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UTILIZATION OF BEND-TWIST COUPLING TO IMPROVE THE PERFORMANCE OF HYBRID MARINE COMPOSITE PROPELLER

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ABSTRACT

Composite materials possess unique coupling effects when compared to monolithic materials. These coupling effects make a composite propeller shape adaptive or flexible in nature. The flexible marine propellers have number of advantages when compared to conventional rigid metallic propellers. Bend-twist coupling when linked to flexible behaviour will lead to performance improvement. In this work systematically designed hybrid composite propeller made of R glass roving UD/epoxy, S2 glass fabric/epoxy and Carbon UD/epoxy is analyzed for various stacking sequences and blade setting angles using fluid-structure interaction and response, performance curves are plotted between the rigid propeller and propeller made with different ply sequences. The effect of blade setting angle on the performance is also investigated. The results showed that well designed composite propeller will out-perform the metallic propeller.

Key words: Bend-Twist Coupling, Hybrid Marine, Composite material

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1. INTRODUCTION

1.1. Marine Propeller

A propeller is an interface between an engine and ship that creates thrust in the forward direction by effecting a net change in momentum to a propulsive fluid in the direction of motion. Propellers create thrust by introducing a small change in velocity to a relatively large mass of water compared to those of various jet propulsion devices. The blade shaping gives a radial twist which gives a local water angle of attack for each blade section at the design operation. Traditionally, marine propellers are made of manganese–nickel–aluminum–bronze (MAB) or nickel–aluminum–bronze (NAB) for their superior corrosion resistance, high-yield strength, reliability, and affordability. However, it is expensive to machine metallic materials into complex propeller geometries. Moreover, metallic propellers are subject to corrosion and cavitation damage, fatigue-induced cracking, and have relatively poor acoustic damping properties that can lead to noise due to structural vibration (Mouritz et al., 2001). Thus, there is an increased interest in the use of composites as alternate materials.

Composite materials have high-strength-to-weight and stiffness-to-weight ratios, which can lead to substantial weight savings. The use of lighter composite materials also means the blades can be made thicker and more flexible to improve the hydrodynamic performance by increasing the cavitation inception speeds. Moreover, composites can offer the potential benefits of reduced corrosion and cavitation 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 by automatically adjusting the shape of the blade. When the operating condition changes from the design values, the blade geometry becomes sub-optimal relative to the changed in flow. Consequently, the rotor efficiency decreases, and the rotor may be subjected to strength, vibration and stability issues. The effect is more severe when a rotor is operating in a spatially or temporally varying inflow.

Fiber-reinforced composites are extensively applied in various structures such as aerospace, renewable energy, and marine applications, because of its light weight, high strength and corrosion resistance, better fatigue characteristics, lower life-cycle costs.

In recent years, there has been an increased interest in the use of composite materials in a wide variety of marine applications to improve the performance of marine structures under a range of operating conditions. The inherent material and mechanical properties of composite structures, including but not limited to strength-to-weight and stiffness-to-weight ratios, anisotropy, and life-cycle costs, makes the use of composites for marine propellers a viable alternative to the metallic propellers that are currently prevalent. However, until recently, there existed very little simulation and design tools for composite propellers due to the lack of reliable manufacturing methods and lack of a large, systematic performance database [6, 7]. The weight savings can also allow for the design of thicker and more flexible blades that increase cavitation inception speeds. Most importantly, composites can be hydro-elastically tailored to optimize the energy efficiency of the propeller. A composite propeller can be designed to passively adapt to the changing environment (flow) by utilizing the load-dependent deformation coupling inherent in its anisotropic properties. The bend-twist coupling phenomenon is effectively used in [1, 2, 3 and 4] to improve the cavitation performance of a marine propeller. Different stacking sequences are chosen for analysis and optimum stacking sequence is presented for the chosen materials to give better open water performance.

1.2. Open Water Characteristics

A measure of the ratio of the axial velocity to the rotational velocity is defined as the advance coefficient :

$$J = (V_a/nD) \tag{1}$$

Where, D is the diameter of the propeller.

Thrust and torque of the propeller are expressed as

$$T = K_T \rho n^2 D^4 \tag{2}$$

$$Q = K_Q \rho n^2 D^5 \tag{3}$$

Where, KT is the thrust coefficient and KQ is the torque coefficient. Rearranging the above expressions:

$$K_T = T/(\rho n^2 D^4) \quad (4)$$

$$K_Q = Q/(\rho n^2 D^5) \quad (5)$$

The propeller open water efficiency is defined as the ratio of the thrust power to the power delivered to the propeller when working in open water with a homogeneous wake field and with no hull in front of it. The thrust power is the power delivered by the propeller to the water. The open water efficiency is expressed as:

$$\eta = (TV_a/Q\omega) = (J * K_T/2\pi K_Q) \quad (6)$$

The open water efficiency, thrust and torque coefficients are all non-dimensional parameters that are functions of the advance coefficient.

1.3. Present Work

In the present work, three composite materials are chosen for design and analysis of hybrid marine propeller. The properties of which are presented in table 1. Three blade setting angles used are 20^0, 25^0 and 30^0 degrees.

2. METHODOLOGY

In order to evaluate the performance of marine propellers, a series of coupled hydrodynamic and structural analyses are carried out. Coupled analyses are necessary as the fluid flow conditions around the blade and the resulting fluid pressures depend on the geometry of the deformed blade, while in turn the structural deformations and blade geometry depend on the fluid pressures. An iterative scheme is required to determine the equilibrium state at which the fluid pressures and the structural geometry are consistent for both the hydrodynamic and structural analyses, as shown in Fig 4.13.

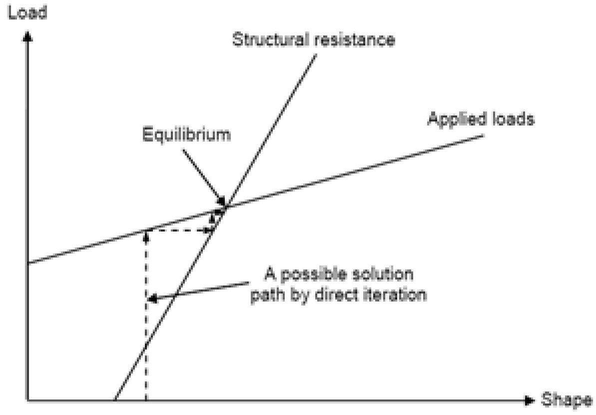

Figure 1 Equilibrium of applied loads and structural resistance [5].

The hydro-elastic model basically accounts for the fluid structure interaction (FSI). The displacement field, $\{d\}$, is determined using the finite element method in structural model, and the hydrodynamic pressure field, $\{f\}$, is determined using the finite volume method in the hydrodynamic model. The equilibrium between the hydrodynamic and structural forces is obtained by the hydro-elastic model. That is, the hydro-elastic model determines the displacement vector $\{d\}$ which satisfies the equation,

$$[K]\{d\} = \{f\} \tag{7}$$

Where, $[K]$ is the structural stiffness matrix which can be tailored by laminate lay-up sequence. The steps involved are: Transfer of surface pressure and viscous shear data from the hydrodynamic analysis to the structural analysis. The displacement field is determined by the structural model for the given pressure distribution. At the first iteration the pressure is that of the original blade. Structural analysis basically calculates the deformations and shape that result from the applied pressures and viscous shear stresses. Transfer of updated surface shape data from the structural analysis to the hydrodynamic analysis. The hydrodynamic model mesh is updated based on the displacement field determined in the previous step. The updated position of the section points on the hydrodynamic model is that of the closest node in the structural model. A new pressure field is determined from the hydrodynamic model based on the new shape. The new pressure field obtained from the hydrodynamic model is mapped onto the structural model. The process is repeated until the convergence is achieved and equilibrium is found, i.e. analysis is stopped when the propeller shape is the same (to within a small tolerance) from one cycle to the next.

3. RESULTS AND DISCUSSIONS

The open water characteristics as obtained from the above analysis are presented for the rigid, and three stacking sequences with the variation of blade setting angle. Three stacking sequences are chosen as follows, along with the values of bend-twist coupling coefficient and the corresponding twist angle in Table. 1. From fig 2, S2 has outperformed S1 and S3 with highest efficiency of 80%. For $\beta=25^0$, S2 has produced high efficiency compared to S1 and S3 as shown in fig 3. And finally for $\beta=30^0$, S2 efficiency is more compared to S1, and S3. This is because of the high bend-twist angle the S1 has produced as shown in Table1. This trend is observed for for S2 irrespective of stacking sequence as shown in fig 4,5,6,7 and 8.

Table 1 Stacking sequences for the analysis.

S.No		**K/b(GPa-m^3)**	$\boldsymbol{\theta_y, degrees}$
S1	$(45_{s2}/-45_{s2}/22.5_c/-22.5_c/90_c/45_c/67.5_{Rg}/0_c/67.5_c$ $/-67.5_{s2}/90_{s2}/60_{s2}/\overline{-60}_{s2})_s$	58.4	2.65548
S2	$(45_{s2}/-45_{s2}/22.5_c/-22.5_c/90_c/45_c/-45_{Rg}/0_c/67.5_c$ $/-67.5_{s2}/90_{s2}/60_{s2}/\overline{-60}_{s2})_s$	-8.12442	0.049097
S3s	$(45_{s2}/-45_{s2}/22.5_c/-22.5_c/90_c/45_c/-30_{Rg}/0_c/67.5_c$ $/-67.5_{s2}/90_{s2}/60_{s2}/\overline{-60}_{s2})_s$	13.47555	-1.52235

Beta=20^0

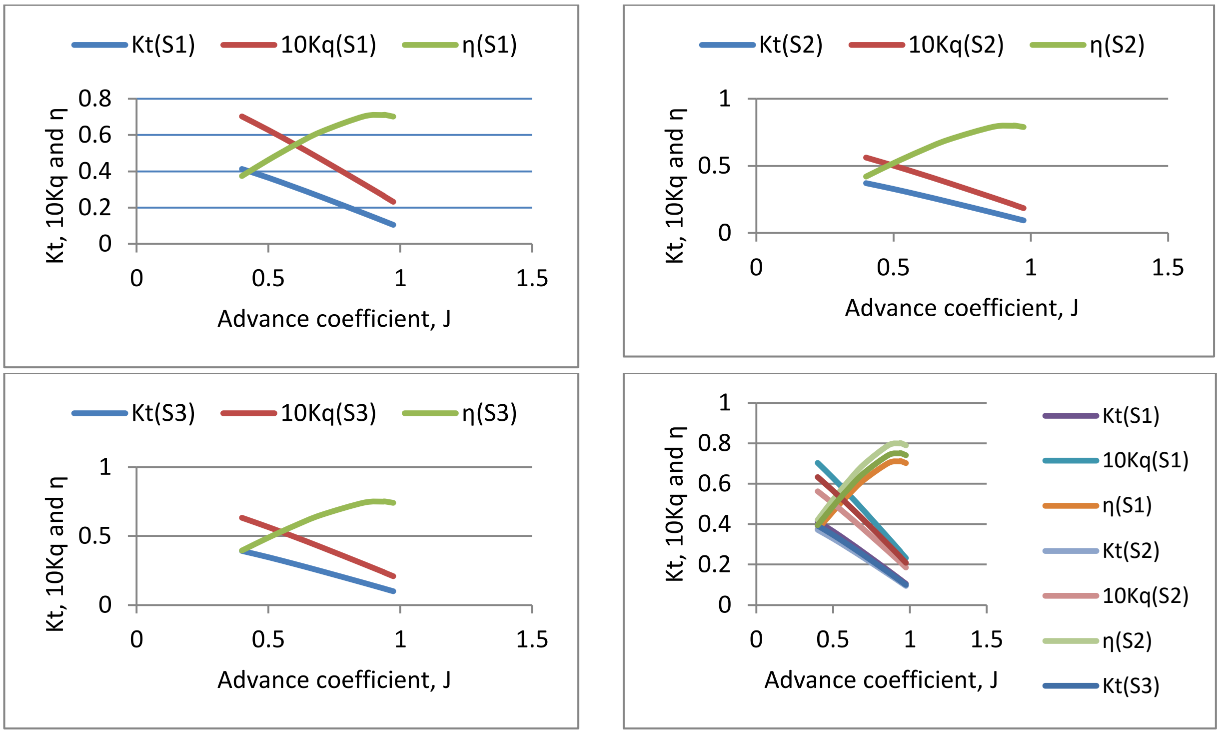

Figure 2 Comparison of open water characteristics at $\beta=20^0$

Beta=25^0

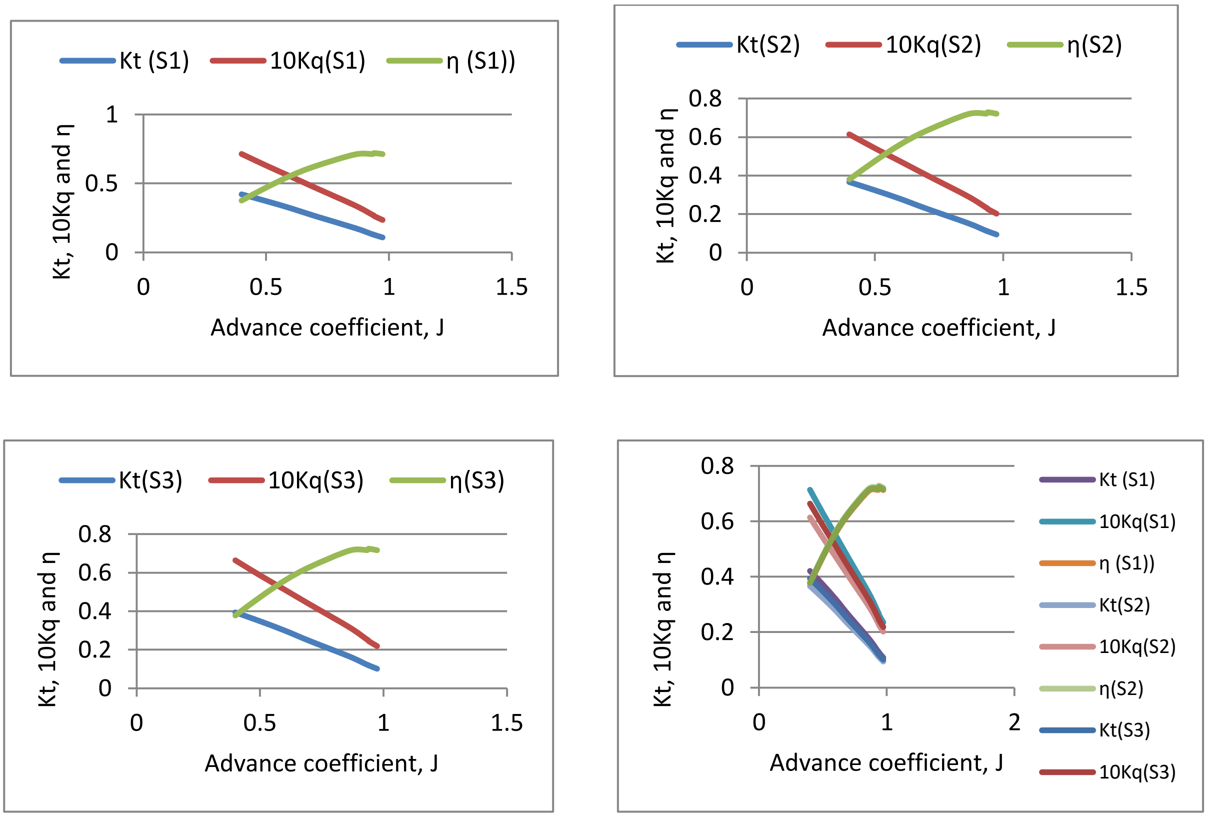

Fig 3. comparison of open water characteristics at $\beta=25^0$

Beta=30^0

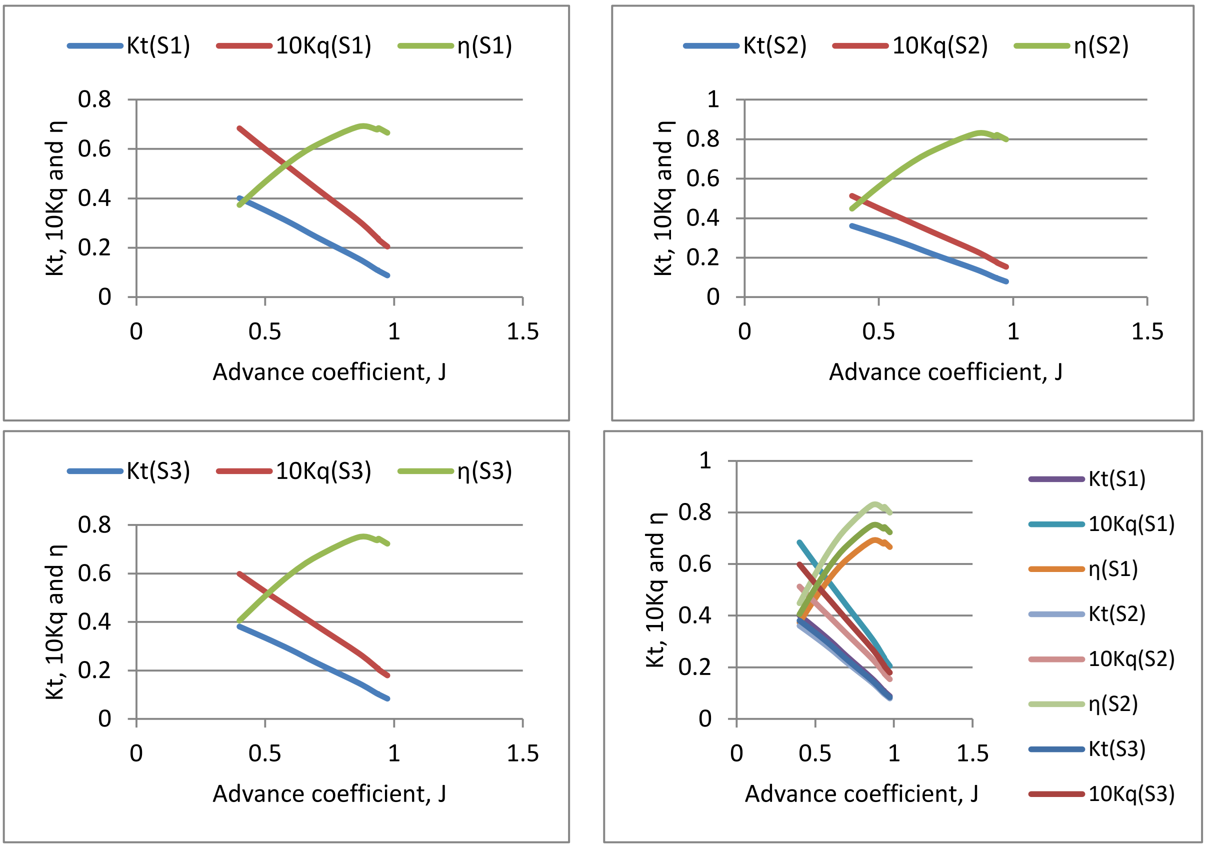

Figure 4 Comparison of open water characteristics at β=30^0

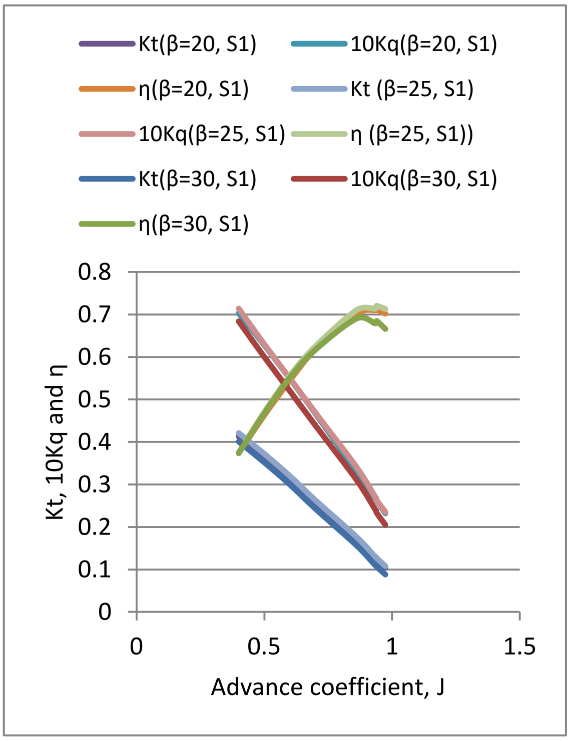

Figure 5 variation of open water characteristics with sequence 1, at different β

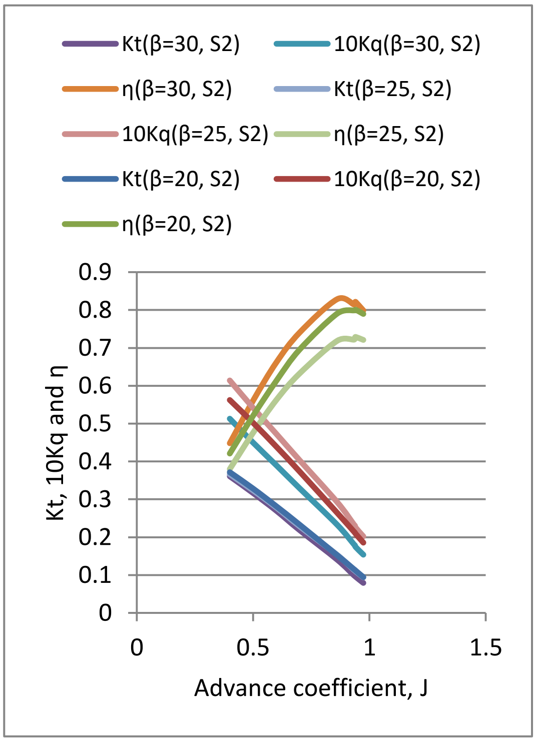

Figure 6 Variation of open water characteristics with sequence 2, at different β

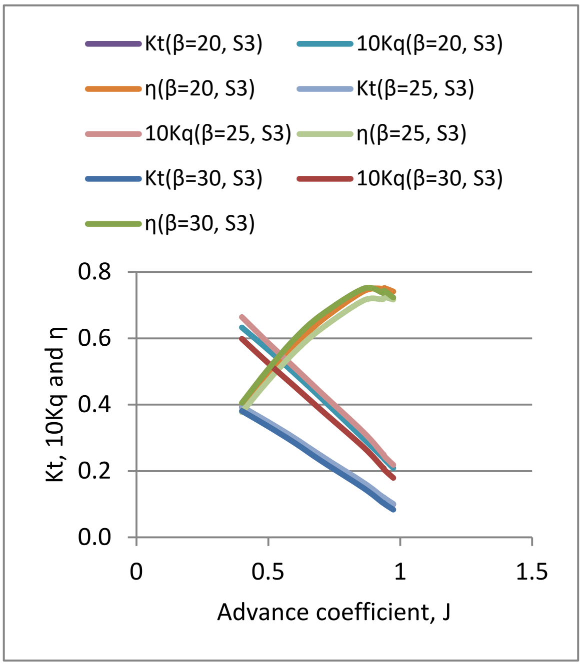

Figure 7 Variation of open water characteristics with sequence 2, at different β

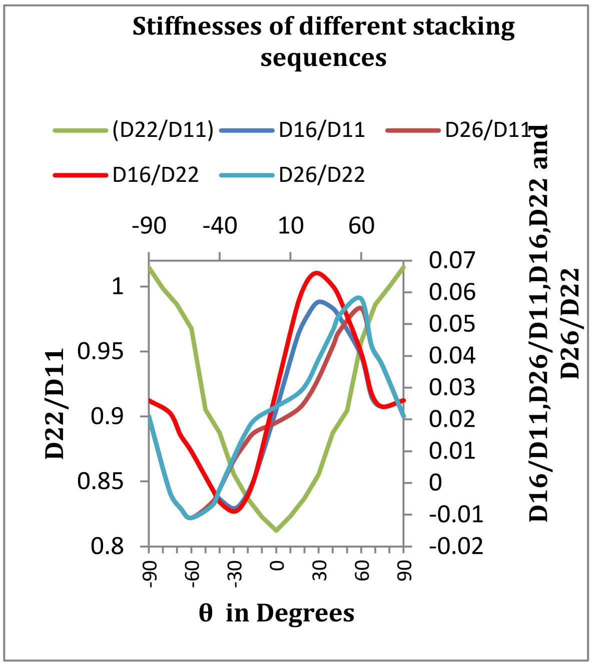

Figure 8 Stiffness variation with sequence

4. CONCLUSIONS

The results presented above, which are obtained through the two-way fluid-structure interaction have shown that properly designed hybrid composite marine propeller can replace a conventional metallic propeller as far as performance is concerned and other inherent advantages of composite materials. The bend-twist coupling effect will aid the designer in this direction which is evident from the results presented.

REFERENCES

[1] S.Solomon Raj, and P.Ravinder reddy. “Performance evaluation of composite marine propeller using L8 orthogonal array,” International Journal of engineering science and technology, Vol.3, No.11, November 2011.

[2] S.Solomon Raj, and P.Ravinder reddy., “Design of hybrid composite marine propeller for improved cavitation performance,” International Journal of Innovative Research in Technology & Science (IJIRTS), Volume 2, Number3, May 2014.

[3] S.Solomon Raj, and P.Ravinder reddy., “Effect of stacking sequence on the performance of a marine propeller”, International Journal of applied engineering research”, Vol.6, No.20, 2011.

[4] S.Solomon Raj, P.Ravinder Reddy, “Bend-twist coupling and its effect on cavitation inception of composite marine propeller”, International Journal of mechanical engineering and technology”, Vol.5, Issue 9, pp.306-314, 2014.

[5] Jose Pedro Blasques, Christian Berggreen, Poul Anderson., “Hydro-elastic analysis and optimization of a composite marine propeller”, Marine structures, Vol.23, pp.22-38, 2010.

[6] Y.L.Young, “Dynamic hydroelastic scaling of self-adaptive composite marine rotors,” Composite structures, Vol.92, pp. 97-106, 2010.

[7] Ya-Jung Lee, Ching-Chieh Lin., “Optimized design of composite propeller”, Mechanics of advanced materials and structures, 11, pp.17-30, 2004.