

4.1 SPECIFICATIONS OF IMPULSE TURBINE

- a. Rated Power = 75 KW
- b. Rated Speed = 2400 rpm
- c. Steam Flow Rate = 1500 Tonnes/Hr
- d. Type = Impulse
- e. No of Stages = Single
- f. Temperature of Steam = 537° C
- g. Ampient Temperature = 40° C

The given data for calculating the velocity and driving force of the wheel is given as follows.

Velocity of the steam = 1200 m/s Nozzle angle = 20 degree
 Blade velocity = 375 m/s Blade velocity coefficient = 0.75
 Mass flow = $m = 0.5 \text{ kg/s}$

First of all draw a horizontal line and cut off AB equal to 375 m/s to some suitable scale representing the velocity of the blade. Now at b draw a line BC at an angle of 20 degree and cut off BC equal to 1200 m/s to the scale to represent the velocity of steam jet entering the blade.

The following values are measured from the velocity diagram.

BE = $V_w = 1130 \text{ m/s}$ BF = $V_{w1} = 190 \text{ m/s}$
 CE = $V_f = 410 \text{ m/s}$ DF = $V_{f1} = 310 \text{ m/s}$

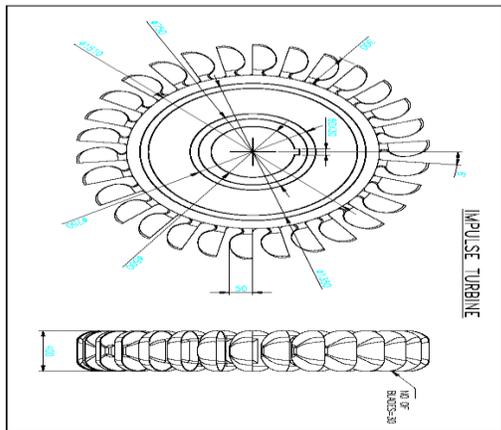


Fig – 3: Blade angle at inlet = 29 degree.

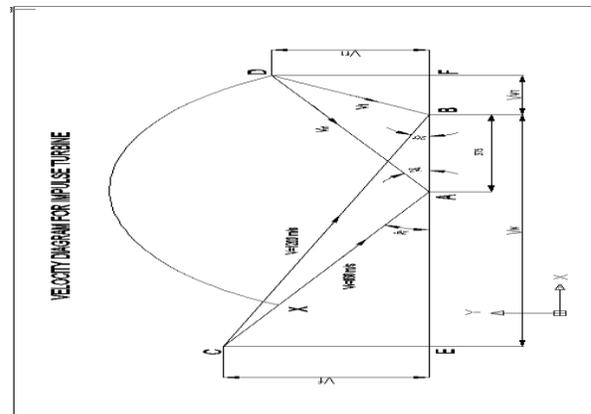


Fig – 4: Velocity diagram for impulse turbine

4.2 PROPERTIES OF THE BLADE MATERIALS

Table -1: Mechanical properties

Mechanical Properties	Austenitic Alloy	Titanium Alloy	Plastic Reinforced Carbon	304 Stainless Steel
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YOUNG'S MODULES (N/m ²)	179XE+9	110XE+9	120XE+9	196XE+9
POISSONS RATIO	0.30	0.32	0.25	0.29
DENSITY (kg/m ³)	7970	4540	1440	8000
TENSILE STRENGTH (Pa)	758XE+6	220XE+6	120XE+6	505XE+6

Table -2: Thermal properties

Thermal Properties	Austenitic Alloy	Titanium Alloy	Plastic Reinforced Carbon	304 Stainless Steel
THEMAL CONDUCTIVITY (W/m-K)	17.3	7.10	24.3	16.2
SPECIFIC HEAT (kg/KJ-K)	0.460	0.528	0.432	0.5

V. FINITE ELEMENT ANALYSIS

Finite Element Analysis (FEA) is a computer-based numerical technique for calculating the strength and behavior of engineering structures. It can be used to calculate deflection, stress, vibration, buckling behavior and many other phenomena. It also can be used to analyze either small or large- scale deflection under loading or applied displacement. It uses a numerical technique called the finite element method (FEM). The primary unknowns in this structural analysis are displacements and other quantities, such as strains, stresses, and reaction forces, are then derived from the nodal displacements.

5.1. Modeling linear layered shell

The Part Modeling Help introduces you to the terminology, basic design concepts, and procedures that you must know before you start building a part. Part Modeling shows you how to draft a 2D conceptual layout, create precise geometry using basic geometric entities, and dimension and constrain your geometry. You can learn how to build a 3D parametric part from a 2D sketch by combining basic and advanced features, such as extrusions, sweeps, cuts, holes, slots, and rounds. Finally, Part Modeling Help provides procedures for modifying part features and resolving failures.



Fig – 5: Modelling linear layered shell

The Finite Element Method (FEM) is a reliable numerical technique for analyzing engineering designs. FEM replaces a complex problem with many simple problems. It divides the model into many small pieces of simple shapes called elements. Elements share common points called nodes. The behavior of these elements is well-

known under all possible support and load scenarios. The motion of each node is fully described by translations in the X, Y, and Z directions. These are called degrees of freedom (DOFs). Analysis using FEM is called Finite Element Analysis (FEA).

5.2. Static Analysis

A static analysis result of structural displacements, stresses and strains and forces in structures for components caused by loads will give a clear idea about whether the structure or components will withstand for the applied maximum forces. If the stress values obtained in this analysis crosses the allowable values it will result in the failure of the structure in the static condition itself. To avoid such a failure, this analysis is necessary. The strength and stiffness properties of the glass/epoxy composite are used for the Analysis.

VI. METHODOLOGY

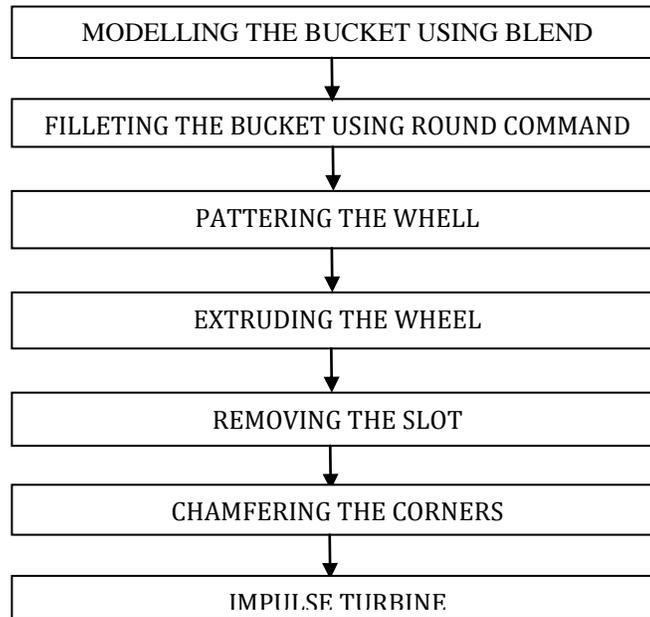


Fig – 6: Flow Diagram for Impulse Turbine Model

SOLID45 Stress Output

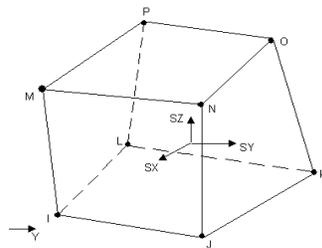


Fig – 7: Solid 45 stress output

The following figure shows the imported model of the impulse turbine model.

PLOTTING STAGE = LINE
 TOLERANCE USED = 0.0001
 SOLVER TYPE = FRONTAL SOLVER

6.1. Meshing Using Ansys

In preparing the model for analysis, Ansys subdivides the model into many small tetrahedral pieces called elements that share common points called nodes. A typical piece (element) is shown in the figure.

Type of mesh = global
 Element size = 0.5
 Mode of mesh = volume
 Key points = all

- a. Red dots represent the element's nodes.
- b. Elements can have straight or curved edges.
- c. Each node has three unknowns, namely, the translations in the three global directions.
- d. The process of subdividing the part into small pieces (elements) is called meshing. In general, smaller elements give more accurate results but require more computer resources and time.

After meshing the model the boundary conditions are applied properly then the final results are obtained. The following figure shows the final results of structural analysis for different materials like austenitic alloy, titanium alloy, plastic reinforced carbon and 304 stainless steel.

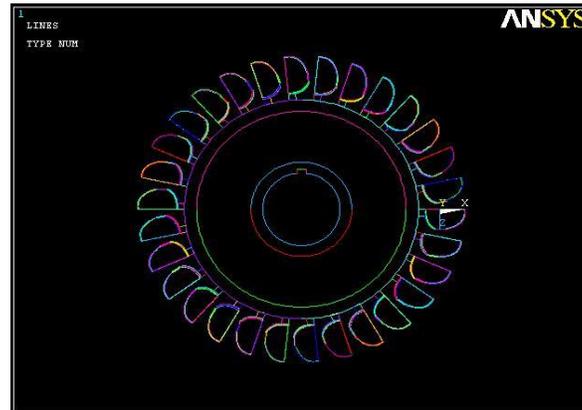
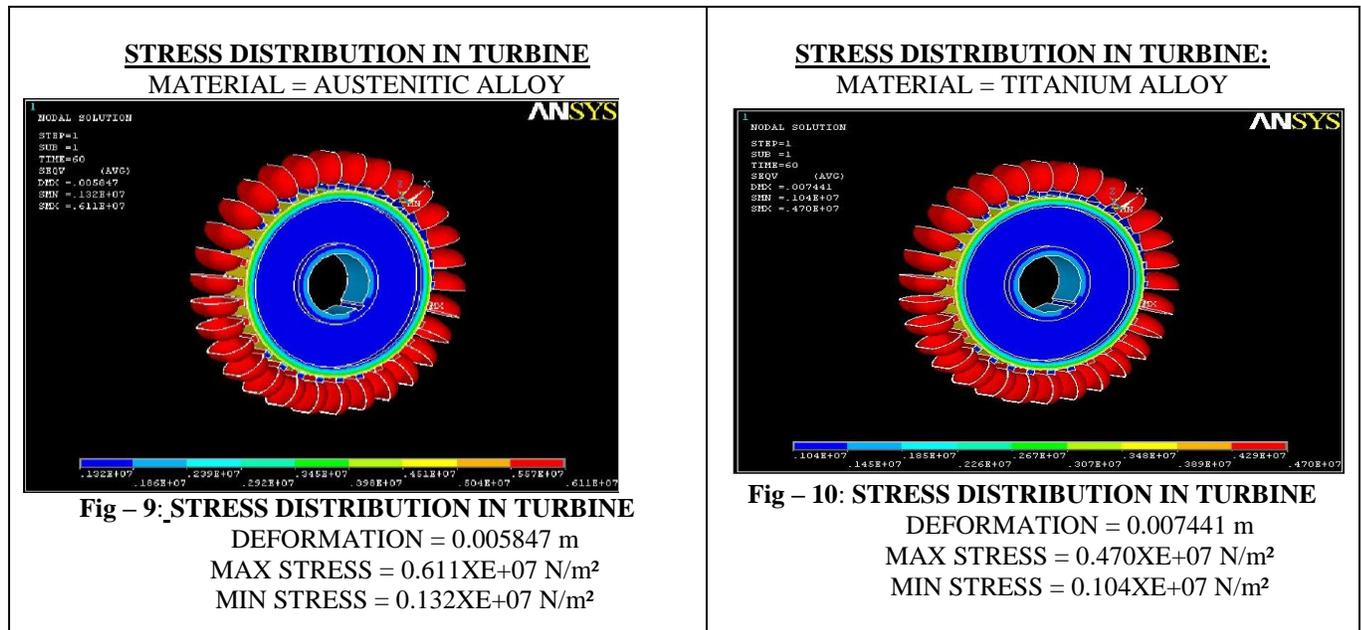
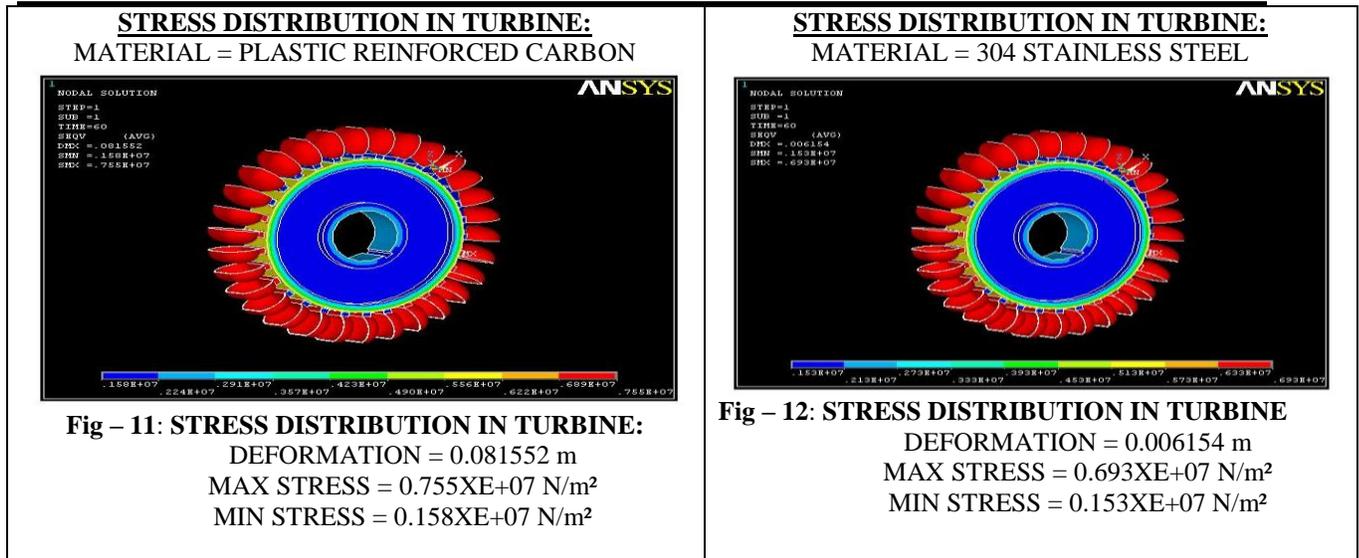


Fig – 8: Meshing using ansys

VII. RESULT & DISCUSSION





The following figure shows the thermal distribution in the turbine for different blade materials like austenitic alloy, titanium alloy, plastic reinforced carbon and 304 stainless steel.

7.1. Austenitic Alloy:

TOTAL HEAT FLOW RATE:

$$\text{HEAT FLOW RATE} = (hPKA)^{0.5} \times \tan h (ml)$$

Where, h = heat transfer coefficient (442 W/m²-K)

P = perimeter of bucket (m)

A = area of bucket (m²)

K = thermal conductivity of material used (W/m-K)

M = mass transfer rate (kg/s)

L = length the bucket.

$$m = (hP/KA) \quad m = (442 \times 89.844 / 17.3 \times 0.0592)^{0.5} \quad m = \underline{196.61 \text{ kg/s}}$$

$$\text{HEAT FLOW RATE} = (hPKA)^{0.5} \times \tan h (ml) \\ = (442 \times 89.844 \times 17.3 \times 0.0592)^{0.5} \times \tan h (196.61 \times 2.2) = \underline{201.66 \text{ Watt}}$$

7.2 TITANIUM ALLOY:

TOTAL HEAT FLOW RATE:

$$\text{Where } m = (hP/KA)^{0.5} = (442 \times 89.844 / 7 \times 0.0592)^{0.5} = \underline{309.56 \text{ kg/s}}$$

$$\text{HEAT FLOW RATE} = (hPKA)^{0.5} \times \tan h (ml) \\ = (442 \times 89.844 \times 7 \times 0.0592)^{0.5} \times \tan h (309.56 \times 2.2) = \underline{59.632 \text{ Watt}}$$

7.3 PLASTIC REINFORCED CARBON:

TOTAL HEAT FLOW RATE:

$$\text{Where } m = (hP/KA)^{0.5} = (442 \times 89.844 / 24.3 \times 0.0592)^{0.5} = \underline{170.52 \text{ kg/s}}$$

$$\text{HEAT FLOW RATE} = (hPKA)^{0.5} \times \tan h (ml) \\ = (442 \times 89.844 \times 24.3 \times 0.0592)^{0.5} \times \tan h (170.52 \times 2.2) = \underline{239.01 \text{ Watt}}$$

7.4 304 STAINLESS STEEL:

TOTAL HEAT FLOW RATE:

$$\text{Where } m = (hP/KA)^{0.5} = (442 \times 89.844 / 16.2 \times 0.0592)^{0.5} = \underline{208.54 \text{ kg/s}}$$

$$\text{HEAT FLOW RATE} = (hPKA)^{0.5} \times \tan h (ml) \\ = (442 \times 89.844 \times 16.2 \times 0.0592)^{0.5} \times \tan h (208.54 \times 2.2) = \underline{190.14 \text{ Watt.}}$$

TABULATIONS:

From the following tabulation the following graphs are drawn and the comparison is carried out for different materials. The comparison is carried out for the max stress, deformation, factor of safety and heat transfer rate.

STRESS RESULT TABULATION:

Material	Max stress (n/m ²)	Min stress (n/m ²)	Deformation (m)
Austenitic Alloy	0.611XE+07	0.132XE+07	0.005847
Titanium Alloy	0.470XE+07	0.104XE+07	0.007441
Plastic Reinforced Carbon	0.755XE+07	0.158XE+07	0.081552
304 Stainless Steel	0.693XE+07	0.153XE+07	0.006154

FATIGUE RESULT TABULATION:

THERMAL RESULT TABULATION

Material	Austenitic Alloy	Titanium Alloy	Plastic Reinforced Carbon	304 Stainless Steel
Heat flow rate (watt)	201.66	59.632	239.01	190.14

CONCLUSIONS

These show satisfactory order of results in approximating the nominal stresses in the blade due to the axial and tangential loading cases. Thus, having confirmed the range of stresses we would expect from ansys calculations, we can be confident in the finite element results.

From the results of the finite element analysis it is clear that a sizeable factor of safety is available with respect to this design stress, even when the correction factor is taken into account.

MATERIAL	FOS
Austenitic Alloy	8.516
Titanium Alloy	4.79
Plastic Reinforced Carbon	1.657
304 Stainless Steel	3.506

Generally, the dominant force in this stress analysis is the tangential force, but at the lower deformation, the most important force is in fact the axial load. All things being equal, one would generally expect the axial load on an impulse turbine to be small, since the impulse turbine at its design point does not experience an appreciable pressure drop across the rotor (in fact a slightly negative degree of reaction might not be unexpected).

But the max equivalent stress is induced in the titanium alloy blade material is less when compared to the other materials. But maximum stress is induced in the plastic reinforced carbon material. So that the life of the turbine blade may decreased.

When concentrating on the deformation graph comparison, the materials austenitic alloy and titanium alloy will produce the same deformation as compared to the 304 stainless steel. But the plastic reinforced carbon will produce the more deflection under tangential and axial load.

As a consequence of the significant amount of time spent away from the design point, the result of negligible pressure drop across the rotor is no longer valid and an appreciable axial force is present. Finite element stress analysis results must also be evaluated, but the fact that stress analysis is so much more.

It may be noted that, considering the thermal analysis carried out on the different materials which shows the heat losses due to transfer must be less so that total heat is fully converted to mechanical energy; this may cause the increase in percentage of output power. In this analysis, Titanium alloy blade material provides the less heat losses compared to other materials. But in this case of plastic reinforced carbon material is considerably very high due to its high thermal conductivity. From the analysis the materials like austenitic alloy and titanium alloy produces the better structural and thermal behavior than the existing material.

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