ISSN 2229-5518

Static and Dynamic Analyses of a Ship Propeller

Arjun B Curam, Ejaaz Ahmed, M Vishaal Rao, Akash

Abstract— Ships and underwater vehicles like submarine and torpedoes use propellers for propulsion. These propellers consist of a varying number of blades, and have also been constructed using different materials as time has passed by. The purpose of this project was to model ship propellers based on a standard 4 blade INSEAN E779a model, and varying it with respect to materials, number of blades and rake angles. Here, the procedure used to model and analyse the propeller blades have also been discussed. SOLIDWORKS v2013 was the software used to model the propellers, while ANSYS 14.5 was used to perform Static Structural and Computational Fluid Dynamic Analyses of these propellers. The Analyses were carried out for 2 materials, namely Aluminium and Carbon- Fibre Reinforced Plastic, for rake angles of 0˚ and 4.05˚. The results obtained from the CFD and Static Structural analyses helped determine which propeller performed the best when being compared across different parameters like velocity of water around the propeller, pressure developed by the propeller, stresses, deformations and strains developed within the propeller when subjected to a thrust. The modifications made to the propeller in terms of material, number of blades and rake angles suggested which variant of the propeller is best suited for different requirements of the Ship. For higher speeds, the 3 bladed propellers proved to be more effective, while the 4 bladed propellers were seen to experience lesser stress and deformations due to the thrust. Along with the effect of the rake angle, the features and disadvantages of CFRP too have been discussed.

Index Terms— Aluminium 5052, ANSYS, , Carbon Fibre Reinforced Plastic, Computational Fluid Dynamics, Rake Angle, Static Structural Analysis, SOLIDWORKS.

1. Introduction

A ship is a large watercraft that travels around deep water bodies like the oceans, carrying passengers or goods for various purposes like defence, research and fishing. The various types of ships include high-speed craft, tugboats, factory ships, dry cargo ships, liquid cargo Ships, passenger vessels, liners, luxury cruising yachts, warships. Yet, no matter how light or heavy they are, their movement is enabled by a phenomenon called propulsion. This is possible by a machine known as propeller.

Marine propulsion is the mechanism of generating thrust to move a ship across the water surface. Most modern ships are propelled by mechanical systems consisting of an engine turning a propeller. Marine engineering is the discipline concerned with the engineering design of marine propulsion systems.

In this project, a total 8 of ship propeller blades were modelled using the modelling software SOLIDWORKS. These propellers consisted of both 3 blades and 4 blades, and were designed by taking magnitude of skewness and rake Angles into account. **[7]** The .STEP files of these models were then transferred to the analysis software platform ANSYS, where they were analysed both statically and dynamically. The blades were analysed for 2 materials, namely Aluminium 5052 and Carbon Fibre Reinforced Plastic (CFRP). A comparative study between these propellers was made based on the stresses and strains developed in the propellers, deformations within the propellers, pressures created by the propellers, and variation of velocity of water around the propeller.

Properties of Aluminium 5052

- Young’s Modulus= 69.3 GPa
- Poisson ratio= 0.33
- Mass density= 2.68 gm/cc
- Damping coefficient= 0.03

Properties of CFRP

- Young’s Modulus= 116.04 GPa
- Poisson ratio= 0.28
- Mass density= 1.6 gm/cc
- Damping coefficient= 0.018

Evidently, the density, damping coefficient and Poisson’s Ratio of CFRP is lesser than that of Aluminium and it’s vice versa when it comes to Young’s Modulus.

Disadvantages of CFRP

Like any other material, CFRP too has its own disadvantages that would dissuade manufacturers from using it
1. Carbon Fibre requires a mould in order to prepare an acceptable product, which is not very easy.
2. Carbon Fibre is also a very expensive material.
3. Once a Carbon Fibre structure is dented, it cannot be repaired like a structure made of any other conventional metal. On damage to the structure, it will in all likelihood be replaced.
4. Though a lot of research is being conducted, there has been no clear cut solution to recycling products of Carbon Fibre

2. PROPELLER TERMINOLOGY

Rake: Rake is the amount in degrees that the blades of the propeller angle perpendicular to the hub

Pitch: Pitch may be denoted as the unit distance moved by a point on the propeller when it completes one revolution
Skew: The transverse sweeping of a blade such that viewing the blades from the fore or aft shows an asymmetrical shape is called Skew.

Radius: The distance from the centre of the hub to the blade tip.

Hub: It is a solid cylinder located at the centre of the propeller, bored to accommodate the Shaft

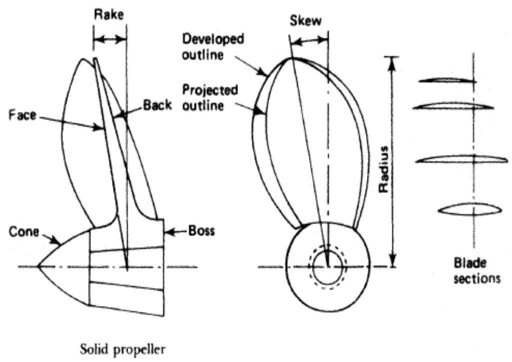


Fig 2.1 Propeller Terminology

3. LITERATURE SURVEY

V. Ganesh and et al [1] modelled and analysed a propeller blade of a torpedo for its strength. CATIA software was used for developing the blade model, while modal analysis and static structural analysis were carried out for both Aluminium and CFRP on ANSYS. By considering the design of the propeller blade on the basis of a cantilever beam, the hub was taken to be the fixed end where there was no deformation. On carrying out modal analysis for both aluminium and composite propellers, they found that the maximum displacement for composite propeller is less than the Aluminium propeller.

Mohammed Ahmed Khan and et al [2] carried out the dynamic analysis of Propellers of different materials, namely Aluminium, CFRP and GFRP. The solid model of propeller was developed using CATIA V5 R17 and using HYPER MESH, a tetrahedral mesh was generated for said model. They carried out static, Eigen and frequency responses analyses of both aluminium and the composite propeller on ANSYS. They also calculated inter- laminar shear stresses for composite propeller by varying the number of layers and found that the percentage variation was about 3.147%.

Barru Harish and et al[3] focussed on the design procedure of four bladed marine propellers, placing specific interest on engines with 85 Bhp, and a ship moving at a speed of 30 knots. The design was modelled on CATIA and Static analysis was carried out on aluminium, R Glass, S2 glass and CFRP (Carbon Fibre Reinforced Plastics) materials on ANSYS. Material results were compared and the stresses obtained were well within the safe limits of elastic property of the materials. .

Palle Prasad, Lanka Bosu Babu [4] worked on the structural analysis of a CFRP (carbon fibre reinforced plastic) propeller blade which was a replacement to the Aluminium propeller blade. They subjected the propeller to external hydrostatic pressure on either side of the blade. From the output of their static analysis and dynamic analyses of the marine propeller, they concluded that the propeller is assumed as a cantilever beam and by varying the material for propeller blade from CFRP to GFRP, the Von- Mises stress is reduced to a percentage of 31.4%.

Vladimir Krasilnikov and at el[5] describe results of numerical prediction of unsteady forces acting on propeller blades using a Reynolds Averaged Navier Stokes (RANS) method. Here, different types of marine propellers were meshed and applied to the analysis of open and podded propellers operating in oblique flow conditions. They presented results obtained using this method for podded propeller operating in pulling and pushing modes, and points out the differences in forces experienced. For these propellers, in the range of heading angles from -45 to +45 the RANS method showed predictions of unit and propeller forces which agreed well with the test data.

Dr. Y. Seetharama Rao and et al [6] presented a methodology to design a propeller with a metal and composite material, and perform stress analysis in order to evaluate its effectiveness using ANSYS software. Proposed methodology showed substantial improvements in metal propellers. Analytical methods were first carried out to find out stresses in a blade section and then, the mean deflection; normal stress and shear stress were found for both metallic and composite propeller by using ANSYS. From their results of stress analysis, the stresses of composite propeller were obtained are within the allowable stress limit**.**

Djahida Boucetta and Omar Imine [7] investigated the influence of parameters such as skew magnitude, thickness and number of blades on the performances of propellers. They studied the open water performances of a conventional 3 bladed propeller model DTMB 4148, and the flow around the rotating propeller model was analysed in the steady state using RANS approach of the Fluent. They concluded that a particular number of blades had a positive influence on the open water characteristics, and the propeller with four blades provided the best efficiency. Lastly, they found that by incorporating a skew angle on the blade, it improved the hydrodynamic performances of the marine propeller.

Abhijjet H. Kekan and P. S Kachare [8] explained how propeller parameters were based on number of blades, sizing, power and rpm, speed of the ship. He modelled a propeller on CATIA, after which a mesh was generated using

ISSN 2229-5518

HYPERMESH. Static and harmonic analyses were both performed on ANSYS for Aluminium and Composite material based propellers. He found that the deflection of Composite propeller was much lower than the Aluminium propeller, indicating its stiffness. Also, from the Harmonic Analysis, he found out that the operating range of Composite propellers were much higher than the Aluminium propellers.

4. METHODOLOGY

1. 3 bladed and 4 bladed propellers, of Standard INSEAN E779a 4 bladed propeller are modelled on Solidworks
2. This standard propeller is Skewed by 20°, has a Rake angle of 4.05° and a diameter of 227.2 mm
3. Propellers are modified according to rake angle
4. Analytical calculations are done for thrust, pitch and thickness variation with radius
5. Meshing of these propeller models is carried out on ANSYS v14.5
6. Aluminium 5052 and CFRP materials are considered for both CFD and Static analyses
7. Static, CFD analyses of the propellers is carried out on ANSYS
8. Comparative study is done based on Pressure developed due to the propeller blades, Velocity of water around the propeller; Stresses, strains and deformations developed within the propeller when subjected to a thrust.

A. Theoretical Calculations

Steps and Equations

Step 1: Providing the geometric specifications of the Propeller

Diameter of the Propeller= 227.2 mm
Number of blades = 4
Propeller Model = INSEAN E779A
Type of propeller = Controllable pitch propeller
Materials considered = Aluminium and CFRP

Step 2: Calculate Pitch, Total area of the circle, Total blade area

$$\text{Given ratio of Pitch/ Diameter} = 1.1 \quad (1)$$

$$\text{Total Area of the circle} = \pi * r^2 \quad (2)$$

$$\text{Total blade area} = \text{total area of the circle} * \text{disc area ratio} \quad (3)$$

Where Disc area ratio= 0.51

Step 3: Calculate Boat Speed, Mass flow rate

$$\text{Speed} = [\frac{\text{RPM}}{\text{Ratio}}] * [\frac{\text{Pitch}}{c}] * [\frac{1-S}{100}] \quad (4)$$

[Assume Ratio=1/2; gear ratio(c) = 1; slip(s) =0]

$$\text{Mass flow} \frac{\text{rate}}{\text{hr}} (m) = \text{total blade area} * \text{speed of the boat} \quad (5)$$

Step 4: Calculate Advance Velocity, Thrust

The thrust (T) is equal to the mass flow rate (m) times the difference in the velocity (v)

$$T = m * (Vb - Va) \quad (6)$$

$$\text{Where Advance Velocity } Va = Vb * (1 - w) \quad (7)$$

[w= wake fraction]

Step 5: Determine variation of Pitch and Thickness along the radius

To determine the pitch along the radius of the propeller blade, the Pitch at 25%, 50%, 60%, 70%, 80%, 90% of radius being represented by $P_{0.25}$, $P_{0.5}$, $P_{0.6}$, $P_{0.7}$, $P_{0.8}$, $P_{0.9}$, respectively was calculated using the formula

$$Px = (x) * \text{Radius of the propeller blades} * \text{(Pitch/ Diameter) Ratio} \quad (8)$$

Similarly, the thickness of the blade section could be found for the radii, using the blade thickness fraction= 0.05= (t_0/D), which means

$$t0 = D * 0.05 \quad (9)$$

Hence, to estimate the thickness along the radius of the propeller,

$$t0 = 0.05 * \text{(R in percentage)} \quad (10)$$

Calculations

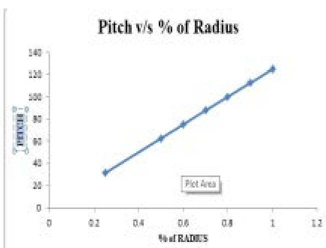
Given ratio of Pitch/ Diameter = 1.1, hence
Pitch= 227.2*1.1= 249.92 mm
Total Area of the circle= $\pi * r^2$
= $\pi * 113.6^2$= 40567.113 mm^2
Total blade area= 40567.113* 0.51= 20689.23 mm^2
Speed= $[\frac{\text{RPM}}{\text{Ratio}}] * [\frac{\text{Pitch}}{c}] * [\frac{1-S}{100}] = [(\frac{1000}{0.5}) * (\frac{249.92}{1}) * (\frac{1-0}{100})]$
= 4998.4 x 60/10^4= 29.99 km/hr
Boat speed = V_b = 29.99/1.6093 mile/ hr = 18.63 mile/hr
Mass flow rate/hr (m) = total blade area* speed of the boat
= 20689.23* 10^{-6}* 29.99* 10^3= 620.47 m^3/hr
T = m (V_b – V_a)
V_a= V_b* (1- w) = 29.99* (1-0.25) = 22.425 km/hr
Hence, Thrust (T) = 620.47* (29.99-22.425)* 10^3
= 4693855.55 N= 4.69 MN
Variation of Pitch along the radius
$P_{0.25}$= (25/ 100)* 113.6* 1.1= 31.24 mm
$P_{0.5}$= (50/ 100)* 113.6* 1.1= 62.48 mm
$P_{0.6}$= (60/ 100)* 113.6* 1.1= 74.98 mm
$P_{0.7}$= (70 /100)* 113.6* 1.1= 87.47 mm
$P_{0.8}$= (80/ 100)* 113.6* 1.1= 99.97 mm
$P_{0.9}$= (90/ 100)* 113.6* 1.1= 112.46 mm

$P_{1.0}$= (100/ 100)* 113.6* 1.1= 124.96 mm

Variation of Thickness along the radius

$t_{0.1}$= 0.1* 113.6* 0.05= 0.568 mm
$t_{0.2}$= 0.2* 113.6* 0.05= 1.136 mm
$t_{0.3}$= 0.3* 113.6* 0.05= 1.704 mm
$t_{0.4}$= 0.4* 113.6* 0.05= 2.272 mm
$t_{0.5}$= 0.5* 113.6* 0.05= 2.84 mm
$t_{0.6}$= 0.6* 113.6* 0.05= 3.408 mm
$t_{0.7}$= 0.7* 113.6* 0.05= 3.976 mm
$t_{0.8}$= 0.8* 113.6* 0.05= 4.544 mm
$t_{0.9}$= 0.9* 113.6* 0.05= 5.112 mm
$t_{1.0}$= 1.0* 113.6* 0.05= 5.68 mm

The following images show the variation of Pitch and Thickness against the % of Radius in graphical form, taking values from what were calculated above. The two graphs were seen to increase linearly, which meant that the Pitch and Thickness of the blade increased linearly from the Blade- Hub intersection up to the tip of the Blade.



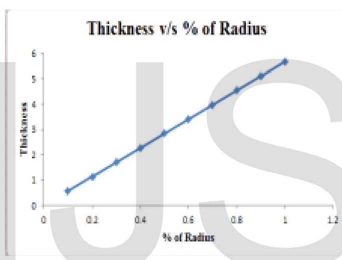


Fig 4.1 Pitch v/s % of Radius Fig. 4.2 Thickness v/s % of Radius

B. Solidworks Modelling

The following were the steps involved in developing the Solidworks models of the propellers

1. A horizontal line of 131.3 mm was drawn, and from the starting point of the same line, a 30 mm vertical line was drawn. These lines represent the length and the radius of the Hub of the Propeller respectively

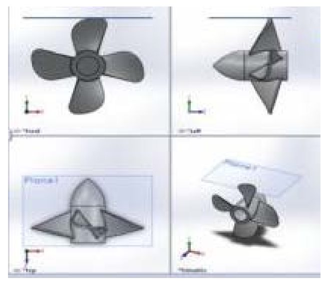
2. From the end of the radius line, a horizontal line of 74.9 mm was drawn. From this point, a spline connected this line to the line representing the length of the propeller. This was curved in such a way that it was concave to the centre of the surface

3. This drawing was revolved about the length, thus completing the hub

4. A rectangle of length 90 mm and breadth 15 mm was drawn at the centre of the propeller, perpendicular to its axis. Another rectangle of the same dimensions was drawn at a height of 113.6 mm above the central axis, angled 74° to the horizontal. This is the radius of the propeller blade. Depending on the rake angle of 0 ° or 4.05 °, this rectangle is either drawn at the centre of the hub length, or 7 mm below respectively

5. The rectangle at the central axis is lofted to the rectangle above, and this forms the initial blade. Upon providing necessary fillets at the blade edges, it is skewed by 20 ° when viewed from the front. Also, a hole of 40 mm diameter is cut at the rear end of the hub, which is where the shaft would be assembled

6. The propeller blade is ready. Depending on the number of blades, a circular pattern of 3 blades or 4 blades is provided, spaced equally around the circumference of the hub



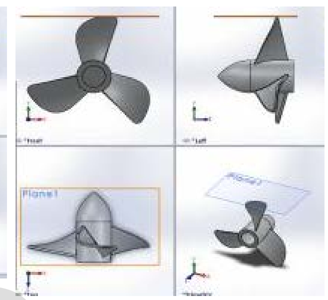


Fig.4.3 4 bladed propeller Fig. 4.4 3 bladed propeller

C. Cfd Analysis On Ansys Workbench

The following steps were followed in order to carry out the CFD analysis of the propeller blade on ANSYS Fluent. **[3]**

Step 1: Geometry

The .STEP files of the Solidworks models of the propellers were chosen as the geometry for the Analysis. On choosing the geometry, the DesignModeler is opened, which leads to Step 2

Step 2: Creating Domain

The DesignModeler is opened and the propeller can be viewed. A sketch is chosen for a plane perpendicular to the length of the hub (here, YZ Plane). The origin of this Sketching Plane is at the back end of the Propeller Hub. A horizontal line is drawn 250 mm behind the axis, and from this very point, a vertical line is drawn 200 mm up. A horizontal line of 586.4 mm is drawn from the end of the vertical line. At this point, a 400 mm vertical line is drawn downwards. The first 2 lines are now cut, and two more horizontal lines of 586.4 mm and 400 mm are drawn respectively, in order to form the rectangle.
Now, the sketch was extruded symmetrically on both sides by 200 mm and the operation was Add Frozen, thus generating the cuboidal domain. Booleans are subtracted with the Target Body being the surrounding Domain, and the Tool Body being

the Propeller inside it. This is crucial in order to obtain a good mesh.

Step 3: Meshing

On closing the DesignModeler, the Meshing model is opened. Here, Inlet, Outlet and Propeller Named Selections were created. The Tetrahedron meshing was applied, which was of Patch Conforming Method. The Advanced Size Function used was Proximity and Curvature and the Relevance Centre chosen was Fine. A particular number of nodes and elements were obtained.

Step 4: Setup

On closing Meshing, the Fluent Setup is opened. Here, the Initial Solver settings were Steady Time, Pressure Based Type and Absolute Velocity Formulation. The Models option was modified as Viscous- k epsilon, Realizable, Scalable Wall Functions. In Materials, Water was added as the fluid, while Aluminium 5052 was considered to be the solid material for the propeller on 4 occasions, while CFRP was considered on 4 other occasions. The Boundary Condition applied at the inlet was a velocity of 8.33 m/s of water. The Solution was initialised keeping in mind the inlet as reference values. The Calculation was made to run for 50 iterations. A graph of x-velocity, y- velocity, k-epsilon and time/iter was obtained.

Step 5: Results

The Results cell is opened, and here is where the streamline, Plane at YZ plane, velocity vector and even the pressure contours were applied.

D. Static Structural Analysis On Ansys Workbench

The following steps were followed in order to carry out the Static Structural Analysis of the propeller blade

Step 1: Defining Material Properties

Based on the Material chosen, the geometric data regarding density, Poisson's Ratio, and Young's Modulus were modified for Aluminium 5052 and CFRP respectively. The values were considered from the tables as mentioned in the previous chapter.

Step 2: Geometry

The .STEP file was chosen again for each propeller, and the geometry was obtained.

Step 3: Meshing and Boundary Conditions

Here, the Model was again subject to the Tetrahedron meshing, which was of Patch Conforming Method. The Advanced Size Function used was Proximity and Curvature and the Relevance Centre chosen was Fine. A particular number of nodes and elements were obtained. The material was changed from the default setting to the required material of the 2 available to us. CFRP proved to be lighter than Aluminium. The propeller was fixed at the hub, and at the intersections of the blades with the hub. **[1]** The calculated value of Thrust, 4.69 MN was applied at the surface of the propeller blades as a Force. **[1]** Finally, the solver settings included Equivalent (Von- Mises) Stress, Elastic Strain and Total Deformation.

5. CFD ANALYSIS

The following results were obtained upon completion of CFD. They include the Pressure contour, Velocity contour and the shape of the Streamline. The 4 bladed propellers had 627011 nodes and 3487492 elements after being meshed. The 3 bladed propellers had 486348 nodes and 2702161 elements after being meshed

The following settings were provided before performing the analysis
a. Initial Solver settings
Steady Time, Pressure Based Type and Absolute Velocity Formulation.
b. Models
Viscous- k epsilon, Realizable, Scalable Wall Functions.
c. Materials
Water as the fluid, Aluminium 5052 or CFRP as the Solid whenever required
d. Boundary Conditions
Inlet Velocity of water = 8.33 m/s

The maximum pressure exerted by the propellers is seen to be at the intersection of the blade and the surface of the hub. As we look towards the tip of the propeller blade, the pressure decreases, and the pressure is at its lowest in the region surrounding the blade.
The velocity contour demonstrates how the velocity of water changes across the surface of the blade. It has a value of 8.33 m/s at the inlet and decreases at the tip of the hub and also between the contact of propeller blades and hub. As we look towards the tip of the blades, the velocity of water is seen to increase, while right behind the propeller hub, it has almost no velocity

1. *4 bladed Aluminium 5052 Propeller, Rake angle 4.05 ˚*

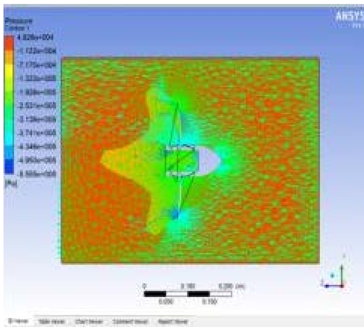
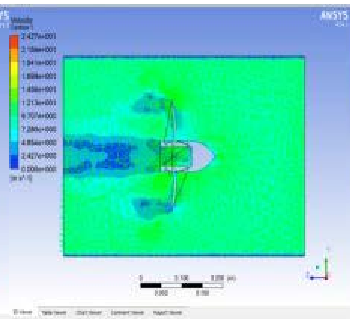



Fig. 5.1 Pressure Contour Fig. 5.2 Velocity Contour

2. *4 bladed Aluminium 5052 Propeller, Rake angle 0˚*

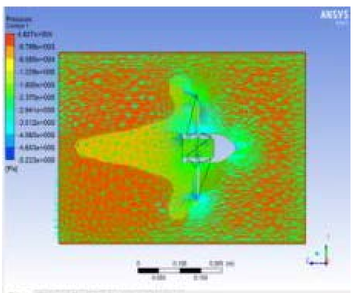
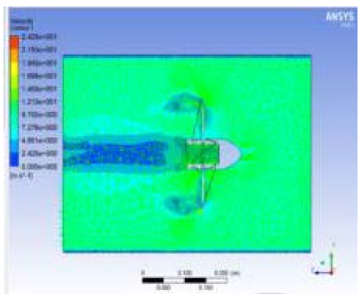



Fig. 5.3 Pressure Contour Fig. 5.4 Velocity Contour

3. *4 bladed CFRP Propeller, Rake angle 4.05˚*

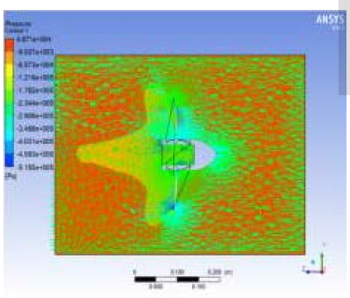
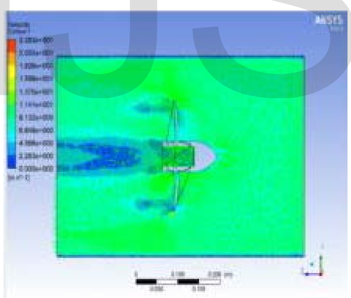



Fig. 5.5 Pressure Contour Fig. 5.6 Velocity Contour

4. *4 bladed CFRP Propeller, Rake angle 0˚*

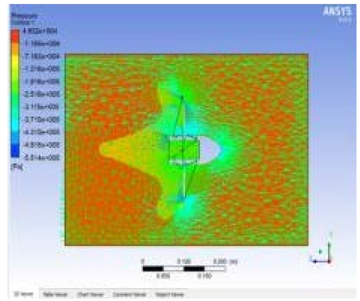
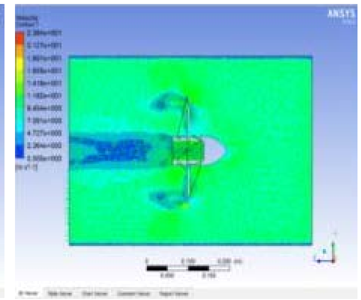



Fig. 5.7 Pressure Contour Fig.5.8 Velocity Contour

5. *3 bladed Aluminium 5052 Propeller, Rake angle 4.05˚*

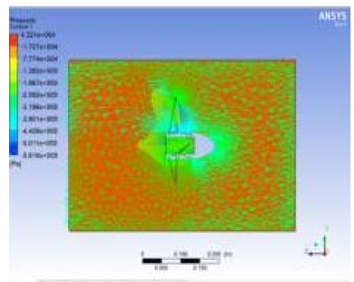
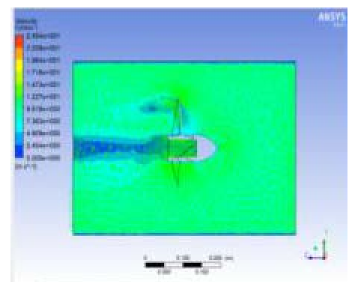



Fig 5.9 Pressure Contour Fig 5.10 Velocity Contour

6. *3 bladed Aluminium 5052 Propeller, Rake angle 0˚*

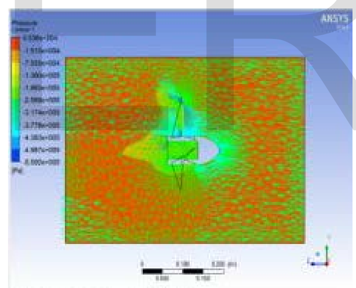
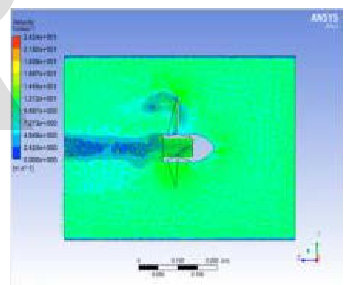



Fig 5.11 Pressure Contour Fig 5.12 Velocity Contour

7. *4 bladed CFRP Propeller, Rake angle 4.05˚*

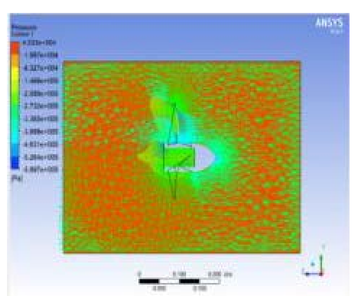
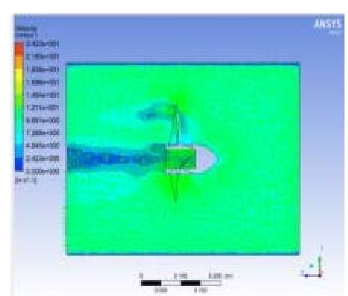



Fig. 5.13 Pressure Contour Fig. 5.14 Velocity Contour

8. *3 bladed CFRP Propeller, Rake angle 0˚*

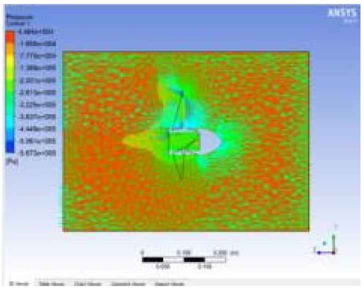


Fig 5.15 Pressure Contour

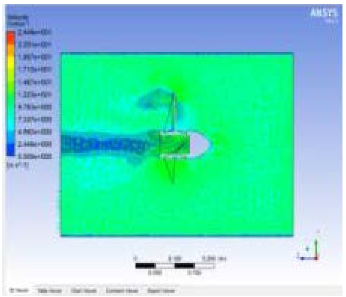


Fig 5.16 Velocity Contour

The best performing propeller in terms of pressure created and the velocity of water around it is observed to be the 3 bladed CFRP propeller, with a rake angle of 4.05̊.

6. STATIC STRUCTURAL ANALYSIS

The following results were obtained upon completion of Static Structural Analysis. They include the Equivalent (Von- Mises) Stress, Elastic Strain and the total deformation. The following were the Boundary Conditions that were applied before solving

a. Hub and points of contact between the blades and hub were fixed
b. Force of 4.69 MN was applied to the blades

The maximum deformation is seen to be at the tip of the propeller blade while the minimum is 0 mm, seen at the hub of the propeller.
The value of the maximum Von- Mises Stress is at the point of contact between the propeller blade and the hub. From the middle of the blade and even at the hub, a very small value exists
The maximum elastic strain is seen at the point of contact between the propeller blade and the hub. From the middle of the blade and even at the hub, a very small value exists.

1. *4 bladed Aluminium 5052 Propeller, Rake angle 4.05 ˚*

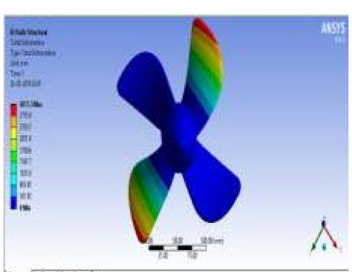


Fig 6.1 Total Deformation

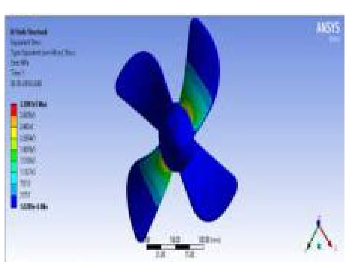


Fig 6.2 Von- Mises Stress

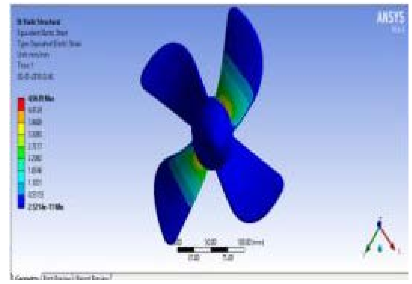


Fig 6.3 Elastic Strain

2. *4 bladed Aluminium 5052 Propeller, Rake angle 0 ˚*

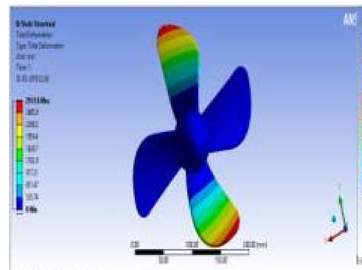


Fig 6.4 Total Deformation

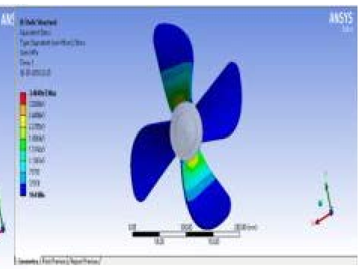


Fig 6.5 Von- Mises Stress

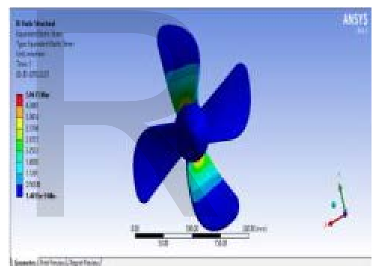


Fig 6.6 Elastic Strain

3. *4 bladed CFRP Propeller, Rake angle 4.05 ˚*

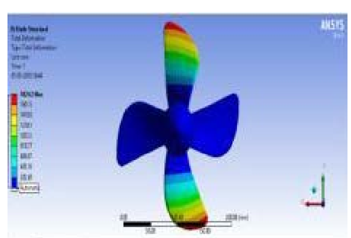


Fig 6.7 Total Deformation

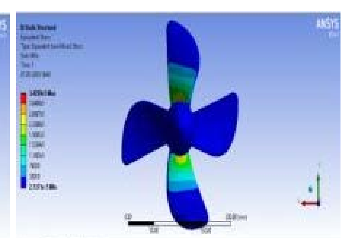


Fig 6.8 Von- Mises Stress

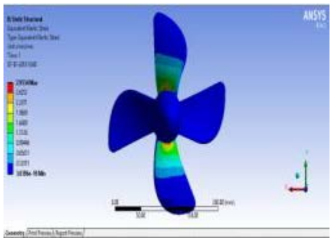


Fig 6.9 Elastic Strain

4. *4 bladed CFRP Propeller, Rake angle 0 ˚*

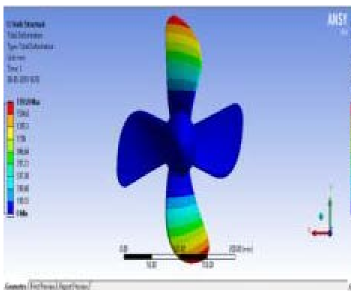


Fig 6.10 Total Deformation

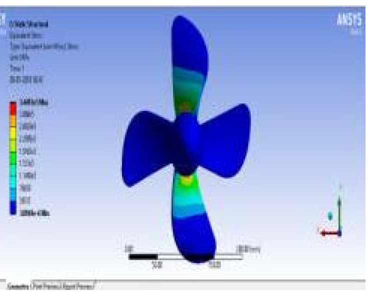


Fig 6.11 Von- Mises Stress

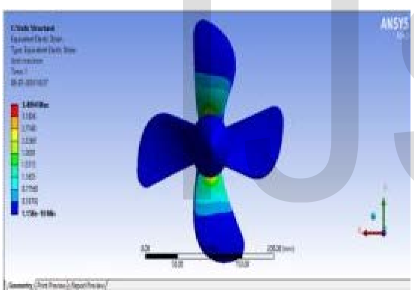


Fig 6.12 Elastic Strain

5. *3 bladed Aluminium 5052 Propeller, Rake angle 4.05 ˚*

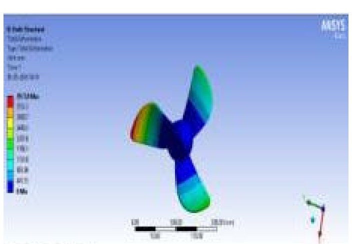


Fig 6.13 Total Deformation

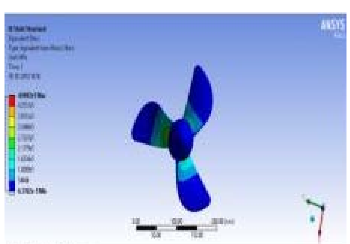


Fig 6.14 Von- Mises Stress

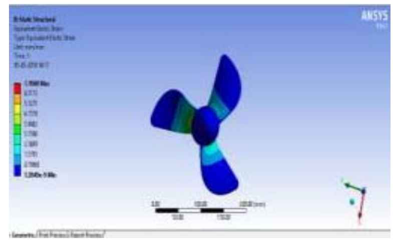


Fig 6.15 Elastic Strain

6. *3 bladed Aluminium 5052 Propeller, Rake angle 0 ˚*

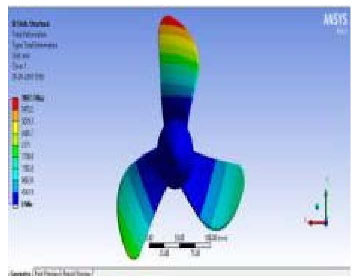


Fig 6.16 Total Deformation

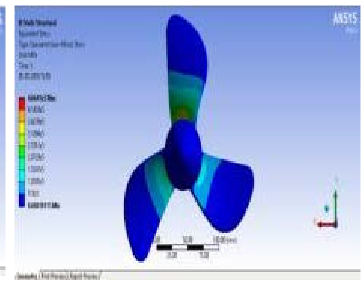


Fig 6.17 Von- Mises Stress

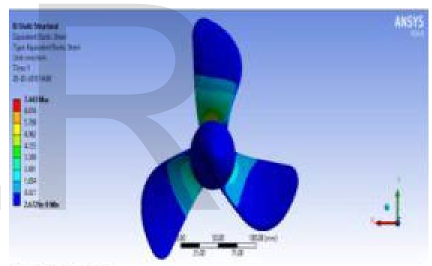


Fig 6.18 Elastic Strain

7. *3 bladed CFRP Propeller, Rake angle 4.05 ˚*

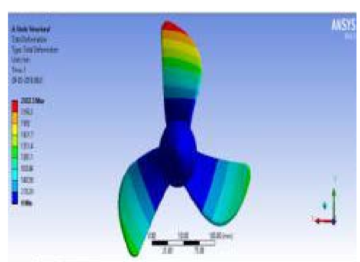


Fig 6.19 Total Deformation

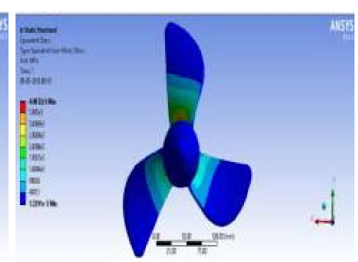


Fig 6.20 Von- Mises Stress

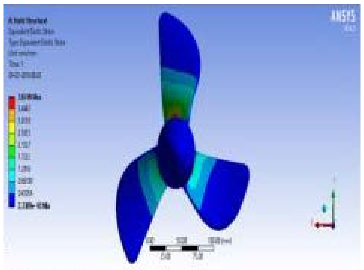
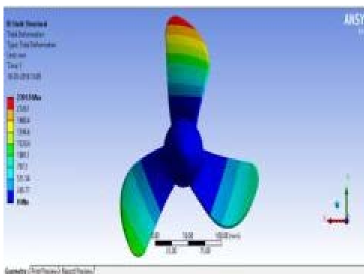


Fig 6.21 Elastic Strain

8. 3 bladed CFRP Propeller, Rake angle 0 ˚



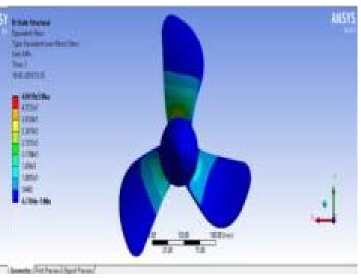


Fig.6.22 Total Deformation Fig 6.23 Von- Mises Stress

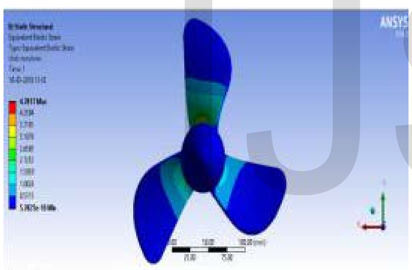


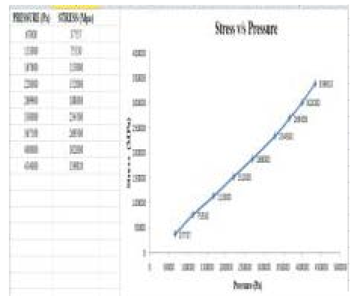
Fig 6.24 Elastic Strain

The best performing propeller in terms of least deformation, least stress and strain developed is observed to be the 4 bladed CFRP propeller, with a rake angle of 4.05̊.

7. RESULTS AND DISCUSSIONS

The graphs of Stress v Pressure have been drawn by taking into account the results obtained in that particular propeller's Static Analysis against that of the CFD Analysis. The graphs of Stress v Strain have been drawn by taking into account the results obtained in that particular propeller's Static Analysis. All propellers of both the materials are seen to follow Hooke's Law and while the blade won't immediately fail; it gradually might crack due to fatigue when it crosses the value of Yield Stress. **[1]**

1. 4 bladed Aluminium 5052 Propeller, Rake Angle 4.05 ˚



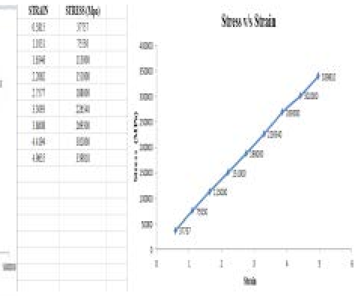
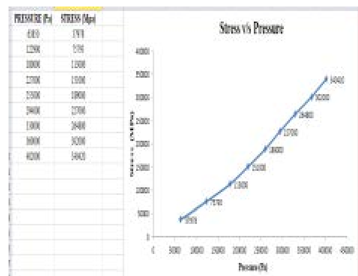


Fig 7.1 Stress vs Pressure Fig 7.2 Stress vs Strain

2. 4 bladed, Aluminium 5052 Propeller, Rake Angle 0 ˚



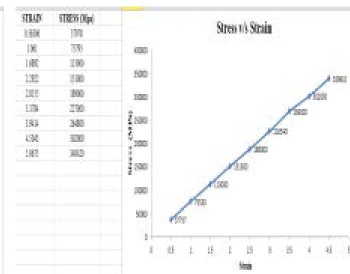
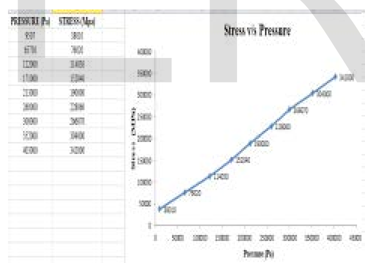


Fig 7.3 Stress vs Pressure Fig 7.4 Stress vs Strain

3. 4 bladed, CFRP Propeller, Rake Angle 4.05 ˚



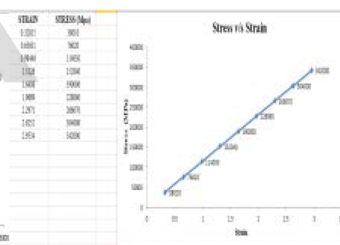
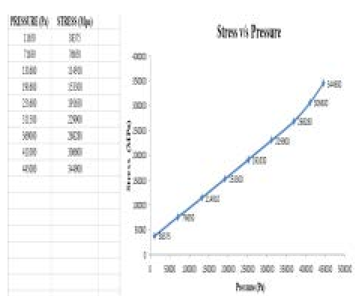


Fig 7.5 Stress vs Pressure Fig 7.6 Stress vs Strain

4. 4 bladed, CFRP Propeller, Rake Angle 0 ˚



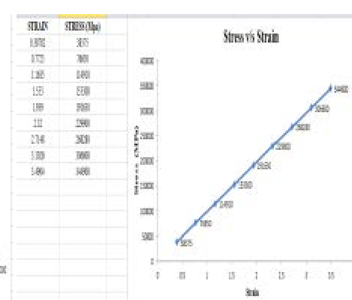


Fig 7.7 Stress vs Pressure Fig 7.8 Stress vs Strain

5. 3 bladed, Aluminium Propeller, Rake Angle 4.05 ˚

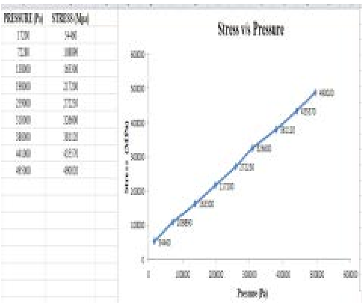


Fig 7.9 Stress vs Pressure

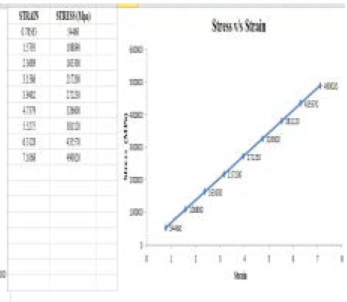


Fig 7.10 Stress vs Strain

6. 3 bladed, Aluminium Propeller, Rake Angle 0 ˚

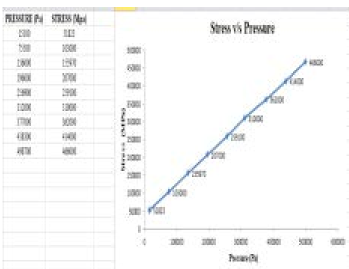


Fig 7.11 Stress vs Pressure

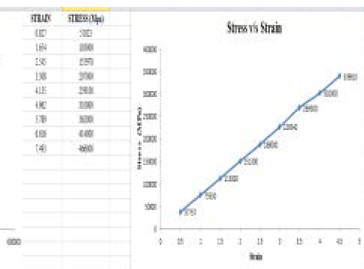


Fig 7.12 Stress vs Strain

7. 3 bladed, CFRP Propeller, Rake Angle 4.05 ˚

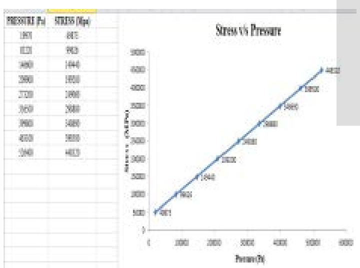


Fig 7.13 Stress vs Pressure

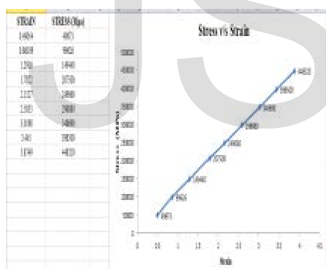


Fig 7.14 Stress vs Strain

8. 3 bladed, CFRP Propeller, Rake Angle 0 ˚

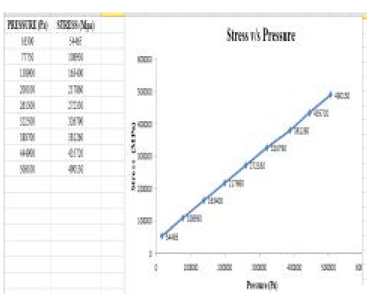


Fig 7.15 Stress vs Pressure

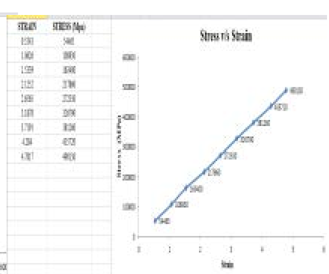


Fig 7.16 Stress vs Strain

These graphical representations provide a view on how these materials behave with respect to increasing values of stress, pressure and strain. Over time the propellers will fail, due to stresses crossing the yield strengths of the materials, but they are seen to withstand high values of forces before the stress developed is too high that it fails due to fatigue.

From the CFD Analysis, the following behavioural patterns were observed for the Aluminium 5052 and CFRP propellers

a. Aluminium 5052 Propellers

The magnitude of pressure created and velocity of water around the blades was maximum for the 3 bladed propellers with a rake angle of 4.05̊. Increasing the rake angle has a positive effect on the pressure created and the velocity of water, but the 3 bladed propellers are seen to perform better than the 4 bladed ones.

b. CFRP Propellers

The magnitude of pressure created and velocity of water around the blades was maximum for the 3 bladed propellers with a rake angle of 4.05̊. Increasing the rake angle has a positive effect on the pressure created and the velocity of water, but the 3 bladed propellers are seen to perform better than the 4 bladed ones.

When the two 3 bladed propellers of rake angle 4.05 ˚ are compared, it is seen that the CFRP based propeller performs better than the Aluminium based propeller in both pressure created and velocity developed. Hence, for higher pressures and higher speeds, 3 bladed CFRP propellers designed with a rake angle of 4.05 ˚ can be used. The charts below represent how CFRP performs better than Aluminium

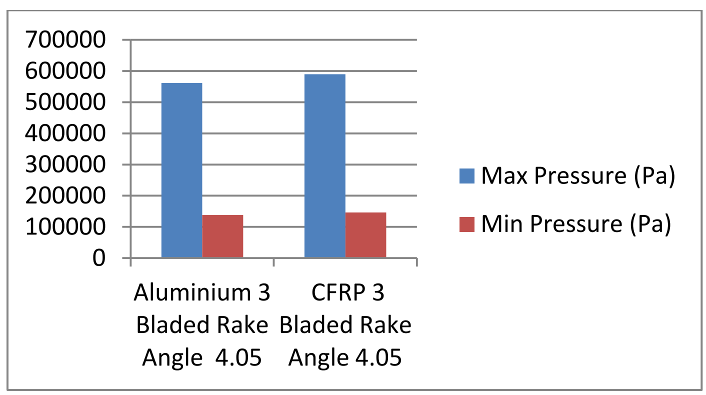


Fig 7.17 Comparison of Pressures created

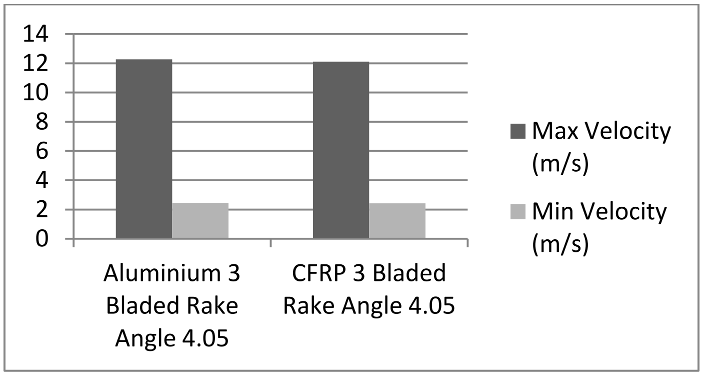


Fig 7.18 Comparison of Velocity developed

From the static structural analysis, the following behavioural patterns were observed for the Aluminium 5052 and CFRP propellers

a. Aluminium 5052 Propellers

The magnitudes of deformation, von- mises stress and strain experienced least for the 4 bladed propellers with a rake angle of 4.05̊. Increasing the rake angle and the number of blades has a positive effect on reducing the deformation, von- mises stress and strain experienced

b. CFRP Propellers

The magnitudes of deformation, von- mises stress and strain experienced least for the 4 bladed propellers with a rake angle of 4.05̊. Increasing the rake angle and the number of blades has a positive effect on reducing the deformation, von- mises stress and strain experienced

When the two 4 bladed propellers of Rake angle 4.05 ˚ are compared, it is seen that the CFRP based propeller performs better than the Aluminium based propeller in terms of deformations, stresses and strains developed. Hence, for lower deformations, stresses and strains, 4 bladed CFRP propellers designed with a rake angle of 4.05 ˚ can be used. The charts below represent how CFRP performs better than Aluminium

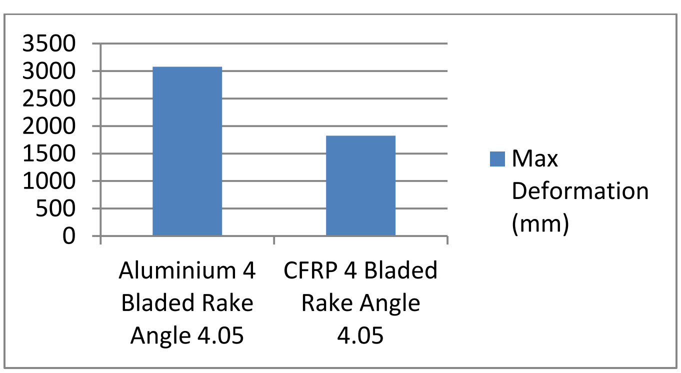


Fig 7.19 Comparison of Deformations induced (mm)

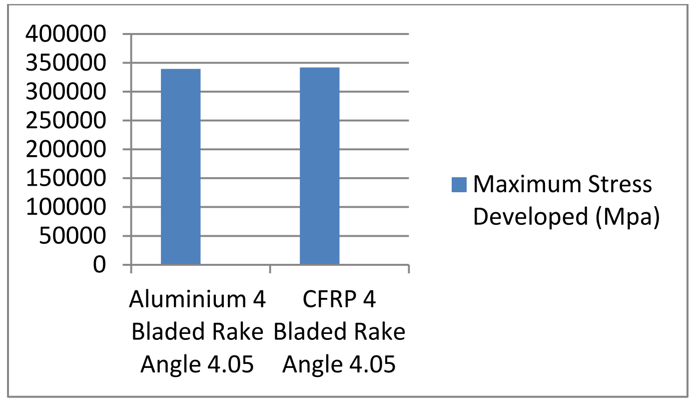


Fig 7.20 Comparison of Stresses developed (MPa)

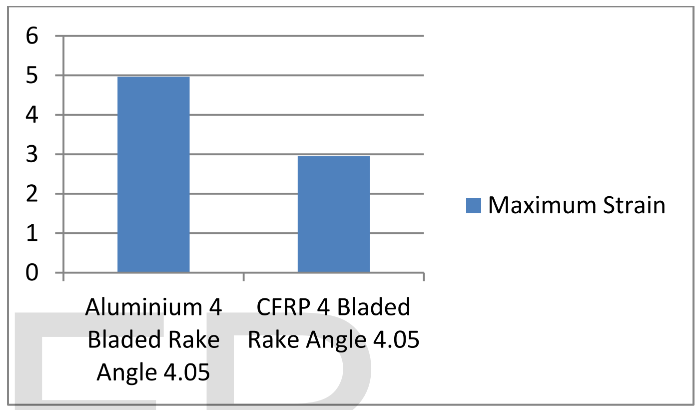


Fig 7.21 Comparison of Strains developed

8. CONCLUSION

As per the values of stress, strain and deformation, the boundary conditions were taken correctly. The behaviour of the propeller was assumed to be like that of a cantilever beam, and hence, the deformations were maximum at the tip of the blade and zero at the blade- hub intersection. It was assumed that the blade was a cantilever beam fixed at the hub end.

1. CFD Analysis carried out on the Aluminium and CFRP propellers helped prove that the Pressure created by the 3 bladed CFRP propeller of rake angle 4.05˚was 5% better than that of the Aluminium propeller of the same number of blades and rake angle. The velocity of water created around the region of the blade tip by the CFRP based propeller though was around 1.3% lower than that by the Aluminium propeller

2. Static Structural Analysis carried out on the Aluminium and CFRP propellers helped prove that the stress developed in the 4 bladed CFRP propeller of Rake Angle 4.05˚was about 0.67% more than that developed in the Aluminium propeller. The strains and deformations seen though were 40.5% and 40.7% respectively less in the CFRP propeller when compared to the Aluminium propeller **[8]**

ISSN 2229-5518

3. The Stress v Pressure plots proved that wherever greater stress was developed in the propeller that was where more pressure was created by the propeller. The Stress v Strain plots proved that the curves were linear, and that both the materials obeyed Hooke's Law until they eventually fail due to fatigue

4. The Aluminium propeller was seen to be heavier than the CFRP propeller by 40.3%. **[1]**

5. While rake angle doesn't seem to play a large role in the velocities of water around the blade tip or the deformation of the Propeller, it is observed that the pressure created increases by 6% and the stress developed and strain induced reduce by 7% and 18% respectively.

6. For boats or ships where higher pressures and speeds are the requirements, the 3 bladed propeller of CFRP material, with rake angle 4.05 ˚ is seen to perform better than the Aluminium propeller. If lesser deformation and strain are the requirement, then the 4 bladed propeller of CFRP material, with rake angle 4.05 ˚ is seen to perform better than the Aluminium propeller. Hence, CFRP is seen to outperform Aluminium on both counts.

8.1 Future Scope

1. The present work consists of only Static Structural Analysis and CFD Analysis, and can also be carried out for Modal Analysis
2. Work can be carried out to see which of the materials between Aluminium and CFRP can reduce Noise, and even cavitation.
3. Different materials like GFRP, Epoxy Resin can also be tested.

ACKNOWLEDGEMENT

The authors acknowledge, to Dr. H C Nagaraj, Principal. Nitte Meenakshi Institute of Technology for providing the support and infrastructure to carry out our project. We would also like to thank Dr. J Sudheer Reddy, HOD, Department of Mechanical Engineering of Nitte Meenakshi Institute of Technology for their valuable suggestions and support

REFERENCES

[1] V. Ganesh, K. Pradeep, K. Srinivasulu, Modeling and Analysis of Propeller Blade for its Strength, International Journal of Engineering Research & Technology (IJERT)Vol. 3 Issue 2, February – 2014

[2] Mohammed Ahmed Khan, Khaja Shahnawaz Uddin, Bilal Ahmed, Design And Dynamic Analysis on Composite Propeller of Ship Using Fea, International Journal of Advanced Trends in Computer Science and Engineering, Vol.2 , No.1, Pages : 310 - 315 (2013))

[3] Barru Harish, Kondapalli Siva Prasad, G. Uma Maheswara Rao, Static Analysis of 4-Blade Marine Propeller, Journal of Aerospace Engineering & Technology, Volume 5, Issue 2

[4] Palle Prasad, Lanka Bosu Babu, Design And Analysis of the Propeller Blade, International Journal Of Advances In Mechanical And Civil Engineering, Volume-4, Issue-2, Aprl.-2017

[5] Vladimir Krasilnikov, Zhirong Zhang and Fangwen Hong, Analysis of Unsteady Propeller Blade Forces by RANS, First International Symposium on Marine Propulsors smp'09, Trondheim, Norway, June 2009

[6] Dr. Y. Seetharama Rao, Dr. K. Mallikarjuna Rao, B.Sridhar Reddy, Stress Analysis of Composite Propeller by Using Finite Element Analysis, International Journal of Engineering Science And Technology (Ijest), Vol. 4 No.08 August 2012

[7] Djahida Boucetta and Omar Imine, Numerical Simulation of the Flow around Marine Propeller Series, Journal of Physical Science and Application 6 (3) (2016) 55-61

[8] Abhijeet H. Kekan & P.S Kachare, Static and Dynamic Analysis of Composite Ship Propeller Using FEA, International Conference on Mechanical and Industrial Engineering (ICMIE), Pune, 15th July, 2012