Design and Analysis of the Propeller Blade

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Abstract: Propellers are used for propulsion of ships and other underwater vehicles. It has a complex geometry and also analysis of such complex component under various controlling parameters is difficult with conventional formulae is very difficult and cumbersome. So the current studies uses finite element method to perform analysis of a propeller blade. This project is primarily concerned with the modelling and design study of a 3 blade INSEAN E779A model propeller blade in order to determine its strength. CATIA software is utilized to generate the blade model, which necessitates high-end modelling. Materials used for the analysis are Composite Materials instead of conventional aluminum alloy as many studies show better performance with composite material. The study gives acomparison of structural analyses of GFRP (Glass Fiber Reinforced Plastic) and CFRP (Carbon Fiber Reinforced Plastic) material and suggests the best Fiber reinforced composite material for the propeller.

KEY WORD: CATIA V5, ANSYS-WORKBENCH, CFRP, GFRP & Propeller Blade

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INTRODUCTION

The propeller of a ship is the most important component since it provides the necessary power. Fiber reinforced polymers are widely utilized in the construction of a variety of constructions, including maritime propellers. The hydrodynamic elements of composite marine propeller design have gotten a lot of attention since they're crucial for forecasting deflection and performance of the propeller blade. Understanding the factors that impact the hydrodynamic behavior is necessary for building an efficient marine propeller. The study could only be done with the computer since the propeller is a complicated shape.The benefits of substituting metal with a FRP composite are its lower weight and corrosion resistance. Another significant benefit is that the composite propeller's distortion may be adjusted to increase performance. Propellers revolve at a consistent speed, which increases the engine's efficiency.The inflow angle is close to the pitch angle when the ship sails at the intended speed. The inflow angle is narrower when the ship is sailing at a slower pace. The inflow angle is close to the pitch angle when the ship sails at the specified speed. The inflow angle is reduced while the ship is sailing at a slower speed.

When a result, as the ship's speed drops, the strain on the propeller rises. When the input angle is distant from the pitch angle, propulsion efficiency suffers as well.When the inflow angle is low, the propeller's efficiency can be enhanced by reducing the pitch angle. For better corrosion resistance, high-yield strength, dependability, and affordability, maritime propellers are traditionally constructed of manganese-nickel-aluminum-bronze (MAB) or nickel-aluminum-bronze (NAB).

Furthermore, metallic propellers are prone to corrosion, cavitation damage, fatigue-induced cracking, and have poor acoustic damping characteristics, resulting in noise from structural vibration.

1.1 PROPELLER PRINCIPLE:

Propellers are based on Bernoulli's principle and Newton's third law. They work by throwing mass in the opposite direction you want to go, which, according to Newton's third rule, creates an equal and opposite response

It is based on the principle of push and pull.

Marine propellers come in a variety of shapes and sizes.

- A propeller with a variable pitch
- Skewback propellers are propellers that are angled backwards.
- Modular propeller is a term used to describe a propeller that is made together

A Propeller with a variable pitch

A propeller with a variable pitch Controllable pitch propellers is one type of marine propeller. With ships, this propeller offers numerous advantages. These benefits include the capacity to maneuver the sea craft backwards, as well as the ability to employ the "vane"-stance, which provides the least amount of water resistance while not utilizing the propeller.

Skewback propellers are propellers that are angled backwards

A skewback propeller is an advanced form of propeller used on German Type 212 submarines. The blade tips of a skewback propeller are swept back against the direction of rotation, similar to scimitar blades used on some aircraft. The blades are also angled backward along the longitudinal axis, giving the propeller a cup-like look. This design maintains thrust efficiency while lowering cavitation, resulting in a quiet, stealthy design.

Modular Propeller is a term used to describe a propeller that is made together

A modular propeller allows the boat's performance to be more controlled. When only the pitch or the damaged blades need to be changed, there's no need to replace the entire prop. Boaters will be able to improve their performance at different altitudes, water activities, and/or cruising by being able to change pitch.

LITERATURE REVIEW

Y. Hara, Y. Yamatogi.[1] "Performance evaluation of composite marine propeller for a fishing boat by fluid structure interaction analysis".
Dunna Sridhar.[2] "Friction Resistance calculation on ship using CFD".
D. W. Taylor [3] studied the speed and power of ships for the designing parameters of the propeller like Pitch, Diameter, no of blades etc.
Ab Volvo Penta [5] carried down the propellers from inboard propellers and theory for introduction like History and designing of propeller.
The design and analysis are carried out by the reference of Ansys 11.0 User Guide [6], Mohammed Ahmed khan, KhajaShahnawazuddin, Design and Dynamic analysis on composite propeller of ship using FEA [7].

PROPELLER GEOMETRY

Frames of Reference:

It is advantageous to establish a local reference frame with a common axis for propeller geometry, so that OX and Ox are coincident while Oy and Oz rotate relative to the fixed global frame of OY and OZ.

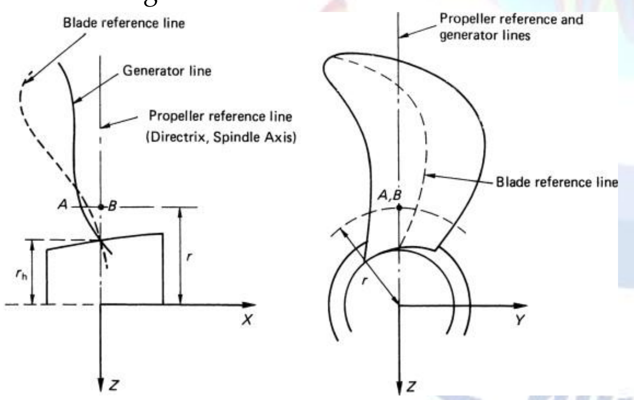

Figure 1: Propeller Geometry with reference frame

Propeller reference line or directory refers to the line parallel to the shaft axis. The spindle axis is used as a substitute for the reference line in the case of a variable pitch propeller.

Generator line:

The pitch helices' intersection with the plane containing the shaft axis and propeller reference line forms this line. The airfoil sections that make up a propeller's blade are specified on the surfaces of cylinders with axes that are concentric to the shaft axis.

Face:

Face or pressure side refers to the side of a propeller blade that faces downstream during a head motion (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 rear or suction side of a propeller blade is the side that faces the general direction of a head motion (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:

The edge of the propeller that pierces the water while it rotates is referred to as the leading edge.

Trailing Edge:

When the propeller rotates, the trailing edge is the edge that follows the leading edge. Pitch Consider a point P on the surface of a cylinder of radius r that starts at point P0 and travels like a helix across the cylinder's surface.

When the propeller rotates, it travels forward, creating a helix. The cylinder contacts the X-Z plane and travels forward at a distance of P when point P has completed one helix revolution, which indicates the angle of rotation: $\phi = 360o$ or 2π .

A rotation of the helix around the cylinder measured normal to the OX axis equals $2\pi r$ in the projection.

The helical line moves forward p distance throughout this rotation and the helix angle is given by: The angle is known as the pitch angle, and the distance p is known as the pitch distance.

Pitch can be defined in a variety of ways.

Pitch between the nose and the tail:

The nose-tail pitch line is a straight line connecting the extremes of the mean line or the nose and tail of a propeller blade. The nose-tail line is used to determine the section angles of attack.

Face pitch:

The face pitch line is a tangent to the pressure side surface of a section, and you can draw as many lines to the pressure side as you like. Although it is rarely used nowadays, it may be found in older drawings such as the Wageningen B series.

Effective or no-lift pitch:

This is the section's pitch line that corresponds to the aerodynamic no-lift line, resulting in zero lift.

Slip Ratio:

The propeller will travel forward at a speed of V = p × n, where n is the propeller's rate of revolution, if it works in a solid medium (has no slip), i.e., if the water through which the propeller "screws" itself does not yield (i.e., if the water did not accelerate aft). A corkscrew is depicted in a similar condition, and because the cork is a solid substance, the slip is zero.

V= p × n is the constant forward speed of the cork screw. However, because water is a fluid that yields, the propeller's apparent forward speed drops with slip and equals the ship's speed V, therefore its apparent slip can be represented as p × n–V.

Skew:

It is the angle formed by a section's mid-chord position and the directrix (θs).

The propeller skew angle (θsp) is defined as the maximum angle that can be drawn between lines travelling from the shaft center line through the mid chord position of any two sections when measured at the shaft center line.

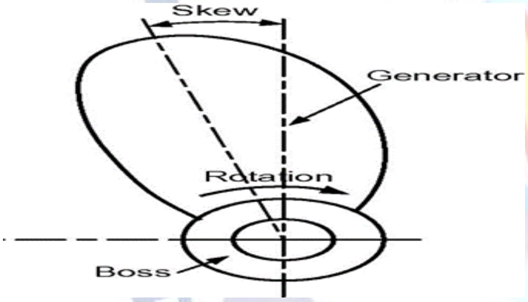

Figure 2: Propeller Skew Angle

The skew can be divided into two categories:

Balanced Skew:

Directrix intersects the mid-chord line at least twice, resulting in a balanced skew.

Biased skew:

In the inner sections, the mid-chord locus crosses the directrix only once.

Rank:

Rake is the distance between the propeller plane and the generator line in the direction of the shaft axis. The generator line rake (iG) and the skew induced rake (is) are the two components of the propeller rake.

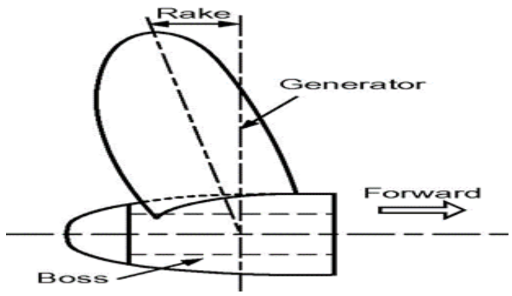

Figure 3: Propeller Rake Angle

Outlines and Areas of Propellers

There are five different propeller outlines and corresponding areas in use:

- ➢ Disc outline (area) (A0)
- ➢ Developed outline (AD)
- ➢ Expanded outline (AE)
- ➢ Outline swept (AS)
- ➢ Outline projected[ap]

Disc Area:

The area of a circle swept out by the points of a propeller diameter's blades is known as the disc area.

Developed outline:

It's a helical perspective, but each section's pitch has been decreased to zero.

The blade's junction with the axial cylinder is turned into a plane parallel to the propeller along the blade reference line.

At any radius, the amount of rotation is equal to the pitch angle.

Expanded blade outline:

This isn't actually an outline in the traditional sense.

The chord lengths are plotted at their correct radial stations around the directrix. As a result, the outline is built by laying off the chord length along a straight line at each 10, radius r. The location of the end points of the chord lines drawn out in the aforesaid manner forms the outline.

Swept Outline:

When the propeller rotates, the leading and following edges sweep this outline. The developed area is slightly larger than the predicted area and slightly smaller than the enlarged area in general.

Outline projected:

When the propeller is viewed along the shaft centerline in the y-z plane, where Z is the number of blades, it is the view of the propeller blade that is really visible. rh denotes the propeller's hub radius. R denotes the propeller's tip radius.

COMPOSITE MATERIAL

A composite material is made up of two components that have distinct physical and chemical properties. When they are mixed, they form a material that is specialized to perform a specific task, such as becoming stronger, lighter, or more resistant to electricity. They can also help with stiffness and strength.

Uses of composite materials:

- aerospace,
- automotive,
- construction,
- marine,
- equipment that is resistant to rust
- consumer goods, appliances/commercial equipment, and others.

PLASTIC WITH CARBON FIBER REINFORCEMENT:

A high-performance maritime propeller necessitates a material with a particularly high strength-to-weight ratio. This unique requirement is met by the fabrication of composite materials. Multiple layers of bonding materials are used to create composite materials (graphite epoxy or boron epoxy). Mechanically, these materials are attached to traditional substructures. Another kind of composite structure comprises of thin graphite epoxy skins linked to an aluminum honeycomb core. Carbon fiber is exceptionally strong, thin fiber created by burning synthetic fibers, such as rayon, until charred, and then layering in cross sections.

GLASS FIBER REINFORCED PLASTIC:

GRP stands for glass-reinforced plastic, which is a composite material made up of plastic and tiny glass fibers. These strands can be randomly organized, flattened into a sheet, or woven into a fabric-like material. The glass fibers are then covered with a plastic resin to create a blended homogenous substance.

V. METHODOLOGY

Step1: Collecting Information's related to The Torpedo Propeller.

Step2: Creating A Design Model of By Using Catia Software.

Step3: The Design Model Is Proceeded to For Analysis by Using ANSYS Software

Step4: Force's Stress and Strain Deformations Are Applied in The ANSYS's Software

Step5: Comparing the Results Obtained from Ansys with Other Results.

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 arearatio
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 theboat
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

THE DESIGN OF PROPELLER BLADE BY USING CATIA V5

The design of a propeller blade by using CATIA V5 R21. Now we have to open the generative shape design and draw a circle with diameter of 45.45mm on sketcher workbench and exit the and extrude the cylinder up to 68.3mm and center a point of right plane at the circular surface.

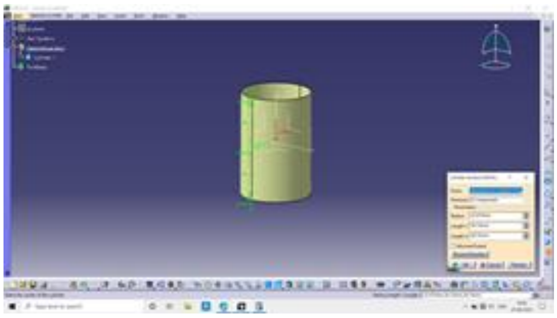

Figure 4: Propeller Shaft design in Catia V5

Draw a line through the point direction with repeated diameter of Z component. Take a circular pattern of instance to regular spacing 2 line with an angle of 90 degrees take a line in between the points of two lines upper point and bottom with respect to support of a cylindrical pattern. Draw another circle on sketcher workbench with a diameter of 227.27mm and exit the workbench then extrude the circular pattern to 68.3mm projection.

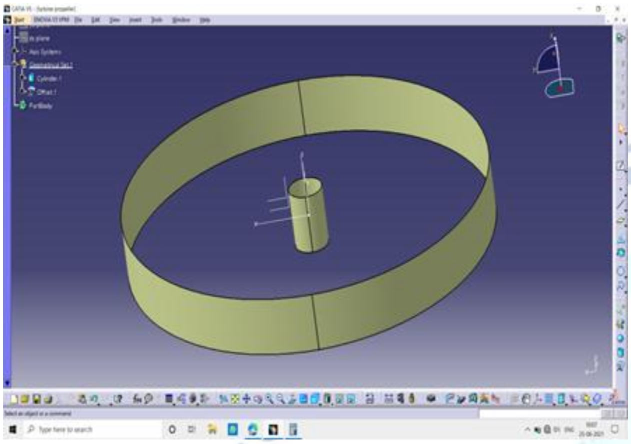

Figure 5: Propeller Shaft design in Catia V5

The liner on before drawn a cylindrical pattern to the new drawn pattern and take the line of point to point and draw it and create the helix with 64mm height and 249mm then create the blade in the process of making extrude, filling, cornering and splitting take the circular pattern and instance four blades with respect the before drawn blade complete the drawing.

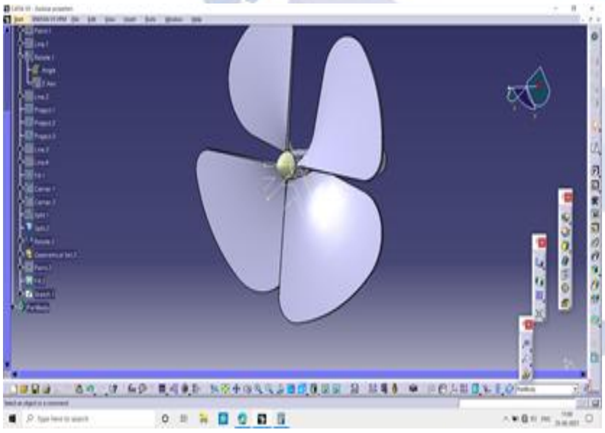

Figure 6: Propeller Blade design in Catia V5

Then open the part modeling to add the thickness to the blade by using thick surface tool and the thickness of blades3mm, convert the surface into the solid using close surface tool.

Procedure for Analysis of Propeller Using Ansys:

Frist Convert the Propeller Catia Design Part into Ansys File Format. Open The Ansys Work Bench. Add The Material to Engineering Data According the Material Properties. Then Add the Material to the Propeller in The Engineering Data (Carbon Fiber Reinforced Plastic) Then Select the Geometry and Import Design Data from The Files.

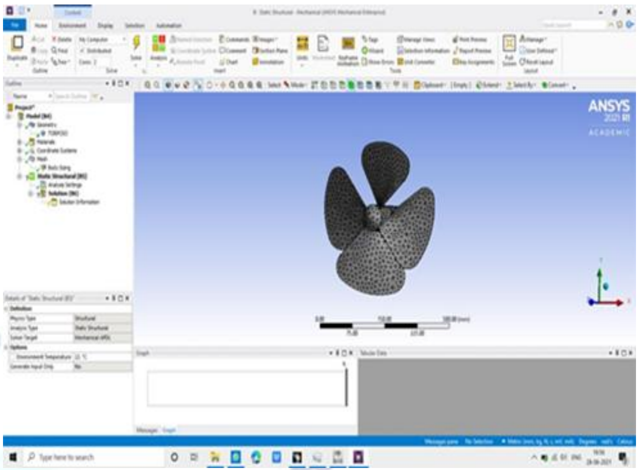

Figure 7: Applying meshing in Design Part

Now Edit the Geometry in The Design Modular and Generate the Imported Design. Again, In Apply the Material for the Design Before Apply the Mesh to the Design. Apply The Mesh (Body Size Meshing) To the Given Design Part. Give The Mesh Size Value Small for Accurate Results.

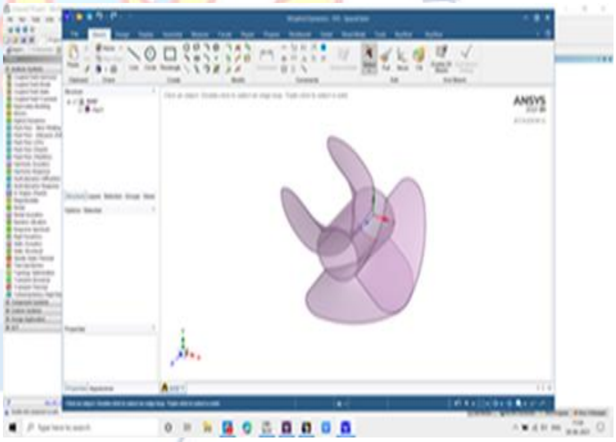

Figure 8: Inserting the fixed support to the propeller

Insert The Fixed Support to The Propeller by Choosing Insert Option in Static Structural. Similarly Insert the Force (Thrust) to the Propeller Blades.

Give The Force According the Calculations. Click On the Option to Apply Total Deformation, Von Mises Stress Distribution, Von Mises Stress Distribution of The Propeller Blade. Now Click on The Solution Button to A Get Results.

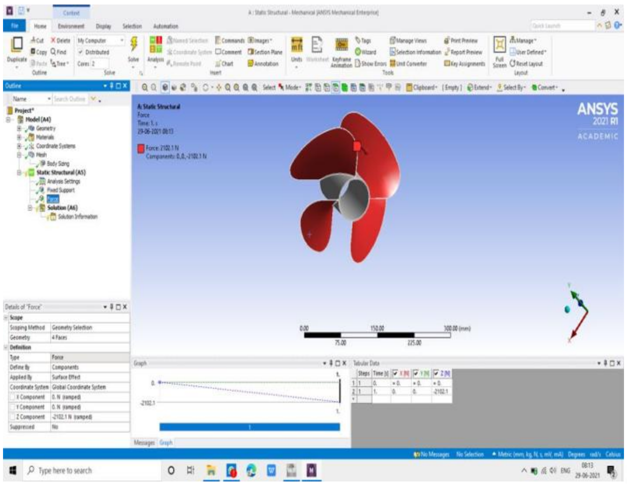

Figure 9: Applying the force on propeller blade

CFRP Material Properties

Young's Modulus: 1160.64 Mpa

Poisson's Ratio: 0.28

Density: 1600kg/m3

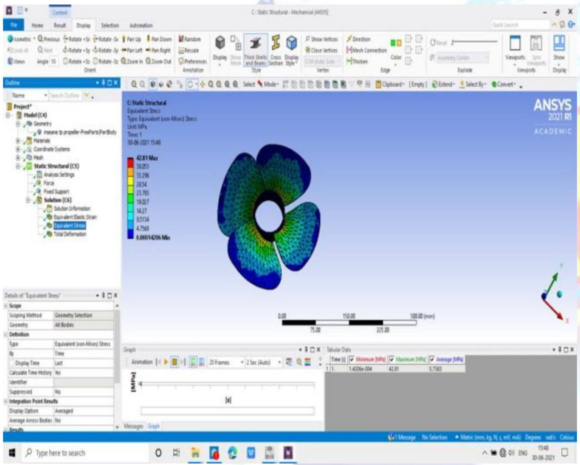

Figure 10: Von mises-Stress Distribution of CFRP Marine Propeller blade in ANSYS.

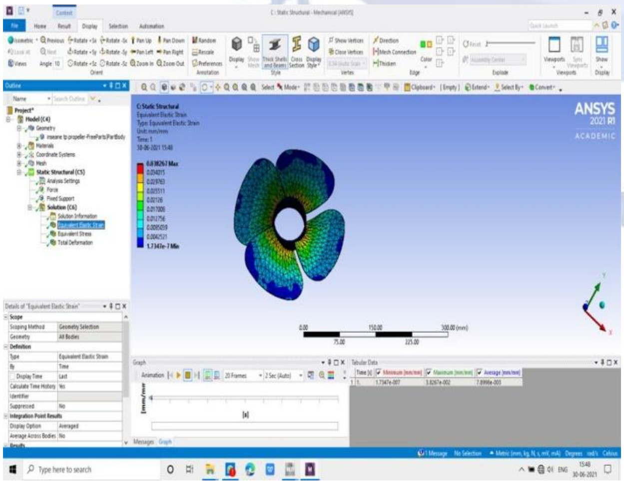

Figure 11: Von mises-Strain Distribution of CFRP Marine Propeller blade in ANSYS.

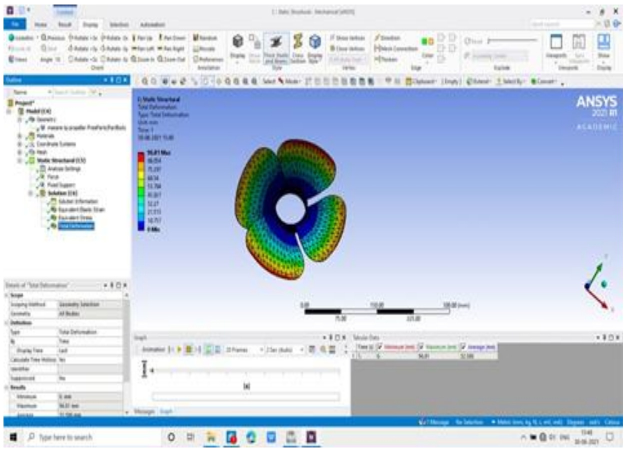

Figure 12: Total Deformation over CFRP Marine Propeller blade in ANSYS

GFRP Material Properties:

Young's Modulus: 7300 Mpa

Poisson's Ratio: 0.28,

Density: 1800kg/m3

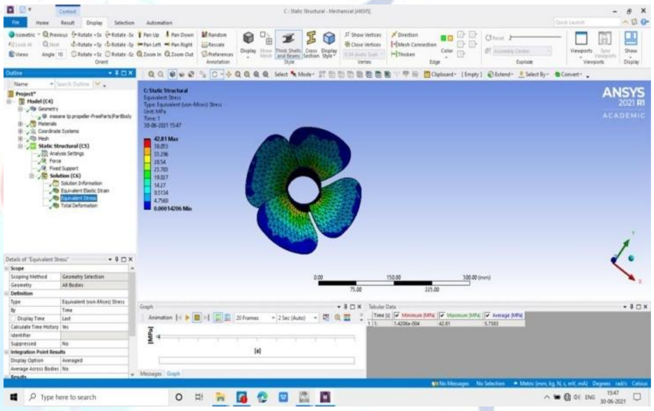

Figure 13: Von mises-Stress Distribution of GFRP Marine Propeller blade in ANSYS.

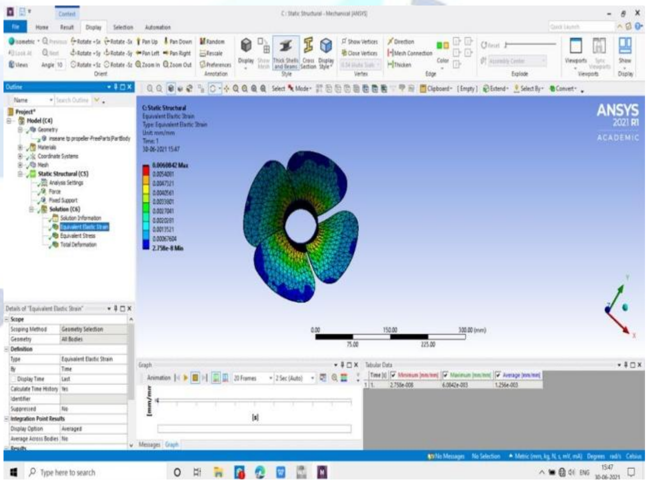

Figure 14: Von mises-Strain Distribution of GFRP Marine Propeller blade in ANSYS.

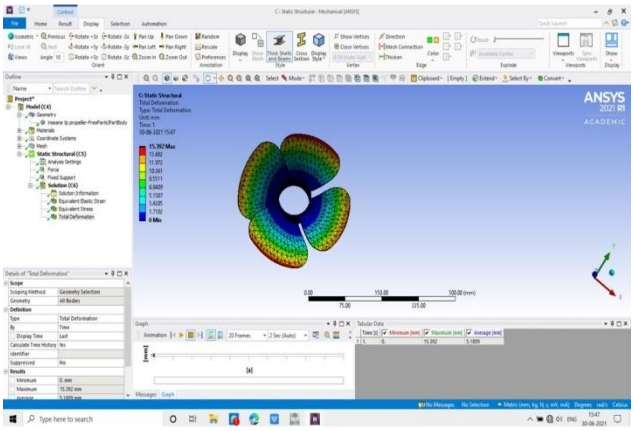

Figure 15: Total Deformation over GFRP Marine Propeller blade ANSYS

VI. RESULS & DISCUSSIONS

S.NO	MATERIAL	VONMISES STRESS	VONMISES STRESS	TOTAL DEFORMATION
		(MPA)	(MPA)	(mm)
1	CFRP	5.7583	3.82e-5	0.00325
2	GFRP	6.4832	6.08e-5	0.0044

CONCLUSION:

1. An explicit dynamic analysis carried out on the GFRP and CFRP propellers on Ansys prove that the Vonmisesstress developed in theGFRP made propeller is 12.6% greater than that of CFRP made propeller.
2. The Vonmises strain developed in GFRP made propeller is 59.1% higher than CFRP made propeller.
3. The total Deformation in GFRP made propeller is 35.4% higher than CFRP made propeller.
4. In our modeled propeller the estimated mass of the GFRP made propeller is 12.5% heavier than the mass of CFRP made propeller.
5. In our modeled propeller the estimated mass of the CFRP propeller was 6.74 Kg and for GFRP and NAB it was
6. 10.28 Kg and 32.01
7. In our modeled propeller the estimated mass of the CFRP propeller was 6.74 Kg and for GFRP and NAB it was
8. 10.28 Kg and In our modeled propeller the estimated mass of the GFRP propeller is 12.5% heavier than for CFRP

So, from the analysis it can be seen that CFRP propeller has less deformation and less Stress-Strain is generated at various loads. Better structural properties are obtained by CFRP material made propeller while keeping a low mass. So according to the results the Carbon fiber reinforced plastic propellers can perform effectively in comparison to Glass fiber reinforced plastic propellers.

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