Design and Analysis of Stress in Mixed Flow Impeller Blade Using Ansys

Aakash Shankar Rai[1] Ghanshyam Satnami[2]
[1,2]Department of Mechanical Engineering
[1,2]RNTU,Bhopal, India

Abstract — A static analysis of two different blades which are of trapezoidal shape and inlet inclined has been done in ANSYS software in order to find the stress distribution on different material. The materials that have been chosen for the study are titanium, stainless steel, Copper and bronze because they are widely used in area of fluid machinery. Then a comparison of von-Mises stress distribution for all the four materials has been done. To perform this work, ANSYS static structure analysis was used. The blade model was designed in ANSYS workbench. In this study one end of blade was fixed and force has been applied on the surface of blade, the see was used as boundary condition. The stress was measured at different value of forces and results are obtained. It has been observed that trapezoidal blade of stainless steel subjected to maximum stress and inlet inclined blade of stainless steel subjected to minimum stress. This work was further proceeding to find out the deformation in both cases of blade for all these four materials and then compared the results obtained from the analysis. It has been found that trapezoidal stainless-steel blade was subjected to maximum deformation.

Keywords: Digital Data and Cybersecurity Protection

I. Introduction

A. Pump

Pump is a mechanical device which is used to converts mechanical energy to hydraulic energy. Pumps can be used for various industrial purposes. Due to load, pressure induced at pump outlet and to overcome this pressure pump generates flow with enough power. At the inlet of the pump, a vacuum is created which forces the liquid from the reservoir to the pump and discharges the liquid at the pump outlet.

B. Classification of Pump

1) Rotodynamic pump
   a) Centrifugal Pump
2) Positive displacement pump
   a) Rotary pump
   b) Reciprocating Pump

C. Centrifugal pump

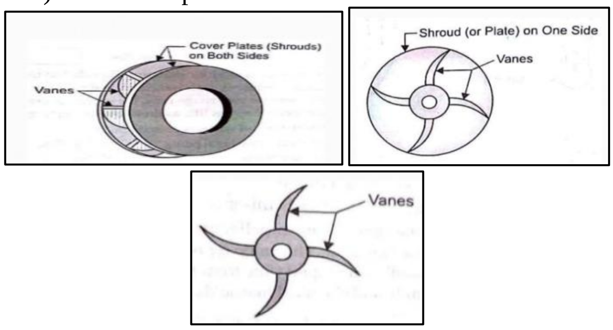
To convert mechanical energy into hydraulic energy centrifugal pumps are used by means of centrifugal force which is acting on the fluid. The principle of centrifugal pump based on the free vortex flow which means that the pressure head increases due to rotation of the fluid and the fluid is rotated by an external torque. At the impeller outlet, fluid leaves the impeller in radially outward.

D. Classification of centrifugal pumps on the basis of different type of impeller

1) Impeller

A rotating part of the centrifugal pump is termed as impeller. A series of backward curved vanes are mounted on the impeller vanes. The impeller contains limited range of blades i.e. the number is chosen to satisfy the motion of the fluid within the preferred direction and the number of vanes varies with the diameter of the impeller and also with the radial depth of the blades. The number of blades are generally lies between 6 and 12.

On the basis of mechanical construction
1) open impeller
2) semi-open impeller
3) closed impeller



(a) Closed impeller (b) semi open impeller (c)open impeller
Fig. 1.1: Types of impellers on the basis of mechanical construction

(i) on the basis of suction
   1) Single suction
   2) Double suction

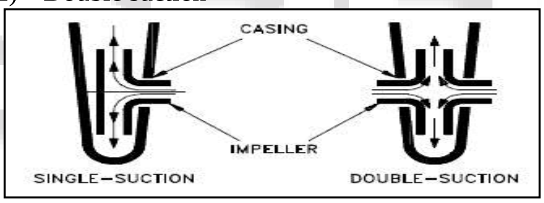


Fig. 1.2: Types of impeller on the basis of suction

(ii) On the basis of direction of flow in reference to the axis of rotation
   1) Axial flow impeller
   2) Radial flow impeller
   3) Mixed flow impeller

E. Types of Blades

$\beta_2 < 90°$ backward curved vanes- the curvature of the blade is in the opposite direction to that of the rotation of impeller.
$\beta_2 = 0$, radial vanes
$\beta_2 > 90°$,forward curved vanes- the curvature of blade in the direction of the rotation of the impeller.

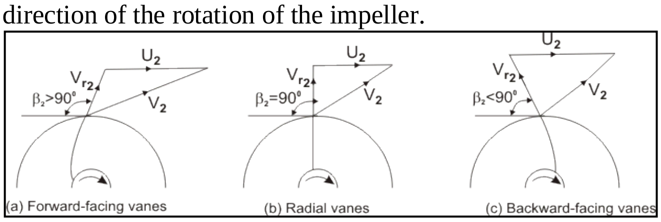


Fig.1.3: Types of impeller blade based on curvature of blade

F. Objective

Comparison of stress on two blades at different position in the meridional annulus having different materials (Copper alloy,

All rights reserved by www.ijsrd.com

Bronze, Stainless steel and Titanium alloy) by using von misses stress distribution theory.

The main objective of the blade design of mixed flow impeller is to realize minimal losses as well as minimum as stresses within the blade section.

on the basis of FEM analysis, the above two models one is inlet inclined and other is trapezoidal one in the meridional annulus were compared to check which is best among them. For design acceptability, von Mises stress distribution theory is used for the safe design of the impeller blade. the optimum design of the impeller blade require proper selection of material. In the present work four different materials namely bronze, Stainless steel, copper and titanium alloy are selected as the material of construction of blade.

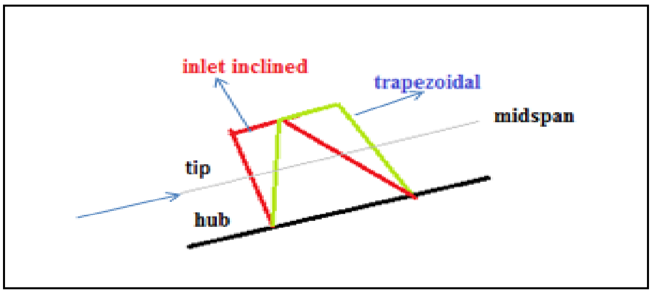


Fig. 1.12: Blade design

II. REVIEV OF LITERATURE

1) A high efficiency mixed-flow pump was optimized by Kim et al. in 2011 by designing it through different optimization techniques. They optimized the vane diffuser of the mixed flow pump by weighted-average optimization technique. The optimized result was then validated with the experimental data by comparing their head, power and efficiency. The model was discretized by using finite volume method and SST turbulence model was used on hexahedral grids to evaluate the efficiency. From the results of the optimization, the efficiency at the designed flow coefficient was improved by 7.05%.
2) In a mixed flow pump impeller, Cao et al. in 2012 developed a loss model to predict the performance of the pump impeller and study their performance curves. The loss model was based on the iterative calculations for two stream surfaces i.e., S_1 and S_2 with the help of continuity and motion equations of fluid. Based on the test data, curves of various losses which varied with different flow rates were analyzed under different blade angles. Moreover, they discussed in details the mechanisms of these losses undergoing inside the mixed-flow impeller.
3) The pump whose impeller with HSRR 1.94 and outlet diffusion angle 90° has been selected Hao et al. [2013].They carried CFD analysis using k-∈ model and observed that as HSRR and blade wrap angle increases the working capabilities and hydraulic efficiency were improved. The impeller blade stresses analyzed by F F Hu et al.[2013] for various flow condition and upgrade the efficiency of the pump. The stress was been analyzed at various flow rates and circumferential speed. The FEM was used to find stress distribution in the blade caused due to rotational inertia or flowing liquid load or combination of both. The result predicted that stresses developed in the blade changes flow rate and speed changes.

Mixed flow pump impeller blades were designed having two different blade positioning in the meridiona lannulus.The stress developed in the pump blades are evaluated using FEM analysis. Artificial neural network (ANN) was used to optimize the thickness of the aero foil blade von-Mises stress. It wasobserved by Srivastava et al. [2014]that the mixed flow pump impeller blade with inlet inclined blade position in the meridional annulus is more suitable with respect to trapezoidal blade as predicted through ANN.

III. THEORETICAL DESIGN ASPECT OF MIXED FLOW IMPELLER BLADE AND METHODOLOGY

1) Firstly, airfoil shape is being designed using online aerofoil tool. The dimension used is according to standard NACA 0010 airfoil shape.
2) To generate the impeller blade surface 7 airfoil shape is combined and a solid geometry model of the impeller blade is generated using geometry modeling workspace in ANSYS software.
3) The solid geometry of the airfoil shape is being generated for two different blade positioning namely inlet inclined type and trapezoidal shape type.
4) The solid geometry is then exported for grid generation after which it is ready for structural analysis.
5) In the static structural workspace, a surface load of 3183 N of uniform distribution type is being applied on the blade surface and further von Mises stress and deformation analysis is done on the same platform.
6) Four different materials such as Titanium, Bronze, Stainless Steel and Copper is being applied on both of the blade positioning.
7) On comparison of maximum von Mises stress and deformation on 4 different materials, the best blade with the most appropriate material type will be used for the design of mixed flow impeller.

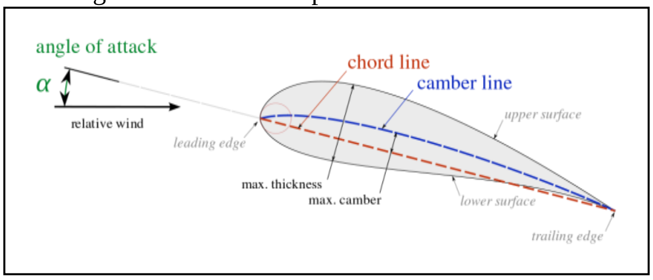


Fig. 2.1: Blade geometry aerofoil profile

A. *NACA Profile*

The NACA four-digit wing sections define the profile by
1) First digit signifies maximum camber as 0 % of the chord.
2) Second digit indicate the distance of maximum camber from the airfoil leading edge in % of chord
3) Last two digits show maximum thickness of the airfoil as % of chord.

For example, the NACA 0010 airfoil has a maximum camber of 0% located 0% of chord at the leading edge with a maximum thickness of 10% of the chord.

All rights reserved by *www.ijsrd.com*

4.2 Material Used for construction of blade

Applied materials	Youngs modulus (MPa)	Poisson's ratio	Density (Kg/mm^3)	Yield strength (Pa)
Bronze	$1.1x10^5$	0.341	$8.86x10^{-9}$	$5.2x10^8$
Stainless steel	$2x10^5$	0.31	$7.7x10^{-6}$	$2.07x10^8$
Titanium alloy	96000	0.342	$4.42x10^{-6}$	$8x10^8$
Copper	$1.1x10^5$	0.33	$8.94x10^{-6}$	$4x10^7$

Table 4.1: Material properties which are used for construction of blade

IV. SOLID MODELING OF MIXED FLOW IMPELLER BLADE

A. *Introduction*

The modeling of the blades was done firstly by designing the airfoil with the given dimensions and then with the combination of 7 airfoils with different radius of curvature. The 2d figure thus obtained is then imported to ANSYS design modeler interface to obtain the 3d image of the blade.

B. *Design of inlet inclined blade*

NACA 0010							
Chord (mm)	50	65	80	95	90	75	60
Radius of curvature (mm)	400	360	320	270	260	250	220
Thickness (%)	100	100	100	100	100	100	100
distance of maximum thickness from leading edge (% Chord)	30	30	30	30	30	30	30
Angle of attack (degree)	6	8	10	12	14	16	18

Table 5.1: Data for inlet inclined blade

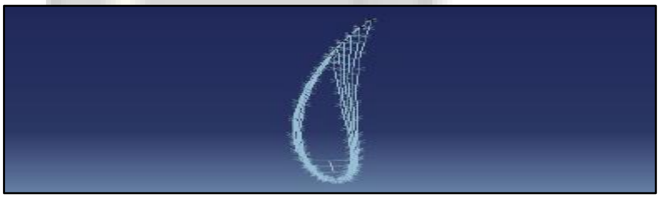


Fig 5.1: Airfoil section

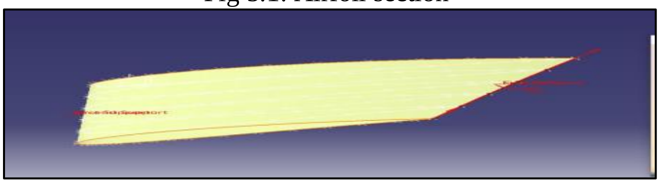


Fig 5.2: Inlet inclined blade

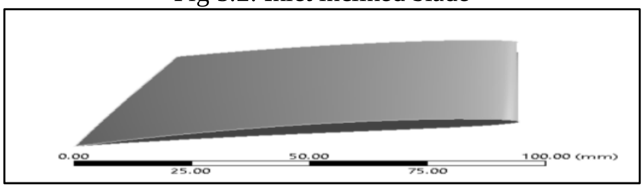


Fig 5.3: Solid model of inlet inclined blade

1) *Meshing*

The 3D structure of the blade is then imported for grid generation in meshing interface of ANSYS software. The partial differential equations that governs the static analysis. The meshing done for each part is volume mesh not surface mesh because here it is totally a solid dense model. The volume meshing will contain tetrahedral mesh elements in unstructured format and for surface it will be triangular or rectangular.

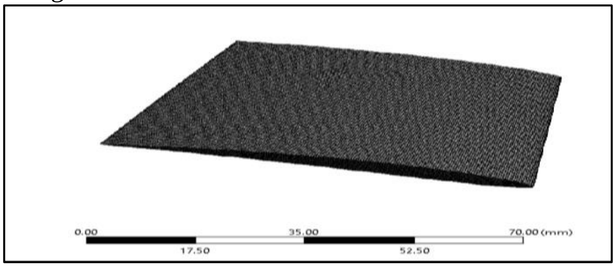


Fig. 5.4: Structured meshing

Number of nodes	1077442
Number of elements	952890

2) *Static Structural analysis*

– Boundary condition

After developing the mesh model, the problem is formulated by providing initial condition like boundary condition.

– Rotation and displacement

In these analysis proper displacement and rotational constraints were provide. Displacement of model was constrained in x, y, z direction.

During the analysis of the single blade, the side which is connected to the hub is fixed which is shown in fig. 5.8. The blade rotation is kept fixed about y and z axis and it is free to rotate about x-axis. The arrow in fig. 5.6 is showing the direction for rotation of the blade and the blue side is showing the fixed side which is attached to the hub.

– Fixed support

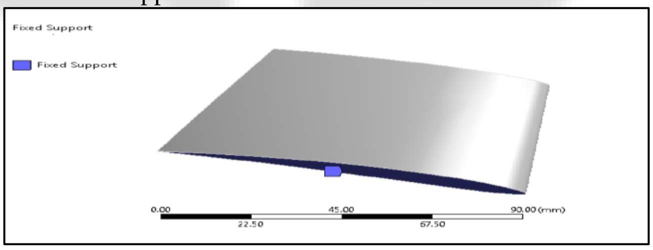


Fig. 5.5: Rotation about x-axis and displacement constrained in x, y, z direction

– Loading

After properly constraining the model, the load is applied. The red surface in fig. 5.6 showing the surface over which these loads are applied. The force is applied about z-axis and magnitude of force used is 3183 N.

– Force applied 3183 N

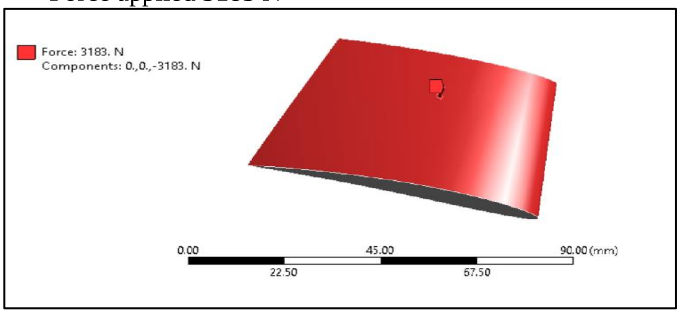


Fig. 5.6: Inlet inclined blade on which force applied

All rights reserved by *www.ijsrd.com*

C. Design of trapezoidal blade

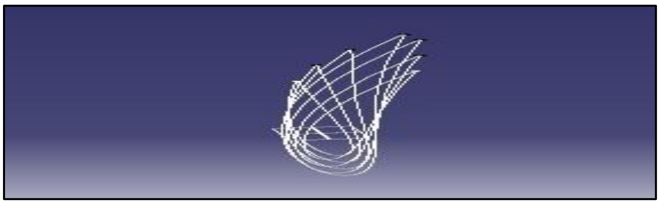


Fig. 5.7: Airfoil section of trapezoidal blade

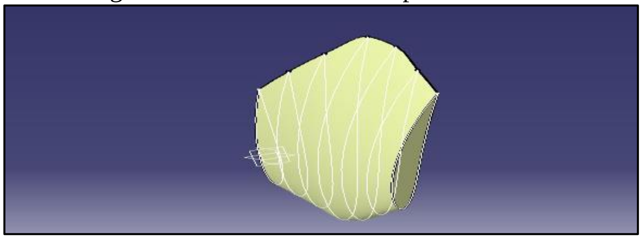


Fig. 5.8: Trapezoidal blade

1) Meshing

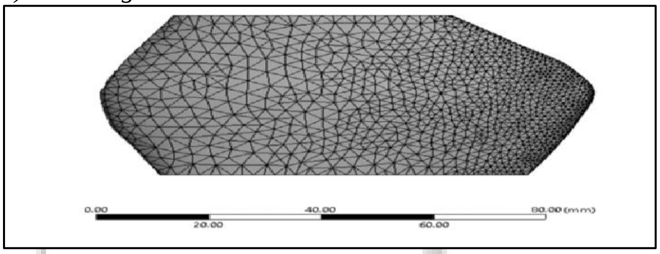


Fig. 5.9: Structured meshing of trapezoidal blade

Number of nodes	22667
Number of elements	11840

2) Static structral analysis

Similarly, the boundary condition and force are used for trapezoidal blade.

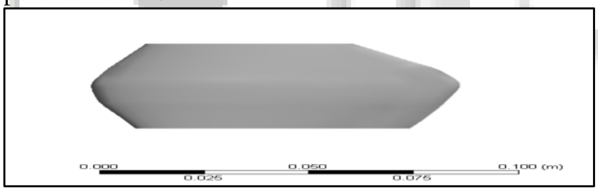


Fig. 5.10: Solid model of trapezoidal blade

D. Rotation and displacement

1) Fixed support -

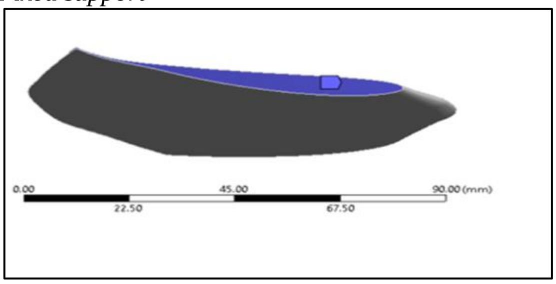


Fig. 5.11 Rotation about x-axis and displacement constrained in x, y, z direction

E. Loading

1) Force applied 3183 N

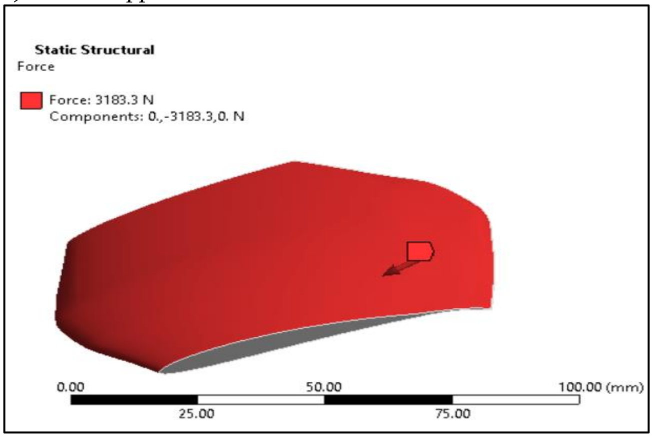


Fig. 5.11: Trapezoidal blade on which force applied

V. RESULTS AND DISCUSSIONS

A. Stress analysis

The von-Mises stress analysis is done for 4 different blade materials namely Titanium, Stainless Steel, Copper and Bronze with force magnitude 3183 N. Firstly, the stress analysis is done on inlet inclined blades and then the same is done for trapezoidal blades as well. Then a detailed comparison is done for finding the blade material with the minimum von-Mises stress and then on comparing for the same material between the two types of blade profiles, an appropriate blade is selected.

1) Inlet inclined blade

Force = 3183 N

Stress analysis

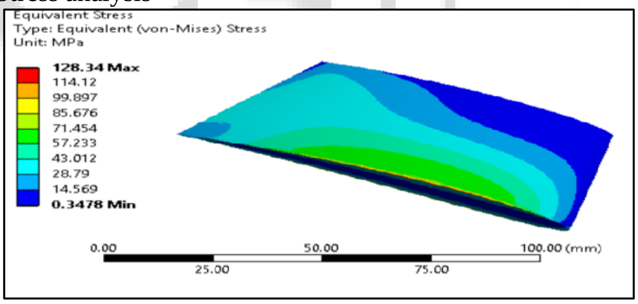


Fig. 6.1 von-Mises stress distribution in Titanium blade

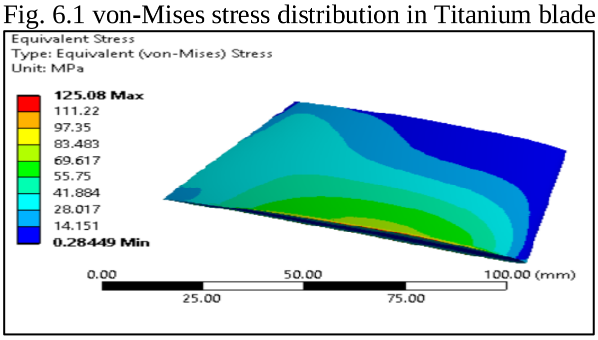


Fig. 6.2: von-Mises stress distribution in Copper

All rights reserved by www.ijsrd.com

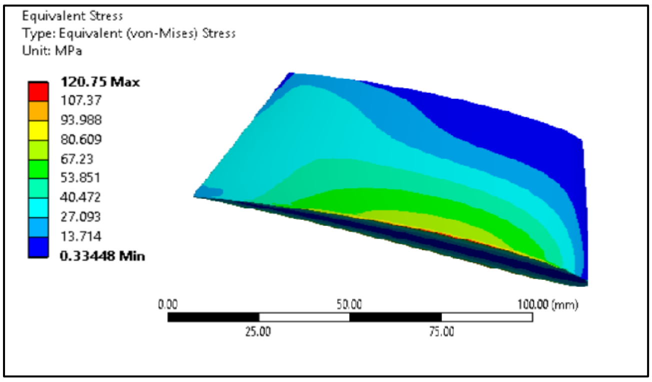


Fig. 6.3: von-Mises stress distribution in Stainless Steel

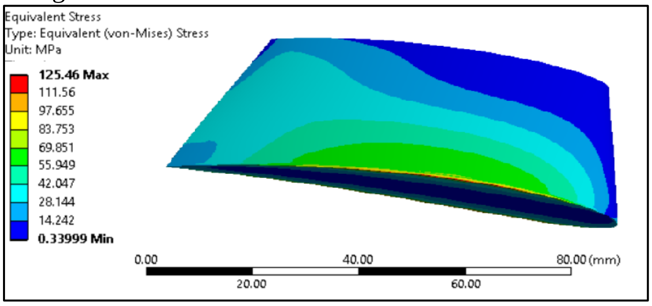


Fig. 6.4: von-Mises stress distribution in Bronze

Materials	Von-Mises stress (MPa)
Titanium	128.34
Copper	125.08
Stainless steel	120.75
Bronze	125.46

Table 6.1: Comparison of von-Mises stress for inlet inclined blade positioning

Figures 6.1 to 6.4 depicted the von-Mises distribution in different materials for inlet inclined blade positioning and the maximum stress observed were tabulated for comparison. On comparing, it was found out that the stress was maximum in case of Titanium blade and minimum in Stainless Steel blade.

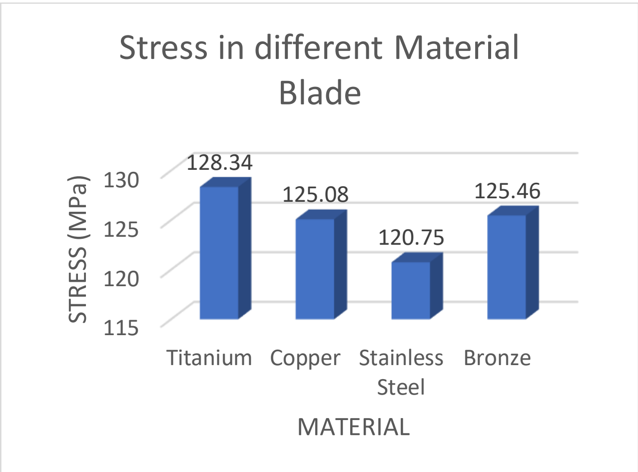


Fig. 6.5: Stress in inlet inclined blades of different materials

B. Stress Analysis on Trapezoidal Blade

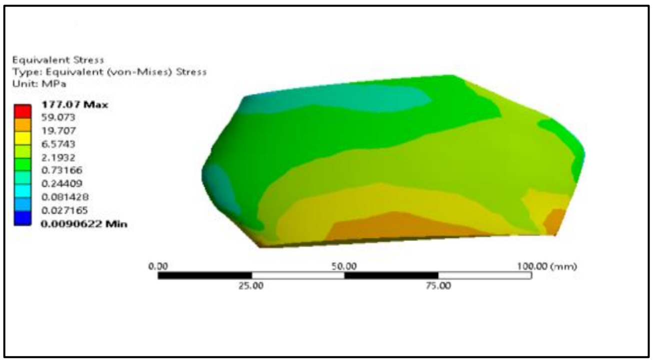


Fig.6.6: Von-Mises stress distribution in Titanium

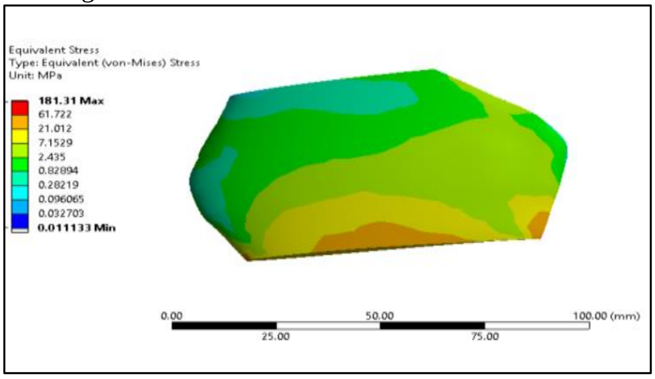


Fig. 6.7: von-Mises stress distribution in Copper

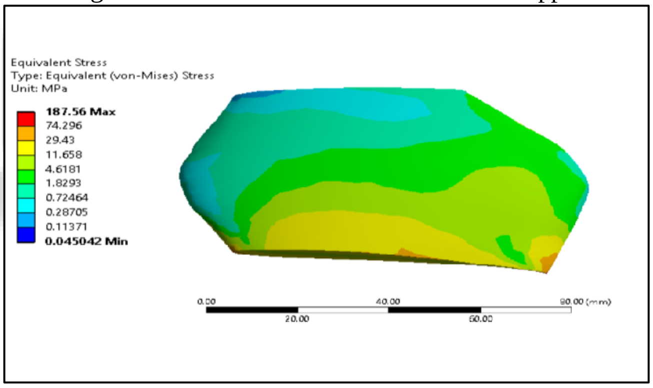


Fig. 6.8: von-Mises stress distribution in Stainless Steel

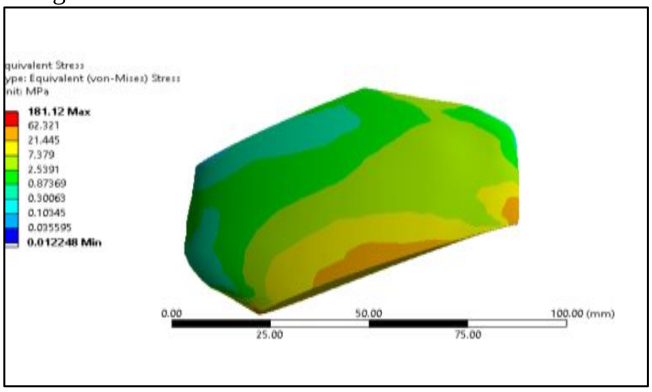


Fig. 6.9: von-Mises stress distribution in Bronze

Materials	Von-Mises stress (MPa)
Titanium	177.07
Copper	181.31
Stainless steel	187.56
bronze	181.12

Table 6.2: Comparison of von-Mises stress for trapezoidal blade positioning

Figures 6.6 to 6.9 illustrated the von-Mises stress distribution along the blade surface in trapezoidal positioning for different blade materials. The maximum stress observed in each material was tabulated in a tabular form for comparison. On comparing, the stress in Titanium blade was found out to be minimum and Stainless Steel blade showed maximum stress for a particular load.

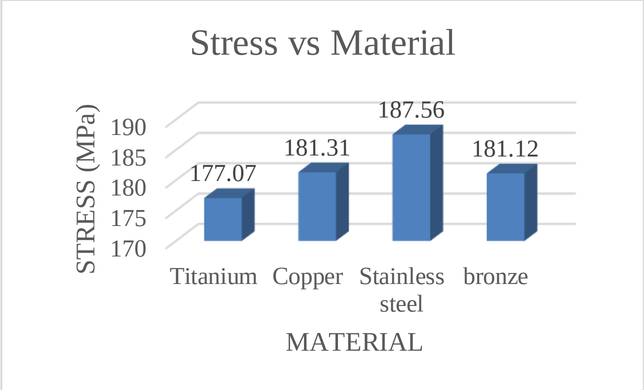


Fig. 6.10: Stress vs material for trapezoidal blade

C. *Deformation analysis*

1) *Inlet inclined blade*

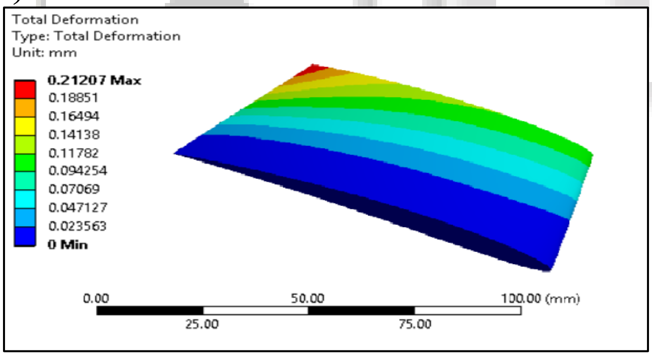


Fig. 6.11: Total deformation in Titanium blade material

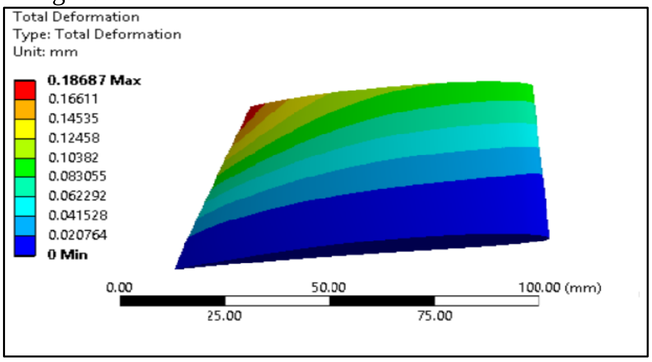


Fig. 6.12: Total deformation in Copper blade material

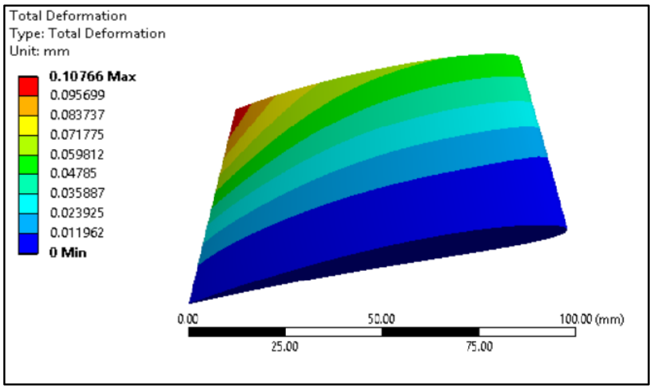


Fig. 6.13: Total deformation in Stainless Steel blade material

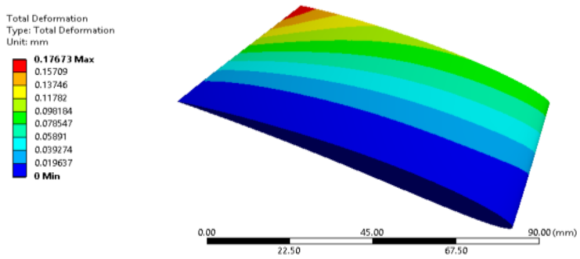


Fig. 6.14: Total deformation in Bronze blade material

Materials	Deformation(mm)
Titanium	0.21207
Copper	0.18687
Stainless steel	0.10766
Bronze	0.17673

Table 6.3: Comparison of total deformation for inlet inclined blade positioning

Figures 6.11 to 6.14 showed the total deformation of the blade for different blade materials in inlet inclined blade position. Table 6.3 showed the comparison of the maximum deformation observed in different blade materials. It was found out that Stainless Steel had the least total deformation and Titanium had the maximum total deformation for a particular blade load.

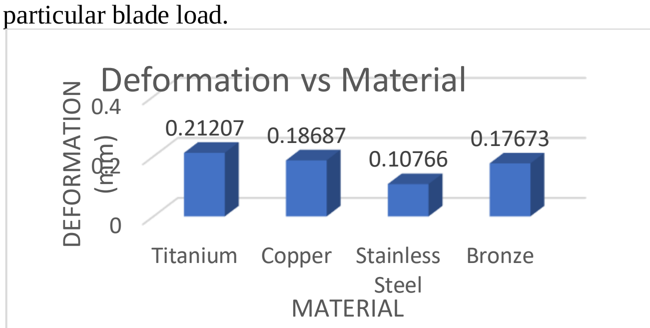


Fig. 6.15: Deformation vs material for inlet inclined blade

All rights reserved by www.ijsrd.com

2) *Deformation in trapezoidal blade*

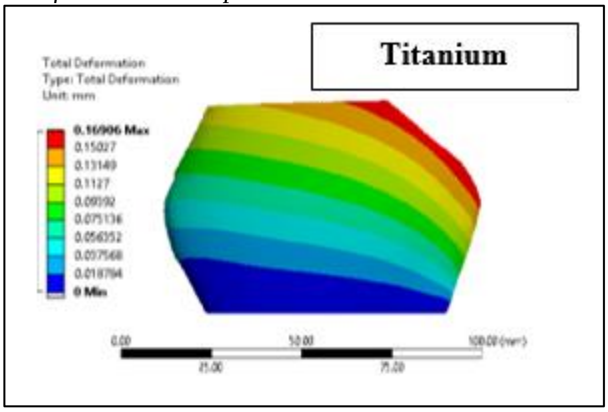


Fig.6.16:Total deformation in Titanium blade material

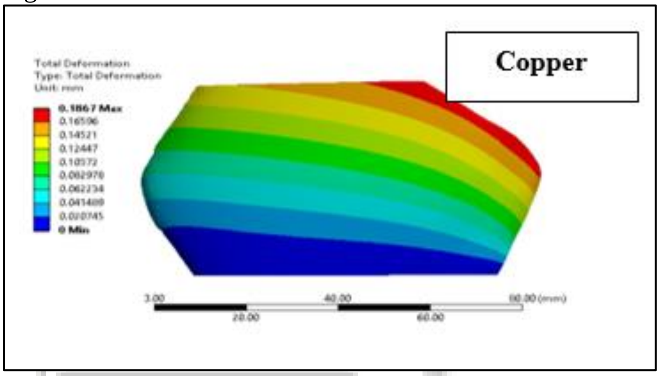


Fig.6.17: Total deformation in Copper blade material

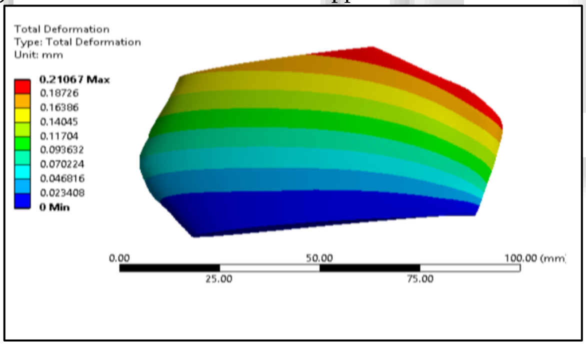


Fig. 6.18 Total deformation in Stainless Steel blade material

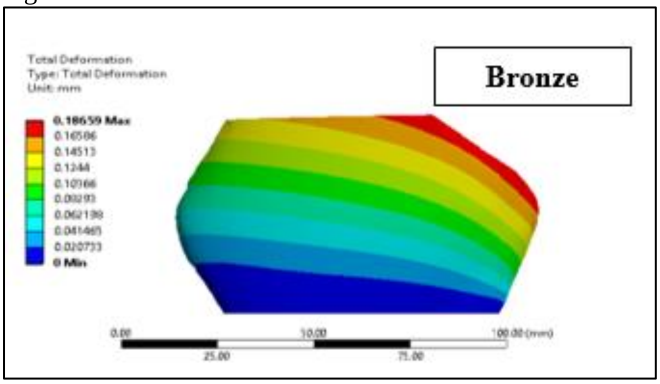


Fig. 6.19: Total deformation in Bronze blade material

Materials	Deformation(mm)
Titanium	0.16906
Copper	0.18670
Stainless steel	0.21067
Bronze	0.18659

Table 6.4: Comparison of total deformation for trapezoidal blade positioning

Figures 6.16 to 6.19 illustrated total deformation in different blade materials for trapezoidal blade positioning and then maximum total deformation was tabulated for further comparison in table 6.4. When compared, it was observed that the total deformation in Titanium material was found to be minimum and Copper had the maximum deformation.

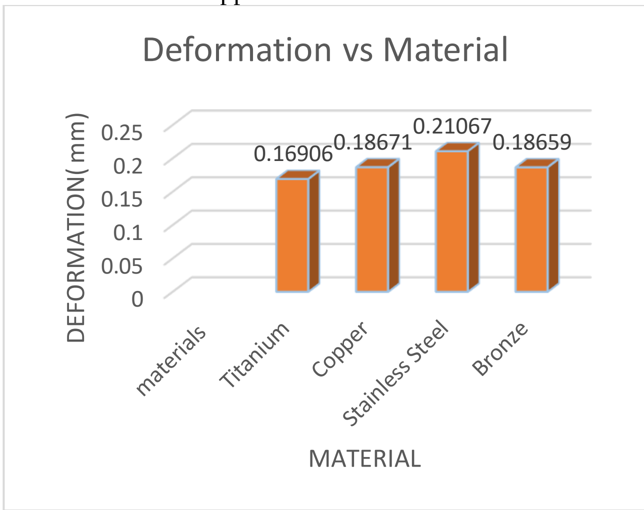


Fig. 6.20: Deformation vs material for Trapezoidal blade

Material	Inlet inclined blade	Trapezoidal blade
Titanium	128.34 MPa	177.07 MPa
Copper	125.08 MPa	181.31 MPa
Stainless steel	120.75 MPa	187.56 MPa
Bronze	125.46 MPa	181.12 MPa

Table 6.5: von-Mises stress comparison of two blades with different material

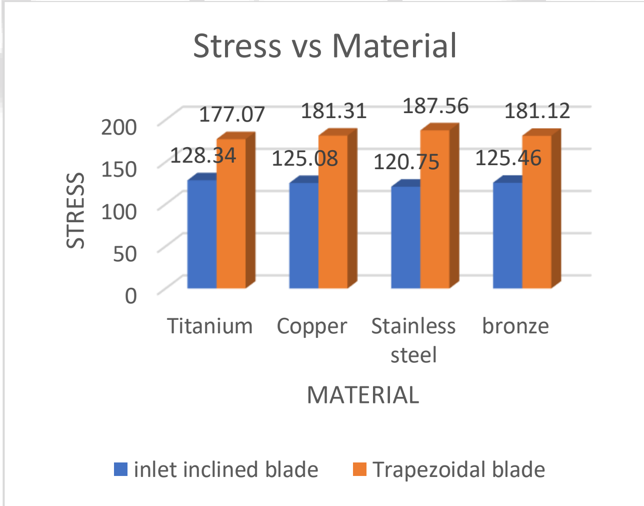


Fig. 6.21: Stress vs Material for both blade

Material	Inlet inclined blade	Trapezoidal blade
Titanium	0.21207 mm	0.16906 mm
Copper	0.18687 mm	0.18670 mm
Stainless steel	0.10766 mm	0.21067 mm
Bronze	0.17673 mm	0.18659 mm

Table 6.6 Deformation comparison of two blades with different materials

All rights reserved by *www.ijsrd.com*

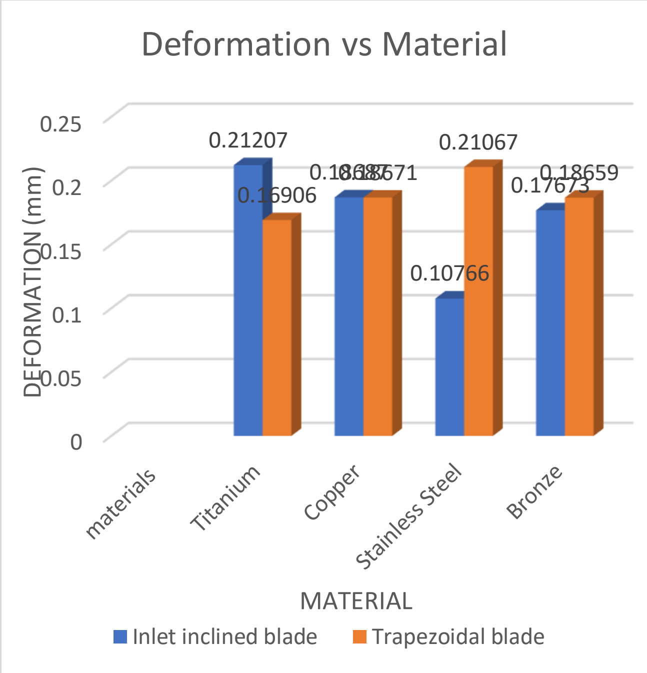


Fig. 6.22: Deformation vs material for both blade

VI. CONCLUSION AND FUTURE SCOPE

The 3D model of mixed flow pump impeller blade developed using CATIA was analysed for von mises stress and deformation with four different materials (Copper alloy, Bronze, Stainless steel and Titanium alloy) using ANSYS 11.0 with similar loading and support conditions. The results obtained clearly indicates that Titanium alloy can be considered as the constructional material for the blades as it gave minimum deformation (at Tip) and minimum von mises stress (at base) out of the four selected materials. In this work other parameters like cost ease of machining and application of hydrostatics loading conditions have not been considered.

REFERENCES

[1] Arunangsu Das, Apurba Kumar Roy, and Kaushik Kumar(2013) "Design and Stress Analysis of a Mixed Flow Pump Impeller".International Journal of Mechanical Engineering and Computer Applications, Vol 1pp.2320-6349.
[2] Bing Hao, Tan Lei, Cao ShuLiang1 and Lu Li(2012). "prediction method of impeller performance and analysis of loss mechanism for mixed flow pump". International journal of Hydro science and Engineering, Vol.55 pp. 1988–1998.
[3] Bing H, Cao S, Tan L, and Zhu B. (2013). "Effects of meridional flow passage shape on hydraulic performance ofmixed-flow pump impellers". Chinese Journal of Mechanical Engineering, Vol.26(3); pp.469-475.
[4] Dash N, Roy AK, and Kumar K. (2017). "Design and Optimization of Mixed Flow Pump Impeller Blades with Hydrostatic Loading and Varying Semi- Cone Angle" Material Today: Proceedings, Vol.5(5); pp.11608-11615.
[5] DivyaZindani, Apurba Kumar Roy and Kaushik Kumar (2016). "Design of blade of mixed flow pump impeller using mean stream line method". 3rd International Conference on Innovations in Automation and Mechatronics Engineering, Vol.23 pp.464-471.
[6] FF Hu, T Chen, D Z Wu and L Q Wan.(2013). "Computation of stress distribution in a mixed flow pump based on fluid-structure interaction analysis". IOP conference series: Material science and engineering vol.52.
[7] Goto. A., 1992, "Study of Internal Flows in a Mixed-Flow Pump Impeller at Various Tip Clearances Using Three-Dimensional Viscous Flow Computations," ASME Journal of Turbomachinery, Vol. 114, pp. 373-382.
[8] Kim, J. H., Ahn, H. J., and Kim, K. Y., (2010), "High-Efficiency Design of a Mixed-Flow Pump," Science China Technological Sciences, Vol. 53, No. 1, pp. 24-27.
[9] Kim JH and Kim KY.(2011). "Optimization of vane diffuser in a mixed-flow pump for high efficiency design". International Journal of Fluid Machinery and Systems, Vol. 4(1); pp.172-178.
[10] Mehta, M.P. and Patel, P.M. (2013) "Performance analysis and optimization of mixed flow pump". International Journal of Emerging Trends in Engineering and Development, Issue 3, Vol.1, pp 647 – 661.
[11] Santosh Shukla, Apurba Kumar Roy and Kaushik Kumar(2015) "Optimization of Thickness of Blades of Different Materials in a Mixed Flow Pump Impeller". International Journal of Applied Engineering Research, Vol. 10 pp. 0973-4562.
[12] Shukla S, Roy AK and Kumar K. (2015). "Material Selection for blades of Mixed Flow Pump Impeller Using ANSYS". Vol.2 pp.2022-2029.