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Some Studies on the Effectiveness of Engineering Materials on the Blade of Marine Propeller Using Modal Analysis

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Abstract: In engineering, resonance is the crucial problem while designing. Every structure has its own natural frequencies where the periodic forces whose amplitude is nearby the damped natural frequencies, which causes structure to vibrate vigorously until the structure fails. The natural frequencies of the structure can be handled by optimising the shape and stiffness to mass ratio of the material and the role of boundary conditions, cross-section of the blade are compact in permitting the frequencies. This proposed work deals with effect of the conventional materials and composite materials of the marine propeller blade using finite element modelling and the structure can be achieved to ensure certain level of safety.

Keywords: Natural frequencies, Modal analysis, Wageningen Propeller blade, Composite materials

I. INTRODUCTION

A marine propeller develops power which helps to move the ship by converting rotary motion by means of thrust. The fluid is accelerated back to the blade due to the pressure difference between face and back surface of the aerofoil shaped blade. Marine propellers are modeled by both or either Newton's third law and Bernoulli's principle. Sometimes marine propeller can be called as Screw Propeller or simply Screw. The propeller geometry and its design is quite complex which involves controlling parameters like taper, pretwist and varying cross-section of the blade which are mounted at a stagger (pitch) angles. An accurate augury of natural frequency for a water vehicle propeller blade is much important at design stage. The natural frequencies of the blade depend on shape, stiffness and mass of the material. Some of the advanced composite materials are existed: Carbon-Carbon (CC) and Carbon fiber reinforce Silicon Carbide (C/SiC), which have higher stiffness to mass ratio and light in weight when it is compared with other materials. But, C/SiC composite material is cheaper than CC composite materials.

Various researchers have been evolved on the marine propeller, M. L. P. Kishore (1) focused on the effect of materials on a marine propeller blade using finite element analysis with Hamilton's Principle. Y. H. Chen (2) and M. B. Priya (3) said that the propeller weight can be reduced and stiffness may increase by changing the blade material with the composite materials. Since for the composite materials, fiber orientation is important criteria to design a blade, so Mohamad S, Qatu (4) investigated on pre twist composite plate using laminated shallow theory and observed the fundamental frequencies are reached maximum when the fiber alignment is perpendicular to clamped edge. Alejandro D. Otero (5) used variable asymptotic beam section (VABS) technique for converting complex wind turbine blade geometry to the equivalent beam stiffness matrix for the composite layup. Zhimin Li (6) carried out the layup technique on the turbine blade at 45^o fiber alignment which shows higher strength in stability. Raymond (7) observed on singing of propeller in the range between natural frequencies 350Hz to 4000Hz and given the different in range of 70% between blades free natural frequencies (in air) and damped natural frequencies (in water). Gordon (8) studied on Carbon-Carbon material which is an advanced composite material possess rich in mechanical properties but high in cost. Y. L Young (9) gives an overview of the structural and fluid models of composite marine propeller blade. There is another advanced material which lowers in cost when it is compared with Carbon-Carbon material is Carbon fiber Reinforced Silicon Carbide Composite (C/SiC) investigated by Walter Krenkel (10). Houzheng Wu (11) studied on mechanical properties of Carbon Fiber Reinforced Silicon Carbide (C/SiC) composite material and given the mechanical properties range for different crystal and phase orientation.

II. BLADE MATERIALS

Since the working condition of the marine propeller is under water, so the material should possess corrosion resistant. To extract the natural frequencies of the marine propeller blade, different materials are used: both conventional and composite materials. Since the composite materials consists high stiffness to mass ratio when it is compared with conventional materials, this means composite materials have high strength and durability hence the metallic materials can be replaced with composite materials. An advanced composite material is also used which is carbon fiber reinforced silicon carbide (C/SiC) composite material which is transient isotropic material have the better mechanical properties when compared with the other materials. In general, C/SiC materials are used were the high strength and high thermal resistance is required. In this paper aluminum alloy, high tensile brass and composite materials carbon epoxy, E-glass epoxy and carbon fiber reinforced silicon carbide materials are explored in table I & II respectively. For modal analysis, three main material properties are required those are young's modulus, poissons ratio and density of the material.

TABLE I
Mechanical Properties of Conventional Materials

Materials\ Properties	Young's Modulus, E in GPa	Poissons Ratio, υ	Desity, ρ Kg/m^3
Nickel-Aluminium-Bronze (NAB)	117	0.34	7600
Nickel- Manganese-Bronze (NMnB)	105	0.34	8000
Manganese-Aluminium-Bronze (MnAB)	125	0.326	7530
Manganese-Bronze (MnB)	105	0.34	8300
Copper-Nickel Aluminium Alloys (CNA)	122.58	0.33	8530
Copper high tensile brass (CHTB)	102.97	0.35	8300

TABLE II
Mechanical Properties of Composite Materials

Properties\ Materials	Carbon-Epoxy	E-Glass-Epoxy	C/SiC
E_X (MPa)	123340	45000	70000
E_Y (MPa)	7780	10000	70000
E_Z (MPa)	7780	10000	70000
υ_{XY}	0.27	0.3	0.25
υ_{YZ}	0.42	0.4	0.25
υ_{XZ}	0.27	0.3	0.25
G_{XY} (MPa)	5000	5000	28000
G_{YZ} (MPa)	3080	3846.2	28000
G_{XZ} (MPa)	5000	5000	28000
ρ (Kg/m^3)	1518	2000	2000

III. CREO MODEL

The three dimensional CAD modelling was done in Creo 2.0 Parametric which is user friendly software. For modal analysis, the geometry was minimized to mono blade of the marine propeller. The dimensions of the Wageningen B4-70 propeller is given in table III

TABLE III
Dimensions of Wageningen B4-70 Marine Propeller

$\frac{r}{R}$	$\frac{C_r * Z}{D * A_E/A_O}$	$\frac{a_r}{C_r}$	$\frac{t_r}{D}$	$\frac{b_r}{C_r}$
0.2	1.662	0.167	0.0366	0.350
0.3	1.882	0.613	0.0324	0.350
0.4	2.050	0.601	0.0282	0.350
0.5	2.152	0.586	0.0240	0.350
0.6	2.187	0.561	0.0198	0.389
0.7	2.144	0.524	0.0156	0.443
0.8	1.970	0.463	0.0144	0.479
0.9	1.582	0.351	0.00722	0.500
1.0	--	0	0.0030	--

Where

r = Radius at particular cross-section,
P/D = Pitch to diameter ratio = 0.9,
A_E/A_O = expanded blade area ratio = 0.70,
t_r = Maximum thickness of an aerofoil,
a_r = Distance between leading edge and centerline at each cross-section
b_r = Distance between leading edge and maximum thickness of an aerofoil
Rake angle = 15°

R = Propeller Radius = 1.06m
Cr = Chord length at each cross-section
Z = Number of blades = 4
D = Diameter of the propeller = 2.12m

A finite element mesh is created to the blade as shown in figure 1 with element size of 10mmwhich creates 18513 elements and 34274 nodes. Each node will have 6-degree of freedom. On the other hand, complete wageningen propeller is shown in figure 2.

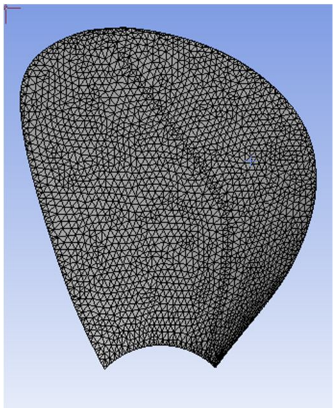

Figure 1: Meshed model for modal analysis

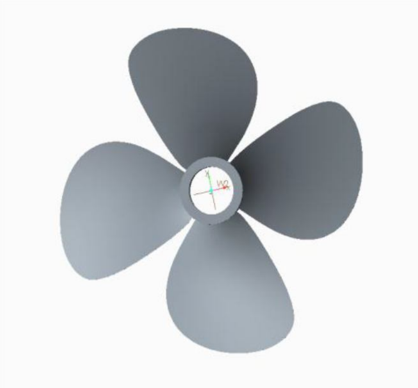

Figure 2: Wageningen B4-70 Propeller

IV. MODAL ANALYSIS

Natural frequencies of the blade is extracted by using Modal Analysis for conventional materials, composite (orthotropic) materials up to 50 layers and advanced composite (transient isotropic) material. Under non-external loading and non-damping conditions, fixed body modal analysis is done to extract the free natural frequencies of marine propeller blade in its root (near hub) by the all degree of freedom system are restricted.

A. Modal Analysis for Conventional materials

The natural frequencies of the marine propeller blade are derived by using the different types of conventional materials. The boundary (fixed) condition of the blade is shown in figure 3

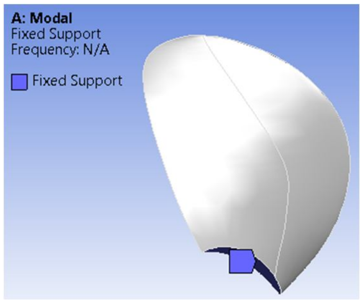

Figure 3: Fixed Condition of the Blade

B. Modal Analysis for Composite Materials

For composite materials, especially for orthotropic materials a proper ply-drop should be created which is shown in figure 4 since the cross-section of the blade is not equal. But for the isotropic composite material the analysis is carried out as like the conventional materials. Whereas the boundary condition for the composite marine propeller blade is same i.e. fixed condition at root of the blade.

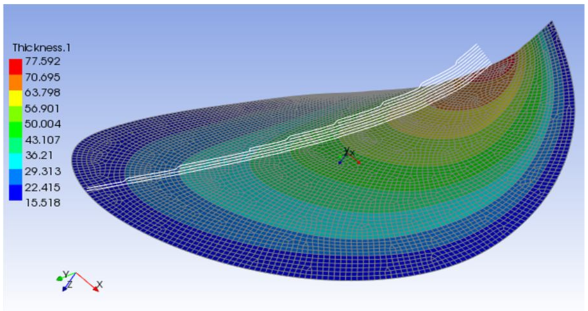

Figure 4: Ply-drop for the Composite (orthotropic) materials

V. RESULTS & DISCUSSIONS

TABLE IV

Natural Frequencies of the Blade for Conventional Materials

Mode No.	NAB	MAB	NMB	MB	CNA	CHTB
1	498.1	518.53	459.92	451.53	482.11	446.35
2	1505.5	1566.9	1389.7	1364.4	1456.6	1352.2
3	1677.4	1737.6	1548.8	1520.6	1617.8	1508.6
4	3143.8	3271.6	2902.6	2849.7	3041.8	2825.7
5	4066.4	4215.7	3754.6	3686.2	3925.1	3649.9
6	5582.6	5781.6	5154.9	5060.9	5383.0	5023.8

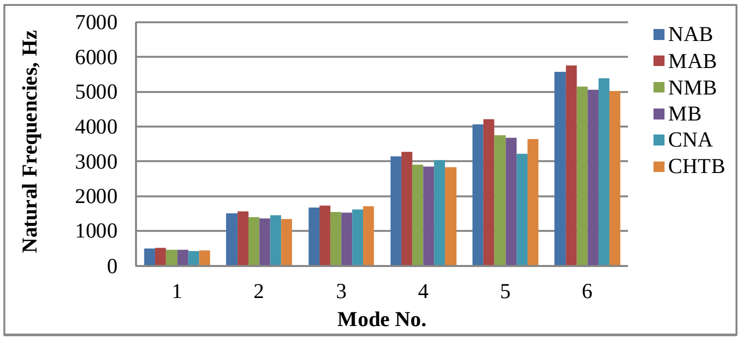

Figure 5: Comparison of Natural Frequencies of Conventional Materials

TABLE V
Natural Frequencies of the Blade for Carbon Epoxy Composite Materials

Mode No.	Carbon - Epoxy				
	10-layers	20-layers	30-layers	40-layers	50-layers
1	553.73	597.04	603.04	604.16	603.79
2	1764.5	1952.5	1982.3	1990.4	1993.6
3	1900.3	2102.3	2139.2	2150.7	2155.0
4	3526.4	3835.3	3892.5	3913.3	3908.0
5	4444.0	4911.2	4972.9	4984.0	4983.4
6	5811.7	6390.6	6470.1	6509.9	6526.9

TABLE VI
Natural Frequencies of the Blade for E-Glass Epoxy Composite Materials

Mode No.	E-Glass - Epoxy				
	10-layers	20-layers	30-layers	40-layers	50-layers
1	399.8	408.56	412.0	410.57	411.45
2	1382.4	1425.0	1435.5	1433.7	1436.0
3	1507.9	1580.5	1590.6	1593.7	1594.7
4	2810.4	2958.2	2961.0	2969.1	2967.5
5	3534.6	3645.5	3664.5	3675.6	3676.2
6	4807.5	4983.1	5016.3	5027.8	5029.6

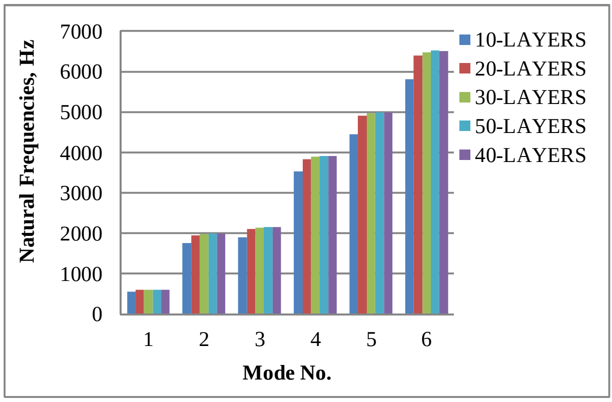

Figure 6: Comparison of Carbon-Epoxy Composite layers

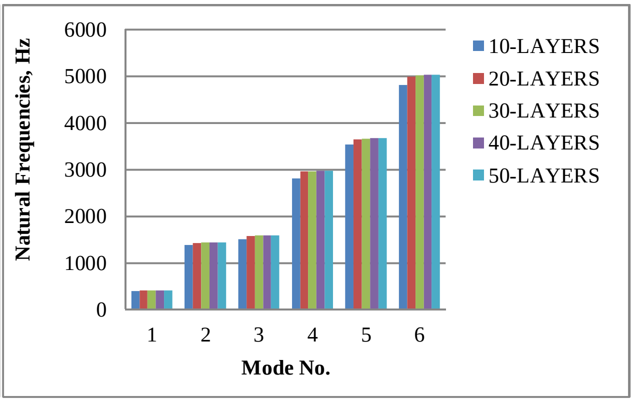

Figure 7: Comparison of E-Glass Epoxy Composite layers

TABLE VII
Natural Frequencies of the C/SiC Composite Material Blade

Mode No.	Natural Frequencies, Hz
1	763.19
2	2319.7
3	2507.9
4	4765.7
5	6093.9
6	8402.1

TABLE VIII
Natural Frequencies of the Blade for Conventional and Composite materials

Mode No.	MAB	Carbon-Epoxy (50-Layers)	E-Glass-Epoxy (50-Layers)	C/SiC
1	518.53	603.79	411.45	763.19
2	1566.9	1993.6	1436	2319.7
3	1737.6	2155	1594.7	2507.9
4	3271.6	3908	2967.5	4765.7
5	4215.7	4983.4	3676.2	6093.9
6	5781.6	6526.9	5029.6	8402.1

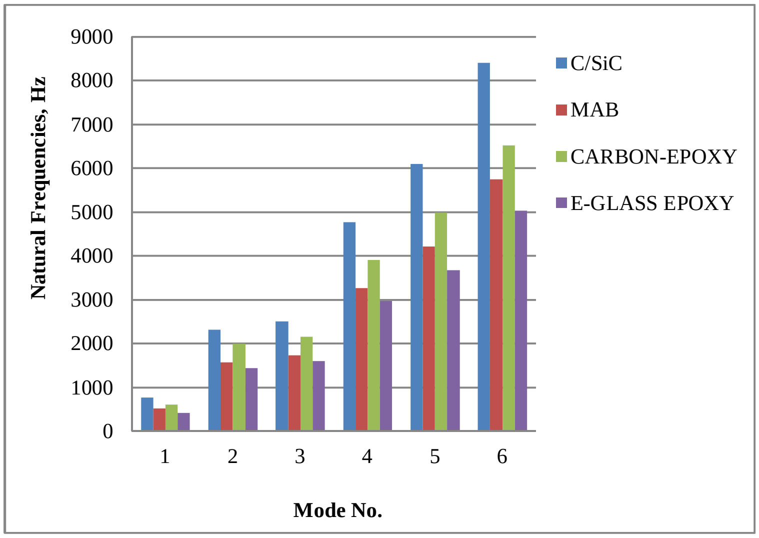

Figure 8: Comparison between conventional and composite materials

The natural frequencies of the marine propeller blade are extracted using Ansys 17 solver. The simulation was done by fixed condition of blade in its root by restricting all degree of freedom.

From TABLE-IV it clearly says that Manganese Aluminium Bronze which has lower density reached higher natural frequencies than Nickel Aluminium Bronze, Copper Nickel Aluminium alloy, Nickel Manganese Bronze, Manganese Bronze and Copper High Tensile Brass. The range varies from 518.53Hz to 5781.6Hz.

Were as in TABLE-V and TABLE-VI show that carbon epoxy and E-glass epoxy with 50-layeres and ply angles with 45/90 have higher natural frequencies when compared with the other layers and the range varies from 603.79Hz to 6526.9Hz and 411.45Hz to 5029.6Hz respectively.

Now coming to the TABLE-VIII shows the final comparison between conventional and composite material blades, the transient isotropic composite material (C/SiC) which have better mechanical properties reached higher natural frequencies raged from 763.19Hz to 8402.1Hz than the conventional materials and orthotropic composite materials.

VI. CONCLUSIONS

By using ANSYS 17 simulation software, the natural frequencies of blade of the marine propeller have been extracted. Under non-external loading and non-damping conditions, fixed body Modal Analysis is done at its root of the blade (near hub) by the all degree of freedom system is restricted. The three dimensional CAD modal was generated by using Creo modelling software and the model was imported to ANSYS. The effectiveness of the materials and mode shapes are observed on the marine propeller blade by using conventional and composite materials and graphs are also plotted. Finally, comparison is done between conventional materials and composite materials. Hence from the results, it is predicted that the composite materials can be enhanced at optimised ply-angles, accurate ply-drop, by changing the number of layers (for orthotropic composites) and varying crystal & phase orientation (for transient isotropic composite) than the conventional materials, as they have the better mechanical properties.

VII. ACKNOWLEDGMENT

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