Hemp Reinforced Polymer Composite for Structural Application of Boat Hull – A Review

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Abstract –

Natural fibres as reinforcement for polymer composite materials have gained popularity in recent years, owing mostly to environmental concerns, regulatory directions, and technological advances. Hemp is one of the most popular natural fibres used as polymer reinforcement due to its exceptional mechanical qualities. It has more cellulose content compared to other commercial natural fibers like flax, coir, PALF, etc. thus enhancing its mechanical performance. Hemp fibres are already attracting global interest by design engineers for the development of composites with wide-ranging applications in the automotive, electrical, construction, and packaging industries. Although several literatures explore different aspects of hemp fiber reinforced composites, there is limited literature that summarizes the surface treatment, processing techniques, mechanical performance and hybridization of hemp fiber composites for boat hull application. Although glass and carbon fibres are commonly employed as reinforcement materials for the same; however, their non-recyclability and ecological hazards especially to the aquatic life is a serious concern for their use in boat hulls. This paper therefore is envisioned to put forth a comprehensive summary of the research work published in the field of hemp fiber reinforced polymer composites for boat hull application.

Keywords: Hemp fiber; Epoxy; Glass fiber; Ecological hazards; Boat hull

INTRODUCTION

Composite materials typically comprise a blend of resin (matrix) and reinforcement (fiber), offering numerous benefits for applications in shipbuilding, marine technology, and marine structures [1]. Composite materials have been explored for use in ship hulls due to their potential for improved mechanical properties compared to traditional materials like steel [2]. In particular, the advantages of composite materials in structure are primarily their lower mass [3], which consequently allows lighter structures, [4] and corrosion resistance [5]. They are also used in the field of ship equipment [6] [7], and they also play an important role in the research of new adaptive and smart materials [8]. The shape of the naval ship's integrated superstructure makes it much less stealthy during surface combat. A composite sandwich structure, on the other hand, is made from different materials and enhances the naval ship's stealth during surface combat [9] [10]. Improved mechanical properties in ship hulls are crucial for enhancing safety, durability, and performance, reducing maintenance costs, and ensuring regulatory compliance in maritime operations [11]. The design of a ship's hull involves creating a detailed description of the structure in several dimensions (geometric, structural, parametric, and structural-and-technological) and then using the information to create the technical documentation needed for constructing the structure under ship hull production conditions [12]. In the face of ever-increasing safety standards and regulations, structural designers must constantly pursue lighter and more efficient constructions [13].

Anthropogenic pollution in marine environments, including fertilizers, pesticides, silt, and microplastics (MP, 1µm-5mm), has increased due to increasing manufacturing and urbanization as a sponge and a vector for the transportation of long-lasting organic pollutants in the ocean, microplastic is one of the primary causes of pollution. [15]

Organisms from multiple functional groups including suspension-feeders (zooplankton, oysters, mussels), deposit feeders (worms), and free-swimming predators (crabs and fish) ingest MP in laboratory experiments and in natural habitats In all lab settings and in nature, MP is eaten by a number of functional groups of organisms, such as deposit feeders (worms), suspension-feeders (algae, oysters as a mussels), and free-swimming predators (fish and crabs). [16]

The study reveals juvenile mussels, Mytilus edulis, to glass reinforced plastic (GRP) dust, under laboratory conditions. The study ran for a period of 7 days, to test for the morphological and potential physiological impacts of GRP. Infrared spectroscopy has revealed that the GRP resin material is poly diallyl phthalate. In mussels, particulate glass and plastics were detected in the digestive tubules and gills, with a suite of inflammatory features observed in all examined organs. In parallel, they study the effect of powdered GRP on swimming behaviour and survival of water fleas, Daphnia magna. Polymer particles and fibreglass adhered to the filament hairs on appendages, including the caudal spine, in exposed organisms. Most importantly, swimming impairment and sinking of the animals were recorded shortly after exposure.

As lighter ships need less energy to propel, they minimize fuel consumption and emissions, which in turn reduces environmental pollution, and weight reduction also suggests a decrease in expenses and air and marine pollution. Composites' reduced weight also means they are more efficient in operation and require less maintenance, which means it can save money. Both the environment and the bottom line can benefit from the usage of composites in naval applications [15]. This phenomenon in composites allows for several practical applications, including lowering construction, exploitation, and maintenance costs by reducing corrosion; lowering the environmental impact of ships; making complex hull forms easier to manufacture; and incorporating electromechanical equipment into the naval power system. Composites outperform coatings in terms of impact and corrosion resistance, and their matrix is far stronger [3].

Natural fibre composites with better mechanical properties, shipbuilders might make hulls that are lighter but stronger, able to endure a wide range of loads, collisions, and corrosive substances. Improving ship efficiency, safety, and durability via the pursuit mechanical properties is crucial to the long-term viability and earn profit to the maritime industry.

REVIEW OF LITERATURE

ISSUES WITH SYNTHETIC FIBER COMPOSITE

The study investigates negative effects of glass reinforced polymer (GRP) on aquatic life resulting from exposure to the GRP spectroscopic fingerprint. Based to the study, water fleas and mussels might be able to spread this new contaminant into the food chain and are also affected by the GRP dust. Poly diallyl phthalate is a compound used in GRP resin, as demonstrated by IR spectroscopy. It is widely acknowledged that phthalates are strong carcinogens, mostly linked to the pollution caused by microplastics [17]

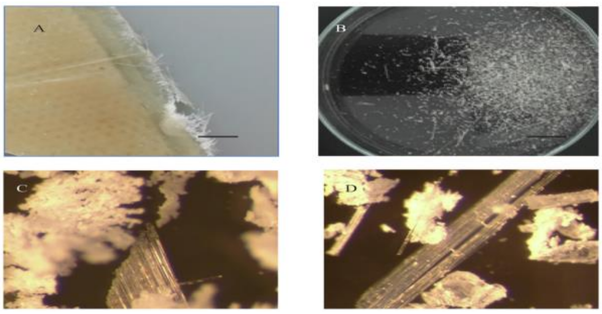

Fig.1 Glass reinforced polymer. A – fragment of a GRP flat sheet, B – powder obtained through cutting, collected in a Petri dish; scale bars 1 cm. C and D – GRP powder x 50 magnification. [17]

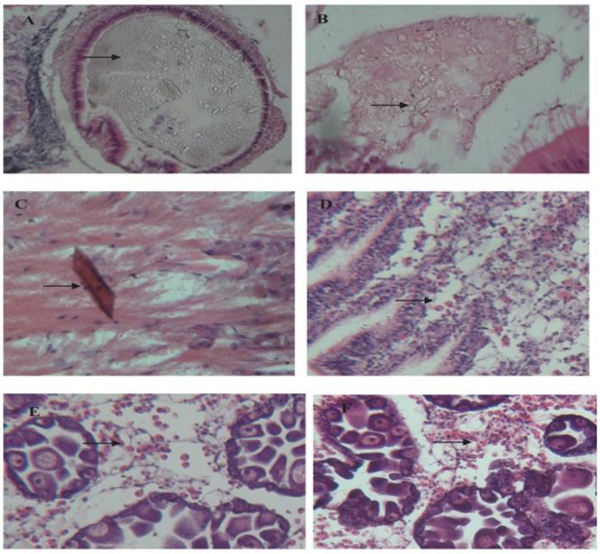

Fig.2 Histopathological conditions in mussel tissues after exposure to GRP powder. Sections of 7 µm, stained with hematoxylin and eosin. (A, B) digestive gland, fragments of GRP particles accumulated in the stomach; (C) fiberglass shard embedded in the connective tissue in the mantle; (D) inflammation of the gills, hemocytes invading the gill filaments; (E, F) egg follicles, female gonad, inflammation of the gonad; arrows point to each pathological condition. Magnification X 100 (A, D, E, F), X 400 (B, C) [17]

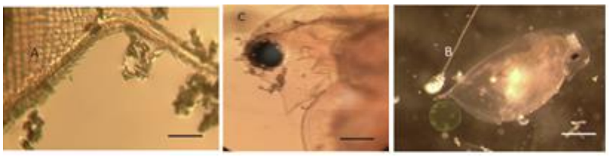

Fig.3 Microplastics of different sizes adhere to zooplankton. A – microplastics trapped between the hairs of caudal spine; size bar 50 µm. B – microplastics and glass fibers surrounding Daphnia, with small fragments trapped on the carapace; size bar 500 µm. C - microplastics clumped around the head and the compound eye.; size bar 100 µm. [17]

The environmental life cycle performance of fiber reinforced composites and glass fiber reinforced composites with find that, for the specific uses, natural fiber composites perform better environmentally. For the following reasons, it is suggested that NFR composites are probably less harmful to the environment than GFR composites in the vast majority of applications.

NATURAL FIBER COMPOSITE

Natural composite materials comprising one or more phase(s) derived from biological origin. Most plastics by themselves are not suitable for load-bearing applications due to their lack of sufficient strength, stiffness, and dimensional stability. However, fibers possess high strength and stiffness but are difficult to use in load-bearing applications because of their fibrous structure. In fiber-reinforced composites, the fibers serve as reinforcement by giving strength and stiffness to the structure while the plastic matrix serves as the adhesive to hold the fibers in place so that suitable structural composites can be made. [5]

Table 1 :Physio-mechanical properties of natural fibers

Fiber	**Density (g/cm3)**	**Tensile strength (MPa)**	**Young's modulus (GPa)**	**Elongation at break (%)**
OPEFB	0.7–1.55	248	3.2	2.5
Flax	1.4	88–1500	60–80	1.2–1.6
Hemp	1.48	550–900	70	1.6
Jute	1.46	400–800	10–30	1.8
Ramie	1.5	500	44	2
Coir	1.25	220	6	15–25
Sisal	1.33	600–700	38	2-3
Abaca	1.5	980	—	—
Cotton	1.51	400	12	3–10
Kenaf (bast)	1.2	295	—	2.7–6.9
Kenaf (bast)	0.21	—	—	—
Bagasse	1.2	20–290	19.7–27.1	1.1
Henequen	1.4	430–580	—	3–4.7
pineapple	1.5	170–1672	82	1–3
Banana	1.35	355	33.8	53

Table 1 shows the physio-mechanical properties of the natural fibres.The use of natural fibres such as jute, sisal, banana, hemp, ramie, coir etc., as reinforcements in plastics is increasing tremendously. Wood flour and other fibres are primarily used as fillers in thermoplastic decking, building materials, furniture and automotive components. Long agricultural fibres such as flax, kenaf, bast, hemp and jute are used as structural reinforcements in thermoplastic/thermoset composites as a replacement of glass fibre.[6]

The chemical composition of natural fibres has significance as their susceptibility to degradation is dependent on individual chemical constituents. Hemicelluloses are hydrophilic in nature and responsible for biological and thermal degradation and high moisture absorption, whereas hydrophobic lignin is mainly responsible for ultraviolet (UV) and fire degradation. An investigation by Pickering et al. on the effects of growth time on the tensile properties of hemp fibres exhibited an increase in strength up to the flowering stage, with an optimum harvest time of 114 days, after which it declined [24]. This has been attributed to changes in the chemical composition of fibres during ageing of plant. This clearly signifies a strong correlation between the structure and chemical composition of hemp fibres that ultimately results in variable mechanical properties of the fibre and the corresponding composites

HEMP FIBRE REINFORCED COMPOSITES

Industrial hemp (Cannabis sativa L.) is one of the oldest plants to be spun into fibres for serviceable products, apart from flax and sisal. It belongs to bast natural fibre category and has been cultivated for more than 12,000 years specifically for the industrial production of ropes, textiles, papers, etc. Hemp plant is a native of Asia, but it quickly dispersed across Europe, Canada and Russia [15].

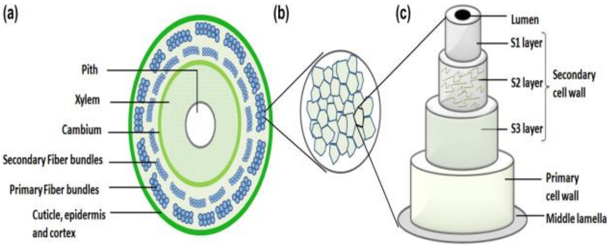

Fig. 4 Hemp fibre structure:(a) Cross section of hemp fibre stem, (b) hemp fibre bundle and (c) elementary hemp fibre.

The hemp stem basically consists of two major parts: the outer bast or bark and the woody core. The outer bast contains three components: epidermis (20–100 μm), cortex (100–300 μm) and phloem and the inner core comprises cambium (10–50 μm) and xylem (1–5 mm) [19].

Harvested hemp is processed using various techniques in order to separate out the hemp fibre bundles. Harvested hemp is initially subjected to retting process which is carried out either on field or in controlled laboratory conditions. During retting, the bacteria and fungi present in the water break down the chemical bonds holding the fibres together and release them from the stem. After retting, stems are dried and bailed out. Hemp fibres mainly are of two types: bast or the outer long fibres associated with phloem, present along the length of the plant stem and hurds, the inner short fibres that arise from the cambium. Hemp fibres have a multi-celled structure in which elementary bast fibres are glued together with pectin or lignin and their length varies between 5 and 55 mm and thickness is about 20 μm. These fibres have a thicker cell wall and a small lumen and consist of 60–70% cellulose, 15–20% hemicelluloses, 2–4% lignin, 2–4% pectin and 1–2% wax [20].

Hemp fibres are particularly rich in crystalline cellulose micro-fibrils that are embedded in amorphous hemicellulose and lignin matrix. The elementary hemp fibre is made of primary cell wall, secondary cell wall and lumen. Secondary cell wall has three sublayers (S1, S2 and S3) and each layer has a distinct micro-fibrillar arrangement. However, the fibre properties, i.e., the fibre strength and stiffness are mainly dependent on the S2 layer as it is particularly rich in helically arranged crystalline cellulose micro-fibrils that act as reinforcement. A schematic representation of the hemp fibre structure is given in Figure 4. The orientation of micro-fibrils in hemp is close to the fibre axis, which results in a low micro-fibril angle. Hence, the Young's modulus and tensile strength of hemp fibre are comparatively high as compared to the rest of natural fibres owing to its low micro-fibrillar angle and high cellulose content. Furthermore, as evidenced by the numerous studies on hemp fibre characteristics, the plant variety, stage of maturation and eco-physiological factors also contribute towards the variability of fibre structure and chemical compositions [21, 22].

The chemical composition, fibre structure and micro-fibrillar angle of the plant fibres are the most important variables that determine the overall properties of the fibres [23].

Hemp fibres potential to replace synthetic fibres as reinforcement in polymer matrices for structural and engineering applications has resulted in a renewed interest in their composites owing to a need for the development of sustainable materials. In general, their renewable nature, relatively low cost, low fossil fuel energy requirements, good mechanical properties and applicability to available processing machines offer several advantages ecologically and economically over conventional fibres as reinforcement in polymer matrices. In natural fibre reinforced polymer composites, the polymer matrix plays an imperative role in determining the overall properties of composites as it not only protects the fibres from the environment but it also helps in load transfer to the fibres thereby governing the final mechanical properties of composites. Hemp fibre reinforced composites with both thermoplastic and thermoset matrices have been developed by several researchers.

APPLICATION OF HEMP FIBRE REINFORCED COMPOSITES FOR SHIP HULL STRUCTURE

The study reveals that water uptake causes the tensile and flexural properties to decrease by 26–74%, while interlaminar and impact strength increases for hemp/epoxy and decrease for flax/epoxy composites. In addition, it is observed that in almost all cases, flax/epoxy has superior properties compared with hemp/epoxy bio composites. It is expected that this research will motivate naval architects and classification societies to consider bio composites as prospective hull materials that provide both structural integrity and environmental sustainability. [10]

Teak sawdust hardened material with 20 w.t% containing epoxy resin has more mechanical properties of Brinell hardness strength with a value of 20 BHN and Rockwell hardness strength with a value of 65 RHN the notch impact strength of Charpy and Izod tests are 2.1875 J/mm2 and 1.75 J/mm2. The water absorption test, both the sample of 10 w.t% and 20 w.t % has the same value as the result, in distilled water there is zero absorption of water and the saltwater is absorbed in 2 % of absorption in the sample. These composite prototypes are efficiently in price value and its durability is very strong enough to build a boat hull.[11]

Table 2: Mechanical properties of (untreated) hemp fiber reinforced polypropylene composites

Fiber/ fraction (%)	Tensile strength (GPa)	Flexural strength (MPa)	Flexural strength (GPa)	Tensile strength (MPa)	Impact strength (J/m^2)
None	20–40	1.0–1.4	42.1	1.1	16
Hemp/ 30	22.1	10.2			
Hemp/ 40	40.2	3.55	73.3	4.1	29
Hemp/ 50	50	6.5	85	4	53
Hemp/ 30	32.3	1.53	48.5	1.67	15.1
Hemp/ 30–70	55	6.7	85	4.7	46
Hemp/ 64	42		63		152
Hemp	34	2.7	41.5	2.3	3.89
Glass/22	88.6	6.2	60	4.4	54.12

CONCLUSION

Hemp Reinforced Polymer Composite have the potential to become one of the leading materials for ship hull .It is expected that it will strongly impact environmental and economic issues such as the renewability of material sources, life-cycle sustainability, end-of-life issues, human and animal health, and others. However, many challenges still prevent their broader inclusion in the global manufacturing systems due to their relatively low level of maturity.

Future work could be directed to improve adhesion (using coating or fibre treatment) between the fibre and the matrix, to improve strength and impact resistance. Higher fibre volume fractions can be used to reduce resin usage, and properties of these higher fibre composites should be determined**.**

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