

Analysis of Turbine Blade Made of Composite Materials used in Steam Turbines

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Abstract- In an impulse turbine the potential energy is first converted into kinetic energy by discharging steam through a carefully shaped nozzle. The steam jet discharged into air is directed onto curved buckets fixed on the periphery of the runner to extract the kinetic energy and convert it to useful work. During the process the blade may fail due to high tangential and axial forces. So a detailed investigation is made over the different turbine blade materials in order to reduce the failures occurred. Analysis is done on 304 Stainless Steel, Aramid reinforced polymer composite, Glass epoxy and Carbon fiber reinforced plastic. Finite element stress, strain and total deformation has been found out. Also thermal analysis has been carried out on the above four materials of impulse turbine blade. Aim of the analysis is to compare how well the blades support the forces exerted on them. The tangential and axial forces on the blades have been calculated. Safe working stress and strain was identified; post solution checks were carried out and confirmed the order of magnitude of the finite element results.

I. INTRODUCTION

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 that, 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 dynamic 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.

A. *Runner and blades*

The blades change the direction of steam released 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. The runner of a de Laval impulse turbine essentially consists of a circular disc fixed to a horizontal shaft. On the periphery of the runner a number of blades are fixed uniformly. The steam jet impinges on the blades which move in the direction of the jet. This movement of the blades makes the runner to rotate.

The surface of the blades is made very smooth to minimize the frictional losses. The blades are generally made of special alloy steels. In most of the cases the blades are bolted to the runner disc. But sometimes the blade and discs are cast as a single unit.

It has been experienced that all the blades do not wear out equally with the time. A few of them get worn out and damaged early and need replacement. This can be done only if the blades are bolted on the disc.

B. *Losses and failure in steam turbine*

Strictly speaking an ideal turbine will do the work equivalent to the isotropic enthalpy or heat drop of the steam used in the steam turbine. But in actual practice the work done by a turbine is much less than isentropic heat drop of the steam used. There are several factors which affect the performance of a steam turbine. All these

factors which reduce the output of the turbine are known as internal losses. Though there are many internal losses in a steam turbine, the following are important from the subject point of view.

C. Nozzle loss

It is an important loss in both impulse and reaction steam turbines, through the nozzle. This loss takes place due to friction in the nozzle and the fraction of eddies.

D. Blade and friction loss

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 different materials for blades of Impulse turbine. It was decided to use four different materials for turbine blades. 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 exhibit creep in high temperature applications such as gas turbine blades. But thermoplastics show these properties at high temperatures also, and these must be considered while designing turbine blades.

II. PROBLEM DEFINITION AND OBJECTIVE

A. Problem definition

In an impulse steam turbine the potential energy is first converted into kinetic energy by discharging steam through nozzle. During the process the blade may get failed due to high tangential and axial forces. For improving the efficiency of a steam turbine, it is of greater importance to reduce the weight of turbine. Even though stainless steel has got high mechanical properties, high density and weight reduces the power output.

Thermal fatigue, deformation and creep stress are the main reasons to decrease life range of the blade. For increasing the service life and attaining maximum efficiency, weight of components have to be reduced. Currently most of the components in a turbine are made of stainless steel which is having high density. Alternate materials for stainless steel can reduce this problem to a great extent.

B. Objective

To identify safe working stress and strain of steam turbine blade. Design the steam turbine blade by changing the blade material to composite. The selected materials are Carbon fiber reinforced plastic (CFRP), Aramid reinforced polymer composite and glass fiber epoxy. To compare the inferences with safe working stress and strain of turbine blade made of 304 stainless steel.

MODEL OF TURBINE BLADE USING PRO-E

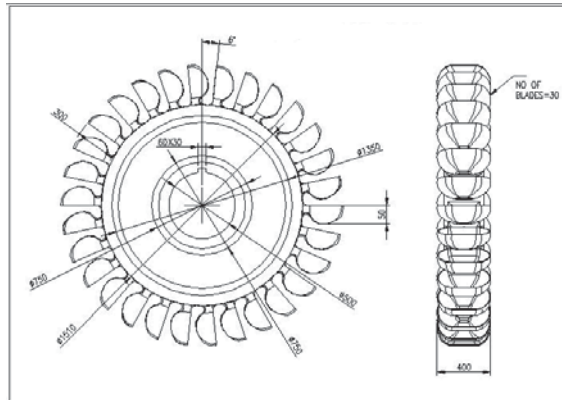


Fig 1.1 2D model of turbine blade

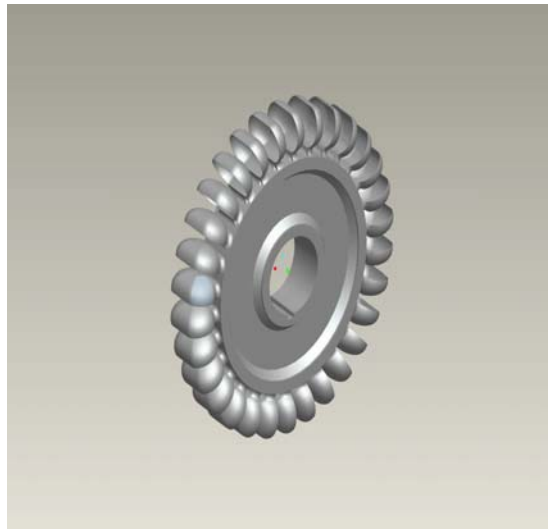


Fig. 1.2 3D model of a turbine blade using PRO-E

III. RESULTS AND DISCUSSIONS

A. *Static structural analysis*

Static structural analysis determines the displacements, stresses, strains, and forces in structures or components caused by loads that do not induce significant inertia and damping effects. Steady loading and response conditions are assumed. The loads and the structure's response are assumed to vary slowly with respect to time. The types of loading that can be applied in a static analysis include:

- Externally applied forces and pressures
- Steady-state inertial forces (such as gravity or rotational velocity)
- Imposed (nonzero) displacements
- Temperatures (for thermal strain)

B. *Transient thermal analysis*

Transient thermal analysis determines temperatures and other thermal quantities that vary over time. Also of interest are the temperature distribution results in thermal stresses that can cause failure. In such cases the temperatures from a transient thermal analysis are used as inputs to a structural analysis for thermal stress evaluations.

IV. SELECTION OF MATERIALS

A. 304 Stainless steel

The most widely used stainless steel is the 304, also known as 18/8 for its composition of 18% chromium and 8% nickel. 304 may be referred to as A2 stainless.

Carbon	0.08 % max
Chromium	18 – 20 %
Iron	Balance
Manganese	2 % max
Nickel	8 - 10.5 %
Phosphorus	0.045 % max
Silicon	1% max
Sulphur	0.03 % max

Table 1.1 Mechanical properties of 304 Stainless Steel

Young's modulus	1.9e+11 Pa
Poisson's ratio	0.275
Density	8000 kg/m ³
Thermal conductivity	14 w/mK
Specific heat	490 J/kgK

ADVANTAGES OF 304 STAINLESS STEEL

It possesses an excellent combination of strength, corrosion resistance and fabric ability. It is available in the widest variety of forms and sizes of any stainless steel.

APPLICATIONS OF 304 STAINLESS STEEL

The list is endless. Almost every conceivable industry uses some of this material in some way. Everything from stove tops to ball point pen barrels and flatware to fasteners has been fabricated from this alloy.

B. Aramid Reinforced Polymer Composites (ARPC)

Aramid fibers are generally prepared by the reaction between an amine group and a carboxylic acid halide group. Aramid share a high degree of orientation with other fibers such as ultra high molecular weight polyethylene, a characteristic that dominates their properties. Aramid fibers are a class of heat-resistant and strong synthetic fibers. The name is a portmanteau of "aromatic polyamide". They are fibers in which the chain molecules are highly oriented along the fiber axis, so the strength of the chemical bond can be exploited. The most popular matrix materials for manufacturing ARPC are Thermosets such as epoxies, vinyl ester and phenolic. These are produced by open mold process, closed mold process and pultrusion method.

Table 1.2 Mechanical properties of ARPC

Young's modulus	1.12e+11 Pa
Poisson's ratio	0.36
Density	1440 kg/m ³
Thermal conductivity	0.05 w/mK
Specific heat	0.14 J/kgK

ADVANTAGES OF ARPC

Good resistance to abrasion, good resistance to organic solvents, nonconductive, no melting point, degradation starts from 500°C, low flammability, good fabric integrity at elevated temperatures, sensitive to acids and salts, sensitive to ultraviolet radiation, prone to static build-up unless finished.

C. Glass Fiber Epoxy

Glass fiber epoxy is a type of fiber reinforced plastic where the reinforcement fiber is specifically glass fiber. The glass fiber may be randomly arranged but is commonly woven into a mat. The plastic matrix may be a thermosetting plastic- most often epoxy.

ADVANTAGES OF GLASS FIBER EPOXY

Fiberglass is a strong lightweight material and is used for many products. Although it is not as strong and stiff as composites based on carbon fiber, it is less brittle, and its raw materials are much cheaper. Its strength to weight are also better than many metals, and it can be more readily molded into complex shapes.

Table 1.3 Mechanical properties of Glass fiber epoxy

Young's modulus	1.20e+11 Pa
Poisson's ratio	0.29
Density	1900 kg/m ³
Thermal conductivity	0.29 w/mK
Specific heat	0.18 J/kgK

D. Carbon Fiber Reinforced Plastic

Carbon fiber reinforced plastic (CFRP or CRP), is a very strong, light and expensive composite material or fiber-reinforced plastic. Similar to glass-reinforced plastic, one uses commonly the name of its reinforcing fibers (carbon fiber) for the composite material. The plastic is most often epoxy, but other plastics, such as polyester, vinyl ester or nylon, are also sometimes used.

Table 1.4 Mechanical properties of CFRP

Young's modulus	1.5e+11 Pa
Poisson's ratio	0.354
Density	1800 kg/m ³
Thermal conductivity	24.3 w/mK
Specific heat	795.5 J/kgK

ADVANTAGES OF CFRP

It has the highest compressive strength of all the reinforcing materials (composites), and it has a high strength to weight ratio and low coefficient of thermal expansion. The density of carbon fiber is also much lower than the density of steel.

SPECIFICATIONS OF IMPULSE TURBINE

Table 1.5 Specifications of impulse turbine

Rated Power	75 KW
Rated Speed	2400 rpm
Steam flow rate	1500 TONNES/HR
Type	Impulse
No. of stages	Single
Temperature of steam	536 °C

V. ANALYSIS AND RESULTS

A. 304 Stainless steel

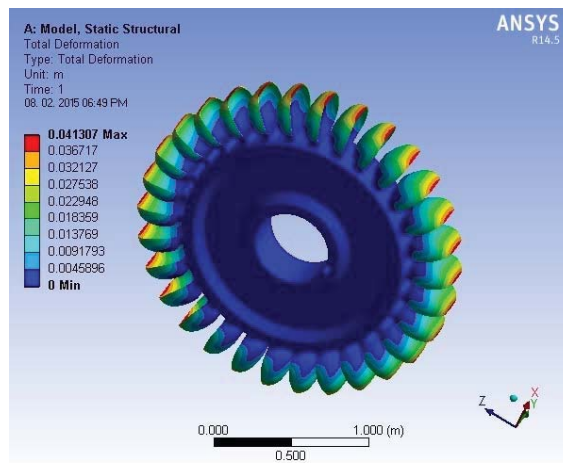


Fig 2.1 Total deformation of 304 Stainless Steel

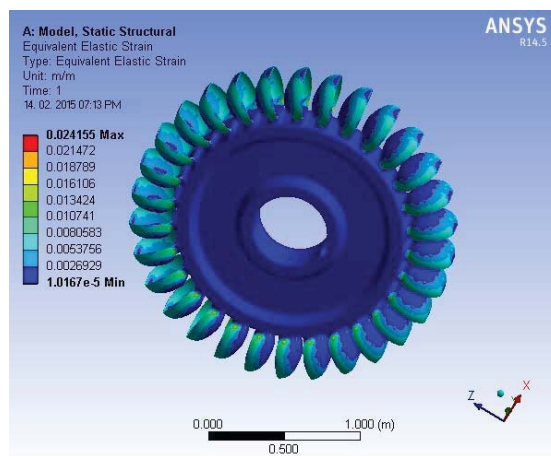


Fig 2.2 Equivalent Elastic Strain on 304 Stainless Steel

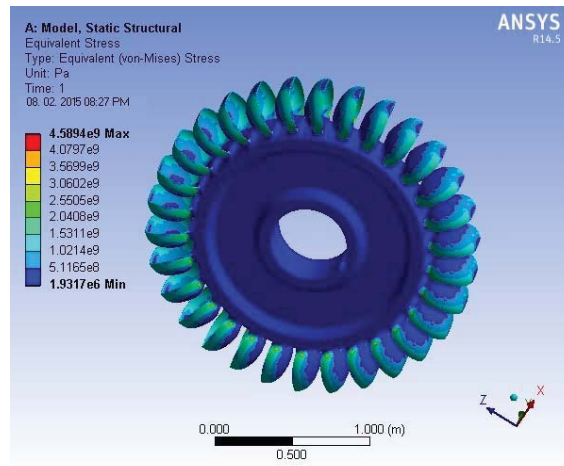


Fig 2.3 Equivalent Stress on 304 Stainless Steel

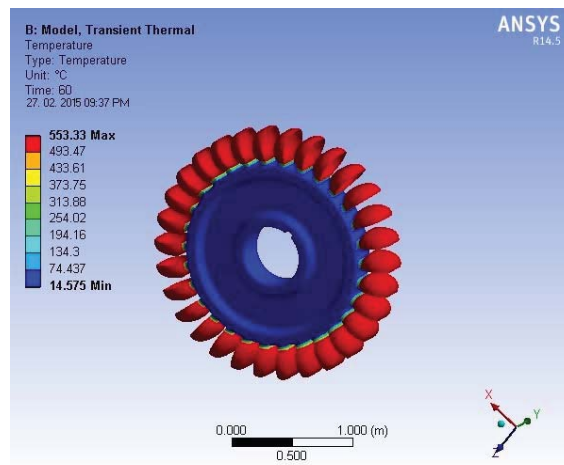


Fig 2.4 Temperature distribution on 304 Stainless Steel

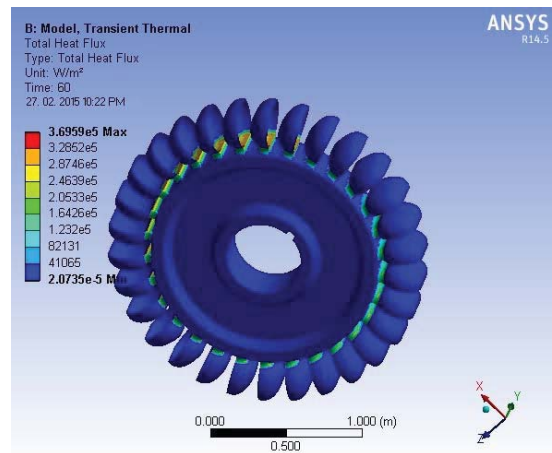


Fig 2.5 Total heat flux on 304 Stainless Steel

B. Aramid Reinforced Polymer Composites

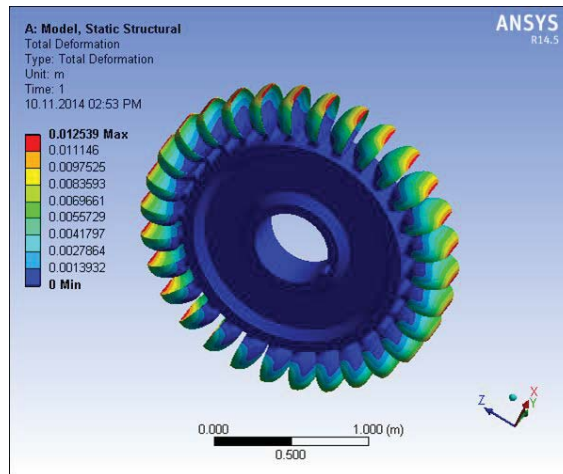


Fig 3.1 Total deformation on ARPC

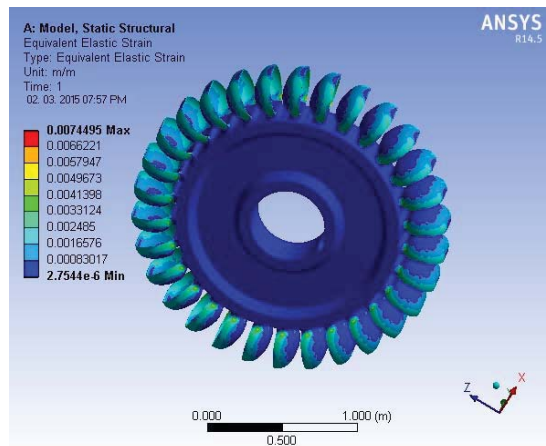


Fig 3.2 Equivalent elastic strain ARPC

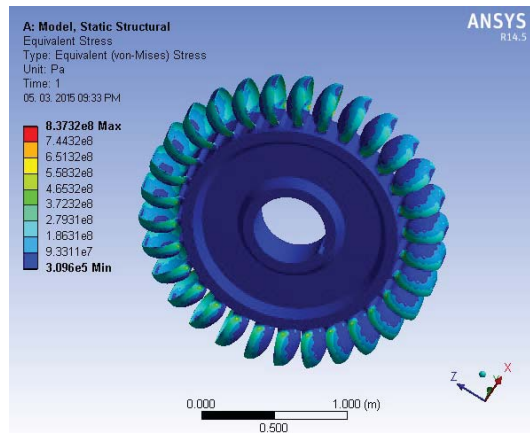


Fig 3.3 Equivalent stress ARPC

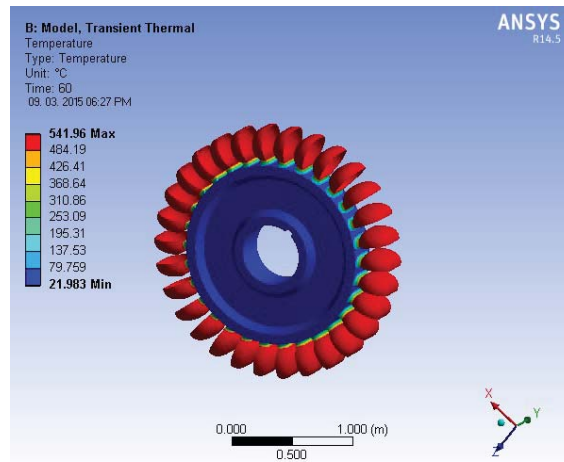


Fig 3.4 Temperature distribution on ARPC

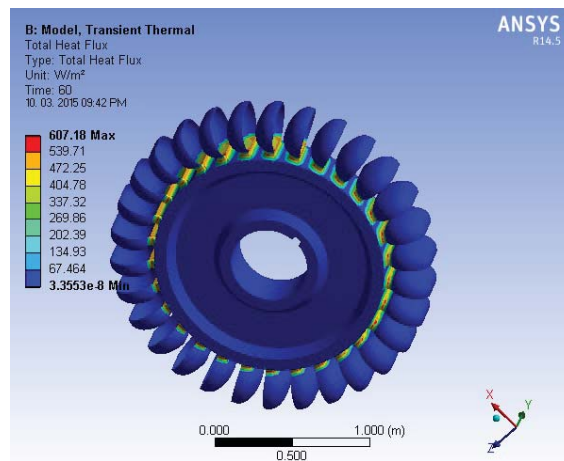


Fig 3.5 Total heat flux on ARPC

C. Glass Fiber Epoxy

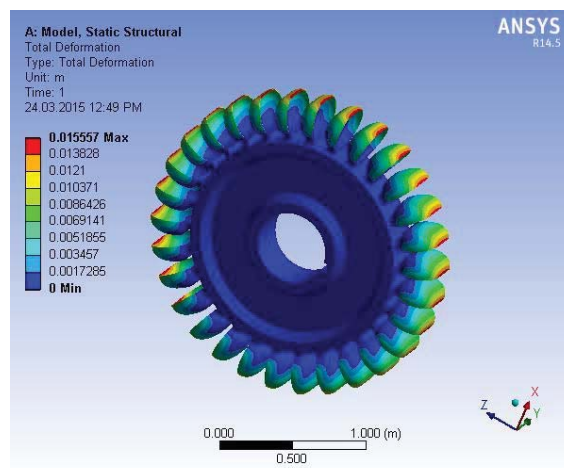


Fig 4.1 Total Deformation on Glass fiber epoxy

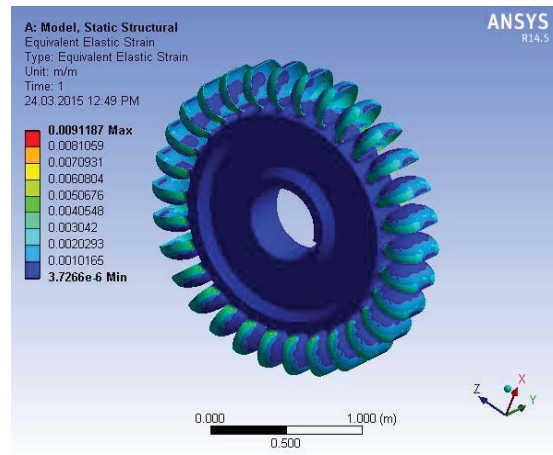


Fig 4.2 Equivalent Elastic Strain on glass fiber epoxy

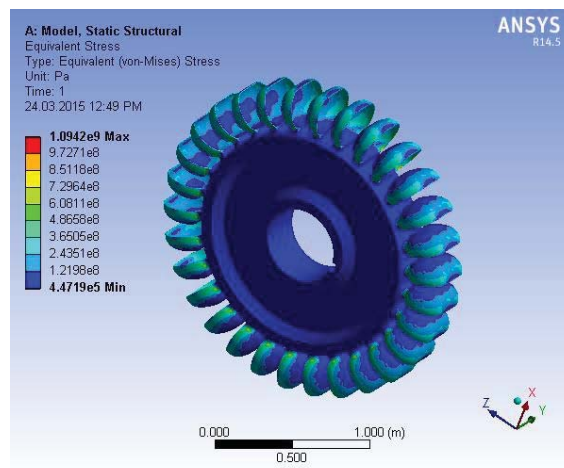


Fig 4.3 Equivalent stress on glass fiber epoxy

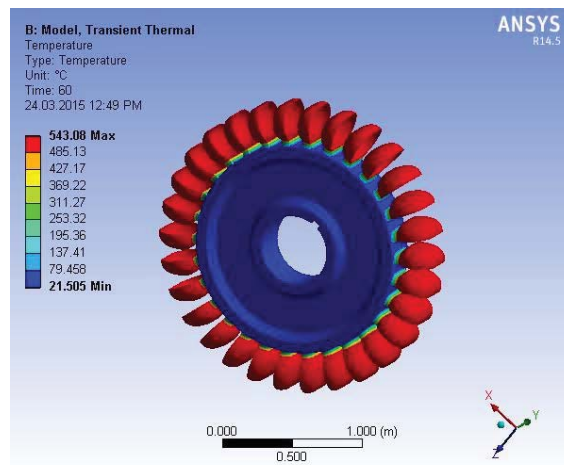


Fig 4.4 Temperature distribution on Glass fiber epoxy

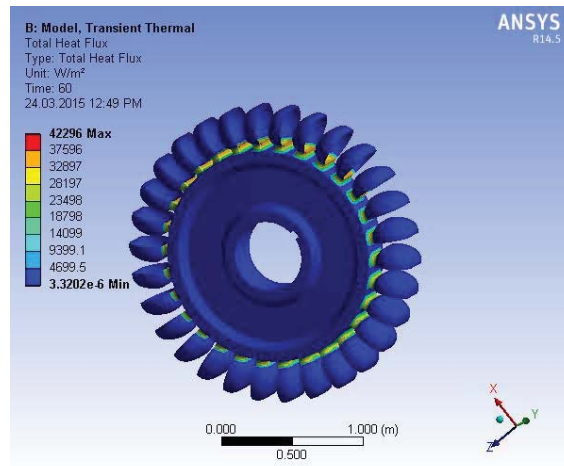


Fig 4.5 Total heat flux on Glass fiber epoxy

D. Carbon Fiber Reinforced Plastic

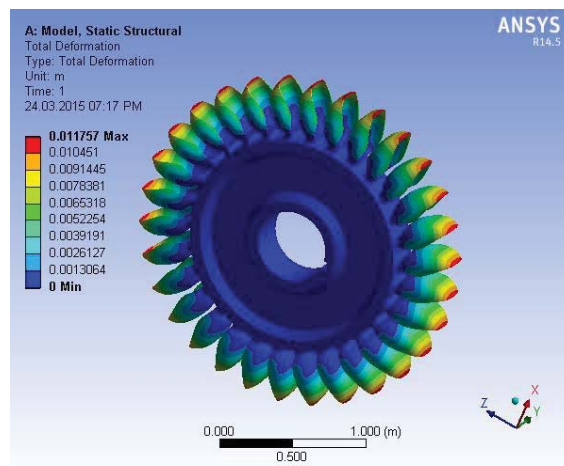


Fig 5.1 Total deformation on CFRP

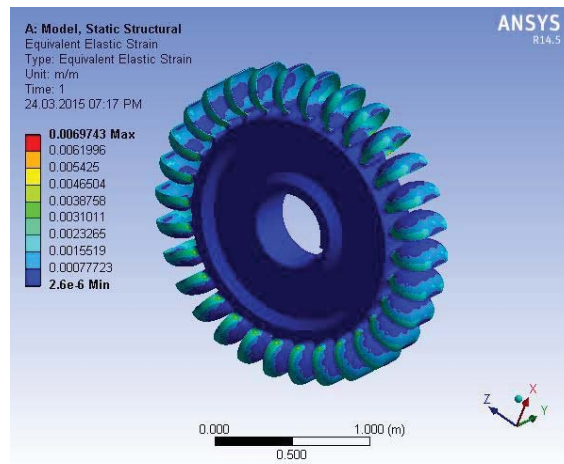


Fig 5.2 Equivalent elastic strain on CFRP

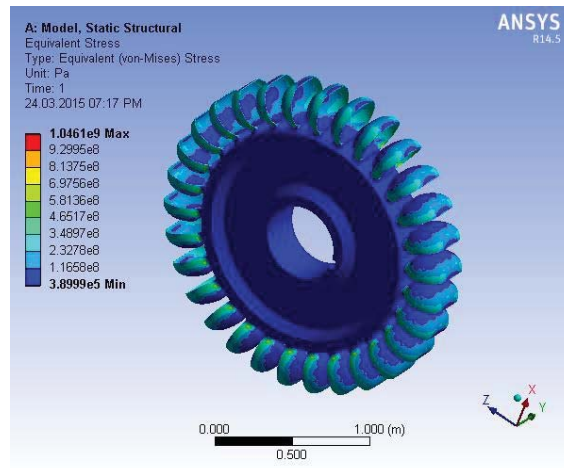


Fig 5.3 Equivalent stress on CFRP

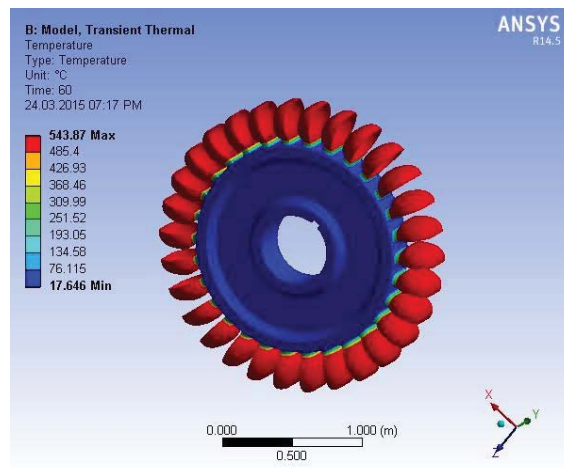


Fig 5.4 Temperature distribution on CFRP

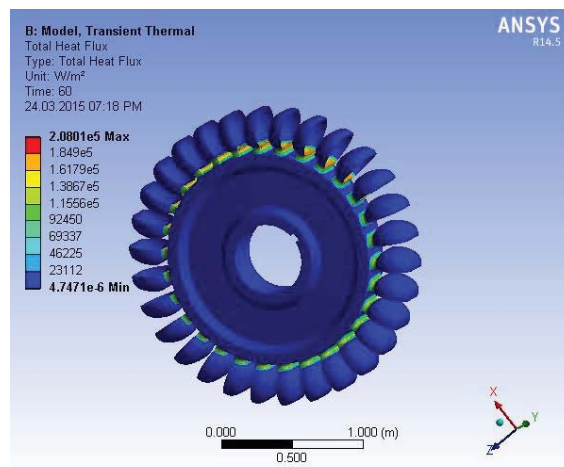


Fig 5.5 Total heat flux on CFRP

VI. FINAL OBSERVATION

	304 Stainless steel	CFRP	ARPC	Glass epoxy
Total deformation	0.0413	0.011757	0.012539	0.015557
Equivalent elastic strain	0.02415	0.0069743	0.00745	0.0091187
Equivalent stress	37185.052	8476.6361	24959.56	8866.3944
Temperature distribution	553.33	543.87	541.96	543.08
Total heat flux	548.52	308.71	607.18	537.12

VII. CONCLUSION

Based on the performance parameters like strain, stress, temperature distribution etc. observed in the study, it can be concluded that the optimized model of composite blade has better efficiency and a prolonged life as compared to the present model. In that Carbon Fiber Reinforced Plastic (CFRP) shows more desirable characteristics when compared with others. The present model has less performance and efficiency for the application in the steam engine for producing electricity, safety is considered more than the cost. In case of thermal analysis done on all models; the effect of temperature is almost same. So the design changes cannot make any thermal problems. So it will be better to choose CFRP for the future uses of steam turbine blades.

REFERENCES

- [1] Recent Technologies for Steam Turbines” Kenji Nakamura, Takahiro Tabei, Tetsu Takano, vol. 56 no. 4 fuji electric review
- [2] Zachary Stuck and Stanley Schurdak, “Steam Turbine Blade Design” Twelfth Annual Freshman Conference 2214United state of America, Conference Session B6, 14th APR 2012.
- [3] Kenji Nakamura, Takahiro Tabei, Tetsu Takano “Recent Technologies for Steam Turbines”, Energy Solution Group, Fuji Electric Systems Co. Ltd.
- [4] “Structural design of modern steam turbine” Christopher-Hermann Richter”et.al:Engineering Failure Analysis > 2010 > 17 > 5 > 1205-1212 Design And Materials For Modern Steam Turbines With Two Cylinder Design Up To 700 MW”
- [5] Tulsidas.D, Dr.Shantharaja. M, Dr. Kumar. K “Design modification for fillet stresses in steam turbine blade” International Journal of Advances in Engineering & Technology (IJAET) Vol.III, Issue I, January-March, 2012. Pp. 343-346.
- [6] A book of “Analysis of Fretting Fatigue Strength of Integral Shroud Blade for Steam Turbine” Proceedings of the International Conference on Power Engineering 2007.
- [7] B. Stanisaa, V. Ivusich “Erosion behavior and mechanisms for steam turbine rotor blades” International Journal of Advances in Engineering & Technology (IJAET), Vol.II, Issue II, April-June, 2011, 110-117.
- [8] T. Misek, Z.Kubin “Static and Dynamic Analysis” of 1220 mm Steel Last Stage Blade for Steam Turbine”, Applied and Computational Mechanics133–140,18th Nov 2008.