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Research Article

Marine Applications of Fiber-Reinforced Polymer Matrix Composites

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Abstract **–** Composite materials are formed by bringing together two or more materials that are insoluble in each other at a macro level. Composites consist of two main elements such as reinforcement (the carrier) and matrix (the binder). These materials are generally classified according to matrix and reinforcement elements. In the classification made according to the matrix element, polymer, metal, and ceramic matrix composites are examined. In this classification, polymer matrix composites are widely used in practice. A polymer matrix from the thermoset or thermoplastic group is reinforced with various types of continuous or short fibers. Composites belonging to this group are widely used in basic sectors such as automotive, aviation, and marine. Especially in the marine sector, polymer matrix composites are used in the construction of marine vehicles (ships, boats, yachts, etc.) and equipment. Marine systems and structures include the hull and shipbuilding industries (ship and submarine masts, propellers, and interior parts), the offshore applications industry (gas pipelines, tendons, and support structures), and the renewable energy sector (turbine devices and rotor blades). The importance of lightweight design is increasing day by day in vehicles used in land, air, and sea transportation. Today, the increase in the value of both safety and energy savings causes research on composite materials to intensify in the marine sector. It is advantageous to use composite materials in many parts so that negative environmental effects such as corrosion, biological pollution, seawater aging, and hydrostatic pressure cause minimal damage to marine structures. With the developments in composite science, the level of use of these materials is increasing in the marine sector, as in every other field. This review presents an overview of the use of polymer matrix composites in the marine industry.

Keywords – Polymer Matrix Composites, Fiber, Marine, Naval Vessels, Applications.

1. Introduction

Fiber-reinforced polymer matrix composites are used in almost every field, such as aircraft, ships, automobiles, sports equipment, and building elements [1,2]. A composite with its usual structure consists of a reinforcement phase and a matrix phase. However, with today's developments, nano or micro-sized particles are added to the matrix phase as a third material [3,4]. In addition, hybrid materials are also used by using more than one fiber [5,6].

Fiber-reinforced polymer composites are widely used in the marine industry due to their properties such as high strength, corrosion resistance, workability, thermal conductivity, lightness, and specific tensile strength [1,7,8]. Equipment such as curtains, decks, masts, and propellers are made of polymer-based composites [1,9,10,11,12]. The use of fiber-reinforced polymer composites is increasing with the guidance of scientific studies carried out in many places, such as fishing boats, submarines, patrol ships, and minesweepers [1,13]. In particular, fiberglass is the material of choice for most oil and gas pipelines going from offshore drilling platforms to onshore facilities [1,14]. Hybrid composites consisting of two different fibers have recently been preferred in propeller production [15].

Composite materials have various disadvantages arising from their nature. In addition, it is necessary to consider the various environmental effects of the use of this sector. The loadings that may occur in the usage area of fiber reinforced polymer matrix composites should be predicted, necessary tests should be done, and appropriate measures should be taken according to the results. Design and manufacturing that meet all the conditions of strength, economy, and functionality, which are the most important elements in an engineering design, should be provided. Table 1 shows recent studies on the components of fiber reinforced polymer composites used in the marine industry.

Table 1. Studies on fiber reinforced polymer components in marine applications [1].

Polymer composite	Marine components	Results Findings	Reference
Aged Basalt/Epoxy/HNT Nano fillers	Bearing	HNT nano reinforcements significantly increased basalt/epoxy composite laminate bearing strength by 18%.	**[16]**
Carbon/Epoxy	Column	Carbon fiber-reinforced polymer (CFRP) exhibited a more superior properties on the material than basalt (BFRP) based on different confinement mechanisms.	**[17]**
Carbon/Epoxy	Tubular steel structure	The Components part exhibited a better structural performance as a result of the strengthening process	**[18]**
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.	**[19]**
Glass/Epoxy	Pile Structure	Semi-linear filled GFRP tubes increased pile ductility and strength.	**[20]**
Carbon/Epoxy	Structural Beam	CFRP strengthens concrete beams with NSM by 5–10%.	**[21]**
Glass/Epoxy	Tubular Column	The SWSSC-filled GFRP tubular columns with gravel aggregates	**[22]**

		exhibited no strength deterioration, whereas those with coral aggregates showed a consistent degradation trend.	
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.	**[23]**

2. Classification and Manufacturing Methods of Composites

An overview of the classification, production methods, and applications of fiber-reinforced composites is presented in Figure 1. In Figures 2 and 3, the general classification and classification of composites by fiber are shown, respectively. On the other hand, in Figure 4, the production methods of composites are indicated.

Figure 1. Classification, production techniques, and applications of fiber reinforced composites [24].

Figure 2. The general classification of composites [25].

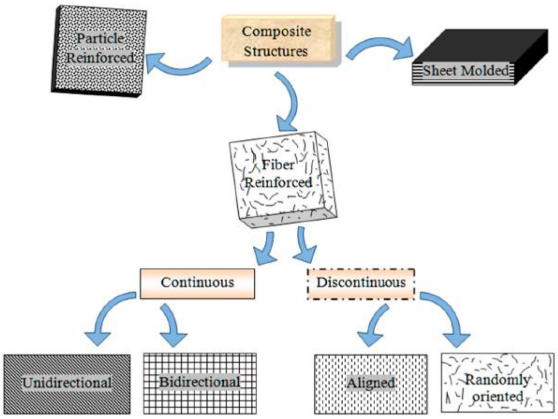

Figure 3. Classification of composites according to fiber [24].

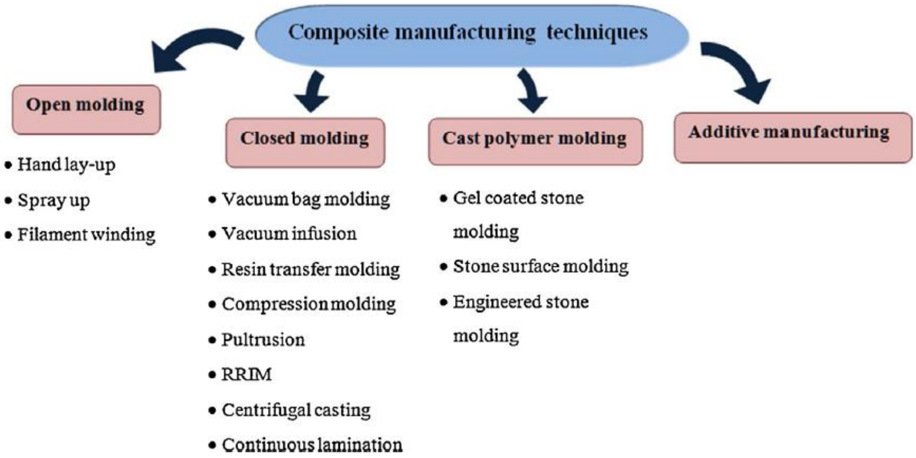

Figure 4. Manufacturing methods for composites [25].

3. Fiber-reinforced polymer matrix composites in the marine industry

3.1 Polymer matrices

Polymers are examined in three groups, namely thermoset, thermoplastic, and elastomer. Table 2 shows the polymers used in the marine industry.

Thermoplastic matrices have high corrosion resistance, easy melting and molding properties, and excellent thermal and electrical insulation [26]. Thermoset matrices are highly resistant to heat. However, they are generally less recyclable due to their strong cross-linked microstructure [26]. Elastomer polymers have the same elastic characteristics as rubber. Elastomers have poor structural integrity but can be easily used in applications requiring high flexibility [26].

Table 2. Polymers used in marine structures [27].

Table 9

Use of a few popular polymers in marine structures (Chandrasekaran and Jain, 2016).

Polymer form	Material	Applications
Thermoplastic	Polyethylene, high-density polyethylene (HDPE), polycarbonate, polypropylene	Hulls of small and lightweight boats, canoes, kayaks, jet skis (Neşer, 2017)
	Ultra-high molecular weight polyethylene	Decks, small jetties, and other floating structures
	Polyethylene, polyamide	Deep-sea flexible/rigid pipe networks
	PVC, polycarbonate, acrylic	Overlaying sheets or paints in sub-marine steel and concrete structures for antifouling purposes
	Acrylic	Windshields, subsea observation enclosures, transparent boat bottoms
	Nylon	Bearings for sheaves, winches, stern tubes, and ropes
	Polypropylene foams, polyurethane foams	Cushions, heat insulations
Thermosetting	Melamine	Lightweight furniture
	Silicone	Antifouling sheets and membranes, water sealing components
	Polymeric resins	Boat hulls, composite components
Elastomer	Rubber	Inflatable boats, flexible piping, shock-absorbing structures
	Neoprene	Weather strippings, gaskets, seals

3.2 Reinforcing fibers

Natural fibers, synthetic fibers, and hybrid fibers are used in marine applications. Although synthetic fibers are used extensively, natural fibers have also been used in recent years. The various fiber types are shown in Figure 5. Tables 3 and 4 show the various properties of the fibers and the important structural components made of fiber reinforced composite, respectively.

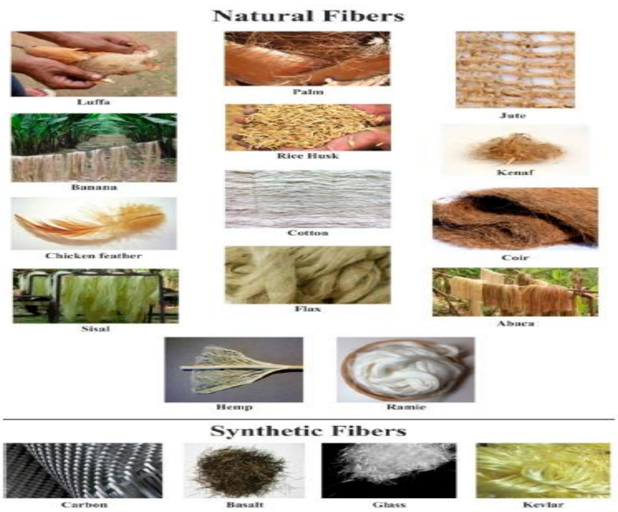

Figure 5. Types of natural and synthetic fiber [24].

Glass fiber has good strength, light weight, easy production, and low cost characteristics. It accounts for more than 90% of worldwide applications in composite structures. The three most common types of glass fibers are E-glass, C-glass, and S-glass. E-glass (electrical) is the most widely used fiber in polymer matrix composites. It has good strength and stiffness but poor impact properties. C-glass (chemical or corrosion) fibers have good chemical resistance. S-glass (hardness) is a glass fiber with improved mechanical and thermal properties [28]. Carbon fiber is the most expensive, but it has the best specific stiffness properties. Although carbon fiber has very good tensile strength and modulus, it has low impact strength [28]. Specified by their excellent impact resistance, aramid fibers have a unique combination of high modulus, high strength, toughness, thermal stability, and chemical resistance [28].

Table 3. Properties of fibers [29].

Material	Density (g/cm^3)	Fiber Diameter (μm)	Young's Modulus (GPa)	Tensile Strength (GPa)
Carbon HM	1.8	7–10	400	20–2.8
Carbon A	1.9	7–10	220	3.2
Boron	2.6	130	400	3.4
E-Glass	2.5	10	70	1.5–2.0
S-Glass	2.6	10	90	4.6
KEVLAR 49	1.45	12	130	3.6
polyethylene	0.97	12	117	2.6

Table 4. Applications of fiber reinforced composites in the marine industry [27].

Composite	Applications
Fibreglass/carbon fibre/aramid fibre in epoxy or other polymer matrices (sandwich panels)	- Hulls and decks of small boats, yachts, cruise catamarans, and ferries - Rigid bottoms of Rigid Bottom Inflatable Boats, kayaks, and canoes - Floating wind turbine platforms and wind, tidal turbine blades - Superstructures of large ships - Small submersibles, submarine pressure hulls
Aramid fibre in epoxy or other polymer matrices (Mouritz et al., 2001)	- Boat keels and bow areas where impact absorption properties are essential
Glass-reinforced plastics, carbon fibre composites	- Furniture and moulded structures in yachts, masts, and booms of sailboats, propellers, podded propellers, propeller shafts, rudders - Risers and tendons in offshore floating platforms These long column-like structures are used for mooring and accommodating drilling operations (Rubino et al., 2020)
Carbon/glass continuous fibre reinforced thermosetting (epoxy/polyethylene) matrices or thermoplastic (polypropylene, polyurethane) (Cao et al., 2017; Davies et al., 2005)	- High-pressure oil/natural gas pipe networks. Thermoplastics used in deep-sea applications since they exhibit elevated water absorption and chemical resistance
Marine plywood, marine plywood reinforced by carbon/glass chopped strand mat (CSM) fibre reinforced epoxy/polyurethane) matrices (Ertug, 2013)	- Bulkheads and deck panels of yachts, cruise catamarans, large passenger ships
Mineral wool (asbestos) sandwich panels comprised of steel facings	- Heat insulating roofing or wall covers in fixed marine structures.
SiC-Graphite particulate composites in copper matrices (Jamwal et al., 2019)	- Marine heat exchangers

4. Some elements used in the marine industry

Propellers, biofouling, and hulls made from fiber reinforced composite are a few examples. Propellers are exposed to vibratory forces, bending forces, axial thrust forces, and centrifugal forces. Figure 6 shows a propeller made of carbon fiber reinforced plastic [25]. Biofouling is the accumulation, colonization, and attack of organisms at micro and macro levels that cause serious problems such as corrosion, alteration of submerged surfaces, increased weight, and entrainment. Figures 7 and 8 show a marine vehicle exposed to biological pollution and the hull of a ship, respectively [25].

Figure 6. Azipod propeller [25].

Figure 7. Effect of Biofouling [25].

Figure 8. Hull of a ship [25].

5. Marine Applications

Fiber-reinforced polymer matrix composites are used extensively civil and military applications in marine industry. The first application of glass-reinforced polymer matrix composites in naval shipbuilding dates back to 1973 with the mine countermeasure ship HMS Wilton. Afterwards, corvettes were designed and made from fiber-reinforced polymers [29]. Examples of military applications can be seen in Figure 9. In civil applications, glass reinforced plastics are used to manufacture fishing boats, small boats (yachts, sailboats, barges, and lifeboats), hovercrafts, and catamarans [29].

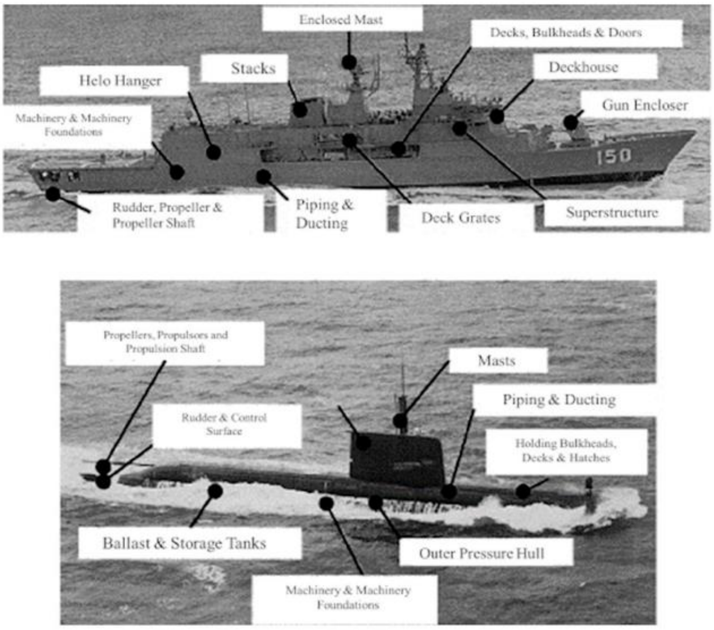

Figure 9. Military applications of fiber-reinforced polymer composites [29].

6. Results and Discussion

As can be seen from the examination, it is obvious that the use of polymer matrix composites provides advantages for structures and equipment in the marine sector. The variety of structures made from these materials is quite remarkable. The field of application in both civil and military fields is quite wide. Studies conducted in recent years reveal the point reached now. Despite their attractive positive features, these structures are exposed to high stresses due to the corrosive effects of the marine environment as well as environmental effects such as wind, waves, and tides. For this reason, the importance of life estimation and damage analysis of structures under the influence of stresses emerges.

7. Conclusion

This research focuses on marine applications of polymer matrix composites. Composite materials, which are used instead of traditional materials due to their many advantages, are also widely used in the marine sector. In recent years, research has been carried out on the design of sustainable, clean, and recyclable products. For this purpose, bio-based materials have been used instead of synthetic materials. In addition, studies on hybrid composites are continuing. With the development of design, analysis, and manufacturing methods, it will be possible to manufacture more economical, reliable, and durable materials with different components. In this way, the application area of composites will increase, and their properties in the places of use will be further improved.

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