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MODELING AND ANALYSIS OF THE SUBMARINE PROPELLER BY USING VARIOUS MATERIALS

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ABSTRACT-*Composites materials are finding wide spread use in naval applications in recent times. Ships and under water vehicles like torpedoes Submarines etc. Torpedoes which are designed for moderate and deeper depths require minimization of structural weight for increasing payload, performance/speed and operating range for that purpose Aluminium alloy casting is used for the fabrication of propeller blades. In current years the increased need for the light weight structural element with acoustic insulation, has led to use of fiber reinforced multi-layer composite propeller. The present work carries out the structural analysis of a CFRP (carbon fiber reinforced plastic) , (Graphite fiber reinforced plastic), Nibral propeller blade which proposed to replace the Aluminium 6061 propeller blade. Propeller is subjected to an external hydrostatic pressure on either side of the blades depending on the operating depth and flow around the propeller also result in differential hydrodynamic pressure between face and back surfaces of blades. The propeller blade is modelled and designed such that it can with stand the static load distribution and finding the stresses and deformation, strain, for different materials aluminium, Nibral and Graphite fiber reinforced plastic ,carbon fiber reinforced plastic materials. This work basically deals with the modeling and design analysis of the propeller blade of a torpedo for its strength. A propeller is complex 3D model geometry. This requires high end modeling CATIA software is used for generating the blade model. This report consists of brief details about Fiber Reinforced Plastic materials and the advantages of using composite propeller over the conventional metallic propeller. By using ANSYS software static, modal analysis were carried out for four different materials.*

1. INTRODUCTION

A propeller is a type of fan that transmits power by converting rotational motion into thrust. A pressure difference is produced between the forward and rear surfaces of the airfoil-shaped blade, and a fluid (such as air or water) is accelerated behind the blade. Propeller dynamics, like those of aircraft wings, can be modelled by either or both Bernoulli's principle and Newton's third law. A marine propeller of this type is sometimes colloquially known as a screw propeller or screw, however there is a different class of propellers known as cycloidal propellers – they are characterized by the higher propulsive efficiency averaging 0.72 compared to the screw propeller's average of 0.6 and the ability to throw thrust in any direction at any time. Their disadvantages are higher mechanical complexity and higher cost Marine propeller is a component which forms the principal part of ships since it gives the required propulsion. Metal matrix composite material is extensively used in the manufacturing of various structures including the marine propeller. The hydrodynamic aspects of the design of composite marine propellers have attracted attention because they are important in predicting the deflection and performance of the propeller blade. For designing an optimized marine propeller one has to understand the parameters that influence the hydro-dynamic behaviour. Since propeller is a complex geometry, the analysis could be done only with the help of numerical tools. Most marine propellers are made of metal material such as bronze or steel. The advantages of replacing metal with an composite are that the latter is lighter and corrosion resistant. Another important advantage is that the deformation of the composite propeller can be controlled to improve its performance. Propellers always rotate at a constant velocity that maximizes the efficiency of the engine. When the ship sails at the designed speed, the inflow angle is close to its pitch angle. When the ship sails at a lower speed, the inflow angle is smaller. Hence, the pressure on the propeller increases as the ship speed decreases. The propulsion efficiency is also low when the inflow angle is far from the pitch angle. If the pitch angle can be reduced when the inflow angle is low, then the efficiency of the propeller can be improved.

Fig 1 Submarine propeller

Traditionally marine propellers are made of manganese-nickel-aluminum-bronze (MAB) or nickel-aluminium-bronze (NAB) for superior corrosion resistance, high-yield strength, reliability, and affordability. More over metallic propellers are subjected to corrosion, cavitations damage; fatigue induced cracking and has relatively poor acoustic damping properties that can lead to noise due to structural vibration. Moreover, composites can offer the potential benefits of reduced corrosion and cavitation's damage, improved fatigue performance, lower noise, improved material damping properties, and reduced lifetime maintenance cost. In addition the load-bearing fibers can be aligned and stacked to reduce fluttering and to improve the hydrodynamic efficiency.

1.2 Types Of Marine Propellers

- Controllable pitch propeller
- Skewback propeller
- Modular propeller

Controllable pitch propeller A controllable pitch propeller one type of marine propeller is the controllable pitch propeller. This propeller has several advantages with ships. These advantages include: the least drag depending on the speed used, the ability to move the sea vessel backwards, and the ability to use the "vane"-stance, which gives the least water resistance when not using the propeller (e.g. when the sails are used instead).

Skewback propeller

An advanced type of propeller used on German Type 212 submarines is called a skewback propeller. As in the scimitar blades used on some aircraft, the blade tips of a skewback propeller are swept back against the direction of rotation. In addition, the blades are tilted rearward along the longitudinal axis, giving the propeller an overall cup-shaped appearance. This design preserves thrust efficiency while reducing cavitation's, and thus makes for a quiet, stealthy design.

Modular propeller

A modular propeller provides more control over the boats performance. There is no need to change an entire prop, when there is an opportunity to only change the pitch or the damaged blades. Being able to adjust pitch will allow for boaters to have better performance while in different altitudes, water sports, and/or cruising.

Propeller Geometry

Frames of Reference

For propeller geometry it is convenient to define a local reference frame having a Common axis such that OX and Ox are coincident but Oy and Oz rotate relative to the OY and OZ fixed global frame.

The line normal to the shaft axis is called either propeller reference line or directory. In the case of controllable pitch propeller the spindle axis is used as synonymous with the reference line.

Generator line: The line formed by intersection of the pitch helices and the plane containing the shaft axis and propeller reference line.

The airfoil sections which together comprise the blade of a propeller are defined on the surfaces of cylinders whose axes are concentric with the shaft axis.

1.3Theory of operation

A propeller is the most common propulsor on ships, imparting momentum to a fluid which causes a force to act on the ship.

The ideal efficiency of any size propeller (free-tip) is that of an actuator disc in an ideal fluid. An actual marine propeller is made up of sections of helicoidal surfaces which act together 'screwing' through the water (hence the common reference to marine propellers as "screws"). Three, four, or five blades are most common in marine propellers, although designs which are intended to operate at reduced noise will have more blades. The blades are attached to a *boss* (hub), which should be as small as the needs of strength allow – with fixed-pitch propellers the blades and boss are usually a single casting.

An alternative design is the controllable-pitch propeller (CPP, or CRP for controllable-reversible pitch), where the blades are rotated normally to the drive shaft by additional machinery – usually hydraulics – at the hub and control linkages running down the shaft. This allows the drive machinery to operate at a constant speed while the propeller loading is changed to match operating conditions. It also eliminates the need for a reversing gear and allows for more rapid change to thrust, as the revolutions are constant. This type of propeller is most common on ships such as tugs where there can be enormous differences in propeller loading when towing compared to running free, a change which could cause conventional propellers to lock up as insufficient torque is generated. The downsides of a CPP/CRP include: the large hub which decreases the torque required to cause cavitations, the mechanical complexity which limits transmission power and the extra blade shaping requirements forced upon the propeller designer.

For smaller motors there are self-pitching propellers. The blades freely move through an entire circle on an axis at right angles to the shaft. This allows hydrodynamic and centrifugal forces to 'set' the angle the blades reach and so the pitch of the propeller.

A propeller that turns clockwise to produce forward thrust, when viewed from aft, is called right-handed. One that turns anticlockwise is said to be left-handed. Larger vessels often have twin screws to reduce *heeling torque*, counter-rotating propellers, the starboard screw is usually right-handed and the port left-handed, this is called outward turning. The opposite case is called inward turning. Another possibility is contra-rotating propellers, where two propellers rotate in opposing directions on a single shaft, or on separate shafts on nearly the same axis. Contra-rotating propellers offer increased efficiency by capturing the energy lost in the tangential velocities imparted to the fluid by the forward propeller (known as "propeller swirl"). The flow field behind the aft propeller of a contra-rotating set has very little "swirl", and this reduction in energy loss is seen as an increased efficiency of the aft propeller.

An azimuthing propeller is a propeller that turns around the vertical axis. The individual airfoil-shaped blades turn as the propeller moves so that they are always generating lift in the vessel's direction of movement. This type of propeller can reverse or change its direction of thrust very quickly.

Fixed-wing aircraft are also subject to the P-factor effect, in which a rotating propeller will yaw an aircraft slightly to one side because the relative wind it produces is asymmetrical. It is particularly noticeable when climbing, but is usually simple to compensate for with the aircraft's rudder. A more serious situation can exist if a multi-engine aircraft loses power to one of its engines, in particular the one which is positioned on the side that enhances the P-factor. This power plant is called the Critical engine and its loss will require more control compensation by the pilot.

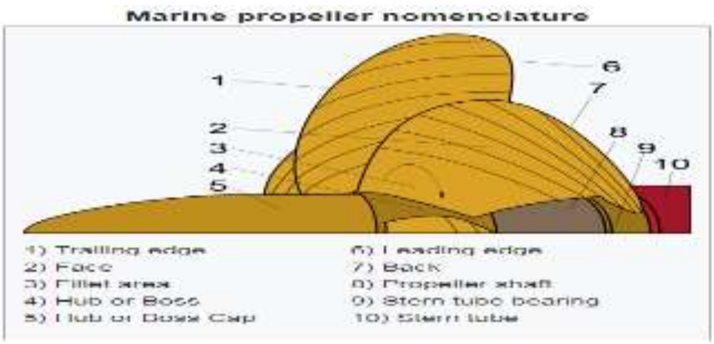

Fig 2 Marine propeller nomenclature

1.4 SUBMARINE:

A **submarine** (orsimply **sub**)is a watercraft capable of independent operation underwater. It differs from a submersible, which has more limited underwater capability. The term most commonly refers to a large, crewed vessel. It is also sometimes used historically or colloquially to refer to remotely operated vehicles and robots, as well as medium-sized or smaller vessels, such as the midget submarine and the wet sub. The noun *submarine* evolved as a shortened form of *submarine boat*; by naval tradition, submarines are usually referred to as "boats" rather than as "ships", regardless of their size (*boat* is usually reserved for seagoing vessels of relatively small size).

Although experimental submarines had been built before, submarine design took off during the 19th century, and they were adopted by several navies. Submarines were first widely used during World War I(1914–1918), and now figure in many navies large and small. Military uses include attacking enemy surface ships (merchant and military), attacking other submarines, aircraft carrier protection, blockade running, ballistic missile submarines as part of a nuclear strike force, reconnaissance, conventional land attack (for example using a cruise missile), and covert insertion of special forces. Civilian uses for submarines include marine science, salvage, exploration and facility inspection and maintenance. Submarines can also be modified to perform more specialized functions such as search-and-rescue missions or undersea cable repair. Submarines are also used in tourism, and for undersea archaeology.

Most large submarines consist of a cylindrical body with hemispherical (or conical) ends and a vertical structure, usually located amidships, which houses communications and sensing devices as well as periscopes. In modern submarines, this structure is the "sail" in American usage, and "fin" in European usage. A "conning tower" was a feature of earlier designs: a separate pressure hull above the main body of the boat that allowed the use of shorter periscopes. There is a propeller (or pump jet) at the rear, and various hydrodynamic control fins. Smaller, deep-diving and specialty submarines may deviate significantly from this traditional layout. Submarines use diving planes and also change the amount of water and air in ballast tanks to change buoyancy for submerging and surfacing.

Submarines have one of the widest ranges of types and capabilities of any vessel. They range from small autonomous examples and one- or two-person vessels that operate for a few hours, to vessels that can remain submerged for six months—such as the Russian Typhoon class, the biggest submarines ever built. Submarines can work at greater depths than are survivable or practical for human divers. Modern deep-diving submarines derive from the bathyscaphe, which in turn evolved from the diving bell

Fig 3 Submarine

2 LITERATURE REVIEW

- V. Ganesh, K. Pradeep, K. Sreeninivasulu [2014] [1] reported on the two distinguished materials for its strength. Aluminum and CFRP are considered for model and static analysis. The high end software for modeling was chosen CATIA and for analyzing ANSYS software was used. The results are compared with the experimental values. By the results the CFRP gives the best one.
- RaminTaheri, Karim Mazaheri [2013] [2] to optimize the shape and efficiency of two propellers. The design methods based on Vortex Lattice algorithm is developed and two gradients based and non-gradient based optimization algorithms are implemented. By implementing a computer code, vortex lattice method was used. From the analysis , approximately 13% improvement in efficiency and approximately 15% reduce in torque coefficient for first propeller and approximate 10% improved for efficiency of the next propeller can be possible.
- N. Balasubramanyam [2015] [3] carried out ANSYS test on both Aluminum and composite propeller. The composite propeller is GFRP. Static and Dynamic analysis are carried out on both the materials. For solid modeling and meshing CATIA-V5 R17 software is used and for analysis ANSYS is used. The results are compared with the Tsai-Wu failure theory and concluded that they are within the safe limits.
- Aditya Kolakoti, T.V. Bhanupraksh, H.N. Das [2013] [4] analyzed on a controllable pitch propeller using CFD. For hydrodynamic designs CFD becomes more encouraged software. For modeling and meshing CATIA – V5 is used. The flow analyses are carried out in three stages. (1) CFD analysis of bare hull (2) open water analysis (3) flow characteristics of propeller when fixed back of the ship hull. Experimental values and CFD results are compared and got approximate variation in results.

Terge sont vcdt et al [3] has focused on the application of finite element methods for frequency response and improve to the frozen type of hydrodynamic loading The thin shell element of the triangular type and the super parametric shell element are used in the finite element model it presents the realistic an dynamic stresses in marine propeller blades. Stresses and deformations calculated for ordinary geometry and highly skewed propellers are compared with experimental results. Chang suppler et al [4] have investigated the main sources of propeller blade failures and resolved problem systematically. An FEM analysis is carried out to determine the blade strength in model and full-scale condition and range of safety factor for the propeller under study is determined. S.javed jalali and farid Taheri et al [5] Carbon fiber reinforced plastics properties were taken from journal of composite materials. A new test method for the simultaneous evaluation of the longitudinal and the shear module of CFRP was introduced under the proposed method, specimens with different span to depth ratios are subjected to three point bending method. Therefore, we name the method the varying span method. The method builds on the inherent low shear modulus characteristics of CFRP. This characteristics leads to a flexural modules which is a function of L/H. Charles A. Harper et al [6] Aluminum material property taken from the hand book of material and process. The non-ferrous metals and alloys offer a wide variety of physical and mechanical properties for using the many industries. Aluminum and its alloys posse’s properties which find wide use in the many industries. Favorable physical properties good strength weight properties, good corrosion resistance, and low density. Combined with economy in material cost and fabrication cost, make this alloy family a basic material of construction for mechanical assemblies

3. MATERIAL PROPERTIES

Properties	GFRP (E-glass/epoxy)	CFRP (Carbon/epoxy)
V_f	0.60	0.60
Density (g/cm^3)	1.95	1.58
E_1 (GPa)	44.60	142
E_2 (GPa)	12.46	10.30
G_{12} (GPa)	4.85	7.20
ν_{12}	0.24	0.27
F_1^{tu} (MPa)	1300	2280
F_1^{cu} (MPa)	691	1440
F_2^{tu} (MPa)	47	57
F_2^{cu} (MPa)	130	228
F^{6u} (MPa)	44	71

Tab 1 Gfrp Cfrp Material Properties

MATERIAL PROPERTIES	NIBRAL
DENSITY	7.5981e-006 kG/MM^3
young's modulus (mpA)	1.138E+05
poisson's ratio	0.29
bulk modulus(mPA)	90219
shear modulus(mPA)	44094

Tab 2 nibral material properties

Aluminium alloy AL 6061:			
Composition of AL 6061:		Properties:	
Al	95.8-98.6	Density	2.7gm/cc
Cr	0.04-0.35	Young's Modulus	68.9 GPa
Cu	0.15-0.4	Poisson's ratio	0.33
Fe	max 0.7		
Mg	0.8-1.2		
Mn	max 0.15		
Si	0.4-1.5		

Tab 3 aluminium alloy AL 6061

3.1 OBJECTIVES OF STUDY

[1] To check strength of marine propeller by static, modal analysis using various material like CFRP,GFRP ,Nibral, AL-6061
[2] To reduce weight of Material by using different material.
[3] To determine static,modal analysis of CFRP,GFRP ,Nibral, AL-6061
[4] Observe the stresses ,strains, deformations.
[5] Finally conclude the suitable material for marine propeller.

3.2METHODOLOGY

Step 1 Collecting information and data related to marine propeller.
Step 2 A fully parametric model of the marine propeller is created in catia software.
Step 3 Model obtained in igs. analyzed using ANSYS 14.5(workbench), to obtain stresses , deformation, strain etc.
Step 4 Taking boundary conditons.
Step 5 Finally, we compare the results obtained from ANSYS and compared geometry with different material

3.3 DESIGNING OF THE MODEL

Specification & Design Procedure In Catia Work Bench

GEOMETRIC SPECIFICATION OF PROPELLER

No.of turns(N)=Height(h)/Pitch(p)r
N=92/276=1/3
Angular rotation(A)=360XN
A=120^O
Height of the propeller(R_O)=100
Radius of the outer blade(R_I)=200

Radius of the inner blade=30
Thickness of blade=4mm
Shaft inner radius=10mm
Shaft outer radius=30mm
Number of blades 3
Weight of Nirbal, aluminum propeller : nearly 2.35 kg.
Weight of (CFRP,GFRP)composite propeller : 1.85 kg.
Hand of operation Left hand
Type of propeller Controllable pitch propeller

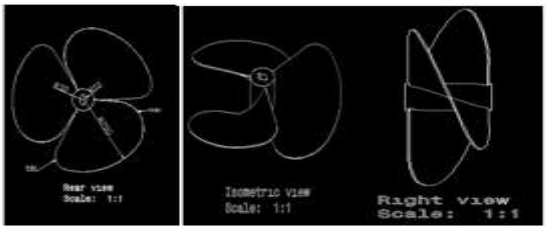

Fig 4 propeller Dimensions

3.4 Design Procedure In Catia

Procedure for Propeller Blade Open CATIA V5 R20 Close the Product Window Start – Mechanical Design – Wireframe and¬ Surface Design – Enter Part Name as Propeller Blade – OK Now we are in a surface modeling - Select Top¬ (XY) plane – Sketch tool Now we are in sketcher workbench - Draw a circle with 60mm diameter – Exit workbench Extrude it with 50 mm on both sides. The total 100 mm height as shown below figures

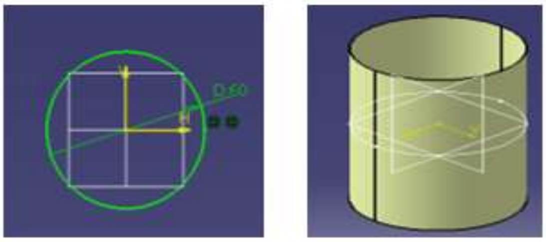

Figure 5extrude in surface design

Create a point on the right plane at a distance of 30 mm from vertical 4 mm from horizontal as shown in Create the helix with 92 mm height and 276 pitch as shown in Create the blade as shown below in by using sweep tool Round the corners with corner tool with R 80 and R 40 as shown below Extrude the rounded sketch with supports as shown below , Split it with split tool as shown below Now enter into part modeling to add thickness to the blade, by using thick surface tool add the thickness 4 mm Thickness to the blade surface into solid using close surface tool Solid model of the blade.
Using edge fillet tool add round at joining location of blade and hub, Pattern blade as shown

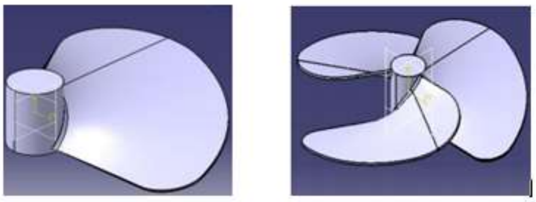

Figure 6 circular pattern

Remove the material as shown , By using pocket tool as shown in Modeling of Propeller Blade by Using Catiav5:

Catia Final Images

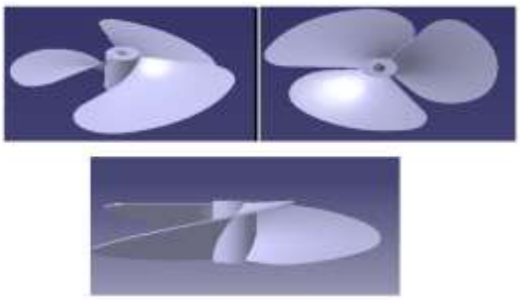

Fig 7 Catia final images

4 PROCEDURE OF STATIC ANALYSIS ANALYSIS:

Create the geomentry in catia workbench and save the file in igs format and open ansys workbench apply engineering data(material properties), create or import the geomentry, apply model(meshing), applyboundary conditions(setup) shown the results(stress,deformation,strain). Meshing And Boundary Conditions Meshing of the marine propeller for coupled field analysis first the marine propeller is imported to ansys workbench for meshing in the static analysis and modal analysis and the marine propeller is meshed with the tetrahedron or quadrilateral meshing is done on the whole 3D model to define and refinement is done on the marine propeller and the meshing style is free or Default meshing. the statics denied after meshing the model is divided into 9575 element s and the number of nodes formed are 17525 and fixed center of the shaft and apply force 1 mpa 307N.m as shown below figures.

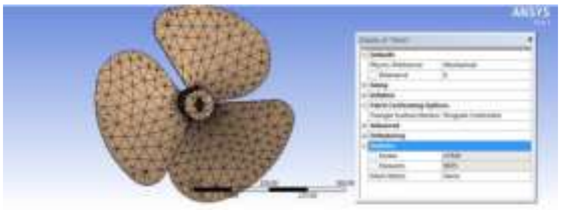

Figure 8 meshing

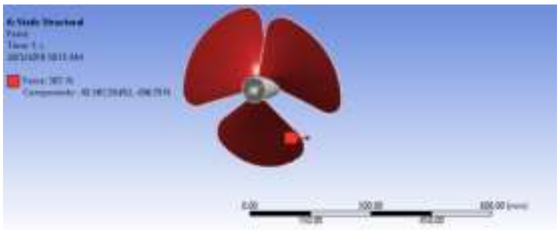

Figure 9 BOUNDARY CONDITIONS

5 RESULTS AND DISCUSSION

The constructed impeller in catia is analyzed using ANSYS 14.5 and the results are as shown in below.

5.1 CFRP MATERIAL: Here the stresses, strains, deformations are obtained by analyzing the marine propeller by using cfrp material, as shown in below figures

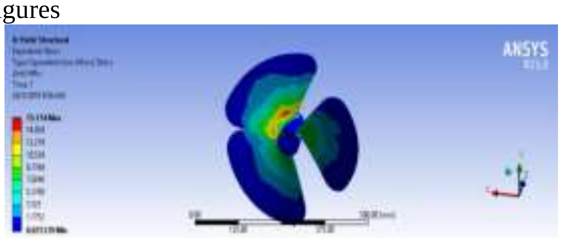

Figure 10 VON-MISES STRESS OF CFRP MATERIAL

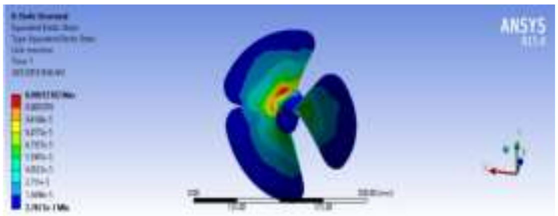

Figure 11 STRAIN OF CFRP MATERIAL

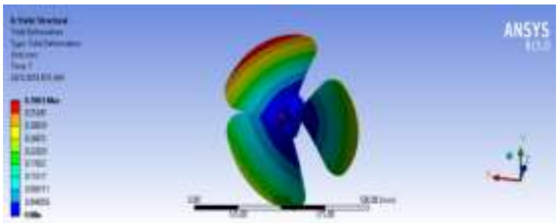

Figure 12 TOTAL DEFORMATION OF CFRP MATERIAL

5.2 GFRP MATERIAL: Here the stresses, strains, deformations are obtained by analyzing the marine propeller by using GFRP material, as shown in below figures

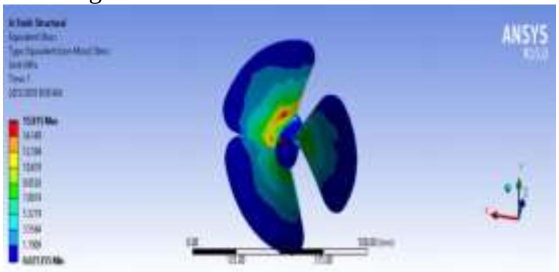

Figure 13 VON-MISES STRESS OF GFRP MATERIAL

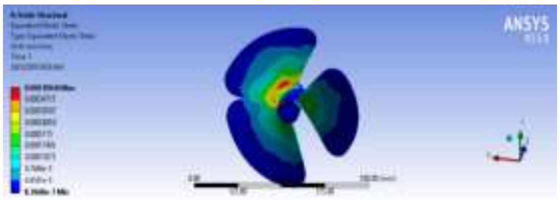

Figure 14 STRAIN OF GFRP MATERIAL

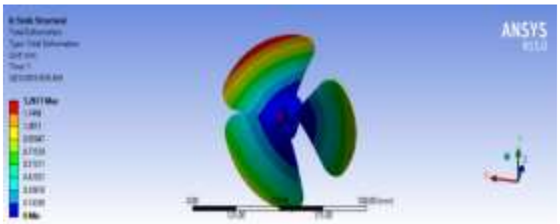

Figure 15 TOTAL DEFORMATION OF GFRP MATERIAL

5.3 NIBRAL MATERIAL: Here the stresses, strains, deformations are obtained by analyzing the marine propeller by using nibral material , as shown in below figures

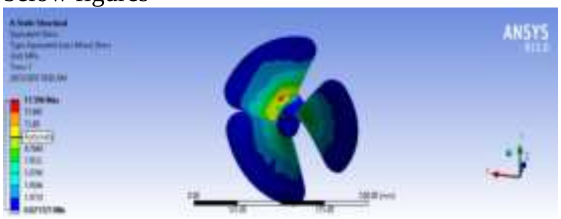

Figure 16 VON-MISES STRESS OF NIBRAL MATERIAL

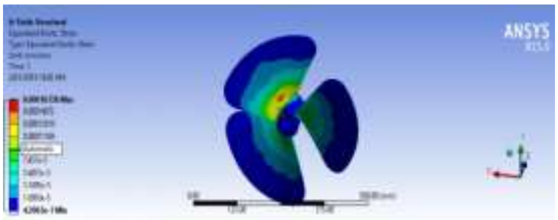

Figure 17 STRAIN OF NIBRAL MATERIAL

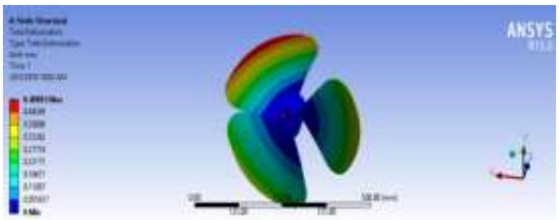

Figure 18 TOTAL DEFORMATION OF NIBRAL MATERIAL

5.4 AL -6061 MATERIAL: Here the stresses, strains, deformations are obtained by analyzing the marine propeller by using al-6061 material, as shown in below figures

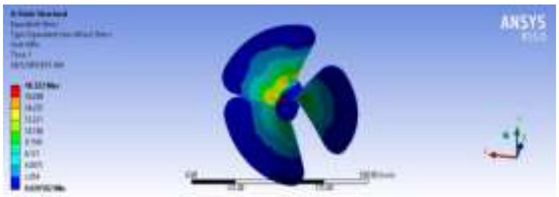

Figure 19 VON-MISES STRESS OF AL-6061 MATERIAL

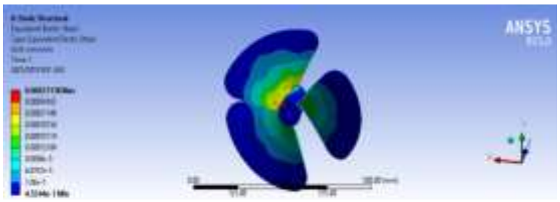

Figure 20 STRAIN OF AL-6061 MATERIAL

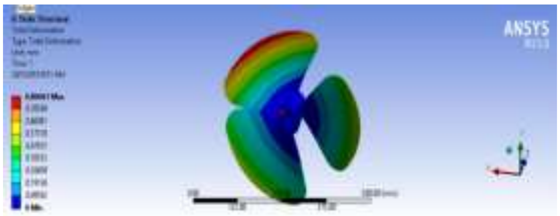

Figure 21TOTAL DEFORMATION OF AL 6061 MATERIAL

5.5 MODAL ANALYSIS: The deformations are obtained below after analyzing the marine propeller by using CFRP material, as shown in below figures.

	Mode	Frequency [Hz]
1	1.	76.225
2	2.	121.134
3	3.	180.205
4	4.	202.147
5	5.	241.227
6	6.	280.445

Table 4 modal analysis

6 CONCLUSION: Modeling and simulation of marine propeller has done using CATIA software. After observing the static analysis and modal analysis values we conclude that CFRP has better stress bearing capacity compared with the other materials and it has better strength when the loads are applied . On doing static analysis of marine propeller it is clear that, the maximum Stress, strains and deformations are induced in Nibral , Al-6061,GFRP materials compared to other materials(composites) CFRP. If we compare stress, strain corresponding deformations of the material composite (CFRP) above result finally CFRP is concluded as suitable material For marine propeller as it has high stress bearing capacity and reasonable manufacturing cost.

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