ISSN: 2348 9510
International Journal Of Core Engineering & Management (IJCEM)
Volume 3, Issue 3, June 2016

MODELLING AND ANALYSIS OF COMPOSITE TORPEDO PROPELLER

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ABSTRACT

Propeller is mechanical device generally used for propelling boats or aircrafts and also used to progress significant plunge to propel the vehicle at its operational speed. It is a type of fan that transmits power by converting rotational motion into thrust. Much has been said and published on the development of the marine propeller from the time of its origin to the present age, but there is more to be done. Marine propellers are often subjected to hydrodynamic forces as they operate under water. Due to this force, vibrations are also induced. So, there is a need for usage of new class of materials like composites for propeller to ensure fail-safe operation. At present, there is an increased need for lightweight components with high strength to weight ratio. As decrease in weight leads to increase in efficiency of vehicle. So, aluminium is generally used material for marine propellers. But, in recent times fiber reinforced composites are being used in naval applications. As composites have higher stiffness and high strength per weight than aluminium, they are used as materials for propellers. The present work deals with modelling and analysis of a torpedo propeller. This project concentrates on the metal and composite strength analysis of propeller carried out by using the finite element method. Propeller is a 3-Dimensional complex geometry, which requires high end CAD software. The propeller model is created in Creo Parametric 3.0 and analysis is carried out in ANSYS Workbench 15.0. The analysis is performed on materials aluminium 6061 alloy, Kevlar fiber reinforced epoxy and carbon fiber reinforced epoxy composite.

Index Terms:— torpedo propeller, CREO 3.0, ANSYS WORKBENCH 15.0, AL 6061, Kevlar epoxy, Carbon Epoxy.

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I. INTRODUCTION

A propeller is a rotating fan like structure, which is used to propel the ship by using the power generated and transmitted by the main engine of the ship. The transmitted power is converted from rotational motion to generate a thrust which imparts momentum to the water, resulting in a force that acts on the ship and pushes it forward. A pressure difference is created on the forward and aft side of the blade and water is accelerated behind the blades. The thrust from the propeller is transmitted to move the ship through a transmission system which consists of a rotational motion generated by the main engine crank shaft, intermediate shaft and its bearings, stern tube shaft and its bearing and finally by the propeller itself.

Propeller is often subjected to various types of forces and pressures. These forces have huge effects on safe operation of marine vehicles. In extreme cases, the blades may shear off from propeller hub leading to hazards. The most essential requirement of propeller material is strength, so that it can withstand the stresses developed. Vibrations are also developed in propellers, and they are highly undesirable whether in stealth point of view or safety.

At present, there is an increased need for light weight components with high strength to weight ratio. So, Aluminium is generally used material for marine propellers. But, in recent times fiber reinforced composites are being used in naval applications. As composites have higher stiffness and high strength per weight than steel and aluminium, they are used as materials for propellers.

All marine vehicles use propellers as means for motion. In present work, torpedo propeller is being used for analysis. Four bladed propeller is being used as model. Propellers are usually cast as a single component. So, its model also as a single component. First two dimensional geometry of blade is drawn and extruded. Twist angle is given to the blade. Hub is created by extruding a circle and rounding front portion of hub. Blade is now patterned over the surface of hub. Thus propeller drawn is exported in to IGES format.

The present work deals with modelling and analysis of a torpedo propeller. This project concentrates on the metal and composite strength analysis of propeller blades carried out by using the finite element method. Propeller is a 3-Dimensional complex geometry which requires high end CAD software. The propeller model is created in Creo Parametric 3.0. The analysis is performed on both aluminium and a composite material. Structural and vibration analysis is done by using Ansys Workbench 15.0.

Modal analysis is performed to obtain natural frequency and mode shapes. While, static structural and hydro structural analysis is performed to determine the strength of material. Analysis is performed on three materials carbon fiber reinforced polymer, kevlar fiber reinforced polymer and aluminium. The obtained deformation, stress and frequency values are calculated. These results are compared to determine the best suitable material for propeller.

II. WORKING PRINCIPLE

Marine vehicles propel on the basis of Bernoulli’s principle and Newton’s third law. As a propeller rotates blade sections near center have lower speed, while blade sections near tip rotate at higher speed. Bernoulli’s principle States that “an increase in the speed of a fluid accompanies a decrease in pressure or a decrease in the fluid's potential energy”. Thus speed of fluid is inversely proportional to its pressure. So, fluid near blade center has high pressure and at tip has low pressure. Due, to this pressure difference fluid flows.

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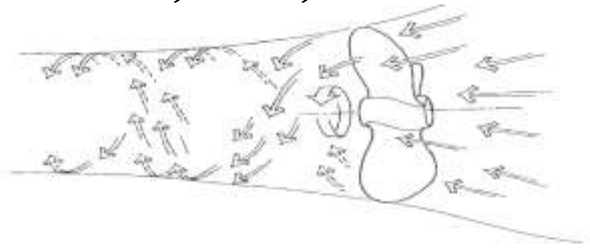

fig. 1 propeller creates pulling power by putting column of water into motion

According Newton's third law of motion "To every action there is always opposed an equal reaction: or the mutual actions of two bodies upon each other are always equal, and directed to contrary parts". So, as propeller exerts a force on the fluid in the same way moving fluid also exerts a force on ship and ship moves. The forward force developed due to pressure difference is called "thrust".

III. MATERIALS BEING USED FOR ANALYSIS

Material selection plays an important role in product design and manufacturing. This is guided by the way the material behaves in the real time conditions according to its use. The material response to the environment stimulus is called property. Based on the application and usage of material, its properties become significant. Aluminium is the third most abundant element in the Earth's crust and its most abundant metal. Aluminium is remarkable for the metal's low density and for its ability to resist corrosion. Due to this, components made of aluminium are light in weight. So, its highly used as a material for marine propellers.

A. Composition of alloys:

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		

B. Carbon Fiber Epoxy Composite:

Carbon fiber epoxy materials are polymer matrix composites. In this, the reinforcement is carbon fiber, which provides the strength and the matrix is epoxy resin, to bind the reinforcements together.

Composition		**Properties**	
Carbon Fiber:	50%	Young's Modulus	: 135 GPa
Epoxy resin:	50%	Poisson's Ratio	: 0.3
		Density	: 1.6 gm/cc

C. Kevlar Fiber Epoxy Composite:

Kevlar fiber epoxy materials are polymer matrix composites. In this, the reinforcement is Kevlar fiber, which provides the strength and the matrix is epoxy resin, to bind the reinforcements together.

Composition	**Properties**

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Carbon Fiber: 50%
Epoxy resin: 50%

Young's Modulus : 95.71 GPa
Poisson's Ratio : 0.34
Density : 1.4 gm/cc

IV. STATIC STRUCTURAL ANALYSIS

Material-1:

Material applied : Aluminium alloy 6061
Density : 2.7 gm/cc
Young's Modulus : 68.9 GPa
Poisson's ratio : 0.3

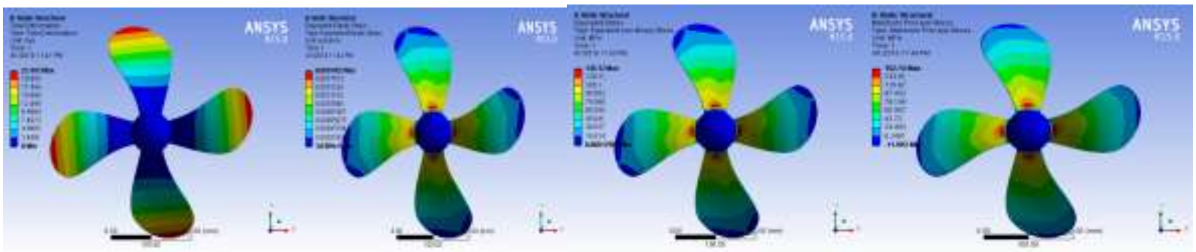

Fig: Stress, strain and deformation in Aluminum 6061

The above figures show:

1. Total Deformation
2. Equivalent (von-Mises) stress
3. Equivalent Elastic Strain
4. Maximum Principal Stress

This analysis is carried out by making all the hub and shaft interfaces as fixed supports. A load of 400N is applied at tip of each blade. The resulting stress, strain and deformations are calculated. Since, force is applied at tip deformations are high at tip and stresses are high at blade hub intersection.

Material-2:

Material applied : Carbon Fiber Epoxy Composite
Density : 1.6 gm/cc
Young's Modulus : 135 GPa
Poisson's ratio : 0.3

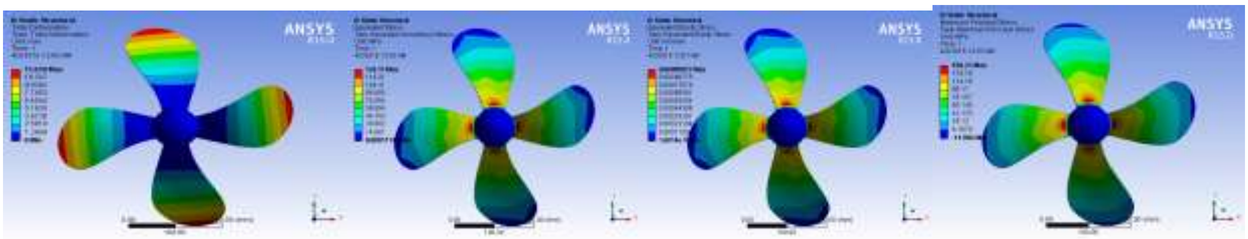

Fig: Stress, strain and deformation in Carbon Fiber Epoxy

This analysis is carried out by making all the hub and shaft interfaces as fixed supports. A load of 400N is applied at tip of each blade. The resulting stress, strain and deformations are calculated. Since, force is applied at tip deformations are high at tip and stresses are high at blade hub intersection.

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Material-3:
Material applied : Kevlar Fiber Epoxy Composite
Density : 1.4 gm/cc
Young's Modulus : 95.71 GPa
Poisson's ratio : 0.34

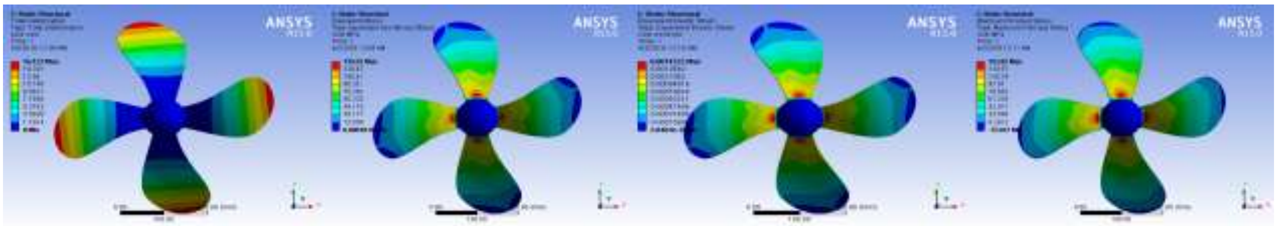

Fig: Stress, strain and deformation in Kevlar Fiber Epoxy

This analysis is carried out by making all the hub and shaft interfaces as fixed supports. A load of 400N is applied at tip of each blade. The resulting stress, strain and deformations are calculated. Since, force is applied at tip deformations are high at tip and stresses are high at blade hub intersection.

Tabular Forms:

Material	Deformation (mm)	Equivalent Stress (M Pa)	Equivalent Strain
Aluminium 6061	22.492	135.12	0.0019
Carbon Fibre Epoxy	11.618	134.11	0.0009
Kevlar Fibre Epoxy	16.123	135.52	0.0014

TABLE-1 Static Structural analysis results

A. MODAL ANALYSIS:

Material-1:
Material applied : Aluminium alloy 6061
Density : 2.7 gm/cc
Young's Modulus : 68.9 GPa
Poisson's ratio : 0.3

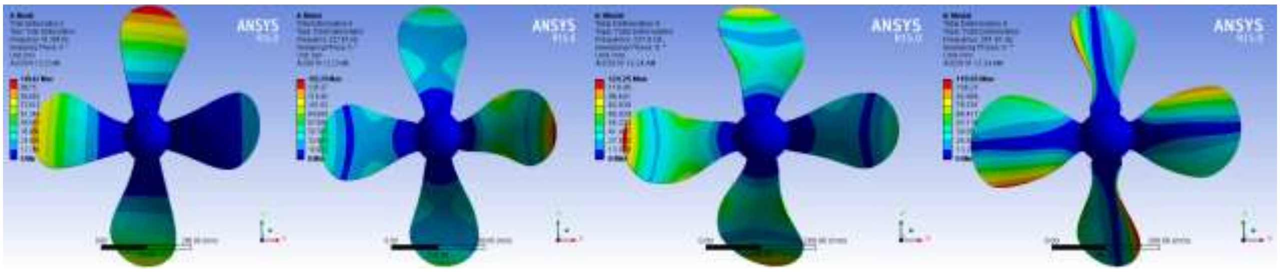

Fig: Total Deformation at modes 2, 5, 8 and 9 in Aluminum Propeller

This analysis is carried out by making edge of hub as fixed support. A rotational velocity of 1200 rpm is applied. A total of 10 modes were extracted. Natural frequencies and mode shapes are calculated.

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Material-2:

Material applied : Carbon Fiber Epoxy Composite
Density : 1.6 gm/cc
Young's Modulus : 135 GPa
Poisson's ratio : 0.3

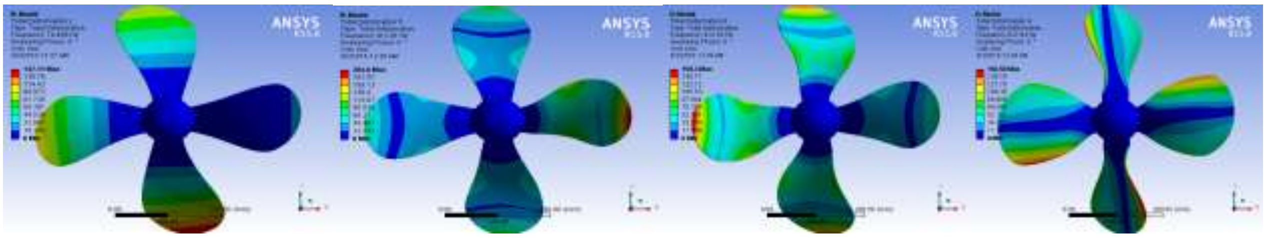


Fig: Total Deformation at modes 2,5,8 and 9 carbon fiber epoxy

This analysis is carried out by making edge of hub as fixed support. A rotational velocity of 1200 rpm is applied. A total of 10 modes were extracted. Natural frequencies and mode shapes are calculated.

Material-3:

Material applied : Kevlar Fiber Epoxy Composite
Density : 1.4 gm/cc
Young's Modulus : 95.71 GPa
Poisson's ratio : 0.34

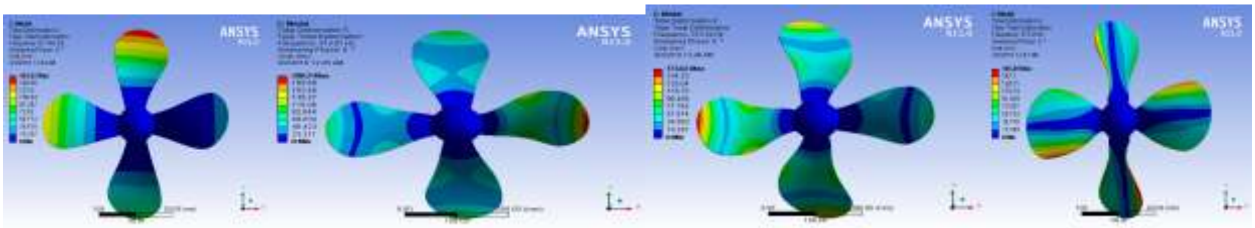
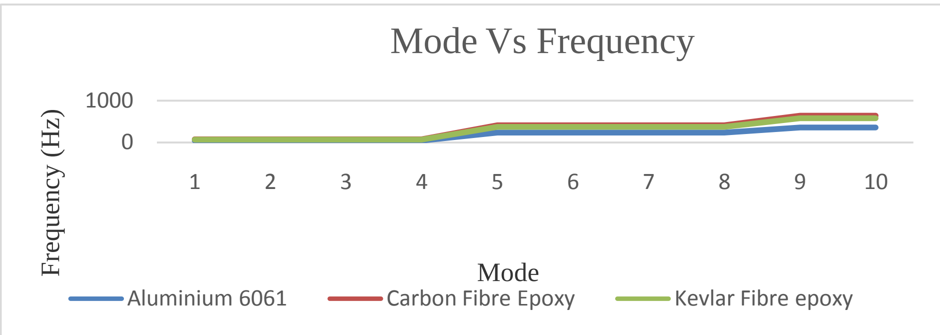


Fig: Total Deformation at modes 2, 5, 8 and 9 in Kevlar fiber epoxy

This analysis is carried out by making edge of hub as fixed support. A rotational velocity of 1200 rpm is applied. A total of 10 modes were extracted. Natural frequencies and mode shapes are calculated.

B. Graphical Comparisons:



Graph-1 Natural frequencies of propellers

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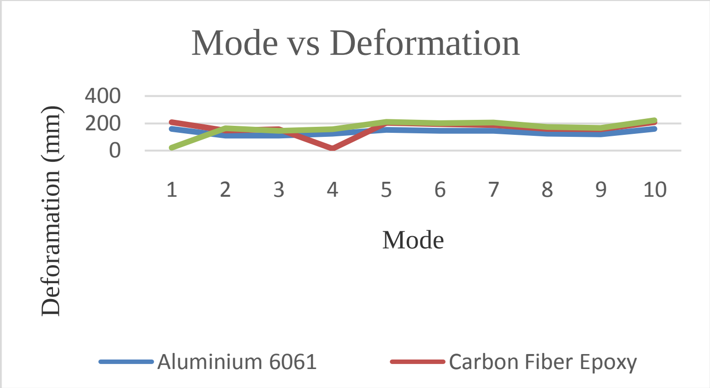
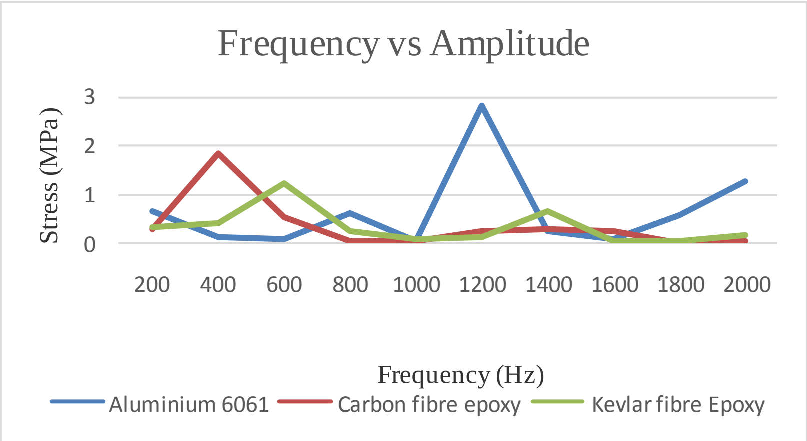


Graph-2 Modal Deformations

HARMONIC ANALYSIS:
Tabular comparisons:

Material	Max Stress in X-Direction (MPa)	Max Stress in Y-Direction (MPa)	Max Stress in Z-Direction (MPa)
Aluminium 6061	2.8049	1.5886	1.0049
Carbon fibre Epoxy	1.8535	2.0099	0.16132
Kevlar fibre Epoxy	1.2253	1.1652	0.46585

TABLE-2 Results of Harmonic Analysis



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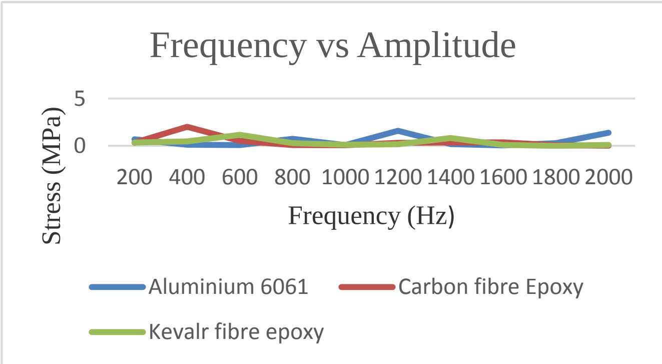
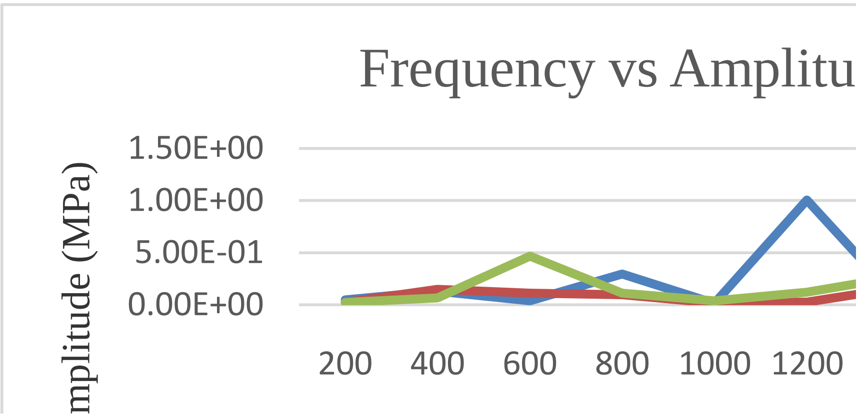
Graph-3Normal Stress in x-direction



Graph-4 normal stress in y-direction



Graph-5 Normal Stress in z-direction

C. Hydro-structural analysis:

The conditions applied for CFX analysis are turbulence is K-epsilon Model and Intensity is Medium. A normal speed of 0.2 m/s is applied and outlet average static pressure is given. For structural analysis, all shaft and hub intersection surfaces are fixed supports.

Material-1:

Material applied : Aluminium alloy 6061

Density : 2.7 gm/cc

Young's Modulus : 68.9 GPa

Poisson's ratio : 0.3

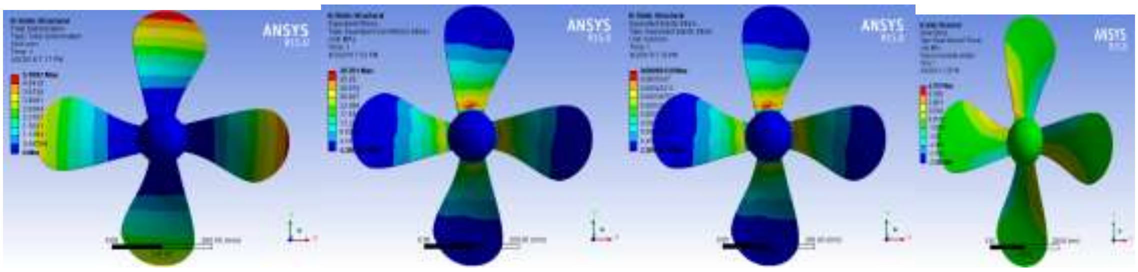


Figure: stress, strain and deformations of aluminium propeller under Hydrodynamic pressure loading

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Material-2:

Material applied : Carbon Fiber Epoxy Composite
Density : 1.6 gm/cc
Young's Modulus : 135 GPa
Poisson's ratio : 0.3

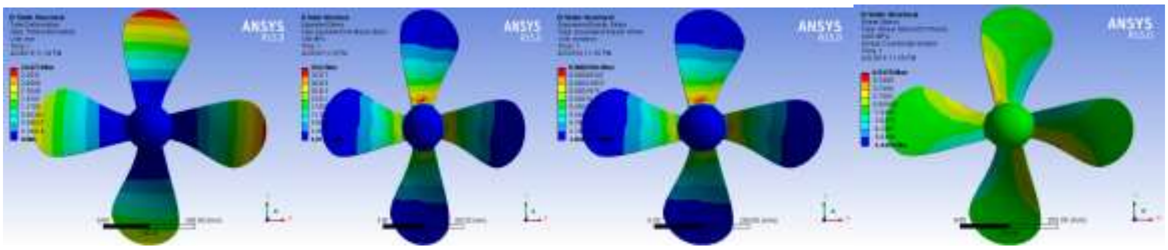

Figure: stress, strain and deformations of Carbon fiber epoxy composite propeller under hydrodynamic pressure loading

Material-3:

Material applied : Kevlar Fiber Epoxy Composite
Density : 1.4 gm/cc
Young's Modulus : 95.71 GPa
Poisson's ratio : 0.34

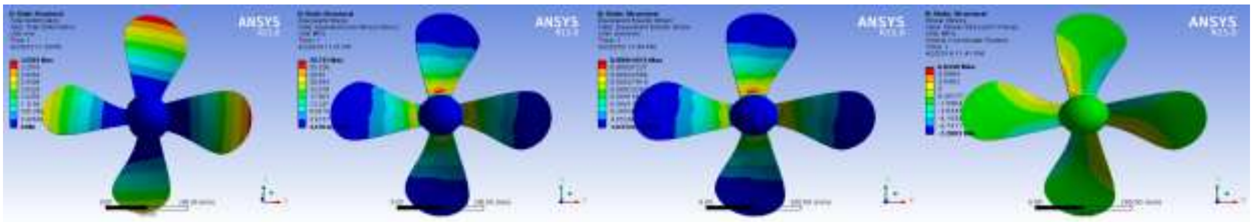

Figure: stress, strain and deformations of Kevlar fiber epoxy composite propeller under hydrodynamic pressure loading

Tabular Comparisons:

Material	Deformation (mm)	Equivalent Stress (MPa)	Equivalent Strain
Aluminium 6061	5.1092	39.701	0.0005
Carbon fibre Epoxy	2.6472	39.62	0.0002
Kevlar Fibre Epoxy	3.6583	39.742	0.0004

TABLE-3 Results of Hydro Structural Analysis

V. Conclusion:

- In this work, we have modelled a torpedo propeller and structural and vibrational analysis is carried out on Aluminium and composite materials. The results of analysis are compared
- The deformation of Carbon fiber reinforced epoxy composite propeller is 11.618 mm and for Kevlar fiber reinforced epoxy composite propeller is 16.123 mm which is much less than aluminium propeller. Show that composite materials are stiffer than aluminium propeller.

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- Modal analysis results show that natural frequencies of Kevlar fiber reinforced epoxy composite propeller and Carbon fiber reinforced epoxy composite propeller are 577.63 Hz and 639.6 Hz, which is 39% and 44.5 % more than aluminium propeller. This shows that operational frequency of composite propellers is more than aluminium propeller.
- Harmonic analysis results show that maximum stresses developed to a sinusoidal wave in carbon fiber reinforced epoxy composite propeller andKevlar fiber reinforced epoxy composite propellerare 30% and 45.53% less than aluminium propeller.
- Hydro Structural analysis results show that under hydrodynamic pressure loading, the deformations of carbon fiber reinforced epoxy composite propellerand Kevlar fiber reinforced epoxy composite propellerare 2.6472 and 3.6583 respectively. Which are less than the deformation of aluminium propeller. This shows the structural strength of composites.

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