Available online at www.elixirpublishers.com (Elixir International Journal)

Mechanical Engineering

Elixir Mech. Engg. 87 (2015) 36049-36054

ISSN: 2229-712X

Structural and Vibrational Analysis of Hybrid Composite Marine Propeller

A Pavan Kumar[1,*], S Praveen Kumar[2] and Sreenivasulu Bezawada[3]

[1]M.Tech Scholar, Department of Mechanical, Madanapalle Institute of Technology & Science, Madanapalle, India

[2]Assistant Professor, Department of Mechanical, Madanapalle Institute of Technology & Science, Madanapalle, India

ARTICLE INFO

Article history:

Received: 4 June 2015;
Received in revised form:
18 October 2015;
Accepted: 24 October 2015;

Keywords

Kcd-32 propeller with 5 blades,
NAB,
Hybrid composite with layers,
Static and modal analysis.

ABSTRACT

The conventional propellers for marine application are the standard Propulsion System for surface ships & underwater vehicles. These propellers are metallic alloy type like NAB (nickel aluminum bronze), NMnB, and MnAlb etc. Because of their high strength and stiffness, But they create more vibrations & noise, expensive machining process ,poor acoustic damping properties ,low corrosion & fatigue performance.The present proposed study on the composite marine propeller which is contrary to metallic propeller properties & has advantages like high strength to weight ratio, stiffness to weight ratio &has most unique characteristic shape adaptability.The propeller design is to be carried by The standard KCD-series model propeller with 5 blades.it require high end modeling to get a required hydrofoil shape is carried in CATIA .The structural &vibration analysis will be done in ALTAIR OPTISTRUCT FEA to compare the metallic & composite to evaluate the suitability of composite material for marine propeller. Than analysis is carried for different layup materials of composite propeller to get an optimum stresses, deflections and normal modes of frequencies.

Introduction

The propeller works based on the Bernoulli's principle and Newton's third law of motion. The ship moves forward by the propeller reaction against the water. The devices like oars, paddle wheels, jets etc. are used to propel the ship.

The marine propeller material selection is based on its strength, weight, corrosion resistance, thermal expansion& ease of manufacturing. The selection of material also considers the light weight, strong, & ductile. The propellers of ship are fabricated by conventional metallic alloys like nickel aluminum bronze, nickel manganese bronze, manganese bronze, stainless steels, cast iron, carbon& low alloy steels, chromium stainless steels, naval brass etc. Because of their high strength and stiffness. But they can produce more vibrations &noise, and poor corrosion and fatigue performance.

The composite material usage in marine industry came into exist in recent years because of their high strength to weight ratios, better corrosion and erosion performance etc.in present development of propellers the they are manufactured with composites like polyamide(nylon powder) ,wood, thermosetting plastics& fiber reinforced composite materials like glass fiber reinforced plastics and carbon fiber reinforced plastics.

The first propeller idea was initiated by Leonardo Davinci in 15th century.at that time the experiments were unsuccessful with screw propellers. Then in 1802, Colonel John Stevens developed the 1st vessel which driven by steam and screw propeller. The manufacturing of marine propeller is most important procedure. The Froude initiates a method for evaluating the propulsion efficiency of ship.

The common experiments which were done with ship models and model propellers are Open water, resistance, cavitation, self-propulsion experiments and wake measurements.

Literature survey

The present literature is based on the theoretical& experimental study on the marine propeller strength and also on usage of composites for marine propeller blades:

The composite propeller performances like characteristic and cavitation were studied under the elastic deformation [1]. In this different model propellers were made with different composites and aluminum and tested for thrust, torque and cavitation fluctuating pressures and compared the results by FSI and experimental procedures.

The surface piercing propeller was made with composite instead of stainless steel [2]. And the loads like hydrodynamic pressure, centrifugal force, gravity were applied and getting the results by long strain nonlinear progressive failure analysis. It was proved that the steel fails with 90% load and carbon/epoxy composite safe with full load.

The main advantage of composite was shape adoptability was used in this [3]. And evaluate and compare the results in uncoupled and coupled bend twist performances with different layup of materials.

The vibrational analysis was done with composite and NAB and compares the results with two different solvers [4].

WJ colclough [5] et al. investigation said that the application of composites instead of NAB for propeller blade. The fiber reinforced plastic composites are used. This usage reduces the 3 basic problems like corrosion, erosion & noise. The author evaluates the different properties of fiber reinforced plastic composite blade & different stress analysis was done. **JK** Russell [6] gives a method for construction of blade with the usage of CFRP as load carrying spar & GFRP as an outer shell of airfoil form**.** The fatigue tests, bird impact trails were done. The measured vibratory strain results were compared with fatigue test results. The main disadvantage of his study is loading edge erosion.

Christoph leyens [7] et al. implemented the composites like silicon carbide fiber titanium matrix composites & fiber reinforced plastics (hydride concept) instead of bulk titanium. The titanium matrix increases the mechanical properties & hybrid blades can improve the weight savings.

Tele:
E-mail addresses: archakam.pavan@gmail.com

Chingchaiehlin [8] study carried in the laminated composites structures. The optimization of stacking sequence was done with genetic algorithm.

Gaufenglin [9] studied the stresses for fiber reinforced composite thruster blades. The multiple layers of braided fiber are used to construct a blade with shell skin. A foam type material is used for core. The 3D-element stress analysis is used for hydrodynamic design constraints. The study gives the minimum deflection at tip of blade & it is quite large compared with isotropic metal blade of same form. Composite blade gives better structural stiffness & strength.

Modelling of propeller

In order to model a propeller, we have to choose a particular series of model propellers and their dimensions like diameter of propeller hub and blades, number of blades, and number of hydrofoil section points.

We have to choose a kcd-32 propeller with 5 blades of 7 hydrofoil sections [10]. The modeling of propeller blade was done in CATIA. First 7 hydrofoil points are exported by excel with macros command. And then we have to rotate each hydrofoil with respect to given angle to get a varying pitch in propeller blade. Use spline command to get a splines on the hydrofoil points. And after that by using multi sections surface options in GSD we have to create blade surface for 7 hydrofoil points.

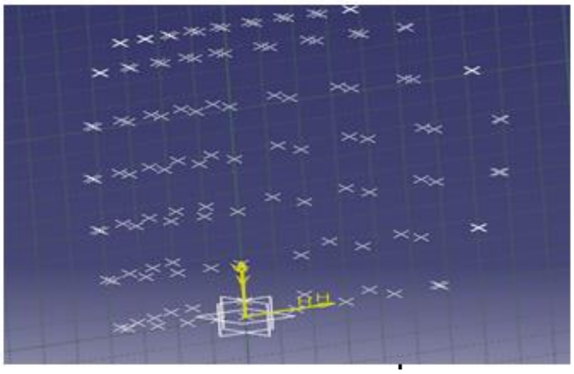

Fig 1.Hydrofoil points

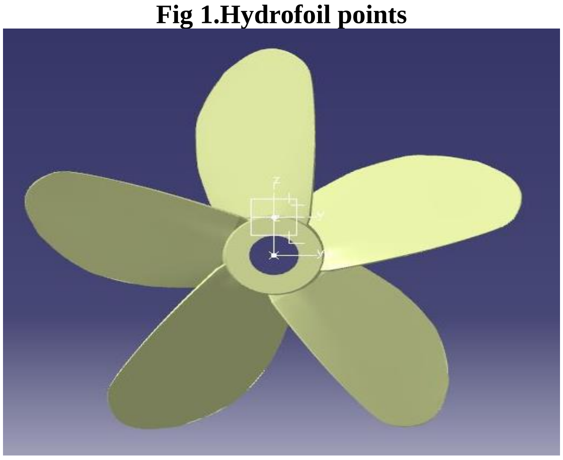

Fig 2 Final model of kcd-32 propeller

Meshing with hyper mesh

The model was imported into the HYPERMESH tool. The propeller blades were meshed with shell elements and hub was with tetra mesh. Automatic mid surface is generated using auto mid surface option. For mid surface of propeller the 2D shell mesh was generated. The no of nodes created were 18352, no of tria3 elements 18772 and no of tetra elements 36360. So total number of elements created 55132.mesh quality checks like jacobian, warpage,skew, aspect ratio, and connectivity were successfully verified.

Fig 3. Meshed model of propeller

Material properties

Table 1. NAB properties

Nickel aluminium bronze(nab)	
Property	**NAB**
Density(Ton/mm3)	7.6e-9
Young's modulus (MPa)	117000
Rigidity modulus (MPa)	43660
Poison's ratio	0.34
Yield strength(MPa)	178.3
Melting point(^{0}c)	650

Table 2 .Composite properties

Composite materials properties			
Material/Property	**R glass roving ud/epoxy**	**Carbon ud/ epoxy**	**S2 glass fabric/epoxy**
Ex (MPa)	53100	142000	22925
Ey (MPa)	12400	10000	22925
Ez (MPa)	12400	10000	12400
Nuxy	0.16	0.16	0.12
Nuyz	0.16	0.2	0.2
Nuzx	0.28	0.16	0.2
Gxy (MPa)	6600	5200	4700
Gyz (MPa)	4140	3800	4200
Gzx (MPa)	4140	6000	4200
Mass density(Ton/mm³)	2e-9	1.6e-9	1.8e-9

Analysis with Altair optisruct FEA

Boundary condition: The contact surface between hub and shaft is fixed in all degrees of freedom.

Forces

Thrust force calculation

According to reference (1)

Diameter of propeller D = 0.406m
Linear velocity V_a = 3.9624m/s
Advance coefficient J = 0.65
Propeller Angular Speed n = 15rps
Angular velocity w = 94.25rad/sec
Efficiency η = 0.57
Thrust coefficient K_t =0.136
Thrust coefficient K_t =Thrust/ρn2D5
Where

ρ =density of sea water=1025kg/m3

Thrust force = K_t* $\rho n^2 D^5$

$= 0.136*1025*15^2*0.406^5$

Thrust force $= 852.21N$

The thrust of 852.21N was uniformly distributed on face side of the blade in between the region 0.7R and 0.75R.The thrust is produced because of the pressure difference between the face and back sides of propeller blades. This pressure difference also causes rolling movement of the underwater vehicle. By applying this type of constraints and forces the propeller acts as a cantilever beam.

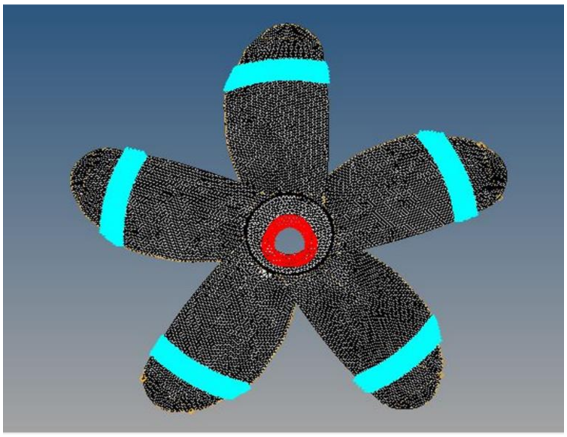

Fig 4. Application of forces and constraints

Results and Discussions

Static analysis

The nodes on the hub and shaft intersection face were fixed in all degree of freedom. And the thrust force of 852.21 was uniformly distributed on the face side of blade between the sections 0.7R and 0.75R.the analysis was first carried out for NAB and next to different composites and different layers.

Analysis of NAB

For NAB the maximum deflection 0.874mm was found at the tip of the blade and maximum vonmisses stress 79.45MPa was at the hub and blade intersection.

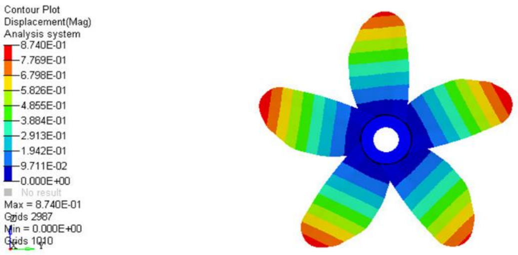

Fig 5. Deflection for NAB propeller

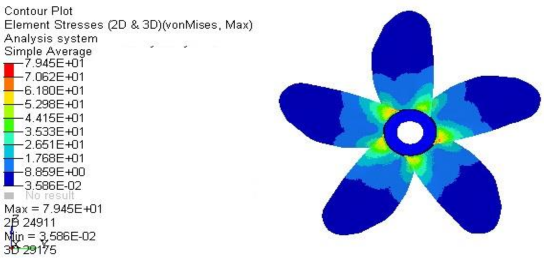

Fig 6. Vonmisses stress for NAB propeller

3 Composites (R glass +carbon ud/epoxy+s2 glass fabric)

For composite PCOMP card image was selected and MAT8 orthotropic properties were given

3 layers

The stacking sequence of three layered composite hybrid blades was (0_{rg} ,45_{c},-45_{s2g}).The max deflection 4.350mm was at tip of the blade and max vonmisses stress was 116.2MPa.

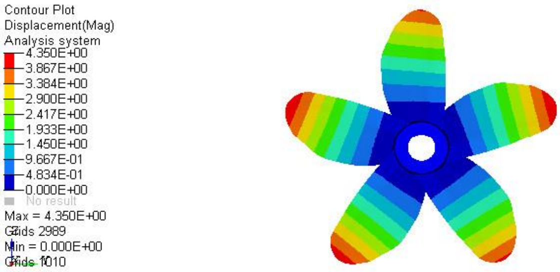

Fig 7. Deflection

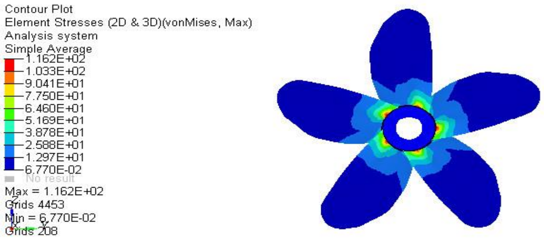

Fig 8. Vonmisses stress

6 Layers

The stacking sequence was (0_{rg} ,45_{c},-45_{s2g},90_{rg},0_{c},45_{s2g}).The max deflection was 3.543mm and max vonmisses stress was 82.27MPa.

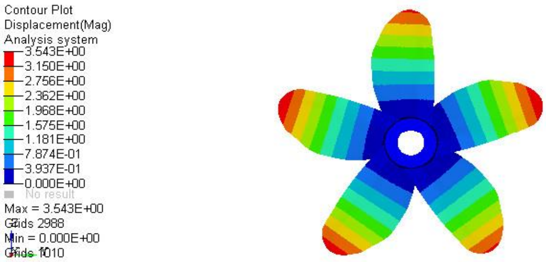

Fig 9. Deflection

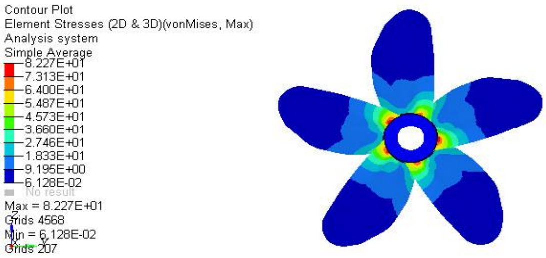

Fig 10. Vonmisses stress

9 Layers

The stacking sequence was (0_{rg} ,45_{c},-45_{s2g},90_{rg},0_{c},45_{s2g},-45_{rg},90c,0s2g).The max deflection was 2.580mm and max vonmisses stress was 65.47MPa.

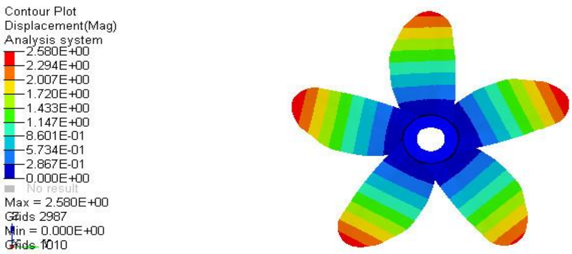

Fig 11. Deflection

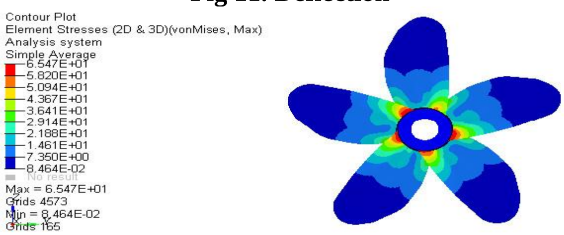

Fig 12.Vonmisses stress

12 layers

The stacking sequence was (0_{rg} ,45_{c},-45_{s2g},90_{rg},0_{c},45_{s2g},-45_{rg},90c,0_{s2g},45_{rg},-45_{c},90_{s2g}).The max deflection was 2.598mm and max vonmisses stress was 67.91MPa.

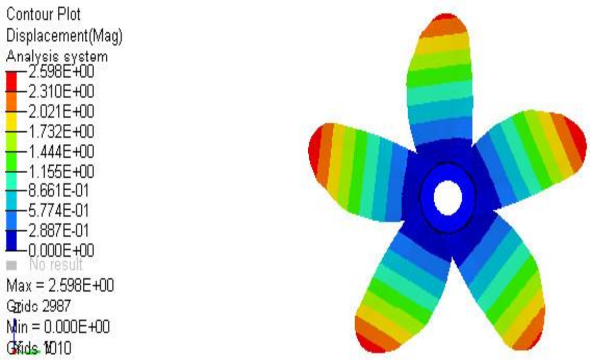

Fig 13. Deflection

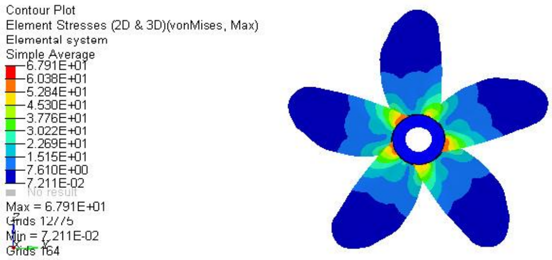

Fig 14. Vonmisses stress

2 Composites (S2 GLASS+CARBON UD/EPOXY)

The stacking sequences were same as the above analysis but instead of 3 composites we use 2 composite and sequence was (s2g,c).

3 layers

The stacking sequence of three layered composite hybrid blades was (0s2g ,45c,-45s2g). The maximum deflection 4.009mm was found at the tip of the blade and maximum vonmisses stress 111.0MPa was at the hub and blade intersection.

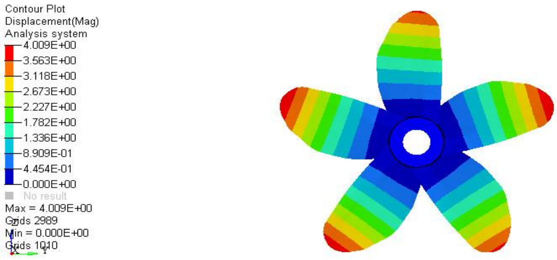

Fig 15. Deflection

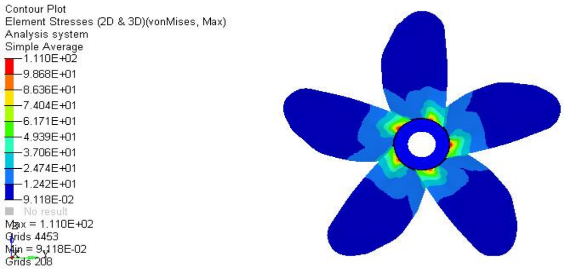

Fig 16. Vonmisses stress

6 Layers

The stacking sequence was (0s2g,45c,-45s2g,90c,0s2g,45c). The maximum deflection 2.413mm was found at the tip of the blade and maximum vonmisses stress 78.70MPa was at the hub and blade intersection.

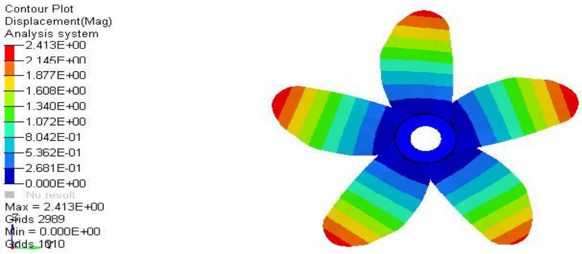

Fig 17. Deflection

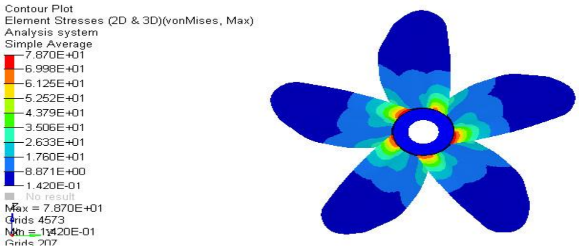

Fig 18. Vonmisses stress

9 layers

The stacking sequence was (0s2g,45c,-45s2g,90c,0s2g,45c,-45s2g,90c,0s2g). The maximum deflection 2.227mm and maximum vonmisses stress 85.68Mpa.

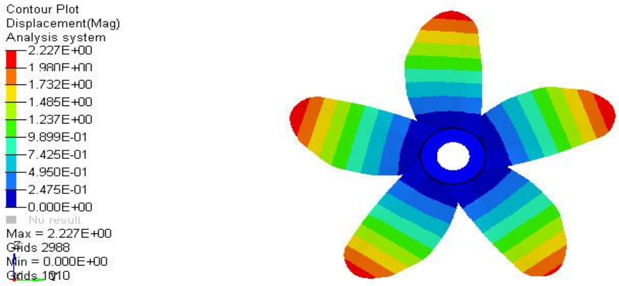

Fig 19. Deflection

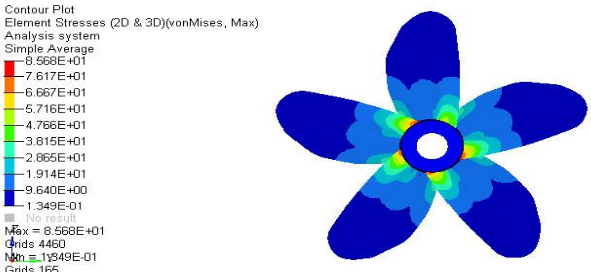

Fig 20. Vonmisses stress

12 layers

The stacking sequence was (0s2g,45c,-45s2g,90c,0s2g,45c,-45s2g,90c,0s2g,45c,45s2g,90c).The max deflection was 2.120mm and max vonmisses stress was 87.61MPa.

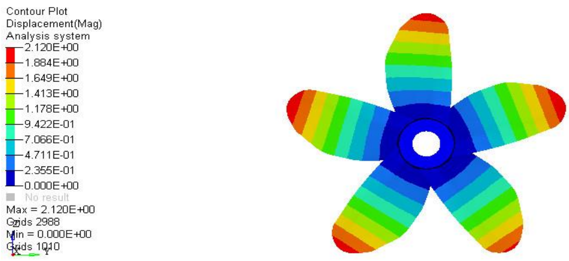

Fig 21. Deflection

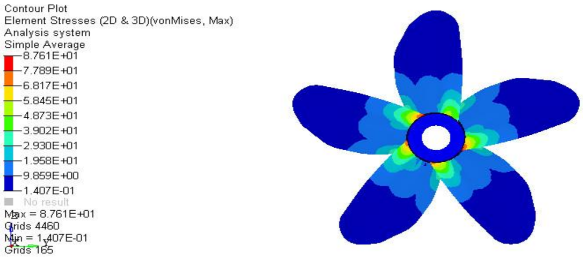

Fig 22. Vonmisses stress

2 Composites(R Glass+ Carbon Ud/Epoxy)

The stacking sequences were same as the above analysis for all layers but instead of 3 composites we use 2 composite and sequence was (rg, c).

3 Layers

The stacking sequence of three layered composite hybrid blades was (0rg ,45c,-45rg).The max deflection 3.545mm was at tip of the blade and max vonmisses stress was 94.73Mpa at the joining portion of blades to hub.

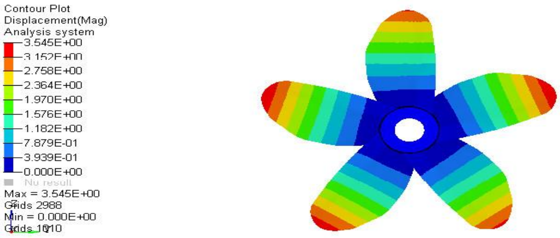

Fig 23. Deflection

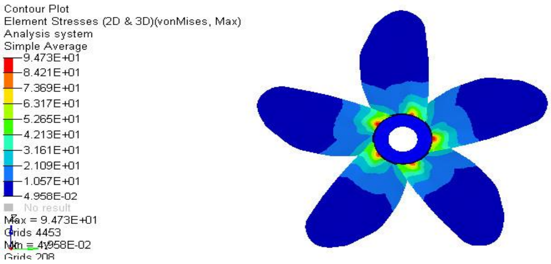

Fig 24. Vonmisses stress

6 Layers

The stacking sequence was (0rg ,45c,-45rg,90c,0rg,45c). The max deflection was 2.276mm at the tip of the blade and max vonmisses stress was 73.66MPa at the intersection of blades and hub.

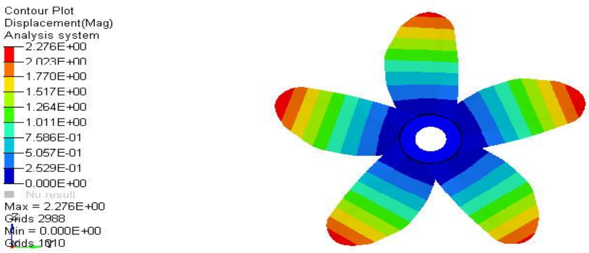

Fig 25. Deflection

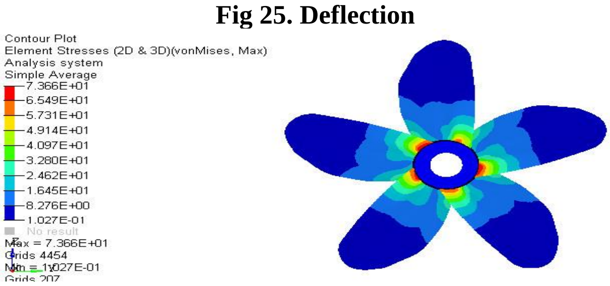

Fig 26. Vonmisses stress

9 layers

The stacking sequence was (0rg ,45c,-45rg,90c,0rg,45c,-45rg,90c,0rg).The max deflection was 2.073mm at the tips of the blades and max vonmisses stress was 72.22Mpa at the joining position of hub to blades.

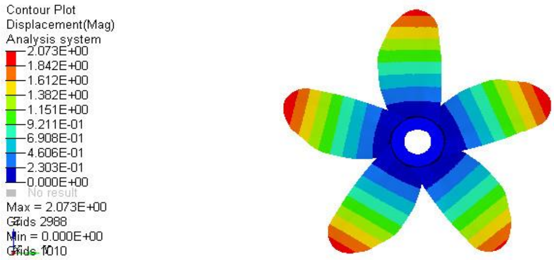

Fig 27. Deflection

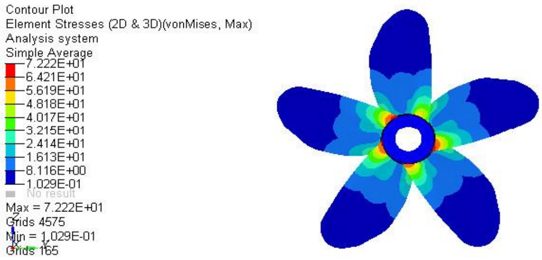

Fig 28. Vonmisses stress

12 layers

The maximum deflection 1.947mm was found at the tip of the blade and maximum vonmisses stress 75.44MPa was at the hub and blade intersection.

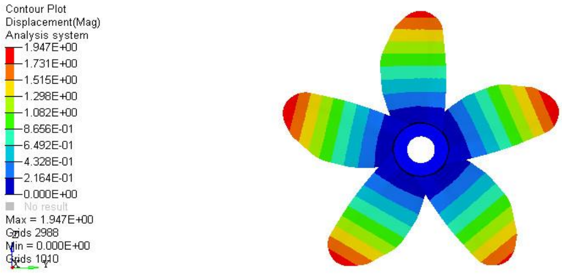

Fig 29. Deflection

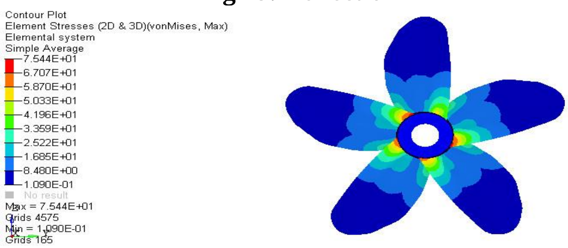

Fig 30. Vonmisses stress

Table 3. Static analysis results for different materials

MATERIAL	LAYERS (PLYS)	DEFLECTION MAX(mm)	VONMISSES STRESS MAX(MPa)
NAB		0.874	79.45
3 Composites (R glass +carbon ud/epoxy+s2 glass fabric)	3	4.350	116.2
	6	3.543	82.27
	9	2.580	65.47
	12	2.598	67.91
2 composites (S2 Glass +carbon ud /epoxy)	3	4.009	111.0
	6	2.413	78.70
	9	2.227	85.68
	12	2.120	87.61
2 composites (R glass+ carbon ud/ epoxy)	3	3.545	94.73
	6	2.276	73.66
	9	2.073	72.22
	12	1.947	75.44

Modal Analysis

The required boundary conditions were, the intersection of hub and shaft face was fixed in all degrees of freedom and mass density of material was given for extracting the first ten mode shapes of both NAB and hybrid propeller with different composite layers.

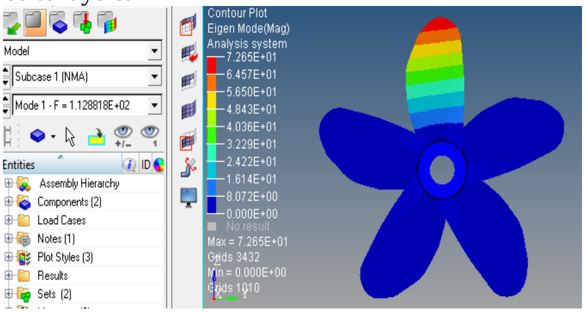

Fig 31. Mode 1 frequency for NAB

Table 4. Modal analysis results for 10 modes of frequencies

Modal Analysis		3 composites (R glass +carbon ud/epoxy+s2 glass fabric)				2 composites (S2glass +carbon ud /epoxy)				2 composites (R glass+ carbon ud/ epoxy)			
Modes (hz)		Layers				Layers				Layers			
	Nab	3	6	9	12	3	6	9	12	3	6	9	12
F1	112.88	108.34	118.14	135.18	135.50	113.67	143.09	146.81	150.76	117.29	144.73	149.13	154.34
F2	117.31	110.44	121.44	140.82	140.45	116.62	150.07	154.96	159.31	119.68	150.53	156.00	161.77
F3	117.75	110.57	121.61	141.09	140.72	116.76	150.36	155.28	159.65	119.82	150.83	156.34	162.14
F4	117.86	110.59	121.63	141.12	140.74	116.79	150.40	155.34	159.72	119.85	150.86	156.38	162.19
F5	120.25	112.43	123.71	143.67	143.23	118.86	153.28	158.35	162.84	121.87	153.64	159.31	165.27
F6	410.98	438.83	441.16	450.90	480.86	439.77	468.51	457.13	468.47	492.00	507.56	497.96	512.76
F7	415.36	438.89	441.51	454.38	485.41	439.87	471.58	461.40	473.02	492.09	509.79	501.95	517.27
F8	415.48	439.47	441.52	454.42	485.58	440.15	471.60	461.50	473.12	492.43	509.82	502.03	517.36
F9	415.73	440.14	441.94	454.51	485.74	440.41	471.98	461.66	473.32	492.74	510.12	502.08	517.42
F10	416.04	440.73	441.96	454.74	486.00	440.64	472.06	461.77	473.40	492.75	510.24	502.35	517.69

Mass Optimisation of Propeller

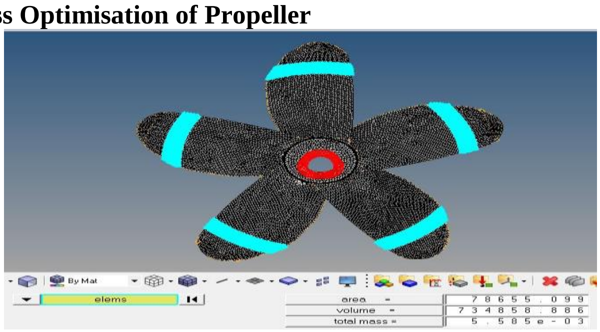

Fig 32. Mass of NAB propeller

Table 5. Mass of propeller with different materials

Material	Layers (Plys)	Mass of total propeller (Kgs)
NAB		5.585
3 composites (r glass +carbon ud/epoxy+s2 glass fabric)	3	2.848
	6	2.848
	9	2.848
	12	2.848
2 composites (s2 glass +carbon ud /epoxy)	3	2.816
	6	2.801
	9	2.806
	12	2.801
2 composites (r glass+ carbon ud/ epoxy)	3	2.879
	6	2.848
	9	2.848
	12	2.848

Conclusions

- In the static analysis, the NAB propeller shows the deflection 0.874 mm and hybrid propeller of 2 composites(r glass+ carbon ud/ epoxy) with 12 layers about 1.947 mm. Because the metallic propeller was higher resistance to deflection than that of composite.
- The composite was having shape adoptable property that's why it adopt its shape with continuous changing of loads by the tides on the sea. So the deflection was more in composite propeller.
- The NAB propeller has von-misses stress about 79.45MPa whereas the composite layered hybrid propeller of 3 composites(r glass+ carbon ud/ epoxy+S2 glass/epoxy) with 9 layers having 65.47MPa.
- In the modal analysis, nab propeller has natural frequencies of 10 modes from 112.88Hz to 416.04 Hz and the hybrid propeller of all layers having better results than NAB. In that 2 composites (r glass+ carbon ud/ epoxy) with 12 layers having natural frequencies from 154.34 to 517.69Hz for 10 modes.
- According to weight optimization, composite propeller has mass of 2.84 kg and it is lower than the NAB propeller of mass 5.58Kg.
- By considering all the analysis results, it can be suggested that the hybrid propeller of 2 composites(r glass+ carbon ud/ epoxy) with 9 layers having better deflection, von-misses stress, weight, and natural frequencies.

References

1. Study on performance of a ship propeller using composite material, Third International Symposium on Marine Propulsors smp'13, Launceston, Tasmania, Australia, May 2013
2. Structural analysis and design of a composite surface piercing propeller,14th European conference on composite materials 7-10 June 2010, budapest, Hungary
3. Development of a shape-adaptive composite propeller using bend-twist coupling characteristics of composites, Third International Symposium on Marine Propulsors smp'13, Launceston, Tasmania, Australia, May 2013
4. free vibration analysis of four bladed propeller using different materials, proceedings of 4th SARC International conference, 30th march-2014, Nagpur, India, Isbn: 978-93-82702-70-2
5. W.J.Colclough and J.G.Russel. "The Development of a Composite Propeller Blade with a CFRP Spar" aeronautical journal, Jan 1972, pp53-57
6. J.G.Russel "use of reinforced plastics in a composite propeller blade" plastics and polymers, Dec 1973 pp292-296
7. Christoph Layens, Frank Kocian, Joachim Haussmann. "Materials And Design Concepts For High Performance Compressor Components"
8. Ching-Chieh Lin, Ya-jung Lee. "Stacking Sequence Optimization of Laminated Composite Structures using genetic algorithm with Local Improvement". Composite structures 63(2004), pp339-345.
9. Gau-Feng Lin "Three Dimensional Stress Analysis of a Fiber Reinforced Composite Thruster Blade" the society of naval architects and marine engineers 1991 George W.Stickle and John L Crigler. "Propeller analysis from experimental data" report No.712, pp 147-164.
10. Analysis of Flow around a Ship Propeller using Open FOAM, Eamonn Colley, Supervised by Dr Tim Gourlay,October2012.