DESIGN AND ANALYSIS OF THE PROPELLER BLADE

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Abstract - 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) propeller blade which proposed to replace the Aluminum 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 modeled and designed such that it can with stand the static load distribution and finding the stresses and deflections for both aluminum and 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 structural analysis were carried out for two different materials

I. INTRODUCTION

Marine propeller is a component which forms the principal part of ships since it gives the required propulsion. Fiber reinforced plastics are 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 behavior. 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 FRP 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.

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.

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.

II. 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.

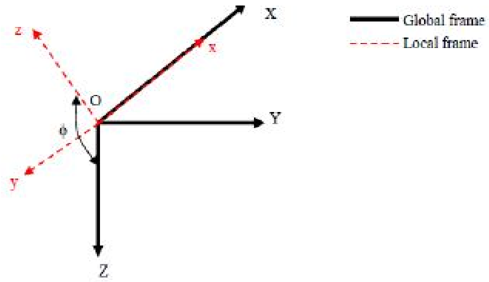


Fig 1: Propeller Reference Lines

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.

Face: The side of a propeller blade which faces downstream during a head motion is called face or pressure side (when viewed from aft of a ship to the bow the seen side of a propeller blade is called face or pressure side).

Back: The side of a propeller blade which faces generally direction of a head motion is called back or suction side (when viewed from aft of a ship to the bow the unseen side of a propeller blade is called back or suction side).

Leading Edge: When the propeller rotating the edge piercing water is called leading edge.

Trailing Edge: When the propeller rotating the edge trailing the leading edge is called trailing edge.

Pitch Consider a point P lying on the surface of a cylinder of radius r which is at some initial point P0 and moves as to from a helix over the surface of a cylinder.

The propeller moves forward as to rotate and this movement create a helix.

When the point P has completed one revolution of helix that means the angle of rotation: φ = 360o or 2π the cylinder intersects the X-Z plane and moves forward at a distance of P.

In the projection one revolution of the helix around the cylinder measured normal to the OX axis is equal to 2πr.

The distance moved forward by the helical line during this revolution is p and the helix angle is given by: θ

The angle θ is termed the pitch angle and the distance p is the pitch.

There are several pitch definitions.

Nose-tail pitch: The straight line connecting the extremities of the mean line or nose and tail of a propeller blade is called nose-tail pitch line. The section angles of attack are defined to the nose-tail line.

Face pitch: The face pitch line is basically a tangent to section's pressure side surface and you can draw so many lines to the pressure side. It is rarely used but it can be seen in older drawings like Wageningen B series.

Effective or no-lift pitch: It is the pitch line of the section corresponding to aerodynamic no-lift line which results zero lift.

Hydrodynamic pitch: The hydrodynamic pitch angle (βi) is the pitch angle at which the incident flow encounters the blade section. Effective pitch angle (θ0) = Noise-tail pitch angle (θ, θnt) + 3-D zero-lift angle where 3-D zero lift angle is the difference between θ0 and θ. θ0 = Hydrodynamic pitch angle (βi) + Angle of attack of section (α) + 3-D zero lift angle and Pitch values at different radii are called radial pitch distribution.

Slip Ratio

If the propeller works in a solid medium (has no slip), i.e. if the water which the propeller "screws" itself through does not yield (i.e. if the water did not accelerate aft), the propeller will move forward at a speed of V = p × n, where n is the propeller's rate of revolution, as seen in the below figure. The similar situation is shown for a corkscrew, and because the cork is a solid material, the slip is zero and, therefore, the cork screw always moves forward at a speed of V = p × n. However, as the water is a fluid and does yield (i.e. accelerate aft), the propeller's apparent speed forward decreases with its slip and becomes equal to the ship's speed V, and its apparent slip can thus be expressed as p × n – V.

Skew

It is the angle between the mid-chord position of a section and the directrix (θs).

The propeller skew angle (θsp) is defined as the greatest angle measured at the shaft centre line which can be drawn between lines passing from the shaft center line through the mid chord position of any two sections.

The skew can be classified into two types:

Balanced skew: Directrix intersects with the mid-chord line at least twice.
Biased skew: Mid-chord locus crosses the directrix not more than once normally in the inner sections.

Rake

The displacement from the propeller plane to the generator line in the direction of the shaft axis is called rake. The propeller rake is divided into two components: generator line rake (iG) and skew induced rake (is) which are defined as

Propeller Outlines and Areas

There are five different outlines and associated areas of propeller in use these are:

- Disc outline (area) (A0)
- Projected outline (Ap)
- Developed outline (AD)
- Expanded outline (AE)
- Swept outline (AS)

Disc area: The area of the circle swept out by the tips of the blades of a propeller diameter.
Projected outline: It is the view of the propeller blade that is actually seen when the propeller is viewed along the shaft centerline normal to y-z plane where Z is the number of blades. rh is the hub radius of the propeller.
R is the tip radius of the propeller.
Developed outline: It is a helically based view, but the pitch of each section has been reduced to zero. The intersection of the blade with the axial cylinder is rotated along the blade reference line into a plane parallel to the propeller. The amount of rotation is equal to the pitch angle at every radius.
Expanded blade outline: It is really not an outline in any true geometric sense at all. It is a plotting of the chord lengths at their correct radial stations about the directrix. Such that the outline is constructed by laying off at each 10.radius r, the chord length along astraight line. The outline is formed by the locus of the end points of the chord lines laid out in the above manner.
Swept Outline: This outline is swept by the leading and trailing edges when the propeller is rotating In general, the developed area is greater than the projected area and slightly less than the expanded area.

Blade Sections-NACA Definitions

Mean line or camber line: It is the location of mid-points between upper and lower surfaces when measured perpendicular to the camber line.
Chord length (c): The distance between the leading edge and trailing edges when measured along the chord line is termed as chord length of the section
Camber: is the maximum distance between the camber line and chord line.
Thickness: of a section is the distance between upper and lower surfaces of the section also measured perpendicular to the chord line.
Leading edges are usually circular having a leading edge radius defined about a point on the camber line.
Typical section used for ship propeller is NACA66 series with the mean line a=0.8

The upper and lower coordinates of the profile are given as:

xU = xCyU=yC+yt , xL=xCyL=yC-yt

where yC is the camber ordinate obtained from the table, yt is the ordinate of the chosen symmetrical thickness distribution.

III. METHODOLOGT

Step 1: Collecting information and data related to spur gear
Step 2: A fully parametric model of the Rspur gear is created in catia software.
Step 3: Model obtained in Step 2 is analyzed using ANSYS 14.(APDL), to obtain stresses , strain deformation strain energy etc.
Step 4: Manual calculations are done.
Step 5: Finally, we compare the results obtained from ANSYS and compared different geometry and material.

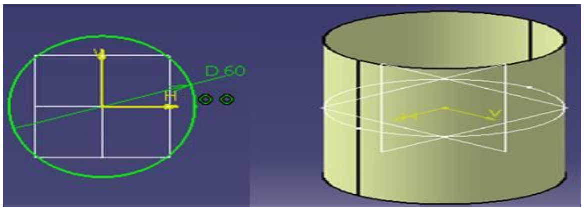
Calculations

Diameter = 227.27 mm
Number of blades = 4
Propeller Model = INSEAN E779A
Type of propeller = Controllable pitch propeller
Material = Aluminum and CFRP
Total area of the circle =ΠR2
=40567.113mm2
Total blade area = total area of the circle X disc area ratio
Given disc area ratio = 0.689
Total blade area =40567.113 x 0.689
= 27950.66mm2
Relation between pitch & pitch angle
Formulae; pitch (p) = 2Πr x tan a

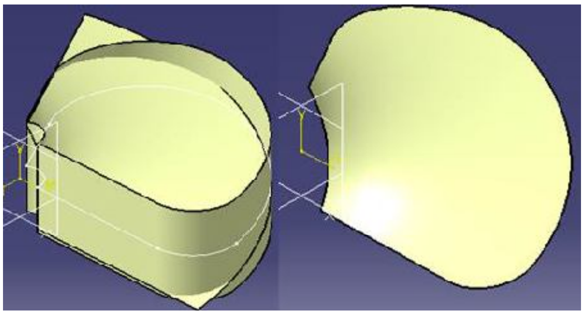
Where @=pitch angle and r= radius and Π
Pitch angle =120
Pitch=2 x Π x 113.635 x tan120
= 1236.66
=1237mm
Speed=(RPM/Ratio) x (pitch/c) x (1-s/100)
= [(1000/0.5) x (1237/1) x (1-0/100)
Assume Ratio=1/2; gear ratio(c)=1;slip=0
=762636 x 60/106
=45.75816km/hr
Boat speed = Vb = 45.75186/1.6093 mile/hr
= 28.4328 mile/hr
Mass flow rate/hr = total blade area* speed of the boat
The thrust (T) is equal to the mass flow rate (m) times the difference in the velocity (v)
T = m (Vb – Va)
Thrust = 2102.097 N

IV. DESIGN OF PROPELLER BLADEBY USING CATIA

The design of propeller blade by using CATIA V5 R16, Now we are in sketcher workbench - Draw a circle with 60 dia – Exit workbench Extrude it with 50 mm on both sides total 100 mm height and Create a point on the right plane at a distance of 30 mm from vertical 4 mm from horizontal as, **Fig**



Create the helix with 92 mm height and 276 pitches Create the blade as shown below in Fig 5 by using sweep tool, round the corners with corner tool with R 80 and R 40 as shown below in
Extrude the rounded sketch with supports as shown below in Fig 7, split it with split tool as shown below in



Now enter into part modeling to add thickness to the blade, by using thick surface tool add the thickness 4 mm (Fig:9), Convert fig:3 surface into solid using close surface tool

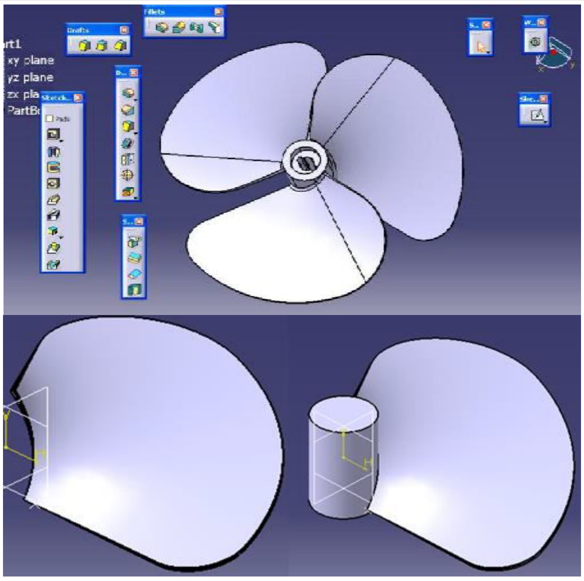


Fig: modelling of propeller blade

V. METALLIC MATERIALS

The most common metals used in marine propeller construction are aluminum, magnesium, titanium, steel, and their alloys.

Alloys: An alloy is composed of two or more metals. The metal present in the alloy in the largest amount is called the base metal. All other metals added to the base metal are called alloying elements. Adding the alloying elements may result in a change in the properties of the base metal. For example, pure aluminum is relatively soft and weak. However, adding small amounts or copper, manganese, and magnesium will increase aluminum's strength many times. Heat treatment can increase or decrease an alloy's strength and hardness. Alloys are important to the marine propeller industry. They provide materials with properties that pure metals do not possess.

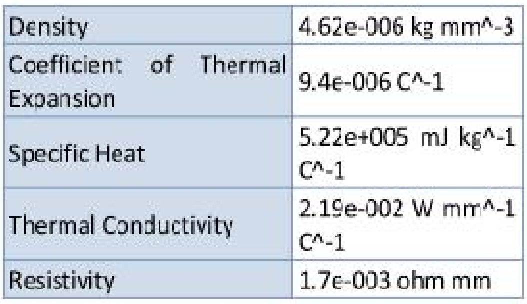
NONMETALLIC MATERIALS

In addition to metals, various types of plastic materials are found in marine propeller construction. Some of these plastics include transparent plastic, reinforced plastic, composite, and carbon-fiber materials.

CARBON FIBER REINFORCED PLASTIC

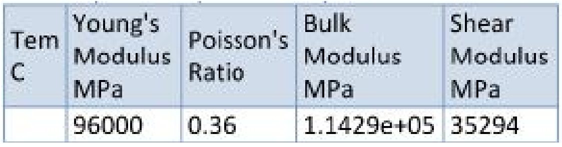
High-performance marine propeller requires an extra high strength-to-weight ratio material. Fabrication of composite materials satisfies this special requirement. Composite materials are constructed by using several layers of bonding materials (graphite epoxy or boron epoxy). These materials are mechanically fastened to conventional substructures. Another type of composite construction consists of thin graphite epoxy skins bonded to an aluminum honeycomb core. Carbon fiber is extremely strong, thin fiber made by heating synthetic fibers, such as rayon, until charred, and then layering in cross sections.

Material Data
Titanium Alloy
Constants



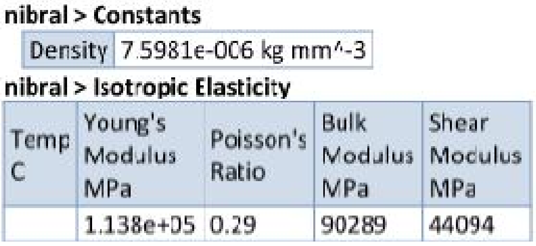
Density	4.62e-006 kg mm^-3
Coefficient of Thermal Expansion	9.4e-006 C^-1
Specific Heat	5.22e+005 mJ kg^-1 C^-1
Thermal Conductivity	2.19e-002 W mm^-1 C^-1
Resistivity	1.7e-003 ohm mm

Titanium Alloy > Isotropic Elasticity



Tem C	Young's Modulus MPa	Poisson's Ratio	Bulk Modulus MPa	Shear Modulus MPa
	96000	0.36	1.1429e+05	35294

Material Data: Nibral



nibral > Constants

Density	7.5981e-006 kg mm^-3

nibral > Isotropic Elasticity

Temp C	Young's Modulus MPa	Poisson's Ratio	Bulk Modulus MPa	Shear Modulus MPa
	1.138e+05	0.29	90289	44094

VI. PROCEDURE OF ANALYSIS PROPELLER USING ANSYS

Meshing of Propeller Blade

The solid model is transfer to the ANSYS WORK BENCH software. With the required commanding the mesh is generated for the model. Generally there two types of meshes are there they are
(i) Tetrahedral mesh
(ii) Hexahedral mesh

The tetrahedral mesh is a polygon consists of four triangular faces three of them are meet at a point called as vertex. It has 6 edges and 4 vertices. In case of hexahedral mesh it has 12 edges and 8 vertices. For the accuracy of the solution hexahedral gives the exact result. In the ANSYS software the internal command setting can be available for mesh generation.

Figure. Fine meshed model of propeller

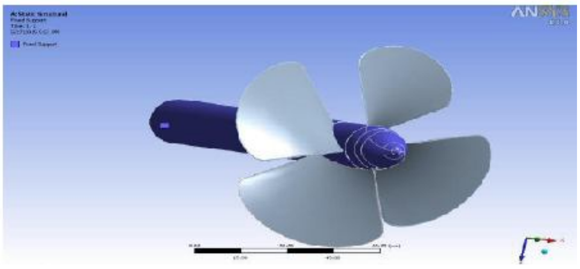


Fig. Boundary conditions applied to the marine propeller blade in ANSYS. Applied load=2102.1 N

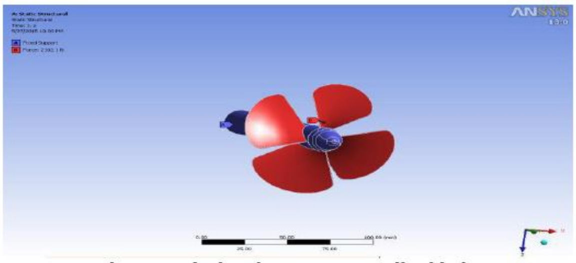


Figure. Loads are applied to the marine propeller blade in ANSYS

VII. EXPLICIT DYNAMIC ANALYSIS

Explicit Dynamic Analysis in ANSYS-WORKBENCH suits us to capture the physics of short-duration events for products that undergo highly nonlinear, transient dynamic forces. It shares the same graphical user interface (GUI). Serving Mechanical engineers who need to study highly complex problems.
Vonmises-stress (Equivalent stress) is very important stress in design this stress tells us wether the design is safe or not.If the vonmises stress is with in the Ultimate strength of the material then the design is safe.

CFRP Material Properties

Young's Modulus: 1160.64 Mpa
Poisson's Ratio: 0.28
Density: 1600kg/m3

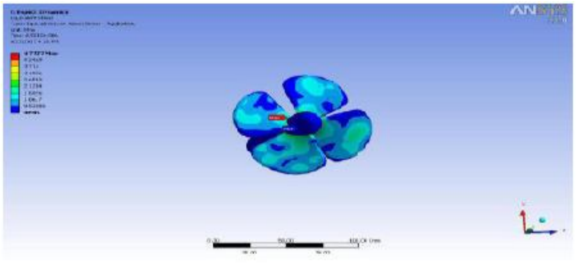


Fig. Vonmises-Stress distribution of CFRP marine propeller blade in ANSYS.

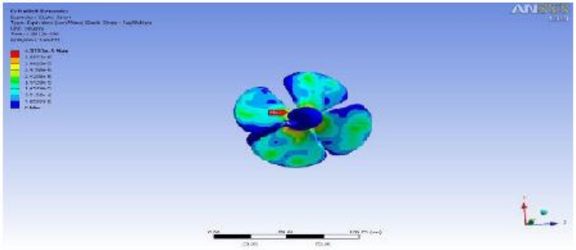


Fig. Vonmises-Stain distribution of CFRP marine propeller blade

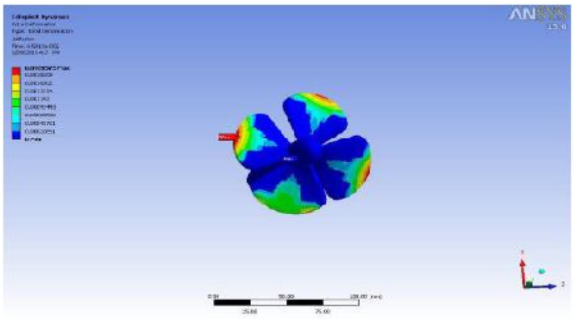


Fig. Total deformation over CFRP marine propeller blade

CFRP Material Properties

Young’s Modulus: 7300 Mpa
Poisson’s Ratio: 0.28
Density: 1800kg/m3

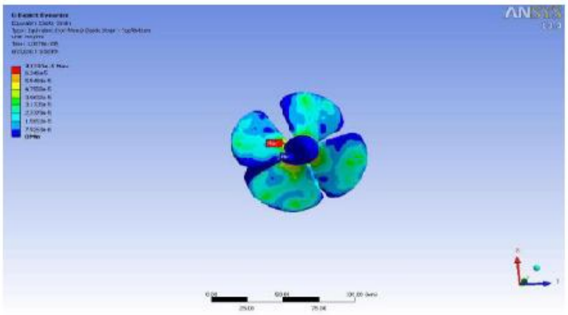


Fig. Vonmises-Stress distribution of GFRP marine propeller blade in ANSYS

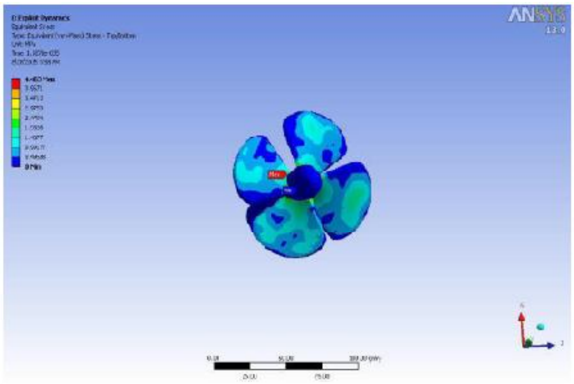


Fig. Vonmises-Strain distribution of GFRP marine propeller blade in ANSYS

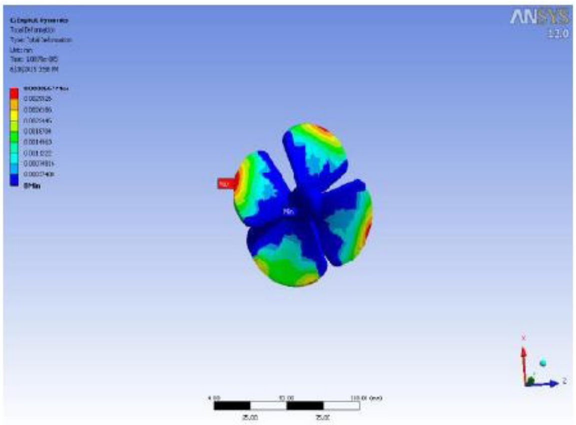
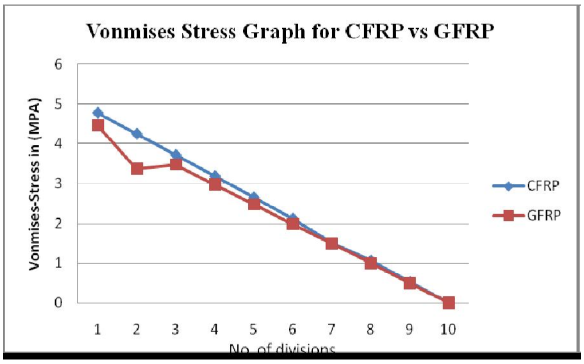


Fig. Total deformation over GFRP marine propeller blade in ANSYS

VIII. RESULTS & DISCUSSIONS

Table1. Result for Dynamic Analysis

S.NO	Material	Vonmises-Stress (MPA)	Vonmises-Strain	Total Deformation (mm)
1	CFRP	4.777	4.3737e-5	0.002857
2	GFRP	4.463	7.8337e-5	0.003366
3	%Difference	31.4%	0.00346%	0.059%



CONCLUSION

From the output of the static analysis and dynamic analysis of the marine propeller, it can be concluded that (i) the propeller is assumed as a cantilever beam i.e., when the load applies on it then the deformation will be formed at the free end and no deformation at the fixed end.(ii) Dynamic Analysis is carried out on turbine blade by varying the material for propeller blade from CFRP to GFRP Vonmises stress is reduced to a percentage of 31.4%.

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