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A Review Assessment of Fiber-Reinforced Polymers for Maritime Applications

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Abstract: Composite materials, comprised of fibre-reinforced polymers, offer a high strength-to-weight ratio, making them excellent for the building of complex, lightweight structures in several industries, including the marine industry. There is an improvement in fuel efficiency and cost-effectiveness in general marine component developments as a result of the lightweight and flexible design characteristics. Fibre-reinforced polymer (FRP) composites are often used to construct boats, ships, and other marine compounds, such as the hull, column beams, piling structures, and other internal ship components, since they meet the aforementioned characteristics. In terms of durability, rigidity, and corrosion resistance, these FRPs may readily replace their conventional metal counterparts. So, this review gives an overview of FRP composites' application in marine industries for various potential applications. Fibre-reinforced polymer composites offer a significant advantage in strength and weight when compared to conventional materials.

Keywords: Marine, fiber-reinforced polymer, light weight, epoxy, shipbuilding

1. Introduction

Combining two or more chemically distinct and insoluble phases may improve the properties and structural performance of a material. Composites have become one of the fastest-growing materials for industrial applications as a result of their light weight and other unique properties. In addition to their more apparent structural applications, composites may be employed in the electrical, thermal, tribological, and environmental fields. Many composites consist of just two components, but those components are carefully selected to give the optimal balance of properties for a particular application. Each consists of the other; the matrix encompasses the dispersed phase [1–5]. Utilising composites has decreased manufacturing costs, making the end product more cost-effective [6, 7]. When many kinds of fibres are joined in a single matrix, a distinct composite material becomes apparent. As is the case with fibre-reinforced polymer composites, hybrid refers to the use of several fibre and particle types embedded inside a polymer matrix. It may be adapted to a range of design requirements at a cheaper price than conventional composites. Because hybrid composites consist of two or more distinct fibre types, the advantages of each may be utilised [8]. Fibre-reinforced polymers (FRPs) as composite materials are used in almost every aspect of contemporary technological processes. This includes aircraft, helicopters, ships, offshore platforms, automobiles, sports items, equipment for

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chemical processing, and even bridges and structures. In recent years, improved FRP variations have emerged, which has contributed to the growing popularity of composites. This is shown by the employment of carbon nanotubes and nanoparticles as reinforcing agents, as well as other innovative reinforcing approaches [9].
The difficulty of constructing lightweight structures is a major challenge in marine and naval applications. Even the heaviest metallic floating structures have structural components comprised of lighter materials, such as polymer-based composites, such as the bulkhead, deck, mast, propeller, etc. [10, 12]. Composite-made boats are more durable and last longer [13, 14] due to their higher corrosion resistance and ability to be flattened to fulfil stealth requirements. The large anisotropy of the materials and the vast differences in mechanical properties (rigidity, coefficient of thermal expansion, etc.) between the adherents are two of the greatest obstacles associated with joining composites and metals. Due to their superior durability, workability, and strength-to-weight ratio (specific tensile strength), fiber-reinforced polymer (FRP) composites have been widely used in the boat building and marine construction industries for decades [15, 16]. In order to construct marine structures economically and evaluate their life cycle, it is crucial to comprehend the behaviour of these regularly used materials under environmental effects over a certain time period (ageing). FRPs have several advantages during construction, including the ability to consolidate parts, thereby reducing the number of parts, joints, and fasteners, providing significant weight reductions and improved stability by lowering the center of gravity, and facilitating easier application to complex shapes and compound curvatures. The "drapeability" of composite materials makes them suitable for use in the construction of hulls, decks, and submarine fairings [17].

Environment-vulnerable marine structural components include vessels, submersibles, and offshore building projects, among others. Thus, the choice of durable materials requiring minimal maintenance is typical. In addition to meeting design standards, ships should be quick, dependable, and resistant to corrosion. Fibre-reinforced polymers (FRP) and other composites have been widely used in the marine industry since their initial extensive usage following World War II, when they were created to overcome the corrosion concerns of steel and aluminium. Manufacturing lightweight commercial ships has been and continues to be a significant contribution to the maritime industry [18, 19]. Composites continue to be used to manufacture gratings, ducts, shafts, pipelines, and hull shells due to their flexibility to meet the marine industry's rising and changing needs [20, 21]. In the marine sector, composites are often used for hulls, bearings, propellers, hatch covers, exhausts, radomes, sonar domes, railings, vessels of various types, valves, and other subsea structures. In recent years [22–24], composite racing powerboats have gained appeal owing to their durability, speed, and safety. If maritime structures are to resist the cyclic environmental loads to which they will be exposed, their fatigue characteristics must be taken into consideration from the outset of their design. To examine the fatigue behaviour of FRP, there is a paucity of widely accessible methodologies and appropriate modern models, in contrast to metallic structural materials. Due to the inherent heterogeneity of FRP, a variety of damage mechanisms, such as matrix cracking, fibre/matrix debonding, fibre fracture, and interlaminar delamination [25, 26], must be taken into account. The cost of materials is often the decisive factor when choosing between composites and mild steel. Since it is possible to construct hulls up to 85 metres in length using the low Young's modulus of simple E-glass composites [27], it is necessary to develop cost-effective hull moulds. Smaller, more precisely shaped pieces, such as bow fairings, rudders [28], funnels, and even trimaran outriggers, will be fabricated from composites owing to the high cost of producing them from steel and aluminium. The capacity to modify the material and combine structural reinforcements with other materials has resulted in the creation of innovative and cutting-edge strategies for enhancing the stealth of warship topsides. A thorough understanding of the long-term behaviour of FRP composites is the result of a tedious procedure that includes research, testing, and trials throughout the design phase. This has resulted in its extensive use in maritime applications. This approach permits the production of FRP composites, which are becoming more common in maritime component designs, in order to construct ships that are both durable and economical to maintain.

2. The History of Fibre-Reinforced Composites

Composites have been in use for centuries. The Egyptians and Mesopotamians began building homes out of mud and straw around 1500 B.C. Sometime after this, in 1200 A.D., the Mongols discovered the composite bow, which they used to further cement their position as the dominant military power. The constraints placed on polymers at the turn of the century increased the need for composites. In the 1930s, the roots of the modern fibreglass industry were established. In 1907, Bakelite, the first plastic, was invented. After this era, the development of the plastics industry led to the invention of vinyl, polyester, and polystyrene. With the introduction of glass fabric in 1935, the fibre-reinforced plastics industry officially began. During World War II, the composites industry shifted from research and development to industrial manufacture (1939–1945). In 1941, Henry Ford began using fibreglass-reinforced polymer (FRP) composites in his automobile production [33]. In 1942–1944, the "Gold-Worthy" father of composite materials started manufacturing glass laminates. In 1946, glass fibre was being used to construct boat hulls. During the 1960s and 1970s, FRP composite knowledge developed dramatically. Beginning in the 1960s, aircraft components such as spoilers, fairings, and floor boards were among the first uses of FRP composites. Carbon fibres, which were invented in 1963 by W. Watt, L. N. Phillips, and W. Johnson, have the potential to be exceedingly durable. After a slow beginning, the composites industry started urbanising and expanding in the 1970s. Group Lotus Car Ltd. initially made fibre-reinforced composites utilising a vacuum moulding technology established in 1972. 1973 saw the introduction of the first Aramid (Kevlar) fibres, which are very resistant to impact. In 1978, they demonstrated that a single silicone rubber tool could be used for vacuum impregnation. As in 1980 and 1985, he used a VARTM silicone vacuum bag and applied vacuum pressure to his testing. In the 1980s and 1990s, the fundamental objective of FRP composite manufacturing was to reduce production costs. As early as 1980, the teams of Covington and Bavmgardner constructed fibreglass rotor blade prototypes. To create this wrapping, filament was used. The pultrusion process was created in 1982 by "Gold Worthy," also known as the "father of composite," and the Composite Materials Institute of India was founded in the same year. Resin transfer moulding was soon used by the automobile sector, the Laser 28 deck, and boat hulls after its introduction in 1985. Hold highlighted the construction of a tape winding machine for manufacturing composite components for main motor blades in a 1986 article. Since 1987, the Advance Composite Manufacturing Centre has provided composite training to R&D firms. Since 1988, large cylinders have been centrifuge-cast. Boyce started using robots in 1989 to improve the process of wrapping resin-impregnated fibres around pins prior to compression moulding. Since the conception of fibre-reinforced composite manufacturing, composite materials have been used in different industries, including the maritime industry and other industries. It is possible to identify four separate generations of composites. In the 1940s, glass fibre-reinforced composites were created, and in the 1960s, high-performance composites were used to create the second generation of composites. In the 1970s and 1980s, the third generation began exploring the composite world for new markets and assets, followed by the fourth generation in the 1990s. Composite or multicomponent materials, such as nanocomposites or biomimetic materials, were introduced [35].

2.1 The Role of Fibre-Reinforced Polymers (FRP) In The Marine Environment

The use of polymer composites in marine applications is nothing new. Because of their high resilience to harsh environmental conditions, these materials are increasingly being used in production [36]. Recreational boats, military ships, and even helicopter landing pads in the middle of the ocean all employ them. There are several instances of composite material use in the water, including submarines, wellhead protection structures for the offshore sector, and oceanographic instruments. When looking at how technology has changed throughout time, it's clear that improvements in materials have been crucial to major technological advances. In retrospect, it's easy to observe how certain media represented or contributed to the growth of various historical periods. From the Stone Age to the Iron Age to the Industrial Revolution to the Nuclear Age to the Information Age, this timeline has it all. A new generation of materials technology, advanced composites [37], has arisen in response to the increased need for performance-oriented materials and structural systems. These cutting-edge materials have been created by fusing together many existing components, each of which has its own advantages and disadvantages. Composites are widely used in so many industries as a result of their complementary characteristics. Due to their superior corrosion resistance and lightweight construction in contrast to metallic structures, FRP materials offer significant potential for application in maritime environments. A wide variety of free and low-cost resources for getting started are readily available. Significant work has been done over the last quarter century to improve our knowledge of the durability of these materials, although design safety factors remain high for loadings other than static cyclic.

2.1.1 FRP Application in Ship, Hull, and Boat Construction

In recent years, fibre-reinforced polymer (FRP) composites have become more popular for use in maritime construction, including boats and yachts. In recent years, efforts have been made to prioritise both the safety of ships and the creation of more sustainable, energy-efficient vessels. More than half of all fishing vessels are currently made from FRP [38], with the fishing sector being the first to show significant interest in FRP commercial boats. Since the end of World War II, the military has been at the forefront of developing composite materials [38]. The Navy and the Army have benefited from using composites in a variety of vessels, including small boats, submarines, patrol vessels, and minesweepers. Experiments with a wide variety of supplementary parts, from modest equipment brackets to propellers, have shown promising results [38].

In terms of stealth performance, composite hulls are comparable to their metal counterparts. Torpedoes cannot affect them since they are immune to magnetism. It is possible to decrease radar cross-sections by designing certain materials that absorb radar radiation rather than reflect it. When submerged, the low levels of harmonic resonance that they have contribute to a much reduced noise level. Because of their thermal characteristics, these materials allow for much smaller thermal footprints [39]. FRPs were not employed to build small boats again for another half century. FRPs have become the norm in this industry. It's because FRPs allow for quick and cheap manufacture on a massive scale [40, 41]. Composites are used for larger ships like cargo ships and tankers [42-43]. The fact that today's hulls are made using state-of-the-art production methods is evidence of the marine industry's rapid technical development. Improvements in composite technology have allowed for the production of better-quality materials with stronger and lighter constructions, which in turn improve sailing capabilities and the shear lives of components. In addition to the general cost reduction brought about by the increasing use of composite materials [44–46], the ability to automate and speed up production processes has contributed to this trend, making the final product more inexpensive and available for use. Sandwich structures, which are common in the shipbuilding industry and consist of two skins with high stiffness and strength put on the exterior of a component and a soft and thick core, are extensively utilised for the development of stronger hulls and decks. Both global and local instability can be avoided because of the combination of the skins' high bending stiffness and the core's capacity to withstand shear and compressive stresses and stabilise the skins. Due to its lower weight, the ship may be able to float higher and flatter, carry more cargo, use less fuel, have less of an impact on the environment, and float higher in the water. Compared to metals, FRPs are far less high-maintenance and provide superior corrosion resistance in water. FRP materials, including aramid, carbon, and glass, are often used as skins for maritime sandwich constructions. Common core materials include honeycomb and polymeric foams (such as polystyrene and polyvinyl chloride). Boats made using aramid fibres (like Kevlar) or carbon to reinforce high-quality resins and ultra-light cores (like Nomex) have unrivalled mechanical qualities and dimensions [47, 48]. There is a growing need for inexpensive, stealthy, long-range, or endurance boats that can operate from near shore. The optimal length for such a vessel is still up for debate, although vessels with a length of 300 feet and a displacement of 1,200 tonnes appear to be the norm in this category [49]. While steel and other metals have proven to be effective building materials, attempts to fully include FRP in ship construction have been delayed by the perceived high risk involved with adopting a structural material without a proven track record [50, 51]. It significantly impedes progress in composite construction. The limits of a structure are often determined by the strength of its weakest link. By placing steel in the hull's core and using lightweight composites at the ship's hull, Kumar and Udaiyakuma [52] employed sugarcane fibre-reinforced polymer to meet the strength and stiffness requirements of a big ship's hull. Hybrid ship hulls use the finest features of both steel trusses and composite sandwich panels. Using a vacuum infusion method, vinylester resin was injected into thin glass fibre skins to encase the PVC foam core of the sandwich plates. The composite skins are designed to primarily endure shear and water pressure stresses [53], while the steel truss is responsible for supplying the bending moment.

Joints made of composite materials and steel are the subject of several current research studies [52]. A reliable connection between the composite and steel parts is essential for these hybrid ship buildings. It may be challenging to link composites and metals because of the composites' high anisotropy and the large difference in mechanical characteristics (stiffness, coefficient of thermal expansion, etc.) between the adherends. Having joints that are not stiff enough causes a lot of unnecessary tension. Two common types of joints are bonded-bolted and co-infused perforated. On the French Lafayette-class frigates, which are 125 metres long and 3,500 tonnes, a composite superstructure is glued and fastened to a steel hull, a relatively new innovation [54]. By decreasing the stress intensity characteristics at a fracture tip, fatigue-strengthening steel constructions may extend their service life once cracks appear. Stress intensity issues may be mitigated by switching to a stiffer FRP plate (either one that is thicker or has a higher elastic modulus) [55]. Increased strength-to-weight ratio, resistance to corrosion, fatigue, and temperature fluctuations, and reduced maintenance costs [56] are only some of the benefits gained by fabricating a nautical propeller out of FRP. Fibre-reinforced polymer is an excellent choice for marine propellers for these reasons and more. Kumar et al.'s [57] sandwich composite panel technique is used to build ship hulls and other marine vessel components. Therefore, studies [58, 60] have been conducted to see whether ultra-light materials like carbon fibre-reinforced polymers (CFRPs) can improve ship efficiency. In spite of this, glass fibre reinforced polymers (GFRPs) are now preferred in the shipbuilding sector [61] due to their lower cost and enhanced practicality. End-of-life disposal methods for composites, like incineration and land filling, may have negative effects on the environment [62]. There has been research on ways to lessen the negative consequences of composite vessel disposal on the environment [62, 63]. Ships have become lighter, and emissions have decreased to help lessen their negative effects on the environment [58, 64–67].

2.1.2 FRP Application in The Oil and Gas Industry

Almost all of the pipes used to transport oil either underground or underwater in the oil and gas sector are constructed of steel. This means that the seawater has the potential to corrode the pipes. Fibre-reinforced polymer composites are preferred over steel for pipe replacement and maintenance, and scientists have been instructed to employ them. Fibreglass is the material of choice for the majority of oil and natural gas pipelines that go from offshore drilling platforms to land-based facilities [68]. However, when high-pressure natural gas has to be transported, FRP pipes are not often employed. Steel rusts and leaks easily, making it a poor material for oil and gas pipelines. Hydroxides and chloride ions in water accelerate the processes that cause metal to leak, fracture, and shatter when exposed to water. High levels of stress hasten the breakdown of such a component. Oil and gas companies need to repair offshore pipelines because of the dangers of corrosion and metal loss. It is common practise to remove the damaged section of pipe (or the whole pipe) and replace it with a new one when a pipe bursts. Instead, welded steel is used to cover the damaged region. Further, steel sleeves are welded or screwed onto the outsides of the tubes to protect them from the elements. Welding steel is a challenging task, whether above or below ground. This is why so much effort has been put into developing reliable methods of repairing objects prone to unexpected failure. The expenses and technical challenges of mending and maintaining the system increase significantly according to the operating pressure and the location of the damaged tube. Reinforced fibre composites have been proposed as a viable alternative to conventional repair methods for these tubular constructions [69, 70] due to their advantageous properties in several areas: low weight, high strength and stiffness, resistance to corrosion, and resilience under fatigue loading. Composite materials with E-glass, aramid, or carbon fibre reinforcement and thermosetting resin are increasingly widely used in these interventions (polyesters, polyurethanes, phenolics, vinyl esters, or epoxies). Pipe repair might include any of the following: stopping the spread of corrosion, restoring the pipe's weight-bearing capacity, sealing off the damaged region to prevent fluid leakage, or all of the above [71].

Research has been done into the possibility of using FRPs in the offshore sector for the construction of a number of primary and auxiliary marine structures. Composites are suitable for use in secondary platform construction for floating installations. Helicopter bridges, pipeline networks, houses, walkways, and staircases are all typical examples. A floating platform may be connected to a subsea structure using risers and tendons. These platforms are often constructed from repurposed oil tankers due to the inexpensive cost of construction and the ability to store crude oil [72–74]. To replace steel pipes, composite pipes composed of thermoset matrix have emerged as a popular option in recent years [75]. Composite pipe is made by encasing or wrapping cured thermosetting with fibre reinforcements. Reinforced thermosetting resin pipe (RTRP) and glass-fiber-reinforced compound mortar pipe (RPMP) are the two most prevalent forms of fibre-glass composite pipes. Fibreglass pipe is also known as fiber-reinforced polymer (FRP) and glass-reinforced epoxy (GRE) in the marine sector (GRE). Glass fibres are used to reinforce a plastic matrix in the production of composite pipes. Most often, synthetic resin is utilised to create the matrix for FRP composite pipes. To the contrary, GRE pipes are often constructed from vinyl ester or polyester. Due to their superior mechanical, chemical, and thermal qualities, fibre-reinforced composite pipes are now the most popular choice on the market. It is resistant to corrosion, has a low thermal conductivity, and has an insulating property. Every year, environmental factors and improper usage cause hundreds of miles of oil pipelines to fail. This necessitates examination, maintenance, or replacement [77]. Costing billions of dollars to repair damage and corrosion in older pipes. To eliminate this complexity and facilitate repairs, a novel technique using fibre-reinforced polymer matrix composite wraps has been developed [78]. Pipe repairs were investigated by Peck et al. [79], who examined the use of a UV-cured vinyl ester matrix wrapped in a glass fibre composite. The finite element technique was used in an experiment to model carbon fibre-reinforced polymer pipelines (CFRP). [80] Reports reveal that scientists studied the connections between the severity of an impact, the kind of layup used, and the boundary conditions to predict the likelihood of defects in a composite pipe. The study presents both numerical and experimental findings, which illustrates the interrelatedness of the two data sets. The effect of loads on the motion of tubular constructions was investigated by Tarfaoui et al. [81]. Scientists have considered using thick cylinders reinforced with glass fibres embedded in an epoxy matrix. The study keeps tabs on the wear and tear caused by both static and dynamic loads, and it accounts for the scale and size effects on the tubular constructions' responses to dynamic loads. Kessler et al. [82] examined a woven carbon fibre-reinforced epoxy matrix composite and found that it could be repaired by looping it around itself. Applications of the composite under pressures greater than 1.0 MPa and temperatures greater than 60 °C have also been investigated, as shown in their studies.

Reassembling the pipe and subjecting it to full pressure allowed us to evaluate the material's mechanical and thermal qualities. To enhance the long-term performance of thick glass-fibre-reinforced polymer pipes used underwater, Tarfaoui et al. [83] performed a finite element study of static and dynamic testing. Two distinct phases comprised the study. We investigated damage initiation and the behaviour of elastic materials prior to presenting a damage prediction model that accounts for changes in material properties upon impact. When everything was said and done, experimental findings were compared to model predictions. The findings revealed useful data that may be used to extend the lifespan of composite buildings in the water. After considering the working pressure, the maximum pressure, and the safety factor, Ajani and Huda [84] proposed a design for a pressure vessel constructed of glass fibre fluid (FoS). The longitudinal and hoop strains of the pressure vessel were experimentally examined. The analysis assumed a breaking strength of 55 MPa. The glass fibre pressure vessel is more than safe to use with high-pressure fluids in a range of applications, with a FoS of 55 and longitudinal and hoop stresses ranging from 1.25 to 3.73 MPa. Shouman and Taheri [85] investigated the effects of internal pressure, bending, and axial stress on composite-repaired pipes. The research found that the stiffness of the pipe was not significantly different regardless of the circumferential orientation of the fibre wrap. Therefore, axial reinforcement is essential for increasing rigidity. Mechanical characteristics and failure behaviour of carbon fibre-reinforced polymer composites were extensively studied by Selzer and Friedrich [86]. Both thermosetting and thermoplastic matrix composites were tested in varying temperatures of water to determine their performance range. The breakdown of the composite interface was found to be accelerated by the softening of the matrix and the loss of fibre-matrix adhesion caused by water absorption. The investigation found that the mechanical characteristics were unaffected by the immersion water temperature. Further, the findings demonstrated that the composites' characteristics were unaffected by the length of exposure after the samples had been saturated. Wei et al. [87] investigated the effect of basalt and glass fibre additions to epoxy resins on the gain ratio and the strength maintenance ratio. In this experiment, resins were submerged in saltwater for various durations of time. Strength in tensile and bending tests decreased as treatment durations increased. And when it came to resistance to corrosion from saltwater, basalt and glass fibre-reinforced composites performed similarly.

Corrosion mechanism studies suggest that reducing the Fe^{2+} content of basalt fibres might improve the seawater stability of basalt composites.

2.1.3 FRP in Naval Applications

The fundamental drive for the use of FRP composites was the need for lightweight, sturdy, and corrosion-resistant naval warships. The primary motivation for these initial uses was the need to protect metals and alloys from corrosion and deterioration and to preserve wood from decay. The primary motivation for using composite materials was the need to lessen the load on the ship's superstructure, which was successfully accomplished. Due to their high acoustic transparency, composites are employed for both subsurface sonar domes and shipboard rodomes [88, 90]. Domes on sonar bows, windows, and hulls are a few examples of FRP components used in recent naval applications. Composites are also gaining popularity for use in autonomous underwater vehicles, robotic fish, and military combat vehicles. Carbon fibre-reinforced composite materials stand out due to their superior mechanical properties compared to those of other FRP composites and their ability to provide electromagnetic shielding for stealth applications, while FRP composites in general have advantageous properties such as high strength-to-weight and stiffness-to-weight ratios. Naval vessels constructed entirely of FRP composite materials are presently in service. Small patrol boats and displacement landing craft were often built using composite materials due to the low rigidity of the hulls and the relatively poor quality of manufacturing at the time. The main reasons why FRP composite materials are not used on bigger patrol boats, mine countermeasure vessels, and corvettes are due to size and performance limits [91-93]. Table 1 below shows the recent studies that have been carried out on FRP components used in the marine industry.

Table 1 - Previous studies works on FRP components in marine application

Polymer composite	**Marine components**	**Results Findings**	**Ref.**
Aged Basalt/Epoxy/HNT Nano fillers	Bearing	HNT nano reinforcements significantly increased basalt/epoxy composite laminate bearing strength by 18%.	[94]
Carbon/Epoxy	Column	Carbon fiber-reinforced polymer (CFRP) exhibited a more superior properties on the material than basalt (BFRP) based on different confinement mechanisms.	[95]
Carbon/Epoxy	Tubular steel structure	The Components part exhibited a better structural performance as a result of the strengthening process	[96]
Carbon Nano fillers/Eoxy	Structural Beam	findings indicated that carbon nanofillers considerably improved the ageing on mode I and mode II interlaminar fracture toughness propagation of composite laminates before and after immersion in saltwater compared to the reference laminate under dry conditions.	[97]
Glass/Epoxy	Pile Structure	Semi-linear filled GFRP tubes increased pile ductility and strength.	[98]
Carbon/Epoxy	Structural Beam	CFRP strengthens concrete beams with NSM by 5–10%.	[99]
Glass/Epoxy	Tubular Column	The SWSSC-filled GFRP tubular columns with gravel aggregates exhibited no strength deterioration, whereas those with coral aggregates showed a consistent degradation trend.	[100]
E-Glass/Epoxy	Hull plate	The E-Glass combination of the chopped strand mat and woven roving mat demonstrated a significant change in improving the overal quality and strength of the composite.	[101]

Fang et al. [102] investigated fibre-reinforced polymer (FRP) composites and seawater sea-sand concrete (SWSSC); the outcomes of their work indicate promising application prospects in marine infrastructure construction due to the elimination of steel corrosion and the use of readily available local materials. In the form of reinforced columns, the combination of SWSSC and FRP provides a potential new application for both materials. This research examined the efficacy of glass fibre-reinforced polystyrene (FRP) interlocking multispirals in enhancing the axial compressive performance of square SWSSC columns. The results of the tests demonstrated that corner spirals greatly enhanced post-peak compressive performance by further limiting the centre spiral and longitudinal reinforcement. Comparing FRP transverse reinforcements, it was discovered that columns with interlocking multi-spirals were more flexible than stirrups with the same amount of reinforcement.Blake et al. [103] use a stochastic method in the design of stiffened marine composite panels as part of an ongoing research initiative to develop stochastic techniques for composite ship constructions. This approach takes into account changes in material properties, geometric indices, and processing techniques at each system level. Common uses for fibreglass-reinforced plastic include yacht hulls, dinghies, canoes, speedboats, and hovercraft. Due to the use of hybrid fibre, which decreases hull weights, hydrofoils and gasoline-powered boats are now practical. Composite materials are required for the construction of high-performance sailboats and motorboats [104, 105]. FRP is utilised for a variety of navy applications, including armament and gun housings, rudders, dry dock shelters, blast shields, missiles, ladders, deck drains, radomes, masts, and stacks. In the maritime sector, fibre-reinforced plastic (FRP) is used for both main and secondary structures, such as housings and attachments.

3. Conclusion

This research examined the application possibilities of FRP polymer composites in the maritime industry. Fiber Reinforced Polymer (FRP) composite materials are being used in the building of commercial and military boats as part of the marine industry's continual efforts to enhance vessel performance. Composite materials made of Fiber Reinforced Polymer (FRP) provide a number of benefits. These include corrosion resistance, high strength-to-weight ratios, and excellent thermal and acoustic insulation. Due to its superior hydrodynamic shapes, flatness for signature requirements, and fatigue strength, FRP is extensively used in the marine sector for the construction of naval ships, recreational boats, and offshore structures. FRPs increase fuel efficiency, weight savings, and corrosion resistance in the marine sector. In the maritime industry, steel and other iron- and nickel-based alloys have been mainly replaced by FRP composite owing to their high production costs and extreme corrosion risk. Consequently,FRP used in marine industry from several literature studies have demonstrated the materials superior properties that have enhance its application in recent times. Further study is necessary to improve FRP utilization and increase maritime industry demand.

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