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Comparative fatigue life estimations of Marine Propeller by using FSI

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Abstract. Generally, inward and outward effects are huge and prime in the rotating components. Based on the working environments of a rotor, the complexity is increased furthermore. In this work also deals the same problem, which is fatigue life estimation of marine propeller for different materials under given Ocean environments by using Ansys Fluent 16.2. The conceptual design of the Marine propeller is modelled with the help of CATIA. Fatigue life estimation on the rotor is key and complex output of this work, advanced methodology is mandatory for computation therefore Fluid-Solid Interaction (FSI) technique is used as advanced numerical simulation. Fluid properties such as density and operating pressure are used to define the Ocean environment in the Ansys Fluent 16.2. In the case of structural simulation, the existing materials such as Aluminium alloy and Stainless Steel are used for fatigue life estimation. Finally, the fatigue life estimation of marine propeller is extended for Composite material to compare the life of a rotor.

1. Fatigue Life and its importance in Marine Propeller

Fatigue is one type of unavoidable complicated effect, which directly affects the endurance of engineering components. So the fatigue life estimations and its estimating methodologies are always considered as key components in structural analysis. Especially, fatigue is prime for complex working environments in the perspective high lifespan for successful mission execution [1]. The fatigue life estimation may provide the endurance of the mission and the corresponding mission's achievement based on the applied load and materials used [2]. In this work, Marine propeller is fundamental component, which is affecting from working conditional dynamic issues. Naturally, rotor is complicated component, due to its dynamic behaviour. Also, complex working environments such as sea water, heat might have provided the additional difficulties with dynamic behaviour in rotor. In hydrodynamics, blade profiles are considered to be an important component because of its critical design at different sections, weight, and the structural parameters with relatively high amplitude and high frequency [3]. Therefore the possibility of failures occurrence in marine propeller is quite high. In order to provide high efficient marine propeller with high lifetime, is compulsorily investigate the featuring creating factors of marine propeller [4].

2. Problem Identification and Solution Process

Naval propellers are critical in fluid structural behavior, which are characteristically using the water in order to produce thrust. Due to the effect of hydrodynamic loads acts in the propellers may cause to fail at unpredictably high an amount, which makes fatigue analysis as important factors in its performance [5]. Life-cycle estimation of naval propellers is crucial to develop their design and maintenance process, since they should have more lifespan with minimum foreign object disruptions as well as low probabilities of failures. Hence the prediction of fatigue lifespan is becoming an essential part of the design process and blade material selection [6]. Generally, the fatigue life of naval propellers depends on a large number of variables, stress state, mode of cycling, and environmental conditions [7].

In this work, fatigue life prediction of naval propeller is estimated using numerical simulation for two different cases with one way coupled environments. External load estimation through ANSYS Fluent is one case and another one is structural analysis on marine propeller with implementation of transferred load [8]. The pressure variations on the marine propeller, safety factor, damage factor, fatigue life factor are estimated with the help of advanced numerical simulations. The reference component of this work is modeled by using CATIA. Numerical results of this marine rotor are analyzed using ANSYS Workbench 16.2, in which the implementation of external load from ANSYS Fluent is plays a key role in the reliability of outputs. For both the cases length wise distribution of life estimation and a safety factor of naval propeller are plotted with the help of principal stresses for the given boundary condition [9]. The standard approach followed in this work is numerical simulation of Fluid-Solid Interaction (FSI), which comprises of the physics behind the fluid interaction and its effect on the naval propeller blade design for understanding the importance of its design. The complete development process is shown in the figure 1.

2.1. Development Process

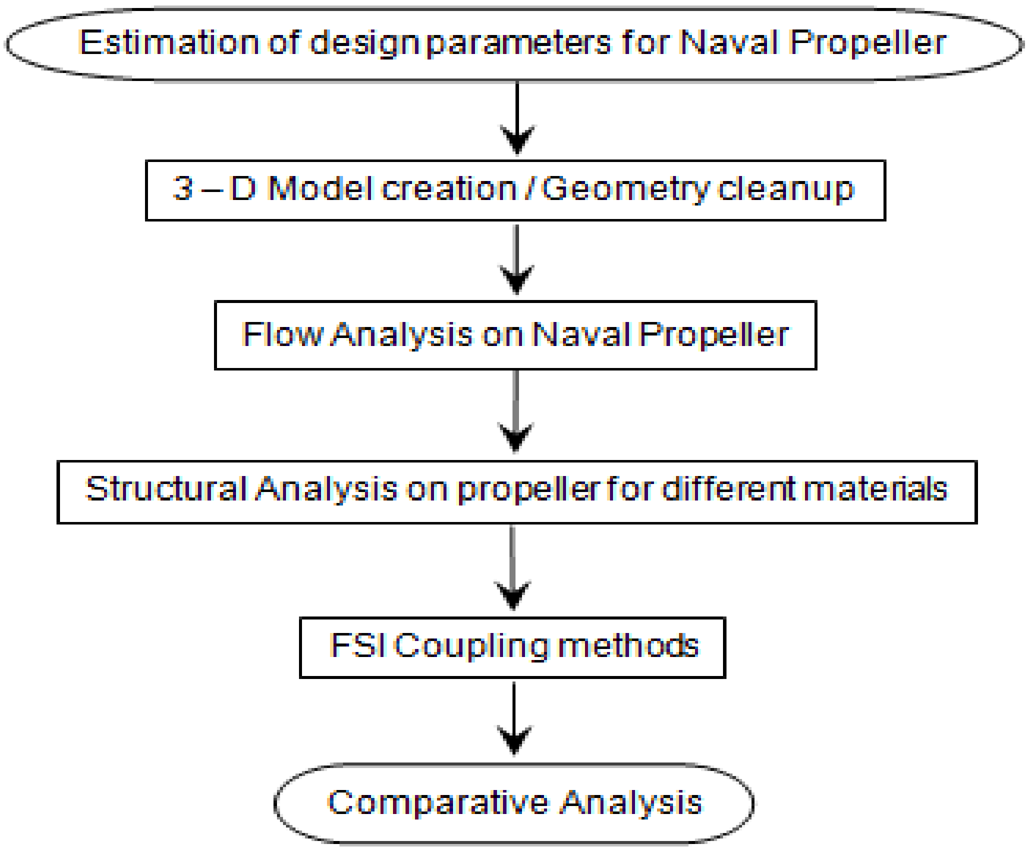

Figure 1. Development process

3. Fluid – Solid Interaction (FSI) Results

Composite materials are unique, in the perspective of dealing complicated problems in an error free manner. So in this work it is suggested to include composite material as one for Marine propeller and there by comparative analyzes are executed between composite material and the existing materials for Marine propeller [12]. Fatigue is a structural parameter which needs a preliminary data to estimate its life for real time applications [11]. The data includes maximum stress with its number of cycles, which are easily available for ductile and familiar materials like aluminium, alloy, stainless steel, etc. while in composite case the structural parameter such as stress, deformation are easy to evaluate but safety factor, damaging factor, fatigue life are very tough to evaluate because of its lack of preliminary data [13]. In this work the preliminary data is obtained from reference [17], which deals the experimental analysis on GFRP. Glass fiber based composites are more capable tackle tough environment, such as tensile load, rotational load, impact load and electrical load. Therefore GFRP is more suitable to use as a working material of slip propeller.

The GFRP laminate properties are extracted from previous work [17] and implemented in composite Marine propeller for fatigue life estimation, in which poison ratio, Young's modulus and density plays a predominant role [14]. Apart from mechanical properties, support reactions and external load details are very important in structural analysis in order to complete the process in a successful manner. Fixed supports are vital in the stress generation of a component by its reactions. Nature of this work in equipped with fixed supports at the hub of marine propeller [15]. So in fatigue life simulation, fixed supports are given primary role and provide in the appropriate place of the marine propeller. Finally the structural outputs are varying each and every object due to its external environmental loads, in this case hydrodynamic loads is severely affecting the performance of a Marine propeller. Generally load extraction from hydrodynamics is a complicated one in computational analysis, which is executed with the help of ANSYS Fluent 16.2 for the velocity of 30 m/s. Therefore in this work fluid-structure interaction is implemented in order to extract hydro-fluid load perfectly. Naturally, load transformation between fluid and solid environment is a tough process. In this work ANSYS is used for numerical simulation, which has advanced technique to link and share the data between solid and fluid environment, which is called coupling. Generally two types of coupling are available in numerical, which are one way coupling and two way coupling. One way coupling is used in the case for external load from fluid environment to solid environment [16].

3.1. 30 m/s forward velocity- Flow Analysis

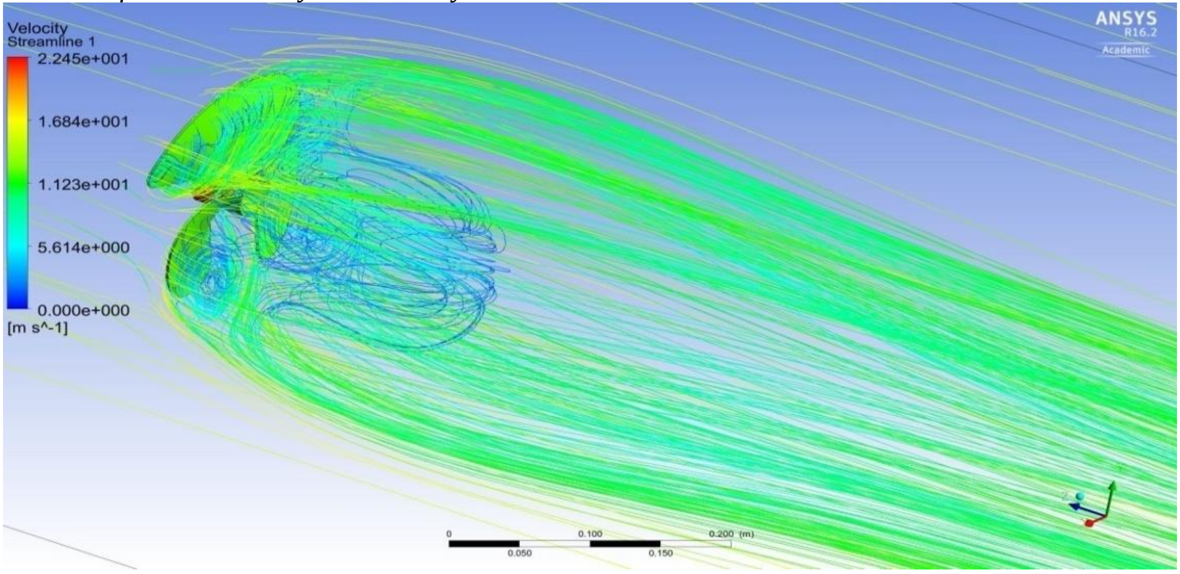

Figure 2. Velocity variation on the Marine Propeller – back side

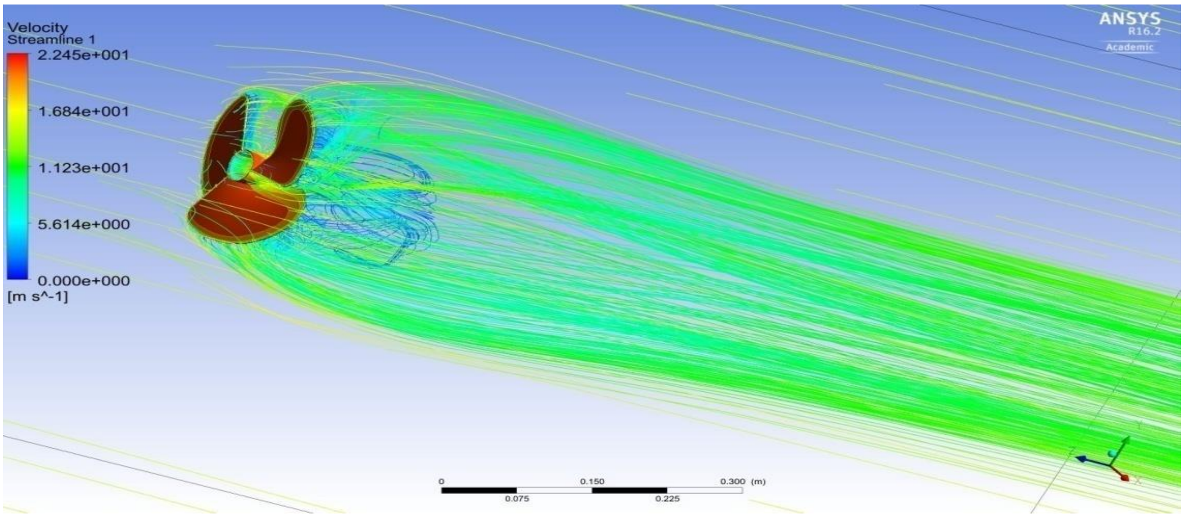

Figure 3. Velocity variation on the Marine Propeller – front side

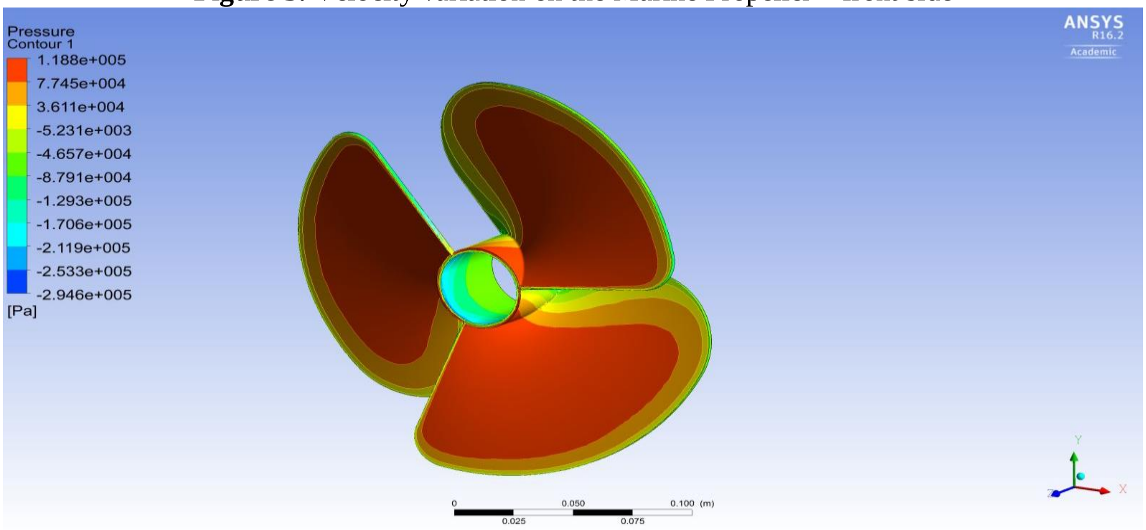

Figure 4. Pressure variation on the Marine Propeller – front side

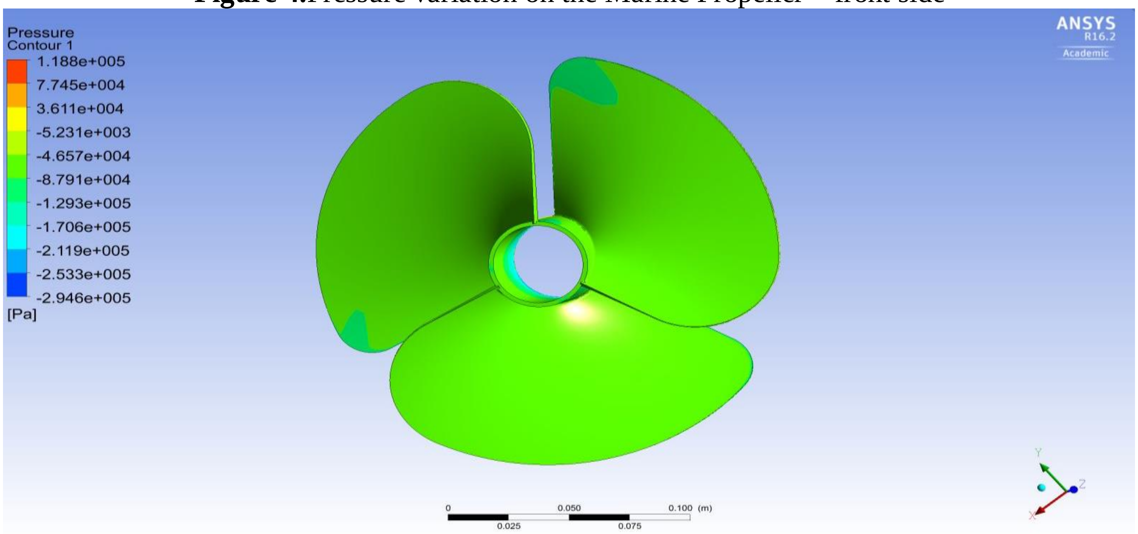

Figure 5. Pressure variation on the Marine Propeller – back side

The velocity and pressure variations are revealed in the various perspectives in figures 2 to 5.

3.2. Structural Results:

3.2.1. Aluminium Alloy

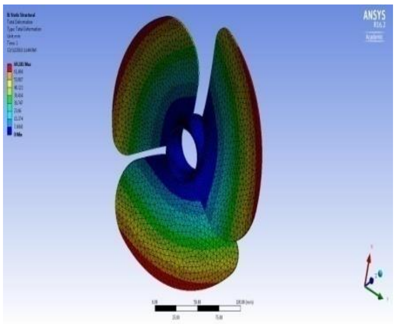

Figure 6. Total Deformation

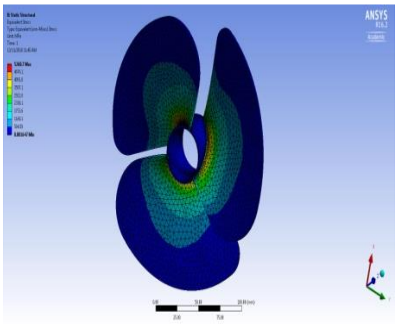

Figure 7. Stress variations

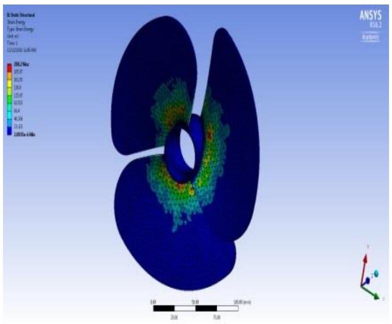

Figure 8. Strain Energy

Total deformation, stress variations and strain energy distributions of Aluminium Alloy's marine propeller are shown in the figures 6, 7 and 8 respectively.

3.2.2. Stainless Steel

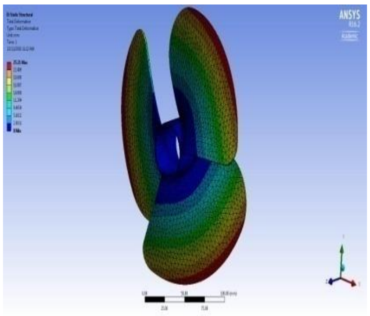

Figure 9. Total Deformation

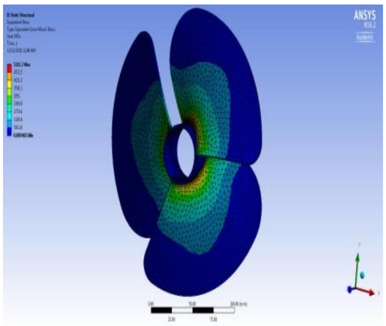

Figure 10. Stress variations

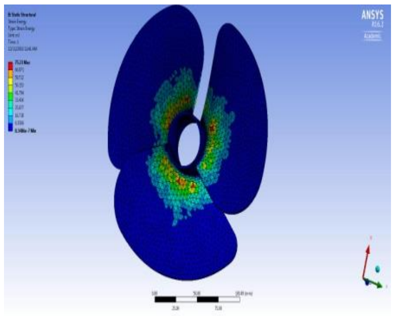

Figure 11. Strain Energy

Total deformation, stress variations and strain energy distributions of Stainless Steel's marine propeller are shown in the figures 9, 10 and 11 respectively.

3.2.3. GFRP

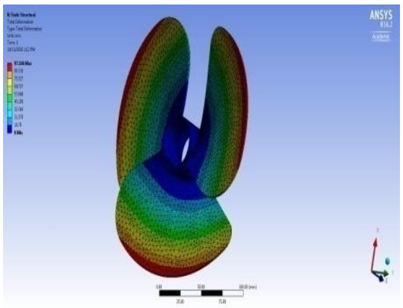

Figure 12. Total Deformation

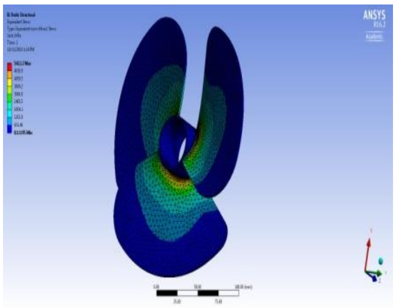

Figure 13. Stress variations

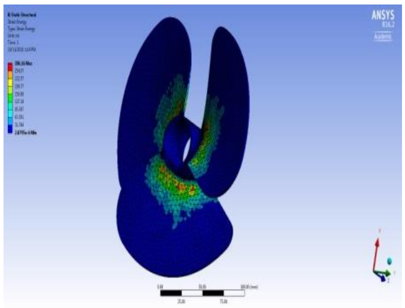

Figure 14. Strain Energy

Total deformation, stress variations and strain energy distributions of GFRP's marine propeller are shown in the figures 12, 13 and 14 respectively.

3.3. Fatigue life estimation

3.3.1. Aluminium Alloy

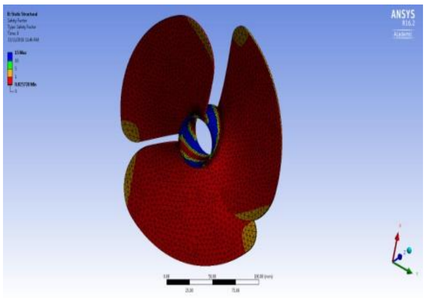

Figure 15. Safety Factor

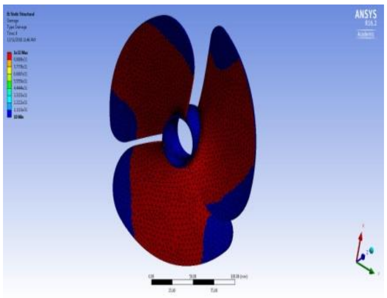

Figure 16. Damage Factor

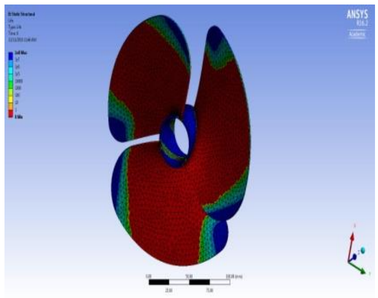

Figure 17. Fatigue Life

Safety factor, Damage factor, and fatigue life variations of Aluminium Alloy's marine propeller are shown in the figures 15, 16 and 17 respectively.

3.3.2. Stainless Steel

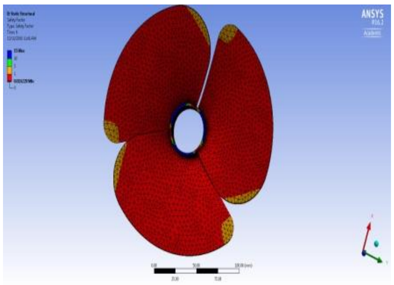

Figure 18. Safety Factor

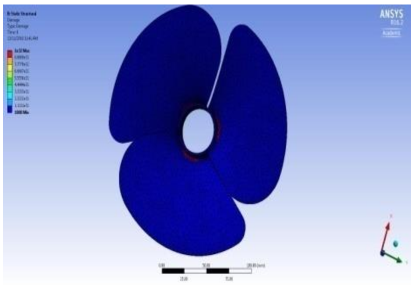

Figure 19. Damage Factor

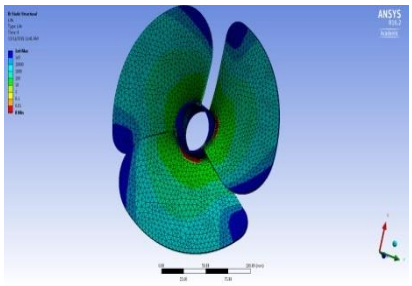

Figure 20. Fatigue Life

Safety factor, Damage factor, and fatigue life variations of Stainless Steel's marine propeller are shown in the figures 18, 19 and 20 respectively.

3.3.3. GFRP

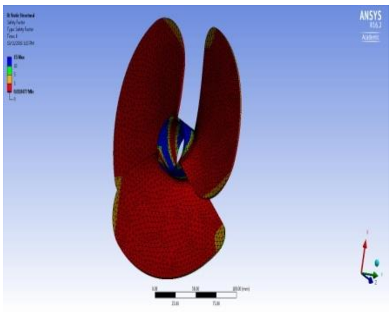

Figure 21. Safety Factor

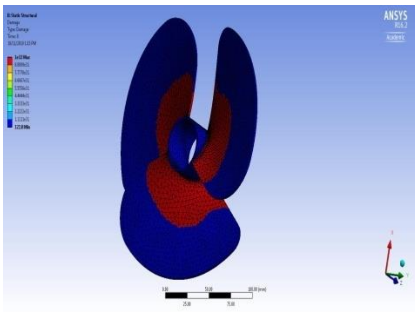

Figure 22. Damage Factor

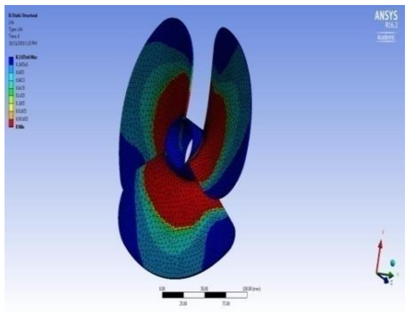

Figure 23. Fatigue Life

Safety factor, Damage factor, and fatigue life variations of GFRP's marine propeller are shown in the figures 21, 22 and 23 respectively. The comparative analyses are carefully noted and listed in table 1. From the table 1, it is understood that, the fatigue life and structural parameters are quite high in aluminium alloy but the same evolution parameters are nearly same for steel and GFRP materials. Therefore in general, stainless steel is good for the construction of marine propeller. But each and every process in the complicated working environments, have integrational effects so comparatively GFRP is having higher strength to weight ratio than stainless steel. Finally, GFRP is more suitable to work as constructional material of marine propeller [17 – 20].

Table 1. Comparative Analysis

Materials Name	Deformation (mm)	Stress (MPa)	Fatigue Life	Damage Factor	Safety Factor
Aluminium Alloy	69.181	5260.7	$1xe^{8}$	$1xe^{32}$	15
Stainless Steel	25.21	5311.7	$1xe^{6}$	$1xe^{32}$	15
GFRP	97.106	5412.2	$8.1435xe^{6}$	$1xe^{32}$	15

4. Conclusion

The numerical analyses on dynamic conditional based problems such as rotodynamics, hydrodynamics, etc are extremely complicated for the solution, which is completed in this work with the help of ANSYS FSI facilities. Conceptual design of marine propeller is the base for FSI analysis, which requires a lot more attention in order to construct a perfect model for numerical simulation. In this paper a design tool, CATIA is used, which is equipped with advanced complicated facilities such as user friendly profile implementation, advanced curved operations, etc. The fine and unstructured meshes are used for the capturing of this marine propeller, which is one of primary factors to provide acceptable solutions. Finally, the coupled FSI analyses on marine propeller are executed for various existing materials such as Aluminium alloy, Stainless Steel. At last, the FSI analysis is extended to marine propeller made-up of GFRP and then comparative analyses are completed. From the various advanced results, it is understood that GFRP based composites are more suitable for marine propeller.

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