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A Review on Recent Development in Advanced Composite Marine Propellers

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Abstract: The present status of research and technological development in the field of composite marine propeller. There is an increasing interest in the marine industry to use composite to improve the hydrodynamics and structural performance of naval structure. Composite materials have high strength to weight and stiffness to weight ratio. The use of composites considerably increased to optimize the physical and organizational reliability of such sea vessels and decrease the expense of establishment and utilisation.
Keywords: Propellers, Composite Materials, Marine application, Material properties.

I. INTRODUCTION

The life quality is significantly influenced by our circumambient material. It might be said that this period is the era of ersatz materials, in which our economy and culture require ever- contemporary materials. The development of connecting materials and renewable energy sources are taken into account due to the diminishing availability of fossil fuel energy supplies. Industrial resources are divided in three distinctive groups by advanced life science, including Alloys, Ceramics, as well as Polymers. Such elements are blended to create composites that incorporate the advantageous characteristics of each element. [14, 20-22]. Synthesised composites are oftenly considered as a structural member under which the potent reinforcement as well as the resilient matrix phase adhere well. Such qualities could be attained via the use of advanced materials that are not possible in absence of the mixture of constituents. [5]. High strength-to-weight ratio is required, advanced materials have a plethora of technological implementations. [20], inexpensive, and simplicity of manufacture are needed. In reality, using composites instead of metals for some applications has led to reduction in weight and reduction in costs [18]. Composite materials have revolutionised structural development today. The development of composite materials must have allowed different architects to employ advanced and improved materials, which has reduced costs, improved efficiency, and improved usage of resources. Many technical constructions, including aerospace, aviation, vehicles, watercraft, sporting goods, structures, and skyscrapers, utilise composite materials in enormous quantities [18, 19]. The conglomeration optimizes the resistance to attrition and degradation. [20] The key factors in a tribological evaluation are fibre diagnosis, alignment, and mass. To acquire a superior erosion characteristic, fibre alignment is recommended opposite to the sliding direction. The adhesive power between the fibre and matrix has a big impact on erosion. In order to increase the bonding property in between the fibre and matrix contact and prevent the presence of humidity in the fibres, chemical investigation is required. [1]. Progress has been made as a result of enhanced composite processing and fibre identification, separation, processing, and interfacial development. Tensile strength and impact strength ratings for composite materials are now on par with those for glass fibre reinforced fibres in terms of stiffness and expense. Composites lesser densities enable more accurate comparisons of certain attributes. Composites are now used in a extensive of load-bearing and exterior activities, such as load-bearing maritime constructions and automobiles exterior under floor panelling. To increase their applicability, including moisture and flame retardance, more study is still needed. In general, the use of composites is expanding quickly, and it would seem that their application has a bright future [2]. War was a major catalyst for many of the biggest composites developments.

In the majority of situations, substituting superstructure, parts, and equipment made from metal and its alloys using modern synthesized material has been a challenging and time-consuming procedure. Metals excel in the majority of applications. Metals are a material that architects, manufacturers, and users feel quite secure and experienced with. Thus, composites are only likely to replace metal in areas where they have a great ability to lower gain and on-going operational expenditures and increase ship accuracy and reliability [3]. Alternative materials were needed for light weight applications in military aircraft. Engineers soon realized other benefits of composites beyond being light weight and strong.

It was discovered that fibre glass composites were transparent to radio frequencies, and the material was soon adapted for use in sheltering electronic radar equipment [17]. Carbon fibres were also developed around this time, it has since been replacing metal as the new material of choice. The composites sector is continually developing, with the whole of the expansion being concentrated, which are continuously pushing the boundaries of size and necessitating cutting-edge production processes, materials, and designs [12]. Every substance maintains having unique molecular, structural, as well as dynamic characteristics, unlike metal alloys [6].

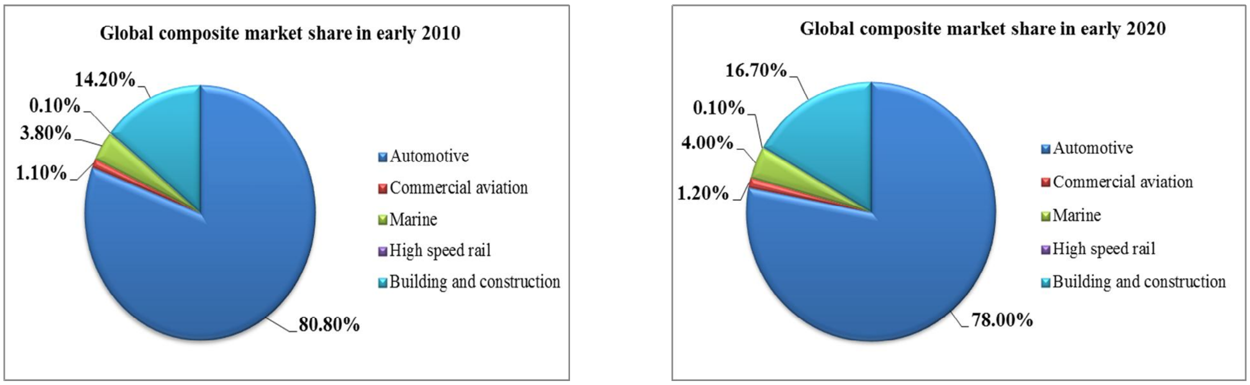

Figure 1 Composite Material market share

Wide spread use of composite materials in industry is due to the good characteristics of its strength to density and hardness to density. The utilization span of such materials has expanded due to the potential for improving these properties utilising cutting-edge technology and different manufacturing processes [15]. The stress strain curve for a composite lies in between the stress strain curves of the fibres and matrix. The comparative volume percentage of the parts will determine the precise position of the composite stress-strain graph line. The composite stress-strain graph will resemble the fibre stress-strain graph if the fibre volume percentage is large [16]. On the other hand the composite stress–strain curve may be closer to the matrix stress-strain curve for a higher matrix volume fraction [10].

Natural material fibres were the first composite materials, and they have existed for millennia. these fibres grown through importance within the thrift and have really shown to be a substantial sector for emerging nations. Because they are biocompatible and regenerative, such fibres have become regarded as ecologically friendly resources. [4]. these fibres for instance, are proven to be effective support in thermoset and thermoplastic composites. The composite are materials that comprise strong load carrying material imbedded in weaker material. In order to support the imposed loads, reinforcement offers strength and stiffness. The matrix or binder maintains the positions and orientation of the reinforcement. Significantly, constitutes of the composites retain their individual, physical and chemical properties, yet together they produce a combination of qualities which individual constituents would be incapable of producing alone [23]. The development of sophisticated engineering materials has been facilitated by decreased weight and improved performance characteristics. Composite materials may be manufactured into intricate and massive forms and have high mechanical characteristics to weight ratios. In addition to cost savings, enhance elastic properties, decrease mould distortion, and offers a finer texture, granules were incorporated to a polymer composite. . Because of environmental and financial advantages, the usage of natural fibre composites is being explored in a wide range of industries. The most widely used meaning is the following one, are multifunctional material system that provide characteristics not obtainable from any discrete material. These cohesive constructions by physically fusing two or more materials that are compatible yet differ in composition and properties.

II. COMPOSITE DEVELOPMENTS IN NAVAL VESSEL

The first impetus for the use of composites in naval crafts sprang from the requirement for sturdy, dependable, lightweight navy vessels. The majority of these early uses were motivated by the desire to combat corrosion issues by steel or aluminium alloys or the ecological degradation of wood. The use of composite materials was also done to lighten ships overall topside mass. Due to their great acoustic permeability, composite materials are also used in undersea sonar domes and rodomes on ships [17]. A variety of naval constructions are now being created utilising fiber-reinforced composites. To improve sustainability performance, there is a requirement for this advancement but the same time reduces the ownership cost of warship and submarines.

For several decades, composite materials were utilised for just few quasi maritime constructions in tiny rafts, however they are currently being investigated for a vast scope of maritime applications. Fatigue parameters serve as a significant predictor for such ultimate limit of maritime constructions susceptible to external fatigue loading, and are now taken into consideration by the developer at the same time. Despite such benefits, it wasn't always easy to implement composite material in warships. Heavy construction and materials prices were a significant barrier, albeit they could be compensated for by cheaper maintenance expenses. Other issues include flame retardancy, submerged damage, impact loads, and endurance under air stream. When contrast to metal building components, the cyclic design approach for composite is currently constrained by the lack of existing techniques and the inadequacy of existing theories to accurately predict the cyclic behaviour. Though various composite materials provide a distinct structural behavior, strict fire safety evaluations are currently a top focus. Big commercial vessels are now allowed to employ composite materials according to International Convention of SOLAS when it is easy to present an equivalent level of safety beneath individual item and management. The collection of fluid at the junction can considerably cause stress oxidation reactions that contribute to the collapse of the fibres [35]. After the Second World War, composite materials were initially utilised to build tiny personal vessels for the American defence force [3]. tugboats, liquid cargo ships, luxury cruise yachts, dry cargo ships and warships are among the several types of ships [24]. In the production of numerous structures, like as optical devices, wingtips, stabiliser tips, antenna coverings, and flight controls, fibre reinforced polymers are widely employed [29]. A huge advancement in watercraft construction was the arrival of sophisticated lightweight composite materials. The development of rigid yet compact constructions with the use of composite mechanics has greatly enhanced production efficiency and improved sailing effectiveness with professional career. Moreover, the use of matrix composites has decreased the costs, bringing the finished product available to a broader audience by automating and accelerating production process [36].

A substance like a sandwich is reinforced plastic composite consists of a central layer and two outside facings. The facings are constructed of many layers of laminates that are joined by a liquid resin. A honeycomb makes up the core material. Small speedboats and support ships were the first objects made of composite materials. These naval vessels were constrained by the low sternness of the hulls and the comparatively poor manufacturing quality. Big naval ships, boats and corvettes are among the latest inventions made possible by minimal composites enhanced architecture, construction, and dynamic characteristics. Although spans have continuously risen over period of time and automation has advanced, it is possible that, starting around 2020, the bodies of semi battleships like freighters are made of composite materials. When a commerce ship is in port or while dry-docking, repairs are typically made via welding. Yet, because welding includes hot-work, repairs for floating offshore units must be made on the spot, necessitating the suspension of some areas of the vessel for safety concerns. Production will be interrupted, and this will be an expensive task. To get around the risks of hot-work connected with welding, adhesive composite modifications can be employed. Patches made of strong fibre composite material are sealed over the flaw, restoring the existing structure's soundness. The ability of composite remedies to adapt to almost any underlying architecture, effortlessly conform to complicated geometries, and squeeze into small spaces makes them appealing as well. Additionally, the anisotropic of composite materials allows for flexibility in design, which helps to optimise costs and performance. Typically, large structural steel panels with a very high critical crack size are used to build marine constructions. A restoration that is efficient at bridging and alleviating the pressure there at point of an expanding fracture is frequently quite simple because of the large critical crack size

TABLE I
COMPOSITE NAVAL APPLICATION

Mine sweeper	Landing craft reconnaissance
Landing craft	River patrol boats
Personnel boat	Crew shelters
Submarine fins	Rope guard
Torpedo tubes	Rudders
Hatch cover	Pilot boat
Submarine sonar dome	Submarine non-pressure hull casing

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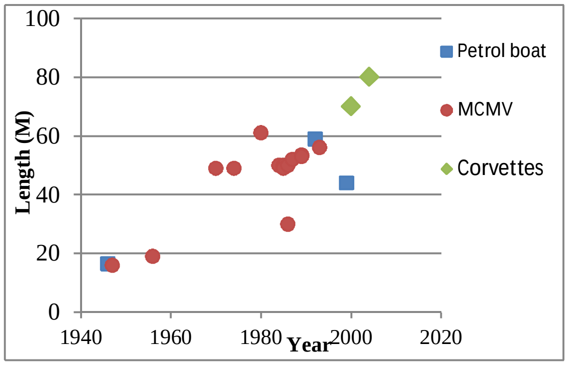


Figure 2 Composite vessel in length Vs year of construction.

Prolonged ships presently constructed of FRP composites are corvettes. The versatile corvettes, created by a Swedish Navy as part of the YS-2000 program, are a great illustration of how composite materials may be used under this context. Visby was among the biggest ships in the navy, measuring 72 meters long, 10.4 metres in breadth, and 620 tonnes when fully loaded. It was created for missions involving anti-submarine warfare, minesweeping, combat, observation, and countermeasures. The Visby corvette had been totally constructed out of sandwich panels reinforced with carbon as well as glass and a vinyl resin matrix. whereas the price of Compared to glass, carbon fibres are five times higher in price. preventing one‘s use for the huge military constructions, this was discovered that utilising some carbon fibres of the reinforcement, in addition to providing appropriate electromagnetic barrier protection, limited the mass of the hull by almost 30 percent without substantially raising the cost of production. The losing weight made possible resulted in less gasoline being used.

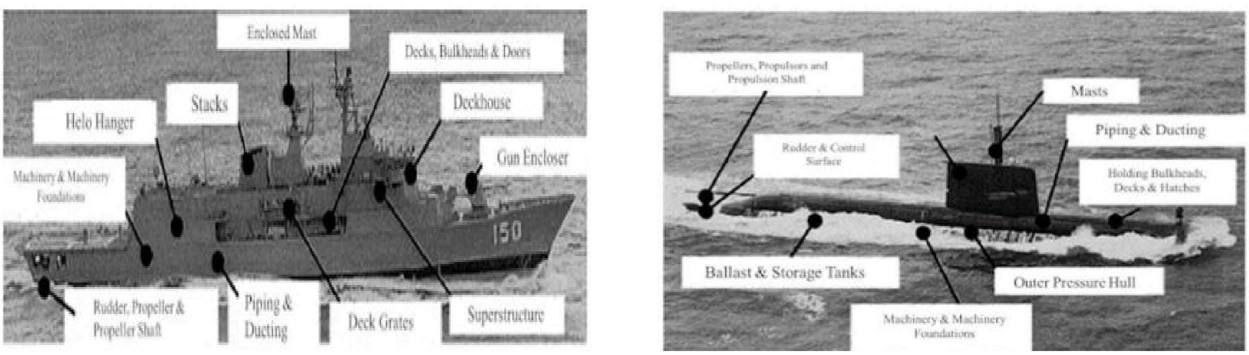


Figure 3 Composite structures in ship and submarines.

Presently the composite ships that are up to 80 to 90 meters long since of technological advancements as in creation and production of composite materials. Utilizing slabs of both reinforcement and matrix, this construction is totally made of composite materials. In fact, ultralight composites offer durability, endurance to submerged seismic energy, and low magnetic capabilities.

The marine sector is going through a phase of change with long-term milestone of being a minimal emmission sector. Moreover, several advancements in use. These innovations, that are predominantly mechanical by nature and mix seamlessly with the benefits of automation and digitalization improve the performance of vehicles and consequently lower overall pollutants. Modern technology and statistics which provide every corporation the advantage are seldom disclosed in the highly competitive marine sector, and after they are, it occurs extremely covertly [37].

III. AN OVERVIEW OF PROPELLER

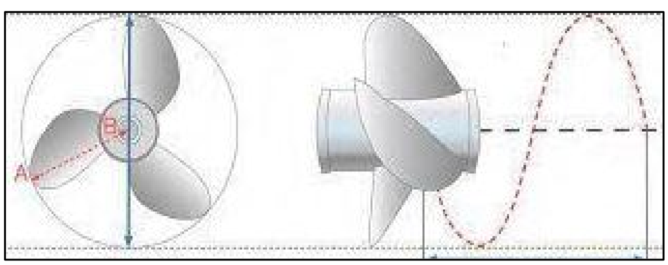
For underwater vehicles the main criteria in selection of the material depends on its strength, stiffness, weight, thermal expansion and corrosion resistant to seawater. The material used for the manufacturing of propeller depends upon the strength, ease of manufacturing, production methods, environment, and weight. The material used for propellers must be light, strong and ductile, easy to cast and machine, and resistant to erosion and corrosion. The ship propellers also manufactured by using commercially available materials. driveshaft, several joints and lastly with the rotor it's own, the pressure out from rotor is communicated effectively to propel the vessel.

The manoeuvring system includes the rotor, which is crucial. The effort to accomplish not just only a high degree of efficiency yet also a great level of consolation, the rotor must be thoroughly developed in combination with every unique vessel.. A propeller's efficiency as well as stability are closely coupled, it plays a significant part in the design phase. Propellers are made to provide optimum efficiency with the least amount of cavitation and surface vibration in the majority of conditions. The push required for vehicle motion is produced by the propeller's spinning. This is the primary cause of the blade building's fragility, including blade surface erosion, decreased blade thicknesses, and pitching surfaces. Due to this, there was a strong cavitation flow on the surface of the blade, which increased the possibility of an imbalanced force developing at the conclusion of propulsion [28]. The influx angle is nearly equal to the pitch angle when the vessel is sailing at its intended speeds. The influx angle is narrower whenever the ship is sailing at a slower pace. Consequently, when the vessel's speed drops, the force on the rotor rises [30]. The stress with high intensity is placed on the propeller's interior structure, thus it's critical to research and evaluate any outside influences on the propellers. Because of the intricate geometry of a propellers, it is required to study the effects using a useful numerical technique [38] Simulations may be employed to forecast the functioning of blades as well as the circulation surrounding them. Consequently, statistical analysis can finally be accomplished more quickly and cheaply than trial thanks to the ongoing development of the forecast of blade efficiency [41].

A hydrodynamics of the propeller, the top and bottom velocities of the hydrofoil move at separate rates. In a hydrofoil, the fluid moving through top moves more quickly than the fluid moving through bottom. This is caused by the difference in pressure between the higher and lower fluid flows. As is well knowledge, the relationship between pressure and speed is inverse [34]. The propeller design usually starts with determining the main particulars such as diameter, mean pitch, blade area. The propeller is determined by the number of blades, its diameter and its pitch and the direction of rotation. The 3-blade propeller is most often used, but the same definitions are valid for the 2-blade, 4-blade and multi-blade propellers [13].

The combined forces at work, termed as a centrifugal force as well as twisting force will have an effect on the design of the rotor in terms of flexural and fracturing [45]. The hub experiences the greatest stressors. The rotor's tip experiences the least amount of force. The strains are dispersed throughout the span's whole length [51]. The propeller torque, thrust and centrifugal forces exerted across each blades as a result of the propeller's rotation around its center all contribute to the forces exerted on the blades of the propeller. The fairly complicated design of propeller blades makes it quite challenging to calculate the stresses brought on by these forces accurately. The effectiveness of the rotor is significantly influenced by its geometry. The difference in pressure between both the sides face and rear surface of the propeller blades is what generates the thrust. The undersea vehicle rolls as a result of this pressure differential. The forward propeller, which rotates in the opposite direction, cancels out this rolling movement. Propeller blades are regarded as cantilever beams since they are fastened at one end and free at the other [27].

The propellers are basically classified on the basis of pitch, such as fixed pitch, controllable pitch, skewback and modular propeller.



Diameter ‘D’ Pitch ‘P’

Figure 4 The blade with diameter D and pitch P

The tip of the blade refers to the portion of the propeller blade that is furthest away from the axis of rotation. The base of the blade is fastened to the boss of a propeller. The front of the propeller blade is the portion of that is visible when observing the propeller mounted at the stem from behind the ship. The rear of the blade is the opposing side. Right hand propeller is a propeller that rotates the ship's forward motion in a clockwise motion.

The propeller is left handed if it rotates counter clockwise when the ship is moving forward. The outer edge of a propeller blade is the portion of the blade that rotates first when a ship is propelled forward. The distal end is the opposite edge.

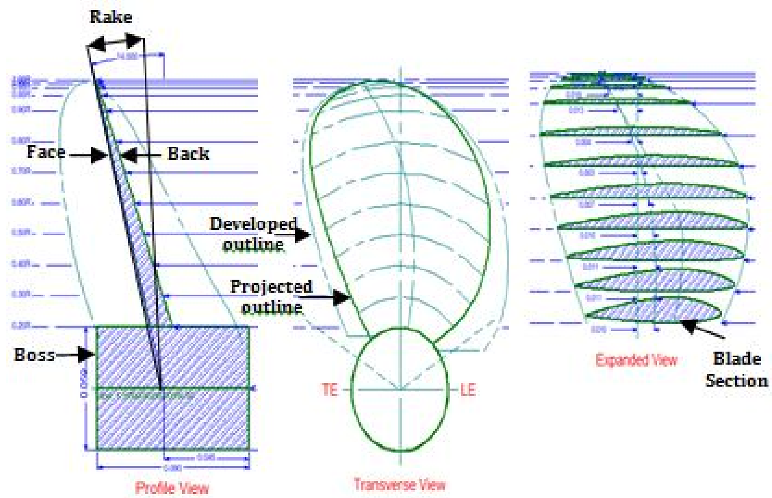


Figure 5 Propeller Terminology

A propeller's blade tips form a circle as it rotates around its axis. The circle has a diameter equal to the D of a propeller. Z stands for the number of propeller blades. The aspect of the propeller blade is defined with relation to or as a part of a helicoidal or screw shape, thus the term screw rotor.

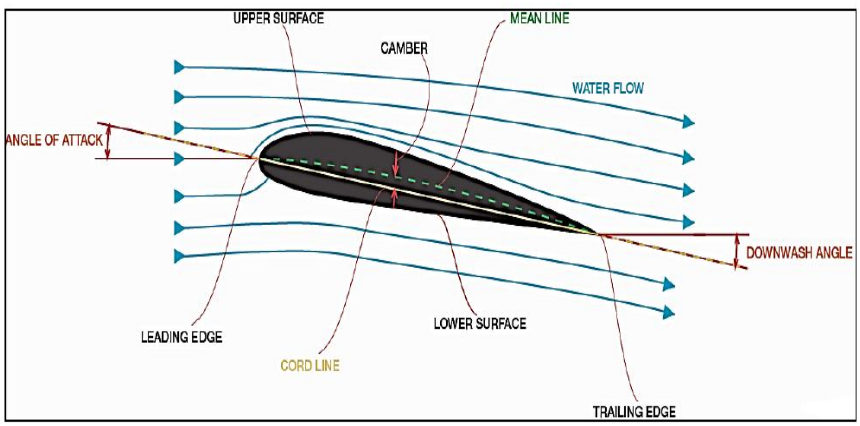


Figure 6 Blade hydrofoil section

Portions of a rotor must be at varying radii through simulating the fan. These portions have their corresponding pitch values indicated and adjusted. Then, each segment that has been turned is reflected it onto perfect circular tube with the appropriate radius [44].

Blade designing is a relatively flexible process, albeit it tends to focus mainly on the standard configuration of the blade by using the systematic series, that are charting created from validated basin tests. The perspective of the design, which displays side profile along with the rotor dimension and rake angle, is presented first. Propellers provide a pressure difference that aids through forward motion of ships [52]. Rake makes use of the propeller's flow direction, which is significantly inside. Additionally, it widens the gap between both the hull and the rotor. The presumptive thickness seems to be the thickness estimated as though the blade ran well all amount to the midline so because rotor thickness decreases distant from the shaft centre [33]. To assist ships or tugboats go ahead, ducted propellers are revolving duct fans that convert rotary movement into thrust power. The tugboat may provide a stronger propulsion power at a slower rotating speed because to the duct. There are two different types such as accelerating duct and decelerating duct. Accelerating ducting propellers are those that operate under conditions of strong loading. So, at a constant flow rate, this rotor aids in enhancing a ship's performance at lower speeds and lessens vibration over the tugging. Less propulsion power is produced by decelerating ducts than by the preceding duct. This is primarily utilised inside the harbour for such modest docking and unloading operations as well as noise reduction concerns [31].

The blade passes through some kind of alteration during design in order to produce the model that would work best like a ship propulsion equipment. Another highest criterion for a ship blade is the need for great speed with just a modest amount of vibration. As a result, it is thought that cavitation leads to turbulence and impaired functioning [34].

In layer cavitation, pressure upon this hydrofoil's upper surface is higher than the flow that is not cavitating. It in turn reduces the hydrofoils' maximum lift, raises drag, alters the pitching moment, and causes the bruit and vibration of propellers as well as an efficiency decline and material erosive processes.

When a solitary abrasion grain strikes the surface, this produces a strong erosion trench which has flawless fracture plane with round stages that is a conventional stiff erosion process. The lowest portions of a element experience more impact from big particle and include a larger granular density [48]. The surfaces that the two granules affected show these trenches on their sides [46]. The content, structure, as well as form of such eroding granules, their speed and degree of attack, and the substance and structuring of the eroded edge call affect how much erosion occurs [47]. Alterations in propeller properties, deflection, as well as cavitation in an experiment conducted using modeling rotors of various elasticity. Cavitation arises when the aqueous medium's localized vapour pressure is lower than the ambient absolute pressure [25]. Deformation lowered the thrust and torque of the propeller. When this deformation remained minimal, propeller productivity rose because the reduction of torque outweighed the reduction of thrust. There may be a sweet spot for distortion since propeller efficiency starts to drop off as distortion increases. At the tip of the blade, elastic deformation predominated. This distortion followed the thrust vector and functioned as the forward rake. The cavitation produced deformation and such deformation changed pitch angles and decreased stresses at the tip of the blade. It is anticipated that this deformation will lessen pressure swings. The Minimum Pressure Coefficient (Cpmin) is used to quantify and analyse the beginning of cavitation. Cavitation inception index (σi) for a particular hydrofoil at a certain approach angle likely to improve with flow Reynolds number. Due to chemical interactions, prolonged operation of the propeller's serviceability, or imbalanced temperature variations during the recrystallization process, the homogenous internal structure may experience these effects. The projection of blade structure is playing an important parameter in study the properties of the propeller structure. The continuous study on the blade projection is to develop the pattern arrangement in specimen preparations [26].

IV. COMPOSITE PROPULSION SYSTEM

The composite propeller blade being a critical and complex element required a very definite production handling to meet nonlinear hydrodynamic force and pressure during under water propulsion [2]. Propeller design should have a minimum power requirements, cavitation, noise, vibration and maximum efficiency conditions at an adequate revolution [7].

Due to greater corrosion protection, maritime rotors are often manufactured with manganese-nickel-aluminum bronze (MAB) or nickel-aluminum-bronze (NAB).However, it is a expensive machine metallic material into complex propeller geometry. Metallic propellers are subjected to corrosion and cavitation damage, fatigue induced cracking and highly relative poor acoustic damping properties that can leads to structural vibration [8]. The inherent frequency of the rotors is significantly reduced when submerged in the water. In both air as well as water, these mode forms are essentially same [50]. Thus there is increase interest in the use of composite as a alternate materials. Composites have better strength to weight ratio and stiffness to weight ratio which can leads to substantial weight savings [10]. The use of lighter composites also means the blade can be made thicker and more flexible to improve hydrodynamic performance. Moreover, composites can offer the potential benefits of reduced corrosion, cavitation damage, improved fatigue performance, lower noise, and improved material damping properties which leads to increases the interest in use of composites. Blades that are thicker may perform better at cavitation, resulting in less vibration submerged. A composite propeller is anticipated to survive the whole life of the vessel, in contrast to an Nickel aluminium bronze alloy propeller, which is anticipated to experience cavitation degradation as well as corrosion and requires periodic replacement. For naval applications, the formulation of the ideal blend of fibres, resins, and cladding lay-up results in the appropriate mechanical and environmental characteristics. The rigorous development experiments include tests for water intake, fouling, and maritime environment durability [17]. The aluminium propeller found to be 40.3 percent bulkier than the composite propeller [24]. Comparing composite blades to traditional metallic blades, there are greater benefits. By using finite element approach, analyse the structural differences between the metal as well as composite propeller blades. Kevlar's ability to distort has many benefits. When comparable to Aluminum as well as E-glass, Kevlar could resist greater amounts of stress. Additionally, when weighed against these two materials, Kevlar weighs less [32]. Generated for aluminium blades on the principle of the shear distortion energy hypothesis, the Von Mises stress is greater than that for composite blades. The blade's tips and edges experience lesser stresses than the mid chord of the blade-hub junction, which is where the stresses are highest [27]. The rotor is thought of as a cantilever beam structure such that when a weight is applied, only the distal end would distort [40].

Among the 3 distinct types of materials, including aluminium, carbon fibre composite and glass fibre composite in both static as well as dynamic analyses. As regard the static and dynamic analyses, the Glass Fibre composite material would perform the best of the three [39]. Importance must be given to the rotor leading and trailing edge debonding malfunction [49]. Blade is often mounted towards the vessel's stern so that it may work in seawater which has been stirred up by the ship's forward motion. A propeller that revolves in the clockwise direction, when propelling the ship forward is called a right hand propeller. A pressure inside the fluid next to a moving blade in a seawater decreases in equivelent to the magnitude of the regional flow rate. Tiny clusters or pockets of vapour occur when the regional pressure falls under the overlying liquid's vapour pressure. Such tiny holes are compressed with a very strong tremendous force when the stream reduces behind of item. The properties of the blade would alter if the bubble region is large enough, including a reduction in power, a difference in torque, significant damage, and severe vibratory stimulation and disturbance [11]. In the propulsion system the blades are composed of fiber composite materials so that a stiff, lightweight design with a high fatigue life is achieved. The fibers for blades are typically oriented to 0o, +45o, and -45o orientations, with 0o being parallel to the blade span direction. Very complicated 3D hydrofoil impeller shape is curiously helicoidally bent out from point to a base [42]. hydroelastic concept considered for composite blades accounts for hydrodynamic structural interactions. When contrast against metallic propellers, composite propellers with bendtwist interface performs more effectively [43]. Grade S standard propeller blades continue to be difficult to manufacture. The rotor construction degrees ISO 484/1 as well as ISO 484/2 which are the strictest tolerances provided for propeller blades, which gives better performance under the extreme condition [9]. Based on wageningen B series profile, the B-series typical airfoil points, outlined airfoil point, and propeller blade made up of different radii are all through appropriate pitch angles when a certain series and kind of airfoil point are needed [27].

V. CONCLUSION

Composite materials have a long history of accomplishment in weight-sensitive and demanding naval uses in which stiffness and strength are needed. Composites provide minimal weight for elevated aircraft at a viable price point because of their lower maintenance costs, which are essentially recovered while service by a reduced use of fuel. result based guidelines just provide the intended objectives and provide a wide range of options to comply with the standards, prescribed guidelines provide detailed instructions on how well the vessel should be constructed.

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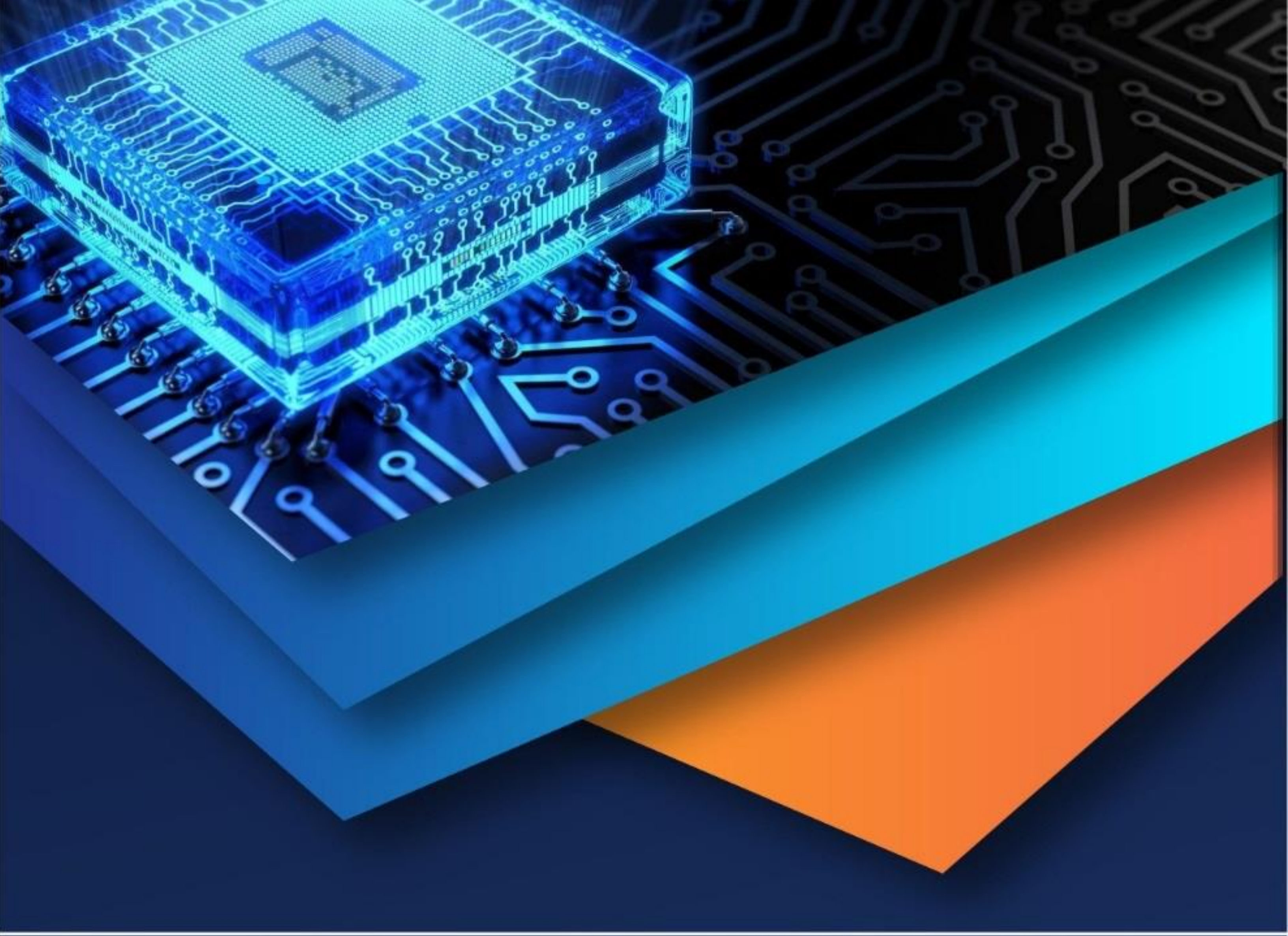

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